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Low Back Pain in Weightlifters: Personalised Exercise Protocols for Elite Athletes

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SUMMARY

Background. Most of us has experienced low back pain (LBP) at least one time during his life, but there is no knowledge on weightlifting athletes. Indeed, LBP is one of the most complained injuries, usually caused by disc herniation. The athlete needs to know the correct training technique to reduce stress on joints and to avoid severe injuries. But once the injury has happened, the role of rehabilitation is crucial, because the athlete needs to return to the sport as soon as possible in an optimal condition.

Objective. To analyze if the personalized protocol and the specific therapeutic exercises adopted are effective in amateur weightlifters.

Patients and methods. LBP has been diagnosed on seven amateur weightlifters out of fifty athletes. We proposed a personalized rehabilitation treatment based on the symptoms of the patients, adapting it to their needs, following them until their return to the sport practice.

Results. All patients returned to the sport practice, most of them at the same level as before the injury. One of them returned to the sport practice gradually, but not yet at the same level, and the last one is getting better results compared to the ones before the injury.

Conclusions. In our experience, personalizing the rehabilitation on the symptoms of the patient is the key point of the rehabilitation program, as long as choosing the right therapeutic exercises for each patient. Pain and load management is the starting point; the specific exercise selection should be decided upon the level of discomfort the patient can work with.

KEY WORDS

Core stability; disc herniation; protrusion; low back pain; weightlifting; powerlifting; rehabilitation protocol.

INTRODUCTION

Low back pain (LBP) is an issue as common as complex, impacting the life of the people negatively, which about 80% of adults experience in their lives (1). Despite the huge amount of source in literature, little is known about LBP and its management occurring in elite sport like weightlifting.

Weightlifting has its roots in ancient Greece, a culture that is well known for celebrating strength and for competition involving weights. It was included in modern Olympics in 1896 and it is the only barbell sport in the Olympic program. It consists of two events: the snatch and the clean and jerk (2) (**figure 1**).

Figure 1. An athlete performing the snatch.

Powerlifting is a similar competitive sport, which includes weightlifting movements, as matter of fact the goal is to lift as much weight as possible. It differs from weightlifting since this sport is made up of three actions: the squat, the bench press and deadlift (3).

CrossFit was defined by researchers as a high-intensity training program and a strength-building conditioning. This sport uses the main elements of gymnastics, weightlifting exercises, and cardiovascular activities as exercise task, to be executed quickly, repetitively, and with little or no recovery time between sets (4).

All these sports are strength sports which require excellent flexibility, balance, and coordination, besides strength. In these sports the spine is exposed to an enormous amount of weight, and if the body is not well prepared, it can lead to injuries. This means that it is essential to learn the correct technique to reduce stress and pressure on the joints and to avoid severe injuries. This could appear as a common issue, but it is challenging to manage in super trained elite athletes (5).

In lifting-weight sports, the musculoskeletal injuries are the most common, due to inadequate strength, technique, insufficient warm-up or stretching, loss of balance (6). LBP is considered one of the most common complaints among weightlifters with incidence rates reaching 40.8%. It is estimated to affect weightlifters with a lifetime incidence of 23% (7).

The two most common injuries leading to LBP in this sport are muscle strains and intervertebral disc bulge or herniation (8). The most common injuries are resumed in **table I**, divided per anatomical locations.

Table I. Injuries and overuse syndromes in powerlifting (9).

Body part	Damage
Cervical spine	NOS, myogelosis, arthrosis, herniated vertebral discs/protrusion, spinal stenosis, and sliding vertebrae
Thoracic spine and thorax	Sliding vertebra, arthrosis, herniated disc/protrusion, hyperkyphosis
Lumbar spine	Disc herniation, sciatica, hyperlordosis and myogelosis
Shoulder	NOS, inflammation
Elbow	NOS, inflammation, arthrosis, dislocation and instability, bursitis. Muscle, tendon, or nerve disorders, epicondylitis
Hand/wrist	Tenosynovitis, arthrosis, ganglion cysts. Fracture, rheumatic disease, ligament instability
Hip	Arthrosis, inflammation, impingement, and strain
Knee	Patellar disorders, meniscus injury, arthrosis, inflammation, cruciate ligament rupture, and ligament instability
Ankle/foot	Flatfoot and splayfoot. Ligament, toe dislocation

PATIENTS AND METHODS

This is a prospective study on case series which analyses the therapeutic rehabilitation protocols among seven amateur weightlifters, powerlifters and CrossFit athletes, with an age range from 25 to 40 years old with a recognized disk protrusion or herniation. We treated seven symptomatic patients out of fifty patients that came to our clinic. All patients gave their signed informed consent to participate according to the Declaration of Helsinki of 1946. The **table II** shows the data of the patients.

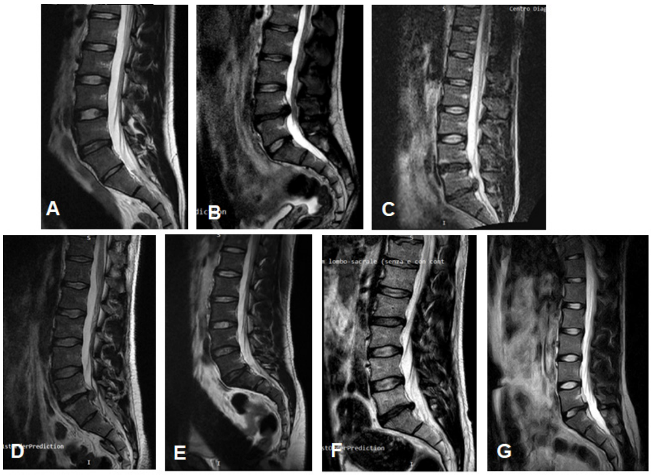

Figure 2. MRI of the patients.

(A) AC protrusion at L4-L5 level; **(B)** GA herniation at L4-L5 level; **(C)** PL protrusion at L4-L5, herniation at L5-S1; **(D)** DP herniation at L5-S1 level; **(E)** VM herniation at L5-S1 level; **(F)** FDF herniation at L5-S1 level; **(G)** MI herniation at L5-S1 level.

For each athlete a MRI was made, showing a disc protrusion or a disc herniation. They are shown in the following **figure 2**. The diagnosis was made by physiatrists or orthopedists, and the athletes came to our observation for the rehabilitation program. In order to get full background of the patients, we executed a physiotherapeutic assessment:

- Data and features of the patients, as shown in **table II**.
- Local examination: palpation, ROM, strength.
- Neurological examination: sensitivity, reflexes, motility.
- Clinical tests: SLR, crossed SLR, slump test. These tests should elicit familiar symptoms to patients.

These tests were positive for all patients. Depending on the symptoms of the patient and pain characteristics, a different rehabilitation treatment or specific instrumental physical therapy may be added to the program when needed. The general rehabilitation protocol was divided in three parts, and then each part was personalized on the patient:

1. Tolerable and modified training (when possible, depending on the symptoms).
2. Physical therapy.
3. Life and training recommendations and contra-indications.

The rehabilitation treatment is described in the following **table III**, divided per patients.

We chose different therapeutic exercises for each patient, but there were common basic exercises, essential to the rehabilitation of all of the athletes:

- Hip thruster.
- Lunges (crossed, with one knee up, moving the hip onward…).

Table II. Information about the patients.

Variables	Data						
Name	AC	GA	PL	DP	VM	FDF	MI
Age*	25	28	31	34	29	40	29
Sport	Powerlifting	CrossFit	CrossFit	CrossFit	Powerlifting	CrossFit	CrossFit
Diagnosis	Protrusion	Herniation	Protrusion/herniation	Herniation	Herniation	Herniation	Herniation
Level	L4-L5	L4-L5	L4-L5 (p) L5-S1 (h)	L5-S1	L5-S1	L5-S1	L5-S1
Time MRI	After 2 weeks	1 month	2 days	1 year	1 week	2 months	1 months
Pain duration	1-2 months	5-6 months	1 months	6 months	2 weeks	8 months	6 months
Stop**	6-7 months	6-7 months	2 weeks	No stop	3 mo	1 year	2-3 weeks
Drugs	Cortisone	-Medrol 16, 1 x4 days; ½ x4 days, ¼ x6 days -Xinepa easy 2/die x1 month	Ozone injection therapy + cortisone, from 4 mg x5 days to 0.5 mg	None	None	Cortisone 1 mg	4 injections of Voltaren and muscoril Brufen 600 mg 2/die x5 days

*Age at the time of the injury; **stop refers to the time the athlete has not practiced any sport.

- Deadlifts (Romanian, one leg deadlift…).
- Spine mobility: spine twist (lower trunk rotation, associated with breathing, or in different positions…).
- Squat (Bulgarian s., isometric wall s., goblet s…).

Fast walking and running, and TRX exercises were selected and added to the rehabilitation treatment.

Table III. The rehabilitation treatment for each patient.

Time	Therapeutic exercises	Repetitions	Intensity
	Patient AC		
1st day	Barbell row Hip thruster	10-15 reps x 3-4 sets 2' recovery	5-6 RPE
	Frontal plank and Chinese plank Arm and leg extension from the quadrupedal position on instable surfaces (bird dog) Lateral plank with extended and staggered legs From a lunge position, move the hip onward	20-30" + 20-30" x 4-6 sets 20 x 3 s 10-15 for each side 3-4 sets 1' x 4-5 sets	5-6 RPE
3rd week	" " **Before training** From a push up position to triple flexion with an elastic band on feet	" " 20 x 3 s	7-8 RPE
5th week	**Before training** Hip flexion banded high plank Kettlebell swing and elastic band swing	 20 x 3 s 5 + 20 reps x 3-4 s, 1' recovery	7-8 RPE
2 months	**Before training** Scapular abduction against elastic band resistance Hip flexion banded high plank Standing lateral barbell inclinations Kettlebell swing Hip thruster Frontal plank + Chinese plank Post-training Lateral plank with extended and staggered legs Trunk rotation with breathing training, pushing the face with the hand	 12 x 3 sets, 15" recovery 20 x 3 s 4-6 x 3 sets, 15" recovery 5+20 x 3-4 s, 1' recovery 10-15 x 3-4 s, 2' rest 20-30" + 20-30" x 4-6 s 6-8 each side x 4 s 30" + 30" x 4 s	7-8 RPE
	Patient DP		
1st day	Lateral plank with bent knees	30" each side x 3-4 s	
10th day	Lateral plank with bent knees and elastic band around them (opening the legs)	30" each side x3-4s per day	20-30% of 1RM
	Hip thrust with one leg bent to the chest with an elastic band	"	3-4 RPE
	Triple flexion with elastic band on feet and with kb on the belly	40" x 3-4 s per day	1-2' recovery

Time	Therapeutic exercises	Repetitions	Intensity
3rd week	Lateral plank with extended knees with hip lift + one leg lift	3-6 each side x 3-4 s per day, 3" pause	20-30% of 1RM
	Hip thruster within lumbar flexion	6-8 x 4	3-4 RPE
	Spine flexion-extension on foam roller + Jefferson curl	2' + 3 x 4-5 s	1-2' recovery
5th week	Lateral plank with extended knees and hip lift + one leg lift + other leg lift with one weight up	3" stop between movements 3-6 each side x 3-4 s	20-30% of 1RM
	Hip thruster in lumbar flexion	30" x side x 3-4	3-4 RPE
	Spine flexion-extension with the thorax blocked and foam roller + Jefferson curl	2' +3 x 4-5 s	1-2' recovery
7th week	Lateral plank with extended knees and hip lift + one leg lift + other leg lift	3" stop between movements 3-6 each side x 3-4s 3" pause	
	Hip thruster with load and with the spine in neutral position	30" each side x 4 s	
	Triple flexion with elastic band on feet and kb on the belly, starting with lifted legs OR light hip flexion with stuck feet and light load (around 5 kg)	40" x 4 s	
3rd month	Hip thruster with load and with the spine in neutral position (feel the gluteus activation)	14 + 12 + 10 + 8 + 6, 1' recovery	
	Triple flexion with elastic band on feet and kb on the belly, starting with lifted legs OR light hip flexion with stuck feet and light load (around 5 kg)	12 x 3 s	
Patient GA			
1st day	**Odd days**		
	Asymmetrical push-up	10 each side x 3 s	
	Squat	20 x 3 s, 30" recovery	
	Lunge with high knee	12 each side x 3 s 30" rec	
	Hip thruster	15 x 3 s, 30" rec	
	Even days		
	Pull ups with prone grip	5 x 5 s, 2' rec	
	On leg deadlift (don't cross the legs)	12 each leg x s, 30" rec	
	Frontal plank, raise one leg per time	10-14 x 3 s, 30" rec	
	Lateral plank with bent knees	8-12 each side x 3 s, 30" rec	

Time	Therapeutic exercises	Repetitions	Intensity
1st month	**Odd days**		
	EMOM with 4 rings push up	15’	
	5’ recovery		
	EMOM with 5 overhead squats with barbell and 4 kg each side	20’	
	Crossed lunge with weight	10 each side x 3-4 s, 1’ rec	
	Even days		
	Pull ups with prone grip	5 x 5 s, 2’ rec	
	5’ recovery		
	AMRAP with 15-20 deadlift with 1 kg each side + 8 lunges + 15-20 deadlifts with 30 kg + 20” frontal isometric plank + 20” lateral plank with bent knees	10’	
	5’ recovery		
	Lying glute stretch	20” x 6 s	
	Bike	20’ at constant and lowest velocity	
2nd month	**Odd days (2 days)**		
	EMOM + 3-4 hang power snatch with 30 kg barbell	10’	
	5’ rec		
	EMOM + 4 squat clean with 2 barbells (6-8 kg)	10’	
	5’ rec		
	Romanian deadlifts + TRX pullover	8-12 + 8-12 x 3-4 s, 30” rec	
	Lateral plank and band pull	6-8 each side x 3-4 s, 30” rec	
	Hip flexion banded high plank	8-12 x 3-4 s, 30” rec	
	Twist flexibility with a ball between the knees	1’ x 3-4 s, 30” rec	
	Lying glute stretch	20” each side x 6s	
	Even days (2 days)		
	EMOM + 2 hang power clean + 2 barbell push jerk (40 kg)	10’	
	5’ rec		
	EMOM + 2-5 chest to the bar (be careful when going down, control the movement)	10’	
	5’rec		
	AMRAP +10 TRX row + 10 TRX push-ups + 15 TRX squat + frontal plank walking + 10 hip thruster	20’20-30” + 20-30” x 4 s	
	5’ rec		
	Chinese plank + frontal plank (with weight)	1’ x 3-4 s, 30” rec	
	Twist flexibility with a ball between knees	20” x 6 s	
	Lying glute stretch		

Time	Therapeutic exercises	Repetitions	Intensity
4th month	Wall plank	14-20 each side x 2-3 s, no rec	
	Tennis ball massage at wall (optional)	30" each side x 2 s	
	From lunge position, move the load sideways	10-15 each side x 2-3 s, no rest	
5th month	**Odd days (2 days)**		
	From lunge position, move the load sideways	10-15 each side x 2-3 s, no rest	
	Alternate grill pull ups	5 x 5, 60-90" rec	
	5" rec		
	One arm TRX rotation	6-8 each side x 4-5 s, 30" rec	
	3' rec		
	EMOM + 3-4 hang snatch with 30 kg barbell	10'	
	5' rec		
	TRX Australian pull ups with supine grip	Till exhausted x 3 s, 30" rec	
	1' rec		
	Bar arch	30-60" x 3-4 s, 30" rec	
	1' rec		
	Frontal plank + Chinese plank	20-30" + 20-30" x 4-6 s	
	Twist flexibility with a ball between knees	1' x 3-4 s, 30" rec	
	Lying glute stretch	20" x 6 s	
	Even days (2 days)		
	From lunge position, move the load sideways	10-15 each side x 2-3 s, no rest	
	Row/bike	Constant velocity, 20" + 5" rec at lowest velocity, x 5 s	
	3' rec		
	EMOM + 3-4 hang clean with 40 kg barbell	10'	
	5' rec		
	TRX fly chest with BFR	30+15+15+15, 30" rec	
	5' rec		
	Push up with narrow elbows	Till exhausted, x 3 s, 30" rec	
	Twist flexibility with a ball between knees	1' x 3-4 s, 30" rec	
	Lying glute stretch	20" x 6 s	
	Indications for the 5th or 6th day		
	From lunge position, move the load sideways	10-15 each side x 2-3 s, no rest	
	Row/bike + 4 renegade row with push ups	2' x 7 s	
	5' rec		
	Walk climb	4 x 4-5 s, 1' rec	
	Twist flexibility with a ball between knees	1' x 3-4 s, 30" rec	
	Lying glute stretch	20" x 6 s	

Time	Therapeutic exercises	Repetitions	Intensity
	Before training		
	From lunge position, move the load sideways	6-8 each side x 3 s, no rest	
	Crossed lunge	6-8 each side x 4 s, no rest	
	After training (odd days)		
6th month	TRX standing side bands	6-8 each side x 4 s, no rest	
	Half kneeling t-spine rotation	1' each side x 4 s, no rest	
	After training (even days)		
	Lying glute stretch (start with hands, then take them off)	8-12 each side x 4 s, no rest	
	Before training		
	Bear squat	6-8 each side x 3 s, no rest	
	Crossed lunge (increase the lunge gradually)	"	
	After training (odd days)		
7th month	TRX standing side bands	6-8 each side x 4 s, no rest	
	Single arm back row with spine rotation at TRX	" + 30" rec	
	After training (even days)		
	Lying glute stretch with the hip 90/90	6-8 each side x 4 s, no rest	
	Ban thread the needle	"	
	Before training		
	Bear squat	6-8 each side x 3, no rest	
	Bird dog drag diagonally	6-10 x 3 s, 30" rec	
	After training (odd days)		
	Ab wheel roll	4-12 x 4 s, 30" rec	
9th month	TRX standing side bands	6-8 each side x 4, no rest	
	Band oblique twist	10-14 each side x 4, no rest	
	After training (even days)		
	Medicine ball side throw	6-10 each side x 4, 1' rec	
	Lying glute stretch with the hip 90/90	6-10 each side x 4	
	Thread the needle on foam roller	8-12 each side x 4 s, no rest	
	Patient PL		
	Windmill (for coordination)	4 per each side x 3-4 s	
	From frontal plank to lateral plank	12 x 3 s, 15" recovery	
	Lateral plank with bent knees	6-8 each side x 3-4 s, 30" recovery	
	Lateral plank	8-12 each side x 3-4 s, 30" recovery	
1st day	In supine position, bend the knee to the chest and open the legs against elastic band		
	Post training		
	Chinese plank	20" + 20" x 4 s, 30" recovery	
	Frontal plank	"	
	Spine twist supine	12 x 3 s	

Time	Therapeutic exercises	Repetitions	Intensity
5th week	**Before training**		
	From frontal plank to lateral plank	12 x 3 s, 15” recovery	
	Post-training		
	Romanian deadlifts	6-8 x 3-4 s, 30” recovery	
	Lateral plank at the isometric ghd	20” each side x 4 s	
	Frontal plank with weight + Chinese plank	30” + 30” x 4 s	
Patient VM			
1st day	Dead-bug	20 x 3-4 s	
	Lateral plank with knee flexed	20 each side x 3-4 s	
	Isometric quad contraction with a support under the heel	20” contract. + 20” relax x 5 s	
	Hip extension and heel slides	5-8 x 4 s	
	Hip extension with bent legs and one leg flexed at the chest	8-12 x 4-5 s	
	Hip extension with bent legs and one leg on a chair	“	
4th week	Reclining twist	8-10 x 4-5 s	
	Lateral plank with bent knees	20 each side x 3-4 s	
	Isometric quad contraction	20” contract + 20” relax x 5 s	
	Hip extension with one heel slides	5 each leg x 4-5 s	
	Modified step-up (eccentric + concentric without rest)	“	
8th month	Isotonic lateral plank with extended legs	5 each side x 4-5 s	
	Leg twist	5 x 3-4 s	
	Sit-up with hands behind the back + Jefferson curl	4-5 each x 4-5 s	
	From quadrupedal position, inspiration and expiration + vacuum	“	
	Modified step-up	5 each leg x 4-5 s	
Patient FDF			
1st day	**Odd days**		
	Hip flexion banded high plank	8 each leg x 3 s	
	Lateral plank with flexed knees	10 each side x 3 s	
	Isometric wall squat + squat	20” + 10 x 3 s	
	Even days		
	Lunges	8 each side x 4 s	
	Glute bridge with one knee to chest	10 each leg x 3 s	
	From lateral position, abduction of the superior leg and later of the inferior one	10 each leg x 3 s	

Time	Therapeutic exercises	Repetitions	Intensity
3rd week	**Odd days**		
	Goblet squat + squat	12 + 14 x 4 s	
	From plank position, move the knee to the homolateral elbow	12 x 4 s	
	Lateral plank	10 each side x 4s	
	Even days		
	Lateral lunge	10 x 4 s	
	Glute bridge with one knee to chest and arms up	10 each leg x 3 s	
	From lateral position, abduction of the superior leg and later of the inferior one	10 each leg x 3 s	
6th week	**Odd days**		
	Squat	12 x 3 s	
	Lunges with barbell	8 each leg x 3 s	
	Bulgarian split squat	“	
	Cossack lunge with arms up	12 x 3 s	
	- hip thruster	“	
	Cyclette at medium velocity + low velocity	1’ + 2’	
	Even days		
	Bench press	12 x 3 s	
	Barbell roll	“	
	Pull up with elastic band	“	
	Lateral plank	10 each side x 4 s	
	Row at medium velocity + low velocity	1’ + 2’	
3rd month	One leg squat, with the hand pushing on the knee	4-5 each side x 3 s	
	Lateral plank	30” each side	
	Jefferson curl	1’ x 3-4s	
	In supine position, one leg flexion with the other crossed	20” each leg x 4 s	
5th month	“		
	+ from the frog position, move the hip onward and backward	30” x 4 s	
	“		
	Crossed lunge	8-12 each side x 4 s	
7th month	+ Fast walking	1’	
	Running 1-2 x week	2’ x 10s	
9th month	Lateral inclination at 45° hyperextension	8-12 each side x 3-4 s	
	Lateral inclination at crunch	8-12 each side, 3-4 s, no rec	
	Lumbar rotation with one leg crossed	1’ each side x 3 s	
	Fast walking & running	1’ + 2’ x 10 s	

Time	Therapeutic exercises	Repetitions	Intensity
11th month	Crossed lunge with lateral inclination	6-8 each side x 3-4 s	
	Trapezius and SCM self-massage	1' each side x 2 s	
	Spine mobility with lunge	6-8 each side x 3-4 s	
	TRX hip drop	1' x 3 s	
	Lumbar rotation with one knee flexed		
	Fast walking & running	1' + 2' x 10 s	
12th month	**Odd days**		
	TRX hip drop	6-8 each side x 3-4 s	
	Single arm back row at TRX	1' each side x 3 s	
	Even days		
	TRX hip drop	1' each side x 3 s, 30" recovery	
	TRX T-spine rotation	"	
	Patient MI		
1st day	Self-massage with foam roller on the lumbar tract, glutes, hamstrings, calf	2' x 2 s	
	Lateral plank with constant breathing	6-8 each side x 3-4 s	
	Bulgarian split squat with constant breathing	"	
	One leg Romanian deadlifts + contralateral had that touches the floor	"	
	Curl up with the knees bend with constant breathing	10-16 x 3-4 s	
3rd week	**Odd days**		
	(Optional) self-massage with foam roller on the lumbar tract, glutes, hamstrings, calf	2' x 2 s	
	Jefferson curl	6-8 x 3-4 s	
	Deadlifts and Romanian deadlifts with barbell	6-8 + 6-8 x3-4 s	
	Lateral plank with constant breathing	6-8 each side x 3-4 s	
	Even days		
	(Optional) self-massage with foam roller on the lumbar tract, glutes, hamstrings, calf	2' x 2 s	
	Lower trunk rotation	6-8 x 3-4 s	
	Frontal plank and trunk rotation	"	
	Curl up with the knees bend with constant breathing	10-16 x 3-4 s	
7th week	**Odd days**		
	(optional) self-massage…	6-8 + 6-8 x 4 s	
	Romanian deadlifts with barbell + deadlifts	"	
	From lateral plank to Copenhagen position with extended knees and constant breathing	6-8 each side x 4 s	
	One-leg hip thruster	"	
	Even days		
	(Optional) self-massage	2' x 2 s	
	Romanian deadlifts + roman bench	10-15 each side x 4 s	

Time	Therapeutic exercises	Repetitions	Intensity
9th week	**Odd days**		
	(Optional) self-massage…	2' x 2 s	
	Crossed lunge with trunk inclination	4 each side x 4-5 s	
	One-leg hip thruster with trunk retroversion	6-8 each side x 4 s	
	Even days		
	(Optional) self-massage…	2' x 2 s	
	Kipping on bar/rings	10' x 6 s	
12th week	**Before training**		
	From side bridge put a step under the knees and the elbow so that the hip goes down	6 each side x 4-5 s	
	Post training		
	Crossed lunge with trunk and arm inclination	6 each side x 4-5 s	
	One-leg deadlifts with lateral support	6-8 each side x 3-4 s	
	Pistol squat with extended arms on a support	4 each side x 3-4 s	
After 7 months	**Before training**		
	(Optional) self-massage	1' each side x 2 s	
	One-leg hip thruster + Nordic hamstrings exercise revere	4-6 each side + 4-5 x 3-4 s	
	Post training		
	From side bridge put a step under the knees and the elbow so that the hip goes down	6 each side x 4-5 s	
	Active sagittal trunk flexion	4 each side x 3-4 s	

RESULTS

Each patient suffered from LBP due to the herniated disc, but the pain duration changed between the athletes, and it lasted from weeks to many months (**table II**). Every patient went back to the sport practice with different timings: 5 patients out of 7 (71.4%) returned to the sport at the same level as before the injury, and 2 of them (40%) had to change the frequency of their training, being careful to the stretching, mobility and warm-up phases. These two patients had the longest time of pain duration (**table III**). 1 patient (14.3%) out of 7 went back to the sport practice gradually, but not yet at the same level as before. The last patient (14.3%) returned to the sport practice with better results compared to the ones before the injury. Our findings are resumed in the following **table IV**.

DISCUSSION

In our study, we have proposed a rehabilitation treatment for weightlifting elite athletes with LBP: super trained patients like them may be challenging to manage,

Table IV. Results after the rehabilitation treatment.

Variables							
Name	AC	GA	PL	DP	VM	FDF	MI
Time*	3 months after complete recovery	7 months	2 weeks For 6 months monitored training	Training without interruption, removing some exercises	3 months	1 year changing from 6 to 4 times a week training	2-3 weeks The training was adjusted on the symptoms
Level	Higher	Lower	Same	Same	Same	Same with modified frequency and more careful training	Same with modified frequency and more careful training

*After how much time the patient went back to the sport practice.

especially for a first approach and since the literature available is lacking.
According to some studies, lower limb muscle is impaired in patients with LBP: muscle inefficiency (especially the hip muscles), lack of coordination and imbalance can contribute to the develop of LBP, because if the pelvis is unstable, the lumbar spine does not perform the movements properly. In lifting-weight sports the mechanical concept result more relevant with the sport-specific task (10). For this reason, we aim to improve the coordination and the stabilization of the lumbar spine and of the pelvis, and to decrease the spine stiffness.
We should always consider that in sports like weightlifting, the athlete adapts his posture on the exercise and on his sensations, "always making adjustment to the lumbar spine" to execute every rep accurately. This may imply that developing disc herniations is subjective, and does not derive from the lumbar spine position, because every athlete has his own movement's biomechanics. In any case, improving the back muscles strength – as the whole body, too – by using gradual loads provides to a major lumbar stabilization and decrease the risk of LBP and herniations (11).
Our first goal is to ensure that the patient gains confidence in performing movements. We can help him by managing the loads and the pain, and by informing him that most of the disc and hernial phenomena resolve spontaneously. Pain decreases the quality of life, and it should not be considered as an obstacle to undertaking the rehabilitation program, but it must be managed as well as the loads. Approaching exercise with a positive attitude is extremely important and it is going to help during the rehabilitation program. In a first phase pain killers can be suggested in accord with the medical team.
The exercises chosen above were made unique for each athlete and adapted to the symptoms, and they changed almost every two weeks, according to the feeling of the patient. These therapeutic exercises work on the erector spinae, core and hip muscles. An atrophy of these muscles can exist in highly active and elite athletes with LBP (12).
Concerning the deadlift exercise, according to the literature available, it is not bad for LBP as it could appear; instead, it seems to significantly reduce pain intensity and increase strength and endurance (13). Our tissues adapt to mechanical stimuli by getting stronger, not weaker. An enhanced muscles and bone strength promote a greater structural support (13). The exercises have been modified in execution, repetitions, and intensity for each patient. Also, we gave a range of repetitions (a minimum and a maximum number of exercise repetition) so that the patient could adjust the exercise, and so his training, on his pain and sensations.
Fast walking and running were selected: there is strong evidence in literature that this practice is associated with better hydration and proteoglycan content in the intervertebral disc (IVD) (14). Disc damage in sports like weightlifting, where there is a huge axial loading on the spine, can be present, and as the time passes it can lead to disc degeneration (15). Running and fast walking have an effect on the muscles, too: they strengthen the back muscles by increasing their activation through an isometric contraction, and this can be also used for the prevention of LBP (14, 16).
Additionally, we recommend the TRX exercises, such as: TRX hip drop, back row, T-spine rotation, standing side bands, which promote the balance, strength and flexibility develop, especially in the athletes. The whole-body benefit from this training, so it is decisive to choose the most suitable and significant exercise for the patient.
However, it is indispensable to keep in mind that having good muscle activity is certainly a positive aspect, especially for these kind of athletes with a high-demanding spine stability: a lumbar spine lacking of any muscular activity is highly unstable, even under low-entity loads (17, 18).
Focusing on the results, every patient went back to the sport practice. Clearly, the time changes depending on the patient, and so the rehabilitation treatment should change: personalizing the rehabilitation and the training to the patient seems to be necessary, particularly when it comes to alike situations, where the pain is not tolerable anymore and forces the athlete to stop his training and competitions.
Before choosing the surgical management, the physiotherapy intervention should be considered as the first step to enhance the patient condition. The rehabilitation treatment of the élite athlete is characteristic and challenging: in most situations we are dealing with already super trained and strong patients, so knowing where and how to manage the situation is essential. The athlete needs to get back to the sport practice as soon as possible in an excellent condition. First of all, a specific intervention is needed: we suggest to start from the reduction of the symptoms and the muscular control of loads. Progressively, we start with the therapeutic exercises and their variations, choosing the best one and customizing it to the needs of the patient. When it is time for the athlete to go back to the sport practice, we have to ensure his safety: giving the athlete some recommendations and contraindications can guide him during the sport train-

ing. He should be aware of his abilities, strength and limits, and above all to stop (or not) when needed.

Limitations

Our patients were nonuniform for age, weight and morphological type. They were only 7. Also, we did not have a control group.

CONCLUSIONS

The key points of our rehabilitation protocols are:

- Pain education and load management.
- Therapeutic personalized exercises (adapted in execution, repetitions and intensity).
- Training recommendations and contraindications.

But we should be careful: pain does not always indicate a tissue damage; not every anatomical alteration induces pain. Since there is not a one single best exercise, patients could not follow the cookie-cutter approach. Every therapeutic exercise has its own different effectiveness, and no single mode of exercise is superior to another. Also, the exercise selection should be decided upon the level of discomfort the patient can work with. The ultimate goal is the self-care management: when the patient is able to auto correct when executing the exercises.

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None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

FO, MNA: writing, revising, study selection, data collection, data extraction. FO: synthesis methods, final approval. MCV: study selection, data collection, data extraction, supervising. NM: revising, final approval. All authors read and approved the final manuscript.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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Morphological Changes and Pathological Findings in the Achilles Tendons of Diabetic Patients: A Meta-Analysis of Comparative Clinical Studies

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SUMMARY

Objective. There is a greater risk of tendon rupture requiring hospitalization in people with diabetes. Diabetes could induce substantial alteration in Achilles tendon (AT) that could affect its mechanical properties mainly in relation to gait and foot ulceration. Many studies reported AT morphological changes using diagnostic methods in clinical settings. However, there is no quantitative synthesis of the published data.
Methods. A systematic review was conducted using several electronic databases. Only comparative clinical studies comparing AT changes and findings between healthy people and patients with diabetes, with and without neuropathy were included. Studies using ultrasound or MRI were eligible for inclusion.
Results. Seventeen studies comprising 2,938 subjects (5,822 tendons) were analyzed. Increased AT thickness in patients with diabetes was found, but the difference did not reach significance. The weighted Odds Ratios (OR) were all significantly favoring changes in diabetes: 1) overall AT morphological changes (OR 3.5, CI 2.970-4.181); 2) AT fiber disorganization (OR 3.48, CI 2.291-12.1840); 3) tendinopathy (OR 3.5, CI 2.934-4.333), d) enthesopathy (OR 4.08, CI 1.130-14.723), and 4) calcifications (OR 2.38, CI 1.424-3.976).
Conclusions. A trend for increased Achilles tendon thickness was noticed in diabetic patients, especially those with peripheral neuropathy. When compared to healthy subjects, patients with diabetes expressed greater morphological changes in the form of tendon fiber disorganization, calcifications, and enthesopathies. Such anomalies could increase the risk of Achilles rupture, falls and the development of diabetic foot ulcers.

KEY WORDS
Achilles tendon; diabetes mellitus; diabetic neuropathies; ultrasound; magnetic resonance imaging.

INTRODUCTION

Diabetic foot, a major manifestation of diabetes mellitus, is characterized by peripheral neuropathy, and is at risk of diabetic foot ulceration (DFU) (1, 2). DFU is a major source of morbidity, and it is estimated that 50-70% of all lower limb amputations are due to DFU (3). Besides the presence of peripheral neuropathy, altered gait mechanics in patients with diabetes are known to be risk factors for DFU (4).

Patients with diabetes, especially diabetic neuropathy, experience altered range of movement at the joints, one of which is reduced motion at the ankle in dorsiflexion and plantar flexion, resulting in reduced walking speed, cadence and step length (4, 5). Possible explanations have been sought, and the current concepts range from central and autonomic dysfunction to motor neuropathy and soft tissue alterations (4-6).

In addition, during locomotion and propulsion in actions such as walking, running, and jumping, the gastrocnemius-soleus complex translates forces through the Achilles tendon (AT) to allow for plantar flexion of the foot (4, 7). Studies showed an altered leverage around the ankle during walking in people with diabetes due to a reduced AT length and moment arm length (8, 9). It has been demonstrated that tendons of patients with diabetes exhibited a significant inferior biomechanical profile over non-diabetic tendons (10, 11). In mouse models, diabetes induced substantial alteration in AT mechanical properties (12) and similarly following tenotomy (13).

In people living with diabetes, advanced glycation end products have deleterious effects on the biological and mechanical effects of the tendons and ligaments throughout the body, resulting in stiffness and chronic tendinopathy (14, 15). Hence, with such an important role in gait, AT function is of interest, and several studies throughout the literature attempted to characterize the change in AT function in diabetes. Biomechanical studies tend to show an increased stiffness and decreased elongation of the AT with increased plantar pressure during gait in people with diabetes (8, 16). In addition, a community-based case-control study showed that there was a 44% greater likelihood of hospitalization for any tendon rupture in subjects with Type 2 diabetes than in those without (17).

The aim of this meta-analysis is therefore to report evidence-based morphological differences of the AT between healthy patients and patients living with diabetes with or without peripheral neuropathy.

MATERIALS AND METHODS

Search strategy

A systematic electronic search was conducted through a number of databases such as PubMed, Scopus, Google Scholar and the Cochrane Library from 1997 to June 1st, 2021. The combination of keywords such as [Achilles AND Diabetes AND (ultrasound OR MRI)] were used. The references of the deemed relevant papers were checked. All included articles were citation-tracked using Google Scholar to ensure that all relevant articles were identified. Duplicates were deleted. The PRISMA guidelines were followed during the preparation of this meta-analysis (18).

Criteria for study selection

Articles that were deemed irrelevant to the study aim were excluded. Systematic reviews, case series, and all animal model studies were excluded. Included were only retrospective or prospective case-control or randomized control trials that compared AT changes between healthy people (control group) and people with diabetes mellitus (DM group) or with people having diabetic neuropathy (DN group). Methods of investigation were limited to ultrasound and MRI.

Quality appraisal

The Joanna Briggs Institute (JBI) critical appraisal checklist for case control studies was used to evaluate the quality of the included studies (19).

Study outcomes

The searched outcomes were set as follows: AT thickness, any pathological change in AT gross structure at any level (proximal, middle or distal) such as fiber disorganization, tendinopathy, calcifications or enthesopathy.

Data extraction

Data extraction included sample size, both according to individuals and number of tendons, grouped into healthy controls and diabetic subjects with and without peripheral neuropathy. Included as well were the patient demographics, type and duration of diabetes, HbA1C, average body mass index (BMI), as well as tendon morphological changes and pathological findings.

Data analysis

The software StatsDirect (Cambridge, UK) was used for statistical analysis. Continuous variables were expressed in means ± standard deviation (SD). Univariate and multivariate analysis tests were used to look for differences in pooled means between groups. Weighted proportions were yielded using proportion meta-analysis. Heterogeneity was assessed via the I^2 statistic; whenever the I^2 value was superior to 50%, the random-effect value was reported.

RESULTS

Search results

The search yielded 101 results and 4 duplicates were deleted. After title and abstract checking, 36 articles were scrutinized for eligibility. Seventeen papers were excluded: 11 biomechanical studies, 7 using x-rays and 1 study comparing diabetic patients with and without ulcers. In total, 17 studies were retained for analysis (20-36). **Figure 1** shows the flowchart of study identification.

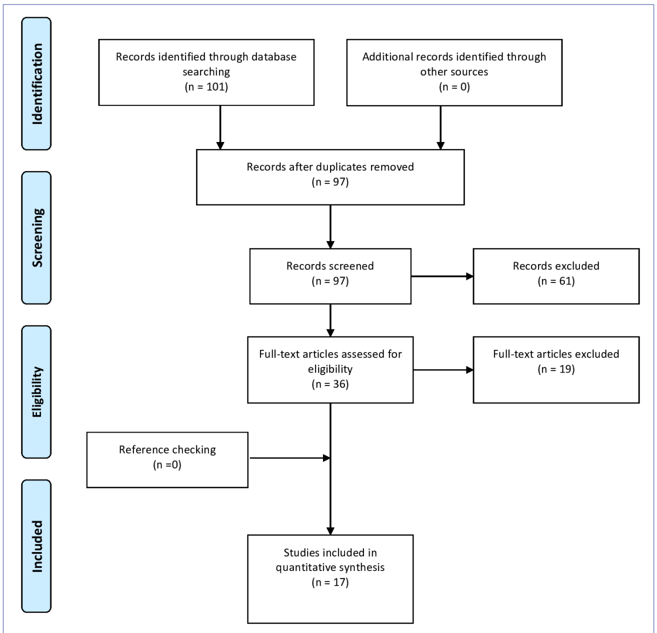

Figure 1. PRISMA flow diagram.

Modified from: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009;6(7):e1000097. doi: 10.1371/joumal.pmed1000097 (18).

Study characteristics results

The 17 studies comprised 2,938 subjects including 1,791 controls, 940 with DM and 211 with DN. The total number of studied tendons in the sample was 5,822. The mean age of the whole pooled sample was 59.7 ± 8.6 years with no statistical difference between the 3 groups. The population sum was divided almost equally based on sex, with 48% males and 52% females with no statistical difference between the 3 groups.

All studies but Papanas *et al.* (20) used ultrasound imaging for AT evaluation. Thirteen studies (22-30, 33-35) reported the mean BMI of their samples with pooled values of 25.8 ± 2 .3, 27.5 ± 2 and 27.5 ± 2.1 kg/m^2 for healthy and DM and DN groups, respectively. The mean duration of DM was of 8.5 ± 4.2 and 12.7 ± 3.7 years for the DM and DN groups, respectively. The mean values of HbA1c were of 7.6 ± 0.7 and 8.1 ± 1.6 years for the DM and DN groups, respectively. **Table I** summarizes patients' characteristics.

Study quality results

Out of a maximum of 10, the mean JBI score for the included studies was 8.6 ± 0.9.

Outcomes

AT thickness

The results of AT thickness are shown in **table II**. Ten studies showed the increasing trend of AT thickness in DM and DN patients, 6 studies reported statistically significant differences between DM and DN with the respective controls, and 3 studies stated no statistical significance between DM and control groups. One study (20) used MRI for Achilles thickness measurements with a significant difference only between DM and control groups ($p = 0.01$). For the remaining "ultrasound studies", there was a trend towards higher thickness in patients of DM group and particularly DN group when compared to healthy subjects, but the difference did not reach significance (**table III**).

AT morphological changes and pathological findings

Based on 8 studies (3,038 tendons in control group and 1,396 tendons in DM group), the weighted proportions of the overall AT morphological changes were 19.5% (95%CI 0.126-0.275, I^2 = 93.5%) and 45.8% (95%CI 0.287-0.633, I^2 = 97.7%) for the control and DM groups, respectively, with an OR of 3.5 (95%CI 2.970-4.181, I^2 = 37%, $p < 0.0001$).

Six studies reported AT fiber disorganization comprising 384 and 584 tendons in control and diabetic groups respectively. The weighted proportions were 12.2% (95%CI 0.091-0.156, I^2 = 31%) and 42.5% (95%CI 0.163-0.712, I^2 = 98%) with an OR of 3.48 (95%CI 2.291-12.184, I^2 = 75%, $p < 0.0001$).

Six studies reported the frequency of tendinopathy if hypo or hyperechoic foci were present, totalizing 2,930 control tendons and 1,160 diabetic tendons. The weighted proportions were 8% (95%CI 0.049-0.119, I^2 = 84.5%) and 25.5% (95%CI 0.195-0.320, I^2 = 82.3%) with an OR of 3.5 (95%CI 2.934-4.333, I^2 = 0%, $p < 0.0001$).

Two studies reported the presence of enthesopathy, totalizing 626 control tendons and 358 diabetic tendons. The weighted proportions were 22.5% (95%CI 0.047-0.873, I^2 = 99%) and 40.8% (95%CI 0.0004-0.958, I^2 = 99%) with an OR of 4.08 (95%CI 1.130-14.723, I^2 = 84.8%, $p = 0.03$).

Four studies reported the presence of calcifications, totalizing 382 control tendons and 540 diabetic tendons. The weighted proportions were 6.4% (95%CI 0.006-0.175, I^2 = 91%) and 13.4% (95%CI 0.043-0.2367, I^2 = 93.7%) with an OR of 2.38 (95%CI 1.424-3.976, I^2 = 48.5%, $p = 0.0008$).

Table IV shows details of ultrasound findings in relation with AT morphological changes and pathological findings. **Figure 2** shows the Odds Ratio forest plots of the AT morphological changes and pathological findings.

Table I. Characteristics of the included studies.

Study	Sample patients	Sample tendons	Groups (patients)			Groups (tendons)			Average age (years)			Gender (Males, %)			Average BMI (kg/m²)			Diabetes type	Mean duration of diabetes (years)	
			C	DM	DPN	C	DM	DPN	C	DM	DPN	C	DM	DPN	C	DM	DPN		DM	DPN
Giacomozzi *et al.* 2005	82	164	21	27	34	42	54	68	56.6	52.7	55.5	13 (62%)	19 (70%)	20 (58%)	25	25.3	27.25	1 and 2	15.1	18.2
Akturk *et al.* 2007	89	178	34	55	-	68	110	-	52.24	55	-	21 (61.7%)	29 (52%)	-	27.5	28.5	-	2	10.3	-
Batista *et al.* 2008	80	160	10	70	-	20	140	-	67	65	-	-	29 (41.4%)	-	-	-	-	2	11	
Papanas *et al.* 2009	54	54	16	19	19	16	19	19	61.6	63.6	63.9	8 (50%)	9 (47%)	9 (47%)	-	-	-	2	12.1	10.7
Abate *et al.* 2012a	1186	2372	993	193		1986	386	-	69.1	68.6	-	95 (43%)	48 (46%)	-	23.6	24.7	-	2	-	-
Abate *et al.* 2012b	69	138	18	51	-	36	102	-	68.5	69.1	-	9 (50%)	24 (47%)	-	23	27.9	-	2	0.58	-
Chieng *et al.* 2013	64	128	32	23	9	64	46	18	59.8	63.9	65.3	9 (28%)	5 (26%)	5 (55%)	23.7	24.6	28	2	10.4	10.7
Abate *et al.* 2014	409	818	273	136	-	546	272	-	63.9	64.6	-	124 (45%)	61 (44%)	-	23.9	25.7	-	1 and 2		-
Evranos *et al.* 2015	111	222	33	43	35	66	86	70	57.1	55.7	59.3	10 (30%)	19 (44%)	18 (51%)	26.6	26.5	25.7	2	6	15
de Jonge *et al.* 2015	92	184	44	48	-	88	96	-	35.4	36.5	-	22 (50%)	24 (50%)	-	24.9	28.1	-	1 and 2	9.4	-
Ursini *et al.* 2017	83	166	40	43	-	80	86	-	58.4	60.8	-	21 (52.5%)	25 (58.1%)	-	28.6	29.2	-	2	11	-
Afolabi *et al.* 2019	160	320	80	23	57	160	46	114	61	60.9	-	30 (42.5%)	34 (37.5%)	-	25.92	25.1	-	2	3.5	-
Lyldir *et al.* 2018	75	150	30	23	22	60	46	44	58.4	59.9	63.3	9 (30%)	10 (43.5%)	6 (27%)	30.3	31.7	31.5	2	8	9
Coombes *et al.* 2019	40	80	7	33	-	14	66	-	55.6	58.6	-	1 (14.3%)	19 (57.6%)	-	27	33.4	-	2	12.5	-
Afolabi *et al.* 2020	160	320	80	80	-	160	160	-	61	60.9	-	34 (42.5%)	30 (37.5%)	-	-	-	-	2	3.5	-
Harish *et al.* 2020	142	284	61	50	31	122	99	55	30-77	30-88	-	35 (57.8%)	41 (50.62%)		-	-	-	2	5.76	
Kuo *et al.* 2020	42	84	19	23	-	38	46	-	65	65	-	10 (53%)	12 (52%)	-	-	-	-	2	9.5	-

C: control; DM: diabetes mellitus ; DN diabetic neuropathy.

Table II. Results of characteristics of Achilles tendon.

Study	Imaging	Portion of AT examined	AT Thickness (mm)			% of AT morphological changes on US*	
			Control	DM	DN	Control	DM
Giacomozzi *et al.* 2005	US	Distal	4 ± 0.5	4.6 ± 1.0	5.05 ± 1.7	-	-
Akturk *et al.* 2007	US	Middle	4.65 ± 0.67	5.16 ± 0.67	-	-	-
Batista *et al.* 2008	US	Middle	5.9	5 ±0.8	-	24.30%	88.60%
Papanas *et al.* 2009	MRI	Middle	6.7 ± 1.4	7.4 ± 1	7 ± 1.1		
Abate *et al.* 2012	US	-	-	-	-	26.80%	68.30%
Abate *et al.* 2012	US	Middle	4.0 ± 0.3	5.23 ± 0.8	-	13.80%	34.30%
Chieng *et al.* 2013	US	Distal	6.1 ± 0.8	6.9 ± 1.0	8.3 ±1.3	-	-
Abate *et al.* 2014	US	Middle	-	-	-	11.70%	25.70%
Evranos *et al.* 2015	US	Proximal	1.8 ± 0.2	1.9 ± 0.3	2.1 ± 0.8	-	-
		Middle	4.5 ± 0.7	4.7 ± 0.6	5.2 ± 0.6		
		Distal	4.2 ± 0.6	4.6 ± 0.7	5.2 ± 0.7		
de Jonge *et al.* 2015	US	Middle	-	-	-	7.25%	11.80%
Ursini *et al.* 2017	US	Distal	4.2 ± 0.8	4.4 ± 1.1	-	57.50%	74.40%
Afolabi *et al.* 2018	US	Middle	4.6 ± 0.56	5.04 ± 0.55	6.1 ± 0.65	-	-
Lyldir *et al.* 2018	US	Middle	4.6 ± 0.75	5 ± 0.75	5.1 ± 0.8	-	-
Coombes *et al.* 2019	US	Middle	4.6 ± 0.15	5.3 ± 0.3	-	-	-
		Distal	3.8 ± 0.07	4.3 ± 0.2	-	-	-
Afolabi *et al.* 2020	US	Distal	-	-	-	15%	43%
Harish *et al.* 2020	US	Proximal	2.89 ± 0.6	3.29 ± 0.71	3.12 ± 0.79	17.9%	44%
		Middle	4.41 ± 0.61	4.72 ± 0.77	4.81 ± 0.7		
		Distal	3.91 ± 0.58	4.60 ± 0.98	4.52 ± 0.98		
Kuo *et al.* 2020	US	Middle	5.1 ± 0.8	4.9 ± 0.9	-	-	-

DM: diabetes mellitus group; DN: diabetic neuropathy group; US: ultrasound; AT: Achilles tendon.

Table III. Thickness outcome pooled results (in mm).

Achilles level	n of studies	n of tendons	Mean thickness control	Mean thickness DM	Mean thickness DN	P-values*
Proximal	2	498	2.34 ± 0.8	2.6 ± 1	2.6 ± 0.7	0.8/0.7**
Middle	9	3,842	4.9 ± 0.8	5.3 ± 0.8	5.3 ± 0.5	0.18/0.1**
Distal	6	1,040	4.3 ± 0.9	4.9 ± 1	5.7 ± 1.7	0.17/0.18**

*P-values of univariate regression analysis; **value between control and DM groups/value between control and DN groups.

Table IV. Details of Ultrasound Abnormalities.

Study	AT abnormality on US		Disorganization of AT fibers		Tendinopathy/hypo-hyperechoic foci		Enthesopathy		Calcifications	
	Control	DM	Control	DM	Control	DM	Control	DM	Control	DM
Batista *et al.* 2008	8/20 (40%)	124/170 (88.6%)	2/20 (10%)	124/170 (88.6%)	-	-	-	-	6/20 (30%)	32/170 (24.3%)
Abate *et al.* 2012	262/993 (26.8%)	132/193 (68.3%)	-	-	262/993 (26.8%)	132/193 (68.3%)	-	-	-	-
Abate *et al.* 2012	5/36 (13.8%)	35/102 (34.3%)	5/36 (13.8%)	35/102 (34.3%)	5/36 (13.8%)	35/102 (34.3%)	-	-	-	-
Abate *et al.* 2014	45/546 (8.2%)	60/272 (22%)	-	-	45/546 (8.2%)	60/272 (22%)	9/546 (1.6%)	32/272 (11.7%)	-	-
de Jonge *et al.* 2015	6/88 (6.8%)	12/96 (12.5%)	6/88 (6.8%)	12/96 (12.5%)	-	-	-	-	-	-
Ursini *et al.* 2017	46/80 (57.5%)	64/86 (74.4%)	7/80 (8.8%)	21/86 (24.4%)	2/80 (2.5%)	23/86 (26.7%)	46/80 (57.5%)	64/86 (74.4%)	0/80 (0%)	3/86 (3.5%)
Afolabi *et al.* 2020	30/160 (18.7%)	86/160 (53.75%)	26/160 (16.25%)	84/160 (52.5%)	10/160 (6.2%)	31/160 (19.4%)	-	-	2/160 (1.2%)	9/160 (5.6%)
Harish *et al.* 2020	19/123 (15.4%)	68/166 (41%)	-	-	6 (4.9%)	27 (17.5%)	-	-	13 (10.6%)	41 (26.6%)

DISCUSSION

Main findings

The AT tendon seems to be thicker among people with diabetes. Many morphological and pathological changes were significantly higher than in healthy patients, namely fiber disorganization, tendinopathy, enthesopathy and calcifications.

AT thickness

The general trend was an increase in average AT thickness between diabetic patients with or without neuropathy and healthy controls. This trend however was not observed in one study (21) in which the control group had higher AT thickness than the DM group. However, this article could be criticized for selection bias, in which the DM group had 70 patients while the control group had only 10. Another study (22) revealed statistical significance only in DN *vs* controls.

AT thickness has been hypothesized to alter gait mechanics by increasing energy expenditure during gait (9), as well as decreasing calf muscle endurance and increasing patient-related symptoms during gait in patients with Achilles Tendinopathy (37). Therefore, further studies are definitely in need to better quantify this outcome.

Despite the difference in location measurement, the AT thickness remained trending towards an increase in DM and particularly in DN group. Perhaps different measures at different locations, including proximal, middle and distal AT should be taken into consideration in future studies to maximize the efficacy of the results. The introduction of the MRI could have an added value as well for its excellent modality of structure delineation (20). It might be more relevant for future research to measure the maximal thickness of AT for better accuracy of this anatomical change. Using this method, Papanas *et al.* (20) found significant thickness difference between both groups via MRI measurements.

Clinical relevance of morphological and pathological changes

The overall AT morphological changes and in particular fiber disorganization were 3.5 and 5.3 times higher, respectively, in DM group compared to healthy people. Tendinopathy (OR 3.5), enthesopathy (OR 4.08), and calcifications (OR 2.38) were also significantly higher. An epidemiological study reported that AT calcification and insertional AT radiological calcifications were significantly higher in people with DM compared to those without DM, with an OR of 3 (38). Another study found that DM can strongly affect post-operative outcomes following surgical repair of acute Achilles tendon tears (39).

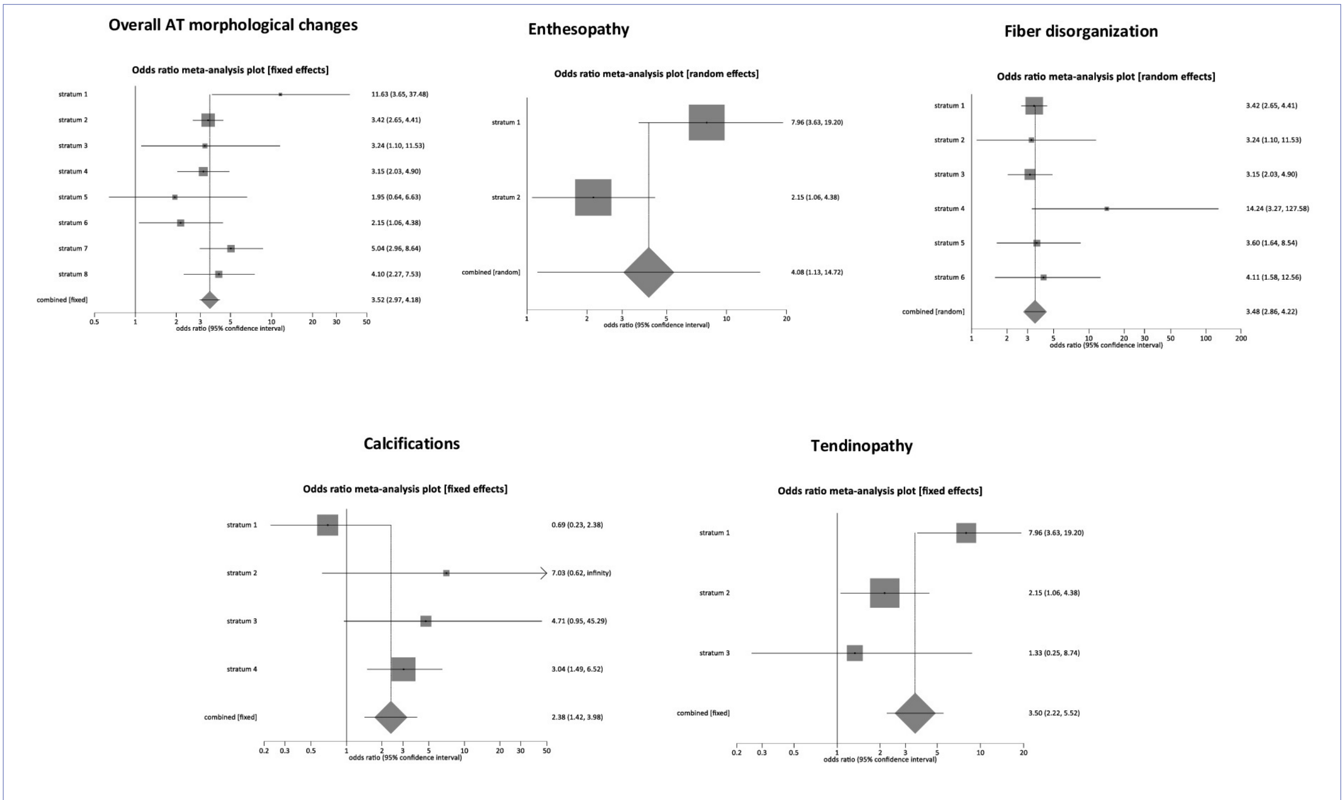

Figure 2. Odds ratio plots.

Additionally, tendon's mechanical properties are determined by the collagen fiber organization which is extremely important for the tendon's ability to adapt to the loading environment (40). Any disruption of these mechanical properties through disorganization of the collagen fibers or disruption by materials such as calcifications can be detrimental to the function of the tendon (40). It has been demonstrated that a persistent state of hyperglycemia could affect the crosslink reaction between collagens and advanced glycosylation end-products, inducing disruption of tendon homeostasis and rupture (41). Therefore, our findings would imply that the AT could be at a higher risk of rupture in this population.

On the other hand, Couppé *et al*. demonstrated that AT modulus, which represents the material stiffness after accounting for tendon dimensions, was higher in diabetic patients compared with controls (17). Petrovic *et al*. reported that AT in people with diabetes and particularly people with diabetic peripheral neuropathy was stiffer and less elongated (9). The degree to which a tendon stretches depends upon many factors such as tendon's tensile stiffness (42). Stiffness in the triceps surae muscle and tendon is thought to be largely responsible for equinus in patients with diabetes which could induce a reduction of its stretching ability thus, restricting dorsiflexion of the ankle joint (43). These changes would lead to a less flexible AT and thought to play a role in the development of plantar ulcers, stress fractures, and even Charcot foot in patients with diabetic neuropathy (17, 44). An increased stiffness and shorter length of the tendon placing the ankle in plantar flexion and resulting in excessive pressure over the metatarsal heads might worsen the deleterious effect of diabetic neuropathy of the foot. Such combination of local hyper-pressure and consequences of peripheral neuropathy would increase the risk of diabetic ulcers in this population.

Limitations

A number of limitations could be noted in this study. Ultrasound values are operator dependent, entailing risk of publication bias. Furthermore, levels for measurements, be it proximal, middle or distal, were rarely defined with no report of reference point. Therefore, the reported values might be affected by the lack of a standard method. Fiber disorganization was not quantified with a scoring system based on the severity of the disorganization. Furthermore, the diagnostic criteria for tendinopathy were not always defined. However, Ranger *et al*. demonstrated greater prevalence of tendinopathy in people with diabetes than controls (OR 3.84) where many tendons were included in their meta-analysis (45). Few studies did not report diabetes duration. However, the mean duration of those reporting this variable was between 8 and 12 years, and that is in line with other studies which found greater duration of diabetes in participants with both diabetes and tendinopathy (of AT and other tendons) compared to those with diabetes but not tendinopathy (45). Four studies did not report the BMI of their samples with the remaining 11 studies showing a pooled men BMI of 27 and 28 kg/m^2 for the DM and DN groups, respectively. Knowing that tendinopathy could be associated with adiposity, BMI may be a possible confounder that could have impacted our result (46-48).

Implication for practice

Our findings would have implications in the management of diabetic foot. A stiff AT mediated by the pathological changes would shorten the tendon and consequently place the foot in equinus position. The resulted great pressure on the metatarsal heads would favor the development of plantar ulcers. Thus, our findings could add support to the rationale behind the use of some specific techniques when treating DFUs. Restoring tendon length, and consequently rectifying ankle equinus, would relieve the pressure and favor wound healing. In fact, it has been demonstrated that AT lengthening or gastrocnemius recession are effective surgical treatments when treating diabetic forefoot plantar wounds (48). Additionally, and since the risk of rupture could be higher with the presence of tendinopathy, our findings would suggest the need for careful monitoring during sport activity or rehabilitation of lower limbs in patients with diabetes.

Implication for research

A reference structure, such AT insertion onto the calcaneal tuberosity, is needed for a standardization of the measurement method for AT thickness. Therefore, the different levels could be better defined. Creating a scoring system for fiber disorganization would be of importance to better assess the severity of this outcome. Additionally, it is of interest to investigate in the future any correlation between the presence of those morphological/pathological changes and the development of ankle equinus, which reflects a higher stiffness induced by these changes.

CONCLUSIONS

Diabetes mellitus induces alteration of the structure of the Achilles tendon. Our review shows a trend for increased thickness of the tendon especially in those with peripheral neuropathy. Furthermore, a significant increase of morphological changes was demonstrated, mainly in the form of fiber disorganization, calcifications, and enthesopathies. These morphological changes could generate higher stiffness and may play an important role in the development of plantar foot ulceration, altered gait with risk of falls along with higher risk of tendon rupture.

FUNDINGS

None.

DATA AVAILABILITY

All data used in this review is appropriately cited.

CONTRIBUTIONS

KY: formulation of research idea. KY, ED: data extraction. KY: data analysis. KY, ED, CA: manuscript writing and reviewing.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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Calcium is Involved in Necroptosis Through the Expression of Phospho-MLKL in Skeletal Muscle Cell in Mice

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SUMMARY
Necroptosis is programmed cell death similar to necrosis, which is mediated by meticulous protein interactions such as those in apoptosis. Essentially, because it is a reaction to inflammation, necroptosis functions similarly to apoptosis and it is thought that necroptosis is an alternative cell death pathway when apoptosis cannot function for some reason. However, the research history of necroptosis is brief, and although there are various studies, many aspects are unknown. Here, we found that calcium was an essential factor for necroptosis in a muscle cell line. After verifying necroptosis was functional in mouse skeletal muscle cell line C2C12, we found suppression of necroptosis by controlling the amount of calcium in the culture medium. Furthermore, the reduced necroptosis was rescued by adding calcium to the culture medium. However, the recovery did not occur when magnesium or sodium was added to the medium. Next, we suppressed certain calcium transporters using inhibitors. Necroptosis was inhibited by reducing the amount of intracellular calcium. These results showed that necroptosis was controlled by the amount of calcium. This finding may facilitate development of new treatment methods for various muscle diseases that involve cell death.

KEY WORDS
Calcium; necroptosis; p-MLKL; C2C12; skeletal muscle.

INTRODUCTION

Cell death is a general and important biological function that is conserved widely among most organisms, in which inflamed or abnormal cells die spontaneously and are replaced by new normal cells. There are several kinds of cell death (1). Among them, apoptosis is the most thoroughly studied. Necroptosis occurs by breaking cell membranes. Pyroptosis is seen after infection by bacteria or viruses. Ferroptosis involves iron and autophagy is a "self-eating system" in which cell contents are transported to lysosomes for degradation.

In this study, we focused on necroptosis. Necroptosis is a type of necrosis, but the molecular mechanism is meticulously controlled by protein interactions and phosphorylation. It is cell death in a defense system against inflamed cells and is thought to function when apoptosis cannot operate. After inhibition of apoptosis, Caspase-8 recruits Receptor-interacting protein kinase (RIPK) 1 and necroptosis begins. RIPK1 binds to RIPK3, serine 231 and tyrosine 232 of RIPK3 are phosphorylated, and then necroptosis is activated. Phosphorylated RIPK3 binds to mixed lineage kinase domain-like protein (MLKL). After serine 345 in mouse MLKL or serine 358 in human MLKL is phosphorylated, MLKL is activated by binding to Inositol phosphate (IP6) (2, 3). Activated MLKL is phosphorylated at tyrosine 363 by Tyro3/Axl/Mer receptor tyrosine (TAM) kinase and moves to the plasma membrane (4). MLKL oligomerizes at the plasma membrane to form pores. The cell then dies from cytosol escaping from the pores. Interestingly, protein synthesis continues in the dying cell. The cell produces proteins involved in inflammation and signals the condition to other cells, which is then targeted by macrophages (5).

In this study, we focused on the importance of calcium in necroptosis. Calcium is a representative second messenger with various roles in apoptosis and axon signaling between nerve cells (6, 7). Most general roles involve bone growth and muscle contraction by release from the sarcoplasmic reticulum. However, many aspects are unknown in the relationship between calcium and necroptosis. Although some studies have examined neuroblastoma and colon cancer (8, 9), few studies have investigated muscle cells. In this study, we found that calcium was involved in necroptosis of muscle cells. Calcium was indirectly involved by regulating the expression of phosphorylated MLKL (p-MLKL). This is a great success that we could understand the calcium-working area in necroptosis and make it narrow. Our results provide novel insights into muscle cells and may provide new approaches to identify causes of muscle diseases or discover drugs.

MATERIALS AND METHODS

Cell culture and differentiation

Mouse skeletal muscle cell line C2C12 was prepared as described previously (10). DMEM (Thermo Fisher Scientific, Waltham, MA) with 10% FBS (Biosera, Kansas, MO) and 1% penicillin/streptomycin (Wako, Osaka, Japan) was used as culture medium. For differentiation, DMEM or DMEM without calcium (Thermo Fisher Scientific) with 2% horse serum (Thermo Fisher Scientific) was used. One day after passaging cells, the culture medium was changed to medium with horse serum. Three days after changing the medium, the medium was renewed. Six days after passaging, reagents that referred in Figure Legends were added to the medium. One day after adding reagents, the cells were harvested and used for experiments.

Western blotting

Western blotting was performed as described previously (11) using C2C12 cell lysates treated with reagents that referred in figure legends. To detect phospho-proteins, Immobilon Signal Enhancer (Merck, Darmstadt, Germany) was used. Anti-rabbit-p-MLKL (S345) (1:1000) (Abcam, Cambridge, UK), anti-rabbit-p-CaMKII (1:500) (ABclonal, Wuhan, China), and anti-rabbit-GAPDH (1:2000) (Eurofin genomics, Tokyo, Japan) antibodies were used as primary antibodies and GAPDH was detected as a loading control. An anti-rabbit IgG antibody (1:1000) (CST, Danvers, MA) was used as a secondary antibody. Detection was performed by a LAS 4000mini (GE Healthcare, Chicago, IL).

PI assay

A propidium iodide (PI) assay was performed as described previously (12). PI was purchased from Nacalai Tesque (Kyoto, Japan). Fluorescence was detected by a microplate reader (Synergy H1, BioTek, Winooski, VT).

Intracellular calcium measurement

Intracellular calcium measurement was performed using a Calcium Kit-Fluo4 (Dojindo, Kumamoto, Japan) in accordance with the manufacturer's protocol. After differentiation, reagents that referred in figure legends were added to cells. One day later, the cells were re-plated in a 96-well plate. One day after re-plating, calcium measurement was performed. Fluorescence was detected by the microplate reader (Synergy H1, BioTek).

RESULTS

Necroptosis induction in C2C12 cells

To confirm that necroptosis occurs in muscle cells, we performed two experiments. First, we detected expression of p-MLKL, a typical marker of necroptosis. Because necroptosis is an alternative cell death pathway when apoptosis is inhibited, inhibition of Caspase expression is needed for necroptosis to occur (13). To induce inflammation in cells for cell death induction, cells were treated with Tumor necrosis factor α (TNFα) and zVAD-fmk (zVAD), a pan-caspase inhibitor. When cells were treated with TNFα only, p-MLKL expression was low. However, when cells were treated with both TNFα and zVAD, p-MLKL expression was high (**figure 1B**). The difference in expression was significant (**figure 1C**). Apoptotic cells die from DNA breakages, whereas necroptotic cells die from breakage of their plasma membrane and cytosol escape (14). Next, we measured the fluorescence intensity of propidium iodide (PI) that is used to evaluate necrosis-like cell death because PI enters cells through the broken plasma membrane. Compared with cells treated with TNFα only, significantly more cells had a damaged plasma membrane when treated with both TNFα and zVAD (**figure 1A**). Thus, we induced necroptosis in differentiated C2C12 cells.

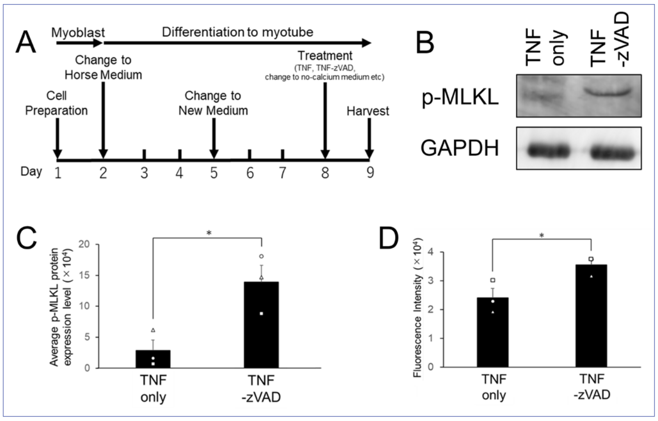

Figure 1. Necroptosis induction in C2C12 cells.

(A) Scheme of experiment; **(B)** Western blotting was performed using C2C12 cells. The cells were treated with 1.5 nM TNFα with or without 18 μM zVAD. P-MLKL was detected and GAPDH was used as a loading control; **(C)** Western blotting in **(A)** was quantified by ImageJ. The experiment was repeated three times (n = 3). Error bars are the standard error and significance was evaluated by Student's t-test (*$p < 0.05$). Experiments were performed in triplicate. Circle dots show 1st trial, triangle dots show 2nd trial and square dots show 3rd trial; **(D)** Fluorescence of propidium iodide (PI) was measured in C2C12 treated with 1.5 nM TNFα with or without 18 μM zVAD. The experiment was repeated three times (n = 3). Error bars are the standard error and significance was evaluated by Student's t-test (*$p < 0.05$). Experiments were performed in triplicate. Circle dots show 1st trial, triangle dots show 2nd trial and square dots show 3rd trial.

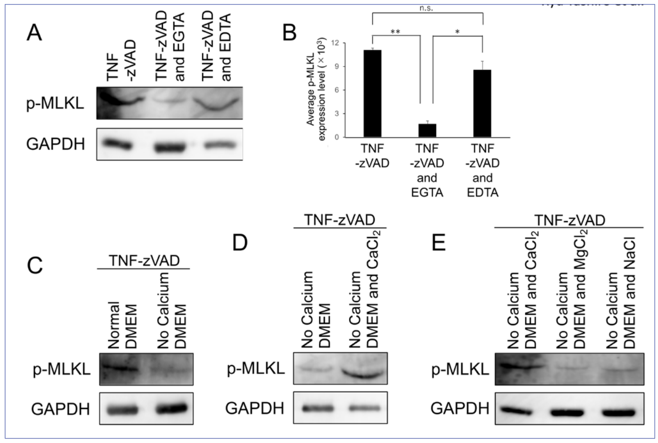

Figure 2. Calcium is involved in necroptosis by controlling p-MLKL expression.

(A) Western blotting was performed using C2C12 cells. The cells were treated with 1.5 nM TNFα and 18 μM zVAD with or without 10 mM EGTA or EDTA. P-MLKL was detected and GAPDH was used as a loading control; **(B)** Western blotting in **(A)** was quantified by ImageJ. The experiment was repeated three times (n = 3). Error bars are the standard error and significance was evaluated by Student's t-test (n.s. = no significance, *$p < 0.05$, **$p < 0.01$); **(C)** Western blotting was performed using C2C12 cells. The cells were treated with 1.5 nM TNFα and 18 μM zVAD in DMEM with or without calcium. P-MLKL was detected and GAPDH was used as a loading control; **(D)** Western blotting was performed using C2C12 cells. The cells were treated with 1.5 nM TNFα and 18 μM zVAD in calcium-free DMEM with or without 4 mM $CaCl_2$. P-MLKL was detected and GAPDH was used as a loading control; **(E)** Western blotting was performed using C2C12 cells. The cells were treated with 1.5 nM TNFα and 18 μM zVAD in calcium-free DMEM with or without 4 mM $CaCl_2$, 4 mM $MgCl_2$, and 4 mM NaCl. P-MLKL was detected and GAPDH was used as a loading control.

Calcium is involved in expression of p-MLKL, a major factor in necroptosis

Calcium is involved in almost the entire process of necroptosis and acts after phosphorylation of RIPK1, a necrosome factor (8, 9). Therefore, we detected necroptosis after the calcium amount was controlled by treating the cells with various reagents. First, we trapped metal ions in culture medium using chelators, namely EDTA and EGTA. As a result, when EDTA was used as a chelator, p-MLKL expression was unchanged. However, when EGTA was used, p-MLKL expression was decreased drastically (**figure 2A**) and the difference was significant (**figure 2B**). Next, we used culture medium without calcium. As a result, there was low p-MLKL expression in cells cultured in the medium without calcium (**figure 2C**). Next, we confirmed whether this effect was rescued by adding calcium to the medium. we added 4 mM $CaCl_2$ to the medium and found that the decreased p-MLKL expression was rescued by supplementing calcium (**figure 2D**). To examine whether the decreased p-MLKL expression was rescued by other metal ions, we added 4 mM $MgCl_2$ and 4 mM NaCl to the medium without calcium and then measured p-MLKL expression. As a result, magnesium and sodium could not rescue the decreased p-MLKL expression (**figure 2E**). Therefore, calcium was involved in necroptosis.

Intracellular calcium is not increased during necroptosis

Calcium was involved in necroptosis, and therefore we measured intracellular calcium in variously treated cells. Interestingly, intracellular calcium after treating cells with both TNFα and zVAD was significantly decreased compared with that in cells treated with TNF only (**figure 3A**). However, because cells die from plasma membrane breakage during necroptosis, it was highly possible that calcium had escaped from the pores in the plasma membrane. we hypothesized that lost calcium was restored by calcium outside of the cells. Therefore, we added 4 mM $CaCl_2$ to the medium of cells treated with both TNFα and zVAD. Unexpectedly, there was no difference in intracellular calcium after adding calcium (**figure 3B**). Additionally, western blotting showed no change in p-MLKL expression with or without calcium in cells treated with both TNFα and zVAD (**figure 3C**).

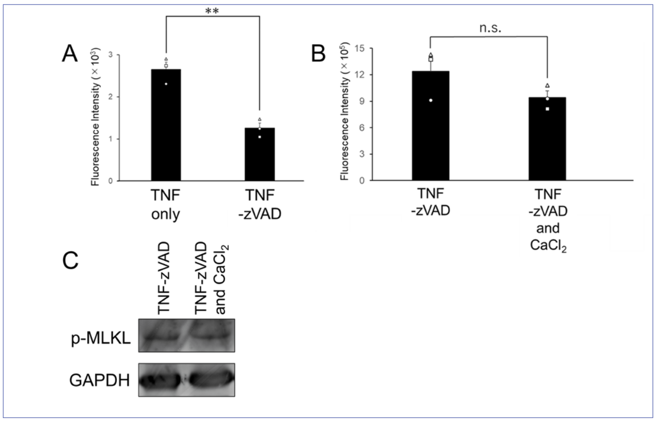

Figure 3. Intracellular calcium does not increase during necroptosis.

(A) Intracellular calcium was measured in C2C12 cells treated with 1.5 nM TNFα with or without 18 μM zVAD. The experiment was repeated three times (n = 3). Error bars are the standard error and significance was evaluated by Student's t-test (**$p < 0.01$). Experiments were performed in triplicate. Circle dots show 1st trial, triangle dots show 2nd trial and square dots show 3rd trial; **(B)** Intracellular calcium was measured in C2C12 cells treated with 1.5 nM TNFα and 18 μM zVAD with or without 4 mM $CaCl_2$. The experiment was repeated three times (n = 3). Error bars are the standard error and significance was evaluated by Student's t-test (n.s. = no significance). Experiments were performed in triplicate. Circle dots show 1st trial, triangle dots show 2nd trial and square dots show 3rd trial; **(C)** Western blotting was performed using the samples in **(B)**. C2C12 cells were treated with 1.5 nM TNFα and 18 μM zVAD with or without 4 mM $CaCl_2$. P-MLKL was detected and GAPDH was used as a loading control.

Inhibiting calcium transporters inhibited necroptosis of cells

It was highly possible that necroptosis was caused by calcium from outside of the cells. Although a large amount of calcium had escaped from the cells, calcium may have also simultaneously entered the cells. Therefore, we determined whether calcium entered the cells during necroptosis. A change in p-MLKL expression was examined when each calcium channel in the plasma membrane was inhibited. Three kinds of calcium channel inhibitors were added to the medium: benidipine, an L- and T-type calcium blocker (15), YM-58483 that suppresses Transient receptor potential channel activity (16), and MRS1845, an inhibitor of Orai1 that acts with STIM1 to detect a shortage of intracellular calcium in the endoplasmic reticulum (17). These channel proteins are all located in the plasma membrane. Therefore, all inhibitors we checked this time decreased p-MLKL expression (**figure 4A**). The decreases were significant with all three inhibitors (**figure 4B**). Next, we used 2,5-di-tert-butylhydroquinone, a SERCA inhibitor that detects calcium in the endoplasmic reticulum membrane and controls the intracellular calcium amount (18, 19). As expected, p-MLKL expression was decreased (**figure 4C**) and not rescued by 4 mM $CaCl_2$ in cells treated with MRS1845, YM58483, or 2,5-di-tert-butylhydroquinone (**figure 4D**). Thus, to induce necroptosis, controlling the amount of intracellular calcium is important, but we could not identify specific calcium transporters that are involved in necroptosis.

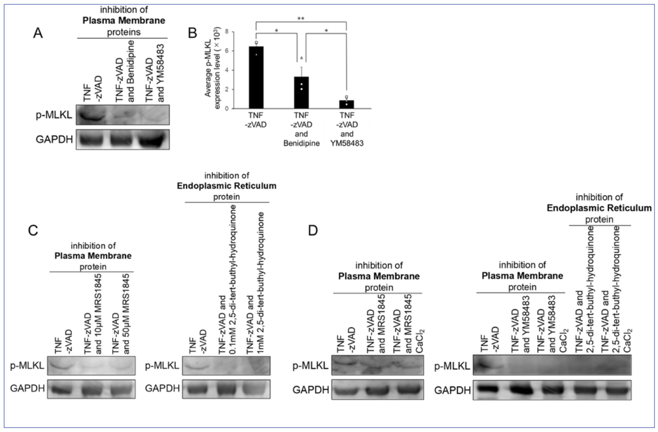

Figure 4. Four specific calcium transporters that have different mechanism could inhibit necroptosis.

(A) Western blotting was performed using C2C12 cells. The cells were treated with 1.5 nM TNFα, 18 μM zVAD, and 500 μM benidipine or 10 μM YM58483. P-MLKL was detected and GAPDH was used as a loading control; **(B)** Western blotting in **(A)** was quantified by ImageJ. The experiment was repeated three times (n = 3). Error bars are the standard error and significance was evaluated by Student's t-test (*$p < 0.05$, **$p < 0.01$). Experiments were performed in triplicate. Circle dots show 1st trial, triangle dots show 2nd trial and square dots show 3rd trial; **(C)** Western blotting was performed using C2C12 cells. The cells were treated with 1.5 nM TNFα, 18 μM zVAD, 1, 10, or 50 μM MRS1845, and 0.1 or 1 mM 2,5-di-tert-buthyl-hydroquinone. P-MLKL was detected and GAPDH was used as a loading control; **(D)** Western blotting was performed using C2C12 cells. The cells were treated with 1.5 nM TNFα, 18 μM zVAD, and 50 μM MRS1845, 10 μM YM58483, or 0.1 mM 2,5-di-tert-buthyl-hydroquinone with or without 4 mM $CaCl_2$. P-MLKL was detected and GAPDH was used as a loading control.

p-MLKL expression is synchronized to p-CaMKII expression

Calcium is involved in necroptosis through p-RIPK1 in cancer cells and its kinase is CaMKII (8). Next, I verified this in skeletal muscle cells. Phospho-CaMKII expression was also decreased in cells cultured without calcium and its expression was also rescued by adding $CaCl_2$ to the medium (**figure 5**). These results indicated that, at least in skeletal muscle cells and as shown in neuroblastoma (8), CaMKII may be the most upstream factor to induce necroptosis by calcium (**figure 6**).

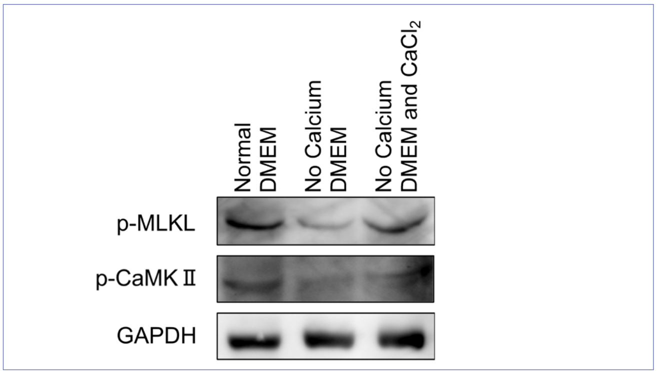

Figure 5. CaMKII might be involved in necroptosis of mouse skeletal muscle cells.

Western blotting was performed using C2C12 cells. The cells were treated with 1.5 nM TNFα and 18 μM zVAD in normal or calcium-free DMEM with or without 4 mM $CaCl_2$. P-MLKL and CaMKII were detected and GAPDH was used as a loading control.

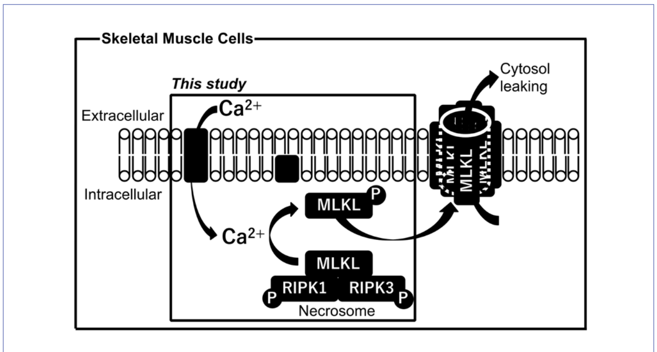

Figure 6. Proposed model in this study.

DISCUSSION

In this study, we found that calcium was needed for necroptosis in skeletal muscle. Previous studies have obtained similar results, but they all examined cancer cells (8, 9). This study focused on muscle cells. Although previous studies were performed using biochemical assays, the position where calcium is involved in necroptosis remained controversial. Here, from calcium in the cytosol to necroptosis, I found that calcium was involved in p-MLKL expression in skeletal muscle cells. This result showed that, at least in skeletal muscle cells, calcium is involved in the process before formation of the necrosome, the complex formed by RIPK1, RIPK3, and MLKL.

As shown in **figure 1**, we evaluated how necroptosis functions in C2C12 cells. Because few studies have examined p-MLKL expression by western blotting in C2C12 cells (20), this result showed that C2C12 cells are useful to study cell death mechanisms. Accordingly, few studies have focused on the relationships between muscle and necroptosis. In muscle cell research, it is common to perform *in vivo* analysis using mice. However, to analyze detailed molecular mechanisms, it is important to perform studies at the protein or cellular level. Our study showed the importance of using cultured cells for preliminary research and its significance for necroptosis.

As shown in **figure 2**, we revealed the importance of calcium in necroptosis. Reducing or eliminating calcium clearly decreased p-MLKL expression. This decreased expression was rescued by adding $CaCl_2$ to the medium. However, magnesium and sodium could not rescue the phenotype. These results showed that calcium was involved in necroptosis by phosphorylation of MLKL. Calcium is involved in necroptosis of cancer cells. However, the two studies of neuroblastoma and colon cancer presented different results on where calcium was involved. At least in skeletal muscle cells, we showed that calcium was involved in phosphorylation of MLKL, which demonstrated how calcium works throughout the whole necroptosis process.

Owing to the involvement of calcium and its import from outside cells, we determined how calcium entered the cells. There are various kinds of transporters to import calcium into cells. we inhibited single transporters and checked for downregulation of p-MLKL expression to determine whether the transporter was involved in necroptosis. Inhibitors of three transporters were employed and all of them reduced p-MLKL expression significantly. Therefore, to undergo necroptosis, it is essential to obtain calcium from outside cells, but the route to obtain calcium is irrelevant. Inhibition of SERCA, which is located at the endoplasmic reticulum and controls intracellular calcium, also decreased p-MLKL expression. In this experiment, calcium efflux occurred after TNFα and zVAD treatment and necroptosis (**figure 3A**). Additionally, calcium influx was not limited because there was no inhibition of calcium transporters in the plasma membrane. However, the endoplasmic reticulum stores calcium (21) and cells might not maintain the calcium concentration by SERCA inhibition. Accordingly, the intracellular calcium concentration may be reduced compared with the normal state. Therefore, the calcium involved in phosphorylation of MLKL was not obtained by cooperating with other proteins and calcium obtained extracellularly may be used.

There are two steps in MLKL phosphorylation. One is the phosphorylation introduced in this study and the other is phosphorylation by TAM kinase. The former is involved in necrosome formation, and the latter is involved in IP6 and polymerization, the last step to form pores in the plasma membrane. RIPK is a kinase, and when activated, it is involved in MLKL phosphorylation. On the basis of our results, calcium might be involved in the step from RIPK3 phosphorylation to MLKL phosphorylation. However, Nomura *et al.* (8) showed that the kinase of RIPK1 is CaMKII, which involves calcium. In their study, if intracellular calcium was limited, the cell survival rate increased and CaMKII activity decreased.

Additionally, because RIPK1 phosphorylation was reduced by ^{32}P in the *in vitro* kinase assay by inhibition of CaMKII, calcium was involved in RIPK1 phosphorylation. However, Sun *et al*. (9) showed that, when necroptosis was functional, intracellular calcium was increased, and when RIPK1 was inhibited, intracellular calcium was decreased. However, because they could not inhibit cell death, they believed that calcium acted at another position compared with the study of Nomura *et al.* (8). In this study, although we also found that calcium was involved in necroptosis, the cells were skeletal muscle and MLKL phosphorylation was induced by calcium obtained from outside of the cells during necroptosis. Zhou *et al*. (22) showed that, during necroptosis of smooth muscle, CaMKII acts downstream of MLKL. Although this study appears to demonstrate known facts, the details of necroptosis may differ in terms of the cell type and experimental conditions, which is why this research is novel.

Necroptosis has been indicated in various diseases, but there are few examples in muscle cells. For example, necroptosis is essential to regenerate muscle cells after inflammation (23). It is also involved in dermatomyositis and polymyositis (24), and Duchenne muscular dystrophy (25). Thus, necroptosis is a developing field. Although factors such as MLKL and RIPK are well known in necroptosis, how and where other proteins and molecules act are unknown, which require further study. This study may contribute to elucidating the mechanisms of skeletal muscle diseases and drug discovery.

CONCLUSIONS

This study showed the importance of calcium in necroptosis using mouse C2C12 cells biochemically. In addition to cancer and smooth muscle, skeletal muscle also requires calcium to perform necroptosis. However, because it was showed by mouse cell lines, new results that are performed *in vivo* or human cell/tissues will be needed in the future.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

RY: conceptualization, data curation, formal analysis, Funding acquisition, investigation, methodology, project administration, resources, software, validation, visualization, writing – original draft, writing – review & editing. YM: supervision.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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A Critical Review on Tendon Structure and Load Remodeling

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SUMMARY

Introduction. As mechanic tendon structures enhancer, muscle-tendon load remodeling has recently been touted as potential strain, force-elongation, and energy storage capacity at both contraction actions and resistance modes. The tendon mechanism has been associated with enhanced stiffness and strain energy to muscle-tendon length complex, however it might be more far-reaching as either force-elongation relationship may be improved or ATP production are poorly understood.

Objective. To determine tendon structure and load remodeling improves muscle-tendon complex via increased tendon activation and muscle contraction. To date, tendon load remodeling on either muscle-tendon performance or tendon force are most common approach, which has produced equivocal outcomes. Tendon performance may be difficult to improve in athletes and individuals with the effectiveness of tendon mechanic properties among physical individual and athletes.

Materials and methods. Critic review literature research was conducted in two electronic databases like PubMed and Web of Science. Resolution for disparity, in conclusion, seem to be due to load remodeling different such as exercise protocols, muscle actions potential and high-quality protocols.

Results. Exploration of the optimal tendon strain, stiffness and force-elongation relationship are required including quantification of load remodeling following optimal resistance and contraction actions. Similarly, further evaluation of muscle contraction studies using high isometric action protocols with tendon load components is required to evaluate mechanism associated with load remodeling.

Conclusions. Until such studies are completed, the efficiency of tendon load remodeling to improve tendon strain energy storage and force-elongation performance remains ambiguous.

KEY WORDS

Tendon elongation; strain; energy storage; stiffness; isometric action.

INTRODUCTION

Considerable research applied has been recently placed on load remodeling of resistance, muscle action and potential energy capacity with tendon structure, its load remodeling explained based on tendon properties (1-3). Increasing on tendon development ratio through low and high force energy of tendon-aponeurosis may improve muscle actions and change muscle transit exercise performances (4, 5). Typical perspectives to increase tendon force energy capacity include the effectiveness of angular speed of maximal based tendon load, muscle-tendon unit and translation fibrils in parallel number increase of cross-sectional area (CSA) (6, 7). Indeed, translation fibrils and transition aponeurosis in turn orthogonal longitudinal-uniaxial shaping tendon force notified to be more than a perfect reflection by energy generation of lengthening linked to isometric tendon arm production and resistance load (3, 5). However, more recently this condition touted tendon load remodeling, composed of tendon elongation, strain and energy storage to force generation by optimal muscle lengthening (8, 9). The mechanism of tendon structure might be more far-reaching as a result, both the muscle contraction actions and force generation metabolism of adenosine triphosphate (ATP) energy (10). It has been required muscle strength or tendon stiffness development, that allows for the precise prescription of tendon loads to optimize tendon adaptation (8). Since the early one work has primarily focused on the force-elongation relationship potential energy effects of load remodeling on jumping performance (11). Indeed, a tendon-aponeurosis performance of sprinter and endurance runners muscle strength increases to load remodeling of tendon strain was observed to energy production at applied tendon strain (11). The fascicular tendon-aponeurosis structures, due to increased tendon loads, produce strain energy (1). However, in the other athletes, as applications of tendon strain is limitation as well as general bias focused on isometric maximal voluntary actions, jumping and running (12, 13). Recent works have addressed these limitations and investigated tendon strain associated with simply tendon energy effects on isometric maximal voluntary contraction that encompasses large force generation and stiffness in trained and untrained individuals (8, 14). Tendon strain, force-elongation relationships in the load patterns of tendon structure in the athlete population is scarce that should be investigated further (9). To date, complex responses to tendon structure have been reported, the potential for performance improvement is unclear (15). Additionally, there were studies reported that low-intense exercises were generally unable to adaptively induce tendon strain and stiffness (16, 17). Specifically, tendon loads on energy generation of resistance training and muscle actions may be an important application for athletes who may have the energy storage capacity of changes tendon load remodeling (18). However, the athletes can protect muscle performance, such as energy storage and tendon stiffness by the way load elongation relationship and strain for training performance improvement (8). This review, therefore, discussed the efficacy of tendon structure to improve training and load remodeling performance, followed by a discussion of research findings to date in respect of muscle-tendon load factors, that study has reported tendon strain energy, elongation, stiffness and load goal strategy.

STRAIN AND STIFFNESS ON TENDON LOAD REMODELING

Active muscle length has effective tendon activation against load remodeling conditioning called strain in any active and passive resistance by muscle-tendon strain complex (1, 2). Mechanism of tendon strain were originally prescribed to enhance tendon elongation and stiffness transformation. Its energy is built from isometric voluntary contraction and active lengthening of muscle stretch reflex, resulting from fascial lengths or titin activation that produce optimal force (3, 19). Positive effects of both muscle and tendon properties as a spring caused by resistance training, increased tendon-aponeurosis stiffness and contractile strength; both mechanical possess on stress-strain relationship to tendons properties can be determined by simple isolated elastic models (12, 20). A comprehensive investigating of tendon strain from training has displayed an altered tendon stiffness in different muscle actions and load remodeling (21, 22). The authors reported that, take into account understanding of tendon structure function to load remodeling during isometric actions, had an impact on tendon elongation, in this conditioning formed isometric high protocol to tendon development in physical individual and athletes (17). The purpose mechanism for the development of the elongation feature of tendon may be due to tension in isometric joint moment arm production and tendon moment lengthening of isometric ramp increased gradually in ratio-dependent mechanism. Indeed, tendon elongation showed that during a countermovement jump there is a production strain, but an isometric actions improve fascicle lengthening during final stage of take-off (12). In this case, isometric condition is anatomic mass expressing into force, the explained proportional section of a muscle-tendon complex length associated with energy strain generation by performing individual maximum tendon load condition (8, 22). Nonetheless, in another study outside of angular speed strategy was performed other tendon motion patterns to strain, therefore, the mechanic properties have been required to evaluate through same movement way (13). The alternative tendon length mechanism applied to strain on muscle actions had an effect within active or passive lengthening during submaximal and maximal angular explosive power movements. Indeed, minimum 100° and maximum 250° isometric lengthening highest energy generation is reflected in tendon load conditioning (12). Another alternative mechanism reported that tendons use stiffness to transmit and maintain forces production from muscular mechanical loadings (14). Tendon strain and stiffness explain tendons can enhance force and power generation through tendon strain energy (23). In particular, tendons improve muscle performance and stiffness during SCC activities, such as jumping and sprinting create a mechanical power pool at high joint moments (21). Most studies investigate the estimated active stiffness associated with tendon strain and elongation in submaximal isometric ramp action. One report has shown tendon structures to stiffness generation with ramp protocol high angular velocity ratios are thought to conduct more effective force capacity (3). Thus, tendon elongation had positive high strain rates were obtained, however the reports determined that isometric actions improved both tendon elongation and stiffness (3). However, following tendon strain of lower compartment muscle-tendon complex, both sprinter and long-distance runners were significantly reduced passive lengthening vastus lateralis within sprinters, and active lengthening was increasing within long-distance runners (9). The applications of these findings may apply to other athletes, as they are likely to undertake active lengthening of tendon and more routine strain of maximal voluntary contraction compared to other contraction. These potential quality control issues are an important functional role in the tendon stiffness (9). Considering studies to date have only used force strain relationship related to tendon and aponeurosis of sprinter and endurance runners that requires further investigation in muscle actions. It is worth noting, however, higher stiffness may be considered between tendon force and strain potential energy generation (11). A common issue with plyometric and isometric training is tendon properties during ramp and ballistic protocol, whereby tendon stiffness under passive and active conditions; *i.e.*, fascicle lengthening of plantar flexors have been reported following submaximal isometric contractions such as passive stiffness, and tendon strain did not change for plyometrics and isometrics (16). Notably, active muscle stiffness reported significantly increased with plyometric. This study showed that unlike previous plyometrics and stretch-shortening-cycle (SSC) than isometric contractions can produce more significant elongation and tensile force in tendon strain (12, 16). These differences could be related to different elongations of tendon structures, such that they can perform from tendon stiffness of isometric knee extension and plantar flexion. Comparison of sprinters and untrained individuals are more compliant and therefore lower tendon stiffness (15).

LOAD ELONGATION CONDITIONING

The most commonly employed fascicular of tendon-aponeurosis show dynamic elastic properties due to increased load effectively, which appears to reflect muscle ultimate load ratios during contraction actions, and time-dependent strain using quickly external loads (1). Load-elongation linear curve determines increased load-related development and response to stiffness-strain rate. This may theory in the tendon structure that can enhance both energy storage depending on force provided by gradually slow contraction at constant lengthening (13). In this case, this investigation reported on the spring nature of tendons after load remodeling, running and jumping affects maximum strain. Based on tendon stiffness and CSA using tendon ability in different sport branches and tendon capacity have reported between energy storage and tendon stiffness to find similar strain energy values (1, 13). The authors explained that tendon force is low in the speeds of movement, but a difficult comparison can be done, in fact the force development rate occurred angular speed of movement, which was explained by an external load (11, 12).

Another work showed the maximal ankle plantarflexion moment for the tendon force-elongation relationship during loading phase may be effective by increasing the tendon stiffness at performing isometric actions (14). Isometric protocols are mostly used for tendon elongation, however, muscle strength increases are only for being more efficient in isometric extension-flexion (43). Indeed, tendons are applied to transmit force derived from external joint torque by the muscle moment arm and it is showing important formation for the triceps surae in the plantar flexors (24). These conditions should be thought to depend on decreased tendon strain and muscle shortening (14, 20). In one research a load-elongation mechanism of muscle strain energy generation was reported on tibialis muscle-tendon complex during tetanic maximum isometric strain values observed at 0.8 to 2.5% dor muscle load modeling (25). However, tendon strain may exert its force transition and energy storage effects through this mechanism by load-elongation relationship during isometric actions, and elongation of tendon-aponeurosis changes can elevate muscle force levels at maximal voluntary contraction followed by isometric ramp (26). As a results, increases in the transfer relationship between muscle force and tendon elongation during decreasing phase ascending as the stiffness of tendon structures. Nonetheless, muscle actions works reported that tendon elongation-force enhancements by SSC effect increased at eccentric action than isometric action (27). Again, a work by reported light and heavy tendon strain, depending on intensity load respectively power and force transducer increased changes, had an effect on stiffness and force transducers during SSC movement (28). These findings have been shown under some conditions, tendon elongations become tendon strain increase during multi-joint sprinting and jumping (15). Based on tendon activities supported in efficient operation technique should have works the potential to create loads remodeling due to tendon strain morphological deformation (29). Importantly, dynamic tendon loads are necessary for evaluating the tendon viscoelastic structure, however muscle actions must include chronic muscle performance works and CSA evaluation for contraction and ballistic mode (7, 16). Based on the benefit, inducing tendon strain to metabolic stress on muscle performance should have been the continuous variability of load volumes (30), however, it is likely the potential tendon structure is important to use by athletes in practice. These tendon sections must be explained by the anatomical CSA (31). The effect of tendon strain on muscle-tendon shortness associated with the load intense outcomes have been previously investigated, however, limited results have been obtained on anatomic elongation tendon-aponeurosis (11). Specifically, muscle-tendon units and CSA facilitate the production of lengthening during angular changes of such as foot and leg joints. In turn, these tendon structures optimize load changes velocity to ATP energy generation of skeletal muscles (30). A recent work has investigated force generation, however many force activation increased walking and running at different speed exercises reached due to tendon lengthening mechanisms (6). Indeed, one research that investigated tendon structures in dynamic motions, as seen for load remodeling to walking and running, shows variance obtained from tendon-aponeurosis structures by force-length performance. Thus, few investigations examined the loading ratios of muscle action associated with maximal voluntary contraction (MVC) at high load, ramp maximum force at low load, submaximal isometric plantarflexion action, and maximal tendon force at sustained actions (32). However, sustained action results indicated that there may be negative loading rate effects on tendon mechanical properties. Lastly, considering the works to date only performed an isometric action not performed trained athletes (3), the safety of tendon elasticity long term of isometric exercises must be further investigated in terms of load remodeling. It is worth noting, however, generally angular elongations of dynamic movements are considered safe for applications (26).

TENDON ENERGY GENERATION WITH LOAD REMODELING

Contractile filaments and tendon structures were originally prescribed to enhance the stress-strain and load towards contraction energy storage; therefore, positional energy storage tendons produce large force based on strain of load and sometimes caused a loss of energy (19, 33). Furthermore, the viscoelastic tendon structure creates a reservoir that returns the energy storage associated with stress and strain in load remodeling (13). Tendon transmits the force contributes to energy capacity and enhances the force-elongation relationship and mechanical strain energy (23).

Initial investigations have demonstrated that tendons performed mechanism of energy storage at resistance training, jumping and other power activities based on spring-like properties can enhance mechanical energy production during eccentric, concentric and isometric actions (13, 34). Similarly, elastic energy of muscle-tendon complex or unit enhance SSC and power output in mechanical efficiency (9). Energy release, which is loaded into a tendon, but tendon loading system to explain energy storage at jump load mechanics occurred the highest power at peak isometric reaching with the elastic mechanism (35). Additionally, tendon strain energy higher jumping sport branch than other applied power activities for athletes (13). However, the tendon capacity of some athletes depends on maintaining the spring properties continuously depending on the limb muscle-tendon unit. Considering that continuing process, the strength and power loads use the elastic capacity of passive tendon structures that tendon energy storage accumulation on elongation with less energy expenditure during concentric action than eccentric action (27, 36). Indeed, a work evaluating muscle-tendon force previously reported that tendons show strain and stiffness energy in submaximal and maximal exercises in athletes and physical individuals (15). However, this work reported that energy storage of submaximal and maximal running performance improves through tendon strain and elongation capacity. To date, different responses to tendon mechanical work have been reported, which makes by series-elastic elements at running and walking speed loads, revealed that run transition speed more muscular fiber work. These results support previous mechanical energy expenditure (37). Nonetheless, a contemporary work (2) reported that tendon structure and spring properties can organize elastic energy storage at landing and jumping. The positive effect was observed 34% higher energy in high load within stiffness. Load remodeling, therefore, shows tendon storage energy to return energy through stiffness and tendon strain (13). A work reported that tendon stiffness and strain changes in energy storage of elastic properties occur to a greater degree in the high load flexors than in the low-stress extensors (38). One of the most critical controls of the tendon distal region at the active stiffness phase compared to the passive proximal region show stress in load remodeling, however, the force energy had greater active stiffness (3). An alternative mechanism works on ATP hydrolysis contraction energy produced mechanical load remodeling movement in concentric action than eccentric action for low response muscle contraction. Alternatively, passive elements are limited ATP hydrolysis while the high potential shows in eccentric actions (18). Performance responses have been replicated in tendon mechanics with concentric and eccentric load transition. Furthermore, in an investigation, by increasing tendon dynamics in contraction strategies of isometric and dynamic eccentric or concentric phases that cause changes in different muscle performance energy, should be seen as muscle behavior in maintaining storage of compartment muscles (39). The strategy of supported stiffness and tendon structure is energy formation in working modes, the available of contractile mechanical force in metabolic control, and is influenced by mechano-chemicals. Muscles use potential energy, pre-end of elastic elements in mechano-chemical warming intervals. If the change of mechano-chemicals in strengthening active muscle and tendon structure is explained, synthesis for energetic systems (ATP/mmol/nm) for elastic stores are affected in stress formation and muscle actions (40). For this reason, energy formations differ in muscle actions and a single fibril shows ATP hydrolysis in the tendon elongation distance. ATP synthesis has direct stability in isometric actions or other muscle actions, but must show potential energy with polarization for the energies of tendon structures that lack stability (41). In contrast, sublocation muscle maximum performance for exercise metabolic energy output was evaluated on high rate of ATP production of muscle elongation or lengthening in strain on time. However, for the muscle-tendon load condition, not only the type of contractions but also muscle lengthening and ATP-resynthesis rate and energy activations are required for force generation energy (10). Indeed, a study investigated that the metabolic stores at negative work increase energy source no different for these reasons, however, ATP hydrolysis actions against energies resistance loaded only the development of strain or SSC (42).

CONCLUSIONS AND FUTURE DIRECTIONS

The lack of studies investigating its effects in athletes from tendon strain and load-elongation force relationship within the existing literature is due to a number of factors, including the tendon loads and exercise protocols. Indeed, this diversity adds a level of critical outcomes to our ability to draw firm conclusions about the tendon structure of load remodeling on exercise and contraction modes. Nevertheless, from the available evidence, an active length may increase tendon strain and stiffness in the linear relationship (**figures 1-3**). This is supported by a recent review conducted at the time of writing this review, which also reported similar benefits (8). Little evidence of muscle-tendon elongation relationship used production of maintenance of power, strength, jump, walking and running for supporting strain and load remodling by energy generation capacity (**table I**). However, as the stiffness is examined in tendon properties, the studies on the evaluation of the force formation and energy capacity of the theories related to the changes in tendon strain and elongation are limited, and it was deemed necessary to examine more comprehensively at future studies. A critical point of view is that the load and elongation of tendon structures are based on high loading and angle change in isometric actions. In studies, force and elastic energies were more pronounced in sprinters than endurance athletes, as a result of more tendon load changes. Further research should focus on the strength and power increases to be obtained from the tendon strain energy in the force-elongation relationship in the load modeling of the tendon. Lastly, similar effects of tendon structure, strain, and elongation relationships on strength and energy capacity should be investigated in specialized power and strength training models of different athletes.

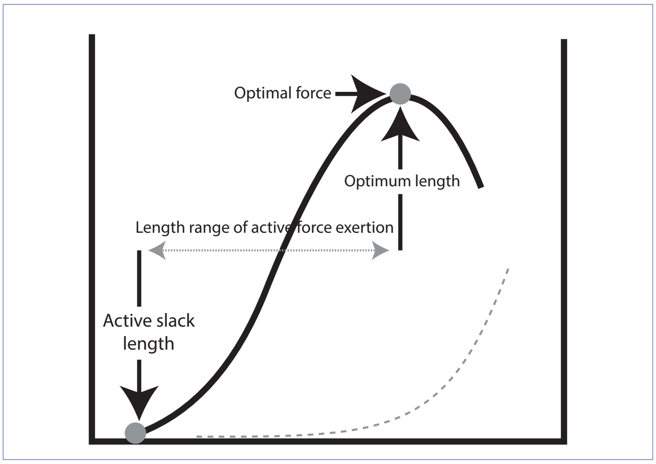

Figure 1. A linear curve representation of tendon strain changes associated with active lengthening and force response to show gradually energy storage forms tendon elongation relationship to optimal force.

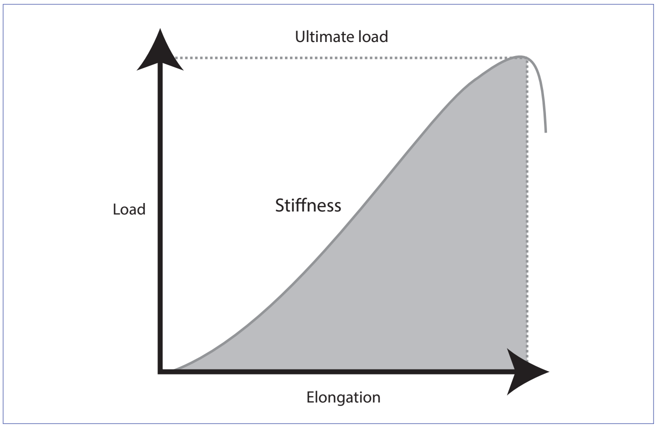

Figure 2. A linear curve representation of load-elongation changes in tendon structure displayed tendon elongation increase due to strain based on load and elastic energy storage.

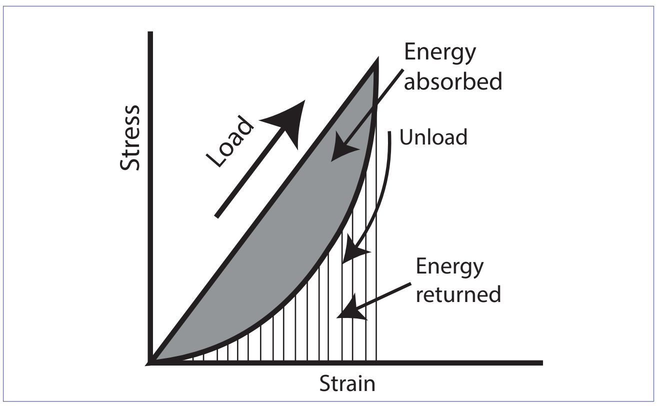

Figure 3. A stress-strain relationship linear representation associated with increased energy return due to the mechanical load remodeling.

Table I. Tendon performance on load remodeling.

Author (year)	Population	Experimental method	Exercise protocol	Main Outcomes	Conclusion
Kubo *et al.* (3)	Sprinters (n = 50) Untrained men (n = 18) Age: 20.4 ± 0.9; 22.2 ± 1.8 years	2 or 3 MVC protocol at a 100-deg ankle angle of medial gastrocnemius	A dynamometer was used to measure active muscle stiffness at peak angular velocities of 100, 200, 300, 500, and 600 degrees·s-1 during a ramp and ballistic contractions	Active muscle stiffness of submaximal isometric contractions at 500 and 600 deg.s-1 was greater in sprinters	A increase in active stiffness at high angular velocities was higher in sprinters due to tendon elongation
Miyamoto *et al.* (9)	Sprinters (n = 22), Long-distance runners (n = 22)	Highest maximal voluntary contraction (50% MVC) with the hip and knee flexed at 80° and 90° of vastus lateralis	A dynamometer was used to evaluate active and passive speed	Tendon stiffness of vastus lateralis at active speed was highest in long distance runners than sprinters	Active and passive stiffness resulted in locomotion speed
Arampatzis *et al.* (11)	Sprinters (n = 28) Endurance runners young male (n = 28) Age: 26.7 ± 5 years	2-3 min submaximal isometric contractions, and 3 maximal isometric force ramp MVC on ankle plantar flexion	A ultrasound was used to tendinous tissue elongation and at MVC maximum tendon force	The sprinters showed higher normalized stiffness of the triceps surae tendon and aponeurosis in the relationship between tendon force and tendon strain	High tendon force increase in sprinters
Wiesinger *et al.* (13)	Ski jumpers (n = 10) Endurance runners (n = 10) Water polo (n = 9) Non-physical active individual (n = 10) Age: 22.2 ± 2.9; 31.5 ± 4.6; 24.2 ± 3.2; 31.0 ± 5.1 years	Submaximal intensity of 1.5 W/kg and a caddence ~70 rpm after 10 min	Lower leg strength was performed on isokinetic dynamometer, muscle CSA at ultrasonography of gastrocnemius medialis, vastus lateralis and rectus femoris, and patellar and achilles tendon length	Tendon strain energy of the patellar tendon was higher in ski jumpers than in water polo players and for the Achilles higher in ski jumpers than runners	No significant difference in tendon energy storage

Author (year)	Population	Experimental method	Exercise protocol	Main Outcomes	Conclusion
Karamanidis and Erpro *et al.* (14)	Elite track and fieldjumpers (n = 67) Recreationally active individual (n = 24) Age: 23 ± 4; 24 ± 3 years	Submaximal 3 MVC protocol with 30, 50, and 80 of maximal joint arm for ankle plantar flexors stiffness and strain	Triceps surae muscle-tendon unit measured through dynamometry and ultrasonography	Jumpers had higher tendon stiffness	Increasing tendon stiffness
Kubo *et al.* (15)	Sprinters (n = 15) Untrained men (n = 15) Age: 20.8 ± 1.0; 0.7 ± 1.8 years	Isometric torque at maximal isometric contraction MVC for knee extension and plantar flexion	MVC, tendon elongation, 100 m race	Tendon stiffness of sprinter was lower than the untrained individual for knee extensor	There is a positive correlation between 100m sprint performance and tendon elongation
Kubo *et al.* (16)	Untrained men (n = 11) Age: 22.5 ± 3.2 years	Isometric and plyometric training (12-weeks) on tendon properties of plantarflexion	1RM, MVC, plyometrics (hopping and drop jumps) on a sledge apparatus, isometric (unilateral isometric plantar flexion)	Tendon stiffness during ramp and ballistic contractions increasing for isometric than plyometric	Ballistic contraction of plyometric training has developed tendon structure
Albracht and Arampatzis (20)	Recreational long distance runners (n = 26) Age: 27 ± 5 years	14 weeks, 5 set, 4 repetition isometric plantarflexion contraction with the ankle joint dorsiflexed	4 repetitions (MVC 90%) for tendon-aponeurosis elongation and stiffness at a dynamometer	Plantarflexion muscle strength 7% and tendon-aponeurosis stiffness 16 % increase	The combined tendon stiffness and muscle strength maintain a high economy of force generation
Epro *et al.* (21)	Track and field athletes (n = 67) Male (n = 35) Female (n = 32) Age: 23 ± 4; 24 ± 4 years	2 or 3 maximal and submaximal MVC at 30, 50, 80% of maximal joint moment arm	The triceps surae muscle strength and tendon stiffness measured in dynamometry and ultrasonography	Increasing tendon stiffness (8.1 ± 11.5%)	Jumping discipline showed a significantly higher triceps surae muscle strength and tendon stiffness
Pentidis *et al.* (22)	Artistic gymnastic athletes (n = 10) Non-athletes (n = 11) Age: 9.2 ± 1.6; 9.0 ± 1.7 years	SJ, CMJ, plantarflexion muscle strength	A force plate, dynamometer, ultrasound for tendon stiffness	No Achilles tendon stiffness	Higher 8.5% strain in athletes

Author (year)	Population	Experimental method	Exercise protocol	Main Outcomes	Conclusion
Mersmann *et al.* (23)	Volleyball athletes (n = 21) Untrained individuals (n = 24) Age: 16.7 ± 1 years	MVC with knee joint angle 60°, 70° and 75°	MVC on a dynamometer for muscle strength evaluation and patellar tendon mechanical properties by ultrasound method	Tendon stiffness is higher in athletes at 86.0 ± 27.1 kN/strain	Higher tendon strain during maximum contractions.
Holzer *et al.* (24)	Men individuals (n = 14) Age: 29 ± 6 years	MVCs were performed at 20° and 10° plantarflexion and 5°, 10°, 15°, 20°, 25°, and 30° dorsiflexion for each trial analyzed peak torque	Maximum voluntary plantarflexion contraction MVC of the right leg with an isokinetic dynamometer	Triceps muscle-tendon unit force increased based on isometric moment torque arm.	Contraction tendon load increased remodeling magnitude.
Maganaris and Paul (25)	Healthy men individuals (n = 5) Age: 22 ± 4 years	Percutaneous tetanic electrical stimulation bipolar wave pulses with a duration of 100 ms were applied at a frequency of 100 Hz for 1 s	20, 40, 60, 80 and 100 % of maximum isometric dorsiflexion moment measured with an isokinetic dynamometer	Tendon strain values increased with load	Increased strain values revealed via the function of dorsiflexion load
Kubo *et al.* (26)	Healthy men individuals (n = 7) Age: 25.3 ± 1.4 years	Ankle static stretching passively flexed to 35° of dorsiflexion for 10 min	An ultrasound was used to measure tendon elongation of medial gastrocnemius muscle at MVC ramp isometric plantar flexion protocol	Tendon elongation and muscle force relationship increased stiffness	Static stretching increased the elasticity of the tendon structures
Fukutani *et al.* (27)	Healthy men individuals (n = 12) Age: 24.2 ± 3.2 years	Concentric at 60°/s following preliminary isometric contraction and eccentric at 90°/s	A dynamometer measured the plantar flexion with knee and hip joints flexed at 0° and 80°, ultrasound measurement included fascicle length, tendon elongation, and pennation angle	Eccentric contraction without preliminary isometric contraction produced preactivation SSC effect	Active tendon elongation-force mechanisms contributed SSC effect

Author (year)	Population	Experimental method	Exercise protocol	Main Outcomes	Conclusion
Earp *et al.* (28)	Physical active men (n = 9) Physical active women (n = 9) Age: 25.8 ± 2.8 years	Single-leg, maximum intensity SCC knee extension at 20, 60, 90% loads of 1RM	3 leg extensions at each load of 1RM with the fastest concentric joint velocity	Vastus lateralis fascicle length, velocity and tendinous length measured by ultrasound	The tendon lengthened significantly less at the end of the eccentric phase. Tendon strain decreased during an SSC movement at loading intensity increases.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

YK: design, writing.

CONFLICT OF INTERESTS

The author declares that she has no conflict of interests.

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ORIGINAL ARTICLE

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Anatomical Variation of the Sciatic Nerve in Relation to the Piriformis Muscle: An MRI Study

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SUMMARY

Background. The sciatic nerve is the largest and thickest branch of the lumbosacral plexus. It separates into numerous branches and exhibits multiple anatomical variations that may result in nerve compression, a factor that is attributed to its location in the pelvis. This study aims to detect sciatic nerve branch variation and its association with the piriformis muscle and to establish the prevalence of each variant using routine pelvic MRI examinations.

Methods. This was a cross-sectional retrospective study of patients who underwent pelvic MRI studies from January 2018 to December 2020. Collected data included patient demographics, anatomical type of sciatic nerve (according to the Beaton and Anson classification system) and history of radiculopathy or sciatic nerve symptoms. Data was collected, and descriptive statistics were analyzed with a $p < 0.05$ considered as statistically significant.

Results. A total of 188 patients were included in the study. The majority (95.7%) of the patients exhibited the type 1 variant, while type 2 and type 3 variants exhibited a prevalence of 3.2% and 1.1%, respectively. No statistically significant difference in history of radiculopathy and sciatica was identified between the different anatomical variants.

Conclusions. The sciatic nerve's anatomical variation in relation to the piriformis muscle can be identified on routine pelvic MRI scans, with most of the detected variants being type 1. This study confirms the anatomical variations of the sciatic nerve in the pelvic region which can be detected on routine MRI.

KEY WORDS

Sciatic nerve; anatomical variation; piriformis muscle; sciatica; MRI.

INTRODUCTION

The sciatic nerve is the largest nerve in the human body which is composed from the union of the ventral roots of the L4-S3 spinal segments (1, 2). Sciatic nerve compression anywhere along its course can lead to various clinical manifestations including buttock and/or leg pain, sensory alterations, and muscle weakness, which are commonly referred to as "sciatica" (3). These manifestations are extremely commonplace, usually affecting adults in their fourth or fifth decades with a life span prevalence of approximately 43% (3). Compression typically occurs as it the nerve exits the spinal canal near its origin and is normally attributed to a herniated disc or other spinal pathology. However, along its course, the sciatic nerve passes in close proximity to the piriformis muscle as it exits the pelvis and could be subjected to compression by the muscle, thereby giving rise to sciatica symptoms in a clinical entity that is referred to as "piriformis syndrome" (1). Nerve compression in piriformis syndrome is thought to result from inflammation or irritation of the nerve as a result of muscle hypertrophy but may also occur due to piriformis muscle or sciatic nerve congenital variations (3, 4).

Beaton and Anson classified the anatomical variation of the sciatic nerve in relation to the piriformis muscle into six types (5). The three most common types are described as follows: Type 1 depicts an undivided sciatic nerve that passes below the piriformis muscle, with a prevalence of 80-90%. Type 2 is when the common peroneal division passes through the piriformis muscle and the tibial nerve division passes below the piriformis muscle. This type is considered the second most common variant with a prevalence of 10-15% (3, 6). Type 3 describes the variant where the common peroneal division passes above the piriformis muscle and the tibial division passes below the piriformis muscle and is the third most common variant with a prevalence of 1-3% (3). Researchers have postulated that certain anatomical types may result in more sciatica-like symptoms (1).

The purpose of this study is to determine the prevalence of the various sciatic nerve anatomical variations in relation to the piriformis muscle in a middle eastern population and how it differs from the international data published in the literature. The study also seeks to establish if there are any correlations between the sciatic nerve anatomical variant and the presence of radiculopathy or sciatica-like symptoms.

MATERIALS AND METHODS

Institutional Review Board approval, IRB-2020-01-303, was obtained for this study (Committee: Imam Abdulrahman Bin Faisal University - Date of approval: October 25, 2020). A cross-sectional retrospective study design was employed. The data were obtained from the patient electronic medical records and included all patients 18 years of age or older, who underwent a pelvic MRI study from October 2018 to October 2020. Studies with axial T1 and/or axial T2 non-fat saturated sequences were included in this study. The exclusion criteria include any pathology related to the sciatic nerve, such as neuritis, neurofibromas, schwannoma, neoplastic processes in or around the sciatic nerve, or significant pelvic bone fractures. Patients were also excluded if they had a history of prior surgery in the hip/pelvic area that may alter the anatomy. Additionally, all duplicate exams and technically inadequate studies (lacking non-fat saturated sequence) were not included.

MR imaging was conducted at our institution with a 1.5 Tesla scanner (Optima MR450w; General Electric, Boston, United States) and a 3 Tesla scanner (Magnetom Skyra; Siemens, Munich, Germany). Evaluation of the sciatic nerve was primarily performed on the axial plane. The protocol and image parameters varied depending on the exam indication. Nonetheless, the standard protocol of the (2D) axial T1-weighted sequence was repetition time (TR) = 1000-1400 ms, echo time (TE) = 11-18 ms, ≤ 4 mm slice thickness, and a field of view (FOV) = 330-370 mm. The standard protocol of axial (2D) T2-weighted sequence was a TR = 2800-3100 ms, TE = 90-95 ms, ≤ 4 mm slice thickness, and a FOV = 330-370 mm.

Three radiologists reviewed the MRI studies, two of whom were subspecialized in musculoskeletal imaging. All the MRI studies contained an axial T1 sequence, which is the most sensitive sequence for the observation of anatomical variation (3). The anatomical relationship between the sciatic nerve and the piriformis muscle was classified according to the Beaton and Anson classification system (3). The presence of a split sciatic nerve, defined as a discrete separation of the common peroneal and tibial nerve bundles by a fat plane (of any thickness) at the level of the ischial tuberosity, was also recorded (**figure 1**). The number and percentage of each type of anatomical variation were recorded in addition to the patient's demographic information. The patient health records were reviewed for any previous history of sciatica or radiculopathy. The patient's file was reviewed for any previous spine imaging that may indicate back pain, radiculopathy or sciatica. Patients were contacted to inquire about any history of low back, sciatica or radiculopathy pain.

Sample size calculation was performed based on previous literature, the expected prevalence of sciatic nerve splitting is 5-15%. Assuming a prevalence of 10%, a sample size of 152 patients was required to achieve an error margin of 4% at a 95% confidence level (5% level of significance). Data was analyzed using the Statistical Package for the Social Sciences (SPSS) and chi-square test of independence was used to assess the association

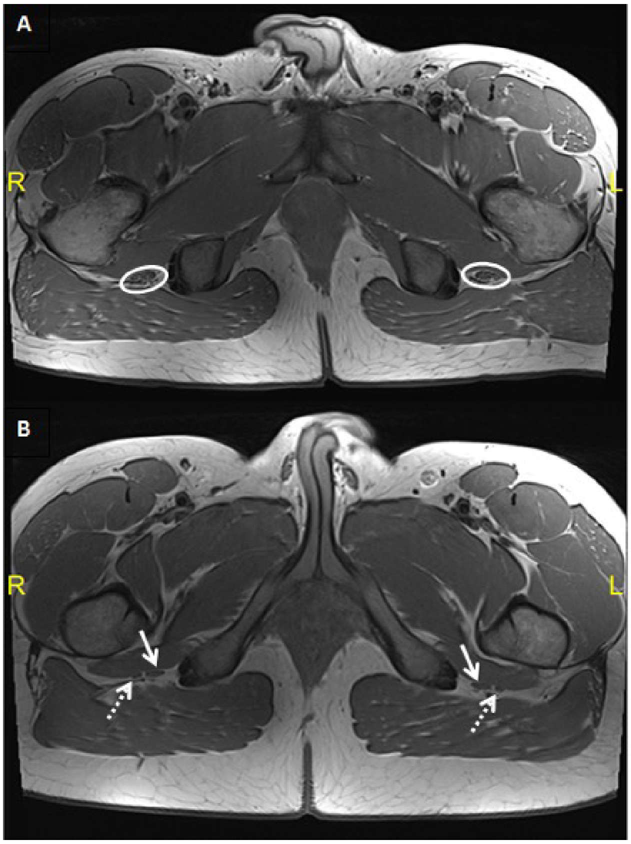

Figure 1. (A) Axial T1-weighted MRI at the ischial tuberosity level revealing a non-split sciatic nerve (white circle); **(B)** Axial T1-weighted MRI at the ischial tuberosity level revealing a split sciatic nerve with common peroneal (dashed white arrow) and tibial (solid white arrow) components of the nerve.

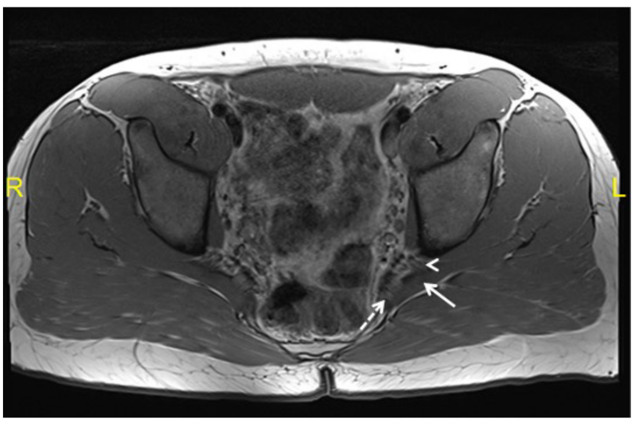

Figure 2. Axial T1-weighted MRI image of type 2 sciatic nerve.

Solid white arrows: piriformis muscle; dashed white arrow: common peroneal component piercing the piriformis; white arrowhead: tibial component passing anterior/below the piriformis.

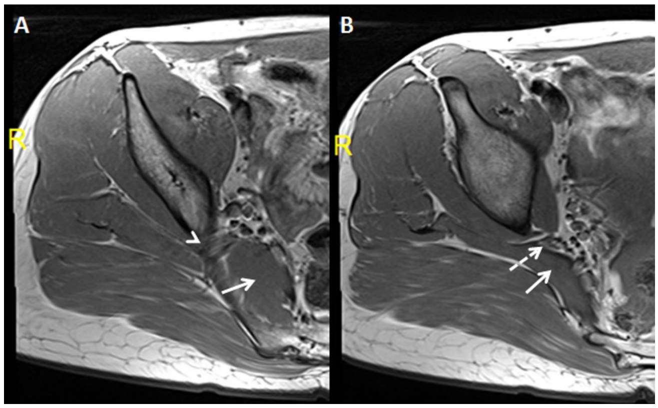

Figure 3. Axial T1-weighted MRI images of type 3 sciatic nerve.

Solid white arrows: piriformis muscle; white arrowhead: the common peroneal component passing posterior/above the piriformis muscle; dashed white arrow: tibial component passing anterior/below the piriformis muscle.

between categorical variables. Hypothesis testing was performed at 5% level of significance.

RESULTS

A total of 188 patients who fit the inclusion and exclusion criteria of the study were included in the study. The patient cohort included 114 (60.6%) males and 74 (39.4%) females (**table I**). The mean age of the cohort was 35.4 ± 16.7 years. Upon review of the sciatic nerve variation types, type 1 was identified in 180 (95.7%) cases, thus making it the most common form. Type 2 was the second most common type which was observed in six patients (3.2%) and type 3 was observed in two patients (1.1%) (**table II**). Patients exhibiting types 4 to 6 were not identified in this study (**figures 2, 3**). Sciatic nerve splitting was documented in 8% of patients, all with type 1 (**table III**).

A total of 43 patients (22.9%) had history of low back pain or radiculopathy, while only 14.4% of the cohort showed signs of compression on spine MRI. There was no statistically significant correlation between the sciatic nerve variation type and the presence of a history of radiculopathy or sciatica, but was associated with older age and signs of compression on MRI (**table IV**). In addition, the presence of nerve splitting was also not associated with history of radiculopathy or sciatica (**table III**).

DISCUSSION

Our current cross-sectional retrospective study explored the prevalence of sciatic nerve variations in relation to the piriformis muscle in a middle eastern cohort. We found that 95.7% of patients had a type 1 variation, while only 3.2% and 1.1% had a type 2 and type 3 variant, respective-

Table I. Demographic and clinical characteristics of the included patients.

	n (%)
Gender	
Female	74 (39.4%)
Male	114 (60.6%)
Age category	
< 18	13 (6.91%)
18-35	103 (54.8%)
35-65	57 (30.3%)
> 65	15 (7.98%)
Variation type	
Type 1	180 (95.7%)
Type 2	6 (3.2%)
Type 3	2 (1.1%)
Splitting	
No	173 (92.0%)
Yes	15 (8.0%)

Table II. Association between splitting and characteristics of the included patients.

	Type 1 (n = 180)	Type 2 (n = 6)	Type 3 (n = 2)	P-value
Gender				0.715
Female	72 (40.0%)	2 (33.3%)	0 (0.00%)	
Male	108 (60.0%)	4 (66.7%)	2 (100%)	
Age category				0.659
< 18	12 (6.67%)	1 (16.7%)	0 (0.00%)	
18-35	97 (53.9%)	4 (66.7%)	2 (100%)	
35-65	56 (31.1%)	1 (16.7%)	0 (0.00%)	
> 65	15 (8.33%)	0 (0.00%)	0 (0.00%)	
Spine MRI compression				0.703
Yes	27 (15.0%)	0 (0.00%)	0 (0.00%)	
No	153 (85.0%)	6 (100%)	2 (100%)	
Splitting				1.000
Yes	15 (8.33%)	0 (0.00%)	0 (0.00%)	
No	165 (91.7%)	6 (100%)	2 (100%)	

ly. These findings are similar to previously published literature in different cohorts, which also showed that the type 1 variant was the most common type detected (79-87%), while other types were less common or even considered rare (1-3, 7, 8). Knowledge of prevalence of different variations is critical to assist during surgical planning and while performing interventional procedures such as total hip arthroplasty, intramuscular injections, and nerve blocks with a goal to subsequently minimizing potential iatrogenic injuries (9).

In our cohort we found that 8% of the patients were shown to have splitting of the sciatic nerve at the level of the ischial tuberosity, which also corresponds with previously published studies with a prevalence 6-9.8% of splitting (1, 3, 8). Variations of sciatic nerve splitting can be a direct cause of piriformis syndrome resulting from nerve compression or entrapment (10, 11). This syndrome has been increasingly detected with the advances in MRI imaging and has been linked to multiple etiologies including trauma, muscle hypertrophy or overuse, and variant anatomy leading to sciatic

Table III. Factors associated with splitting.

	Yes (n = 15)	No (n = 173)	P-value
Gender			0.743
Female	7 (46.7%)	67 (38.7%)	
Male	8 (53.3%)	106 (61.3%)	
Age cat			0.620
< 18	0 (0.00%)	13 (7.51%)	
18-35	10 (66.7%)	93 (53.8%)	
35-65	5 (33.3%)	52 (30.1%)	
> 65	0 (0.00%)	15 (8.67%)	
Spine MRI compression			0.700
Yes	1 (6.67%)	26 (15.0%)	
No	14 (93.3%)	147 (85.0%)	
Variation type			1.000
Type 1	15 (100%)	165 (95.4%)	
Type 2	0 (0.00%)	6 (3.47%)	
Type 3	0 (0.00%)	2 (1.16%)	

Table IV. Factors associated with radiculopathy and sciatica.

	Yes (n = 40)	No (n = 14)	P-value
Splitting			1.000
Yes	3 (7.50%)	12 (8.11%)	
No	37 (92.5%)	136 (91.9%)	
Age cat			< 0.001
< 18	3 (7.50%)	10 (6.76%)	
18-35	8 (20.0%)	95 (64.2%)	
35-65	18 (45.0%)	39 (26.4%)	
> 65	11 (27.5%)	4 (2.70%)	
Gender			0.036
Female	22 (55.0%)	52 (35.1%)	
Male	18 (45.0%)	96 (64.9%)	
Variation type			0.759
Type 1	38 (95.0%)	142 (95.9%)	
Type 2	2 (5.00%)	4 (2.70%)	
Type 3	0 (0.00%)	2 (1.35%)	
Spine MRI compression			< 0.001
Yes	21 (52.5%)	15 (10.1%)	
No	19 (47.5%)	133 (89.9%)	

nerve entrapment (12, 13). Therefore, correct recognition of this anatomical variation can improve the diagnostic accuracy and management decisions of such cases (11, 12).

Interestingly, Wan-ae-loh *et al*. found that in the Asian population type 2 was more prevalent compared to Caucasian or African ethnicities and showed a higher association with nerve impingement and piriformis syndrome in their cohort (14). In our study, the data analysis findings did not identify any significant association between the variation type or sciatic nerve splitting and presence of back pain, radiculopathy or sciatica.

We noted some possible limitations in our current study. The sample size examined was small compared with other studies, with 188 patients, but we believe that our study is adequately powered as per our sample size analysis. Another possible limitation is the retrospective nature of the study, which may increase the likelihood of recall bias.

CONCLUSIONS

The findings of this cross-sectional retrospective study established that type 1 sciatic nerve variant is the most common variant in our middle eastern cohort. Moreover, there was no correlation between the sciatic nerve variant and the presence of radiculopathy or sciatica. Understanding the different variations of the sciatic nerve anatomy and its relation to the piriformis muscle can help plan surgical and/or interventional procedures to minimize potential iatrogenic sciatic nerve injuries and their adverse effects.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

MIA, TMH, SAA-M, MMA: conceptualization, design. IIA, AAA, MMA, THA, HFA: literature research, patients recruitment, data collection. SSA: statistical analysis. All authors: writing – review and editing, final approval.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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Knee Spacers in Periprosthetic Joint Infections: A Narrative Review

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SUMMARY

Introduction. Periprosthetic joint infection (PJI) is a most common causes of failure of total knee arthroplasty. Knee spacers can be static or dynamic and are commonly used in the management of periprosthetic joint infection. Several types of spacers are available including rods, fixator rods, inverse spacers, handmade, molded, or preformed spacers with a cement-on-cement interface. This article provides a detailed review of knee spacers, their differences, and indications.
Materials and methods. In February 2023, PubMed, Embase, Scopus, and Google Scholar were accessed, with no time constraints.
Discussion. Spacers can be static or dynamic. Static spacers do not allow any movement, and should be used in patients with joint instability, insufficiency of the knee extensor mechanism, massive bone loss, and impaired wound healing with skin loss. On the other hand, dynamic spacers allow flexion and extension of the knee.
Conclusions. There is no evidence indicating the best choice when it comes to decide which articulating spacer to use.

KEY WORDS

Knee spacers; periprosthetic joint infection; dynamic spacer; static spacer; two-stage revision knee arthroplasty.

INTRODUCTION

One of the most common causes of failure of total knee arthroplasty (TKA) is periprosthetic joint infection (PJI) (1). PJI is associated with prolonged inpatient stay and high morbidity and mortality with its economic burden estimated to raise to $1,1 billion by 2030 (2). The diagnosis of PJI is based on a combination of clinical findings, laboratory results from peripheral blood and synovial fluid, microbiological culture, histological evaluation of periprosthetic tissue, and intraoperative findings (3). The criteria for the diagnosis of PJI are reported in the **table I**.

Periprosthetic joint infection can be early, delayed or chronic (4). Early PJIs are those occurring within 3 months after a TJR; PJIs with onset between 3 and 24 months are classified as delayed; late PJIs are those occurring over 24 months after a TJR (4). The management is surgical, and can be either one-stage or two-stage. Single-stage treatment became popular in 1985 through the work of Freeman *et al.* (5). This method had the advantage of reducing the number of surgeries, increasing the chances of maintaining motion and soft tissue health, and having lower costs (6). However, it had a low rate of success, which led to the implementation of the two-stage protocol (6). Two-stage revision knee arthroplasty was first described by Insall *et al.* in 1983 (7). Up to that time, PJI had been treated with intravenous antibiotics, arthrodesis, immobilization with a long leg cast, or amputation; by the end of the twentieth century, spacers were introduced in orthopedic practice (5). The idea of spacers first arose to avoid soft-tissue contracture, to reduce the discrepancy between the length of lower limbs and favor some mobility during the time in between prosthe-

Table I. Diagnosis PJI (3).

Diagnosis
Major criteria
Two positive cultures of the same organism
Sinus tract with evidence of communication to the joint or visualization of the prosthesis
Minor criteria
Preoperative diagnosis
Single positive culture
Serum ESR (mm/hr)
Serum CRP (mg/dL) or D-dimer (μg/mL)
Synovial Fluid WBC (cells/μL) or LE
Synovial Fluid Alpha defensin
Synovial Fluid CRP
Synovial Fluid PMN
Intraoperative fundings
Positive histopathology
Positive purulence
Positive molecular findings

sis reimplantation. The first studies on the use of spacers were conducted by Wilde and Ruth in 1988, and Booth and Lotcke in 1989; they reported, respectively, 90% and 96% success rate in eradication of infections (8, 9), the necessary step to proceed with the implantation of a new prothesis in the second stage. To verify clearance from infection, clinical signs of infection and blood cultures must be evaluated.
The main functions of spacers are still debated in literature and are summarized in **table II** (10).
Two types of spacers have been described, namely static and dynamic.

MATERIALS AND METHODS

Literature search

In February 2023 the following databases were accessed: PubMed, Embase, Scopus, Web of Science, Google Scholar. The following keywords were used in combination: Articulating spacer, Static spacer, periprosthetic joint infection, Dynamic spacers, revision TKA. If title and abstract matched the topic, the full text was accessed. The bibliographies of the full-text articles were also screened for inclusion. Disagreements were solved by a third senior author. According to the authors language capabilities, articles in English, French, German, Italian, and Spanish were considered.

STATIC SPACERS

Static spacers do not allow any kind of movement, keeping the joint either in extension or minimal flexion (11).
The main indications for the use of static spacers are (12, 13):
- Joint instability.
- Insufficiency of the extensor mechanism.
- Massive bone loss.
- Wound healing with skin loss.
- Patients with severe uncontrolled infections.

Different static spacers exist:
- Rods.
- Fixator rods.
- Inverse spacer.

RODS

Rods consist of a bar of different materials and sizes. Different types of rods are selected according to the anatomy of the patient encountered, such as Küntscher nails (7-9 mm in diameter and up to 30 cm in length), Steinmann pins (1.5-6.5 mm in diameter made of stainless steel), intramedullary nails, Rush rods (2-6 mm in diameter and up to 40 cm in length) (14, 15). Usually, the spacer is surrounded by antibiotic-loaded cement (16) (**figure 1**).

FIXATOR RODS

Fixator rods have diameters between 8.0 and 14 mm, according to the intramedullary diameter and the height of the patient (17). To guarantee a stable fixation of the rod to the tube connector, several attempts in flexion and exten-

Table II. Main functions of spacers (10).

Functions
Prevent shortening of soft tissue by maintaining tissue tension
Limit hematoma formation and/or proliferation of connective scar tissue and fat tissue
Stabilize joints to avoid dislocation by reducing empty space
Favour localized release of antibiotics
Avoid rigidity
Improve postoperative range of motion (ROM) and functional outcome (10)

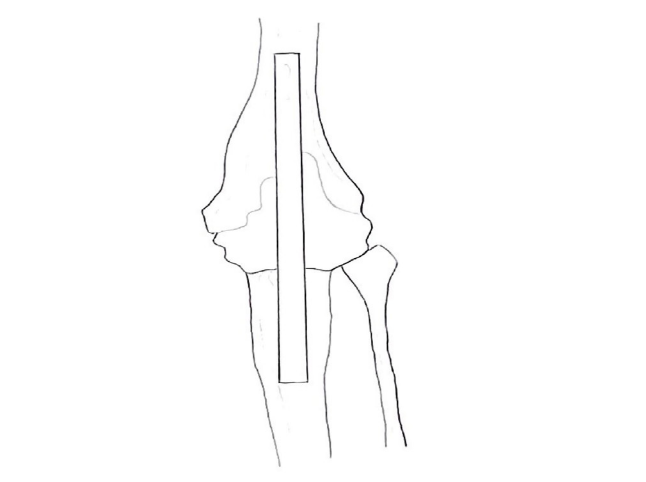

Figure 1. Rod.

sion positions are made until fixation in an extended position is reached. The nut of the connector is positioned medially so that it can be easily accessed when the spacer will be removed. The use of fixator rods allows patients to immediately regain full weight bearing, reducing bed rest complications (17) (**figure 2**).

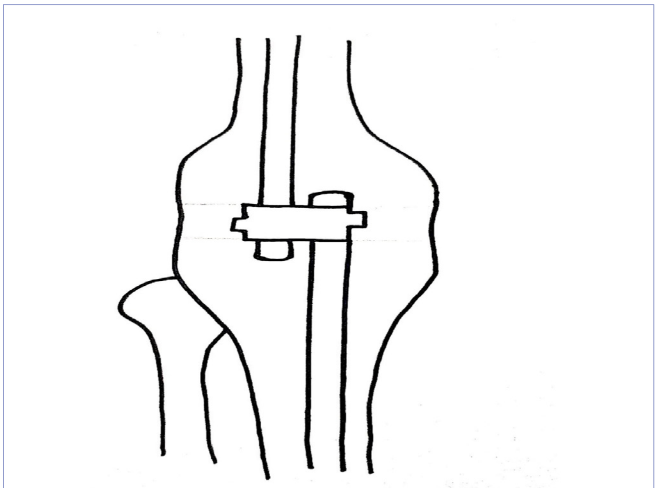

Figure 2. Fixator Rods.

THE INVERSE SPACER

The inverse spacer was designed as an articulating spacer but acts like a static one. The latter is made of independent tibial and femoral components (10). The tibial component is convex while the femoral one is concave. It is made with polymethyl methacrylate (PMMA) cement and intra-operatively shaped under maximum longitudinal tension at 5° flexion and 5° valgus position (10). Hammerich *et al.* suggested the use of a straight-leg brace with this spacer, rendering the spacer a static one (12). Eliminating anterior to posterior translation movements, inverse spacers reduce the range of motion of the resulting artificial "joint" acting as a pure hinge joint (10) (**figure 3**).

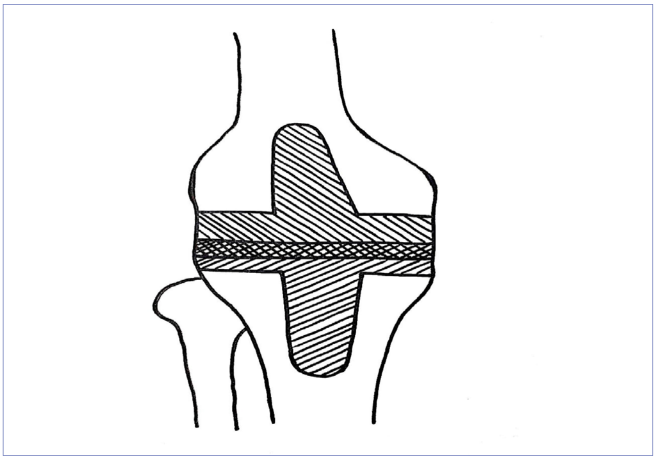

Figure 3. Inverse Spacer.

DYNAMIC OR ARTICULATING SPACER

Articulating spacers allow both flexion and extension of the knee, maintaining the joint space and local delivery of antibiotics, during the interval between surgical stages, and maintain adequate length and some motion of the extensor mechanism.
There are different types of articulating spacers:

- Handmade.
- Molded or preformed spacers with a cement-on-cement interface.
- Prostalac.
- Hoffman, made of metal on polyethylene.

HANDMADE

They are cement spacers without molds that vary in size and shape and are not commonly used (18). Different forms of spacer exist, including beads, balls, flattened blocks and intramedullary dowels/rods of polymethyl methacrylate; they may be constructed intraoperatively using antibiotic-impregnated cement (15). Handmade spacers enable specific tailoring to accommodate individual bone defects and anatomy of patients (19). These are formed around a Steinman pin, Kirschner-wire, or other such metal "endoskeleton", to mitigate the risk of fracture and other mechanical complications. In the knee, handmade spacers can also be constructed around arthrodesis intramedullary nails (19).

MOULDED OR PRE-FORMED SPACERS: CEMENT ON CEMENT INTERFACE

Molded or pre-formed spacers can be divided as follows.

Pre-molded

One type of pre-molded or pre-formed cement spacers are antibiotic spacers, with or without stems, that have non-interchangeable sizes of femoral and tibial components (20). The tibial component is not provided with a stem or an intra-articular post. They include trial of tibial and femoral components for intraoperative sizing (20). When these spacers are used, intramedullary antibiotic cement dowels for the distal femur and proximal tibia are prepared and inserted first, and then additional antibiotic bone cement is used to implant the pre-molded components to the distal femur and proximal tibia (20). A short amount of time needs to pass before engaging in weight bearing activities with one or two crutches to allow wound healing; however, active range of motion is encouraged (20) (**figure 4**).

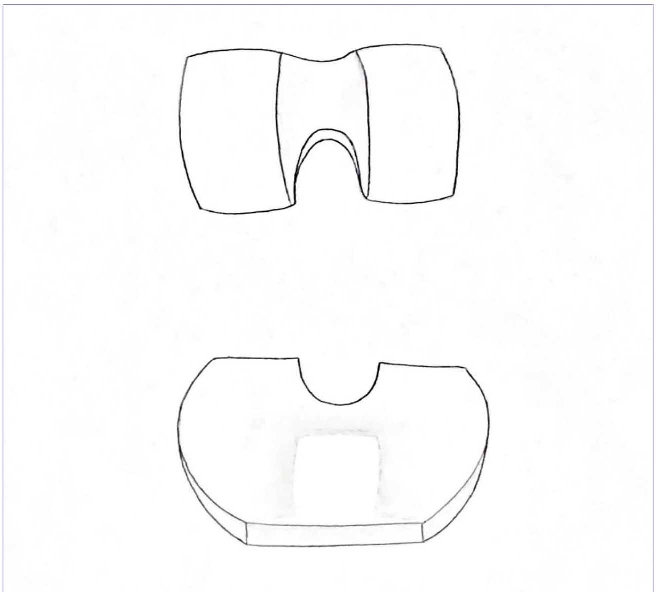

Figure 4. Premolded Spacer.

Surgical molds for intraoperative fabrication (with or without metal femoral runners)

Several types of surgical mold spacers are available. The non-metal molds for the tibia and femoral components are fabricated by the surgeon intraoperatively with the cement mixed with one or two antibiotics (21). Differently from pre-formed ones, the sizes of these molds are interchangeable (20). These cement-on-cement spacers are generally implanted with additional antibiotic bone cement and usually intramedullary dowels (20) (**figure 5**).

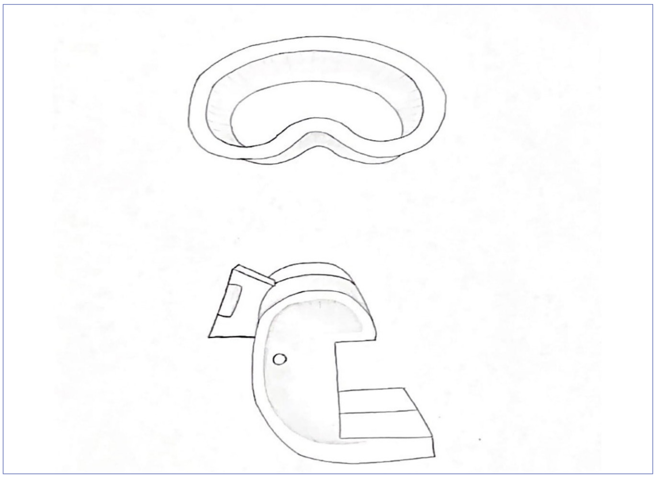

Figure 5. Surgical molds spacer.

PROSTHESIS OF ANTIBIOTIC-LOADED ACRYLIC (PROSTALAC)

First used in 1987, the PROSThesis of Antibiotic-LoadedAcrylic Cement (PROSTALAC) knee spacer consisted of a conventional handmade prosthesis made of antibiotic-loaded cement. In 1991, it was modified by using flexible polyethylene molds to produce smoother articular surfaces on the femoral and tibial components (22). The current PROSTALAC spacer, originally introduced in 1994, has femoral and tibial components both made of antibiotic loaded with acrylic cement; each component is cast in size specific molds (22). The tibial mold enables adjustment in the thickness of the spacer to assist restoration of bone loss and joint stability. It has a post-cam mechanism formed from cement, between two inlay polyethylene (PE) plateaus. The femoral component incorporates small metal runners linked together by a posterior cross bar to prevent posterior dislocation, thus producing a metal on polyethylene bearing (22) (**figure 6**).

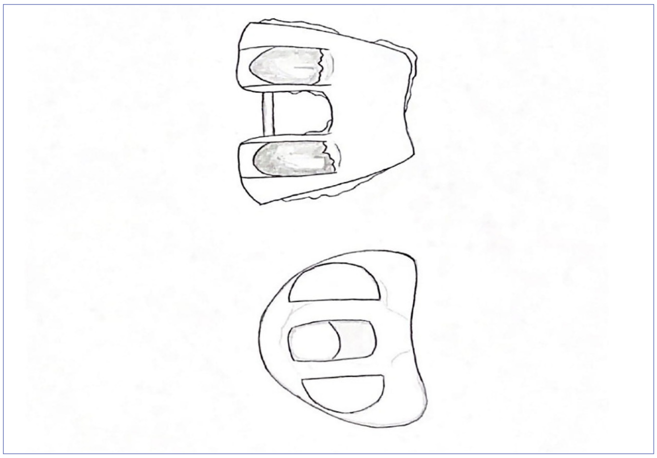

Figure 6. Prostalac.

HOFFMAN

In 1995, Hoffman *et al.* described a new dynamic spacer, made by cleaning and autoclaving the removed femoral component (6). The autoclave should be near the operating room to facilitate aseptic delivery to the sterile field.(23). If a spore test cannot be performed before implant use, the implant should undergo a full-cycle steam sterilization, not flash sterilization (24). During surgery, the femoral component is then reinserted and articulated with a new tibial polyethylene insert, as well as a new polyethylene patella component (6). Theoretically, the use of Hoffman spacer allows patients to achieve full eradication of the infection and satisfactory functional results, limiting the need for a second procedure to implant revision knee components (25) (**figure 7**).

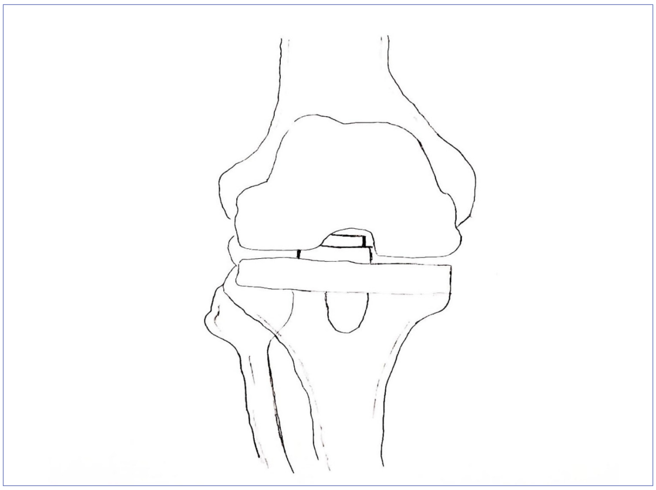

Figure 7. Hoffman.

DISCUSSION

Two-stage exchange arthroplasty with an antibiotic-impregnated cement spacer remains the standard treatment for patients with an infected total knee arthroplasty. Two-stage revision knee arthroplasty has an infection eradication rate between 83% and 91% (26, 27). In this review, we describe the different types of spacers. Static spacers do not allow any kind of movement, keeping the joint in extension and reducing the cost of surgery. The rate of complications following the use of static spacer is 11.2%, mainly tibia and femur fractures (28, 29). Llado *et al.* reported a case of migration of Steimann pins used for the management of PIJ (30). Among the causes of migration there are pin and wire size, smooth surface texture, broken or loose implants, osteolysis, poor bone quality, prolonged implantation time, repetitive movements across the line of axial motion of joints, gravitational forces, capillary actions, respiratory excursions, muscular activities, and traumatic dislodgements (30). Given their mechanical properties, fixator rods can be used in patients with large metaphyseal defects without the use of an external fixator (31). Moreover, they reduce the risk of complications, such as thrombosis or pneumonia, and are easier to remove in the second stage. However, they increase the risk of aseptic loosening, postoperative fracture and patellar instability as well as prolonging intraoperative time (17, 32). Inverse spacers reduce the risk of fracture and dislocations and the post-operative force/friction that occurs at the cement-spacer interface, avoid bone loss and are easy to remove at revision TKA (10). Periarticular bone loss is among the potential problems of static antibiotic-loaded spacer use (21). Calton *et al.* reported a 40% rate of tibial bone loss and a 44% rate of femoral bone loss in 25 patients treated with static spacers (33). Fehring *et al.* validated these results in a retrospective study comparing handmade cement articulating spacers with a static spacer block technique (34). Fifteen of 25 patients (60%) in the static spacer group experienced bone loss directly related to the spacer, with none identified in the articulating spacer group. Articulating spacers allow both flexion and extension of the knee (34). Maintaining the range of motion of the knee before implantation of the articulating spacer is important to restore stability in the tibial platform, the distal femoral cut, femoral and tibial canals, and preserve the gaps using the revision gap balancer (35). Delay in wound healing is reported when using articulating spacers (9). Handmade articulating spacers are less stable, and it is difficult to produce a well-shaped and congruent articular surface (36). Hand-made hip and knee spacers can be 40 to 50% cheaper than prefabricated spacers and spacer molds (37). In fact, the mean price for self-made knee spacer is 514 CHF (450 EUR/505 USD) for non-articulated and 535 CHF (470 EUR/525 USD) for articulated ones. For prefabricated knee spacers and knee molds spacers, the minimum cost is of 1050 CHF (922 EUR/1,030 USD) (37). This is a major economic advantage given the high costs of this surgical procedure (38). Pre-formed spacers have the disadvantage of being limited in size, hence they do not fit correctly in all patients (11). Prefabricated articulating cement implants have enhanced mechanical implant integrity when compared to intraoperatively molded spacers given the tightly controlled manufacturing process (39). Indeed, mechanical integrity of an intraoperatively molded implant is variable and highly dependent on antibiotic dosing and technique. As a consequence of the higher integrity and stability of prefabricated cement implants, obese or poorly compliant patients are less likely to experience a catastrophic mechanical failure of such implant, as they are designed with enhanced articular surface congruency which confers improved anteroposterior stability of the joint, minimizing the risk of implant subluxation or dislocation (39). Surgical molds increase intraoperative time (20). Fewer fractures have been observed with prefabricated spacers as compared to intraoperative fabricated mold spacers. However, there could be a lower concentration of antibiotics in prefabricated spacers. Prostalac is an articulating spacer which seems to induce less bone loss between stages (18). Patients are encouraged to actively mobilize the knee immediately after surgery. The rate of complications in the use of Prostalac is 17%, but it requires longer intraoperative time, and it increases the risk of cement fracture and migration of the component (18, 40). In the Hoffman technique an articulating spacer is made by cleaning and autoclaving the removed femoral component. This procedure has a good cost-effectiveness ratio. A spacer made by autoclaving the infected components has a direct cost of $932, whereas the costs of spacers made by new femoral component and molded cement spacers may reach up to $3,589 and $3,945, respectively (41). The temporary re-use of the femoral component can reduce the cost of the articulating spacer by approximately $1,900/patient, *versus* a new femoral component, and by approximately $1,000/patient, *versus* a molded cement spacer (24). Spinarelli *et al*. reported a re-infection rate ranging from 2.27 to 37%, and a cumulative re-infection rate of 13.7% (23). A recent meta-analysis reported no significant difference in reinfection compared to patients treated with other articulating spacer, but a better functional outcome (25). A systematic review of 30 retrospective studies comparing the two types of articulating spacers (all-cemented or made of bio-inert materials such as plastic or metal) reported a similar control rate of infections between the two groups. However, the articulating spacer made of bio-inert materials had a higher postoperative risk of reinfection and poorer clinical outcome (42). A meta-analysis of 34 articles compared four types of articulating spacers: 3 were all-cement (cement-on-cement handmade, cement-on cement prefabricated, cement-on-cement molded), one was metal-on polyethylene (MOP). There were no significant differences in the rate of reinfection and in the difficulty of reimplantation (43). The major complications in the use of cement-on-cement articulating spacer are extensor lag, spacer subluxation, spacer fracture, extensor mechanism rupture, nerve palsy, periprosthetic fracture, dislocation, instability, arthrofibrosis, hematoma, delayed wound healing (43). The rate of complications associated with the use of cement-on-cement handmade articulating spacers is 8.52%, against 7.69 % and 5.87% respectively of the pre-fabricated and molded ones (43). Metal-on-polyethylene articulating spacers are associated with a lower rate of complications and the absence of spacer fractures (43, 44). It is not always possible to have a second stage because of economic and health reasons, and some patients may refuse reimplantation (45). Cai *et al.* suggest using the spacer as a definitive treatment for PJI. In fact, although the infection relief rate of destination spacers was similar to that of two-stage revision, the complications were higher than those of two-stage revision (45). The use of intramedullary antibiotic dowels for the femoral and the tibial medullary canal in both static and dynamic spacers is expand-

Table III. Complications articulating and static spacers (28, 50).

Articulating Spacer	Static Spacer
Instability	Extension lag
Flexion contracture	Flexion contracture
Aseptic loosening	Aseptic loosening
Delayed wound healing	Delayed wound healing
Knee dislocation	Knee dislocation
Hematoma	Hematoma
Patella tendon rupture	Patella tendon rupture
Patella fracture	Patella fracture
Patella dislocation	Patella dislocation
Deep venous thrombosis	Deep venous thrombosis
Pulmonary embolism	Pulmonary embolism
Nerve palsy	Nerve palsy
Periprosthetic fracture	Periprosthetic fracture
Severe chronic post-operative pain	Migration of the Spacer
subluxation	subluxation
Amputation	Amputation
Fractured Spacer	Fractured Spacer

ing, given the report of frequent positive cultures in the medullary canal at the time of removal of non-stemmed infected total knee components, and the frequent finding of positive intra articular cultures in patients with a variety of knee spacers (46, 47). However, there is no significant difference in the eradication of the infection with IM dowels (48). In addition, many complications have been reported with the use of dowels including migration of a smooth pin out of a cement spacer into the calf (21). Cementless stems are associated with a lower rate of radiographic failure than cemented spacers. However, they have a similar rate of reinfection (49). The complications of static and dynamic spacers are summarized in **table III** (28, 50). Four systematic reviews have analyzed several studies comparing static and dynamic spacers. A review of 48 articles reported no significant difference between static and dynamic spacers in terms of complication, reinfection, reoperation, or knee society score. However, the mean range of motion (100° in articulating spacer *vs* 92° in the static spacer) was statistically significant (28). A systematic review of 47 studies reported a better eradication using articulating spacers, greater ROM, and easier re-implantation (50). A systematic review of 34 articles confirmed the absence of differences with reinfection or difficulty of reimplantation (43). A systematic review of 87 articles reported no differences in peri-operative local complications, rate of non-infection-related complications and rate of reinfection (13). Moreover, no correlations between the mean time to second stage after spacer placement and the mean time to PJI recurrence were found. However, articulating spacer mean active knee flexion was significantly higher using articulated spacers, but this has no clinical relevance (13).

CONCLUSIONS

Periprosthetic join infection is a common cause of failure of TKA. Two-stage revision knee arthroplasty is the gold standard for PIJ. Static spacers are used in case of joint instability, insufficiency of the extensor mechanism, massive bone loss and wound healing with skin loss. There is no evidence of superiority between the different types of articulating spacers, but patient specific characteristics such as bone stock, soft-tissue envelope, and ligamentous stability should be assessed during preoperative planning. For these reasons, the use of given spacer depends on the patient characteristics and the surgical ability of the surgeon.

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DATA AVAILABILITY

N/A.

CONTRIBUTIONS

FO: conceptualization, writing, revision, final approval. SZ: writing, revision, final approval. NM: supervision, revision, final approval. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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ORIGINAL ARTICLE

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Transfer of the Flexor Hallucis Longus Tendon for Neglected and Degenerative Tendo Achillis Rupture: A Prospective Clinical Study

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SUMMARY

Introduction. The Achilles tendon is one of the most frequently ruptured tendons in the human body. Surgical management commonly includes end to end repairs in acute tears, and chronic ruptures require autologous tendon transfer with Flexor hallucis longus or Flexor digitorum longus.

Methods. A longitudinal observational study was done on 22 confirmed cases of chronic Achilles tendon rupture. Two incision technique of FHL tendon transfer with no exposure/debridement of the Tendoachilles was incorporated and functional outcome with American Orthopaedic Foot and Ankle Society Ankle-Hindfoot score, modified RUPP and Achilles Tendon Total Rupture (ATRS) scores both pre- and post-operatively were evaluated. Wound healing time and complications, heel-floor distance, calf circumference, hallux function and morbidity, graft characteristics and anatomic variation of master Knot of Henry were evaluated. Patients were followed up and assessed at 6 weeks, 3 months, and 6 months post-operatively.

Results. The mean length of the FHL graft obtained from 2 incision technique was 8.09 cm. There was significant improvement in the Heel Rise Height Index from 7 to 63% ($p < 0.0001$), mean AOFAS ankle-hindfoot score from 43.9 to 89.6 ($p < 0.001$), mean ATRS Score from 19.6 to 79 ($p < 0.0001$) and mean Hallux MTP-IP scores to 96.3 ($p < 0.0001$) at 6th month follow up was found. 13 (59%) had "Excellent" modified RUPP scores. 20 (90.9%) had Type I variation while 2 (9.1%) had Type II variation in MKH. Mean length of the graft obtained was 8.09cm. Mean wound healing time was about 13 days and only one had wound complication.

Conclusions. FHL tendon transfer has advantages of requiring minimal dissection, being stronger than FDL and PB and it is an in-phase transfer with the same axis of contraction.

KEY WORDS

Chronic Tendoachilles rupture; FHL tendon transfer; 2 incision technique; functional outcome; anatomical variation of Master Knot of Henry.

BACKGROUND

The Gastrocnemius-soleus complex (triceps surae) traverses both the ankle and the knee joint and consolidates as Achilles tendon, which is the largest, strongest and one of the most common tendons to get ruptured. It is innervated by tibial nerve (1). During various activities like walking, running and jumping, the Achilles tendon unit undergoes both eccentric lengthening and concentric contracture. A relatively avascular zone of 2-6 cm proximal to the insertion was described by Lagergren and Lindholm (2). The cause of tendinopathy is multifactorial, including inflammatory, vascular, biomechanical and degenerative causes. Mechanical overuse, as seen in athletes with repetitive microtrauma to the tendon, old age, the anomalous blood supply, intralesional steroid injections, have been implicated in the weakening of the tendon which makes them more prone for ruptures (3). Patient derived outcome scales have become important to surgeons and researchers as they are a measure of improvement in function following the surgical intervention. Comparing the results of different clinical/ surgical interventions will help in constant improvement in the operative techniques. Chronic ruptures are defined as the ruptures which occur after 4-6 weeks following the injury (4). 25% of acute ruptures are missed and progress to chronic Achilles tendinopathy. Patients having Tendoachilles rupture have chronic ankle pain and are unable to walk pain free. They lose the ability to stand on their toes on the affected side, although standing on both toes may be possible with unilateral cases. Patients will not be able to run, as they do not get enough strong push-off by plantar flexion of the ankle. The management of the ruptured tendon is a challenging one. The management of chronic Tendoachilles ruptures is usually different from that of end-to-end suturing done for acute ruptures, as tendon's ends in chronic tears are retracted, undergo degenerative calcification and are atrophied with short and fibrous distal stumps (4). Various procedures have been performed for chronic Tendoachilles rupture including autologous tendon transfer, V-Y myotendinous advancement, Proximal Tendoachilles turndown and other surgeries like transfer/augmentation with tendons of Peroneus Brevis (PB), Flexor Digitorum Longus (FDL), Flexor Hallucis Longus (FHL) tendon. Other materials used are Carbon fiber, Dacron weave and Marlex mesh.

All these surgical procedures have been shown to yield satisfactory clinical results. FHL has mechanical advantage over the other autologous tendon transfers and it is shown to be stronger than the Peroneus Brevis (PB) and twice as strong as the Flexor digitorum longus (FDL) tendon. Another advantage is that it is an isophasic transfer (active in the same phase as the Tendoachilles) and its axis of contraction is the same as that of Tendoachilles (5). FHL, which is also known as the beefy muscle, also provides vascularity to the Achilles tendon. It helps to maintain normal ankle function, decreasing wound healing time, weight bearing, and decrease the wound complications associated with it. Literature review suggests various surgical interventions, although no single technique has been shown to be clearly superior. There exists an anatomical relationship between the tendons of FHL and FDL in the form of tendinous band like interconnections which is known as Master Knot of Henry or Henry's knot. This is anatomically located about 2 cm below the navicular tuberosity and 12 cm proximal to the first Interphalangeal joint. There are different divisions and subdivisions documented in the literature showing variation within different ethnic and racial backgrounds (6-8). This knowledge of the interconnections is very essential to the surgeons during the harvesting of FHL tendon for tendon transfer as they must be released if it is harvested from distal to the MKH. It is also essential to minimize the post-op morbidity and explain probable functional loss. A simple clinical test can help evaluate these interconnections as well (8). The purpose of this study is to assess the functional outcome of all patients who had undergone Achilles tendon repair with FHL tendon transfer at JSS Hospital.

MATERIALS AND METHODS

This was a longitudinal study done in JSS Medical College, Mysuru, India, from September 2019 to September 2021 on 22 patients. Ethical clearance was obtained from Institution Ethical Committee for the study (JSS/MC/PG/5189/2019-20 - Date of approval: November 14, 2019). After obtaining consent from patients, clinically and radiologically confirmed cases with Tendoachilles ruptures were included in the study. Patients who were known cases of Type II Diabetes mellitus, B/L Achilles tendon tears and those with open wound or clinically detectable focus of active infection were excluded from the study.

Tear was confirmed radiologically with USG with which even the defect was noted. MRI was done to confirm the diagnosis. Heel floor distance was measured manually with an inch tape and Heel Rise Height Index, defined as heel-rise height (injured)/heel-rise height (un-injured) and is calculated as percentage. Calf circumference was also measured with an inch tape at 10 cm distal to the tibial tuberosity and average of 3 readings was taken.

After obtaining consent and pre-anesthetic checkup, all the patients underwent FHL tendon transfer by 2 Incision technique performed by a single surgeon.

Under Spinal anesthesia, Tourniquet control was used for all the cases. All the surgeries were performed by the same surgeon. A mini-invasive technique was employed in this study. Surgery was done in supine position with sand bag elevation under the hip to facilitate flexion, abduction, and external rotation. 1st incision was placed Posteromedial to the Tendoachilles. Skin is elevated along with the paratenon to avoid skin necrosis and wound complications, keeping in mind the precarious blood supply in this region. FHL is identified and isolated through 1st incision and confirmed by pulling the tendon and checking for passive dorsiflexion of the great toe. Next, the 2nd incision was placed just below the Navicular tuberosity. Dissection was done between the 1st and 3rd layers of the foot; Master Knot of Henry was visualized, and its anatomical variation was noted (**figure**

1). The interconnections of FHL and FDL were released and FHL was incised as distally as possible through this exposure. The distal stump of FHL was tenodesed to FDL tendon with absorbable suture keeping the great toe in neutral to avoid excessive tension. Tag suture was applied to the proximal stump using Ethibond (Synthetic, Braided and Non-absorbable Polyethylene suture material) 6-0 and the freed FHL is then delivered through the 1st incision. The time required for MKH finding and release, and the percentage of time required was calculated. Graft length (measured from the musculotendinous junction to the distal tip) and graft thickness using graft sizer was also noted intra operatively. Using core reamer of appropriate size, calcaneal tunnel was made with the guidance of angle guide from superomedial to inferolateral direction just medial to the insertion of Tendoachilles under C arm guidance. The tag suture is then drawn through this Osteo-calcaneal tunnel and secured using a titanium interference screw of appropriate size with foot held in 10° of plantar flexion. Thorough wash was given, and wound was closed in layers, by approximating the skin along with the paratenon in the proximal incision. Dressing was done and dorsal slab was applied with foot in 10-15°.

Nowhere in the procedure followed, was the degenerated/chronic tear of Tendoachilles exposed or debrided. The native tendon was left in place. This was done so as to prevent the possible complication of wound healing and skin necrosis due to the precarious blood supply in this region. Broad spectrum IV antibiotic was given for 2 days followed by dressing on post-op day (POD) 2 and switched to oral antibiotic for 5 days if wound was healthy. Follow-up dressings were done on POD 5 and POD 10. Patient was followed up after 2 weeks Post Op, and suture removal was done if healed and healthy. The slab is reapplied for 2 more weeks following which it is converted to boot cast with foot in neutral position at the end of 4th week Post Op. Partial weight bearing is started as tolerated with the help of adjustable quadrangular walker. At the end of 6 weeks, patients are encouraged to wean off the walker and boot cast as soon as possible, and ROM exercises of the ankle are started. Patient is assessed for calf circumference, AOFAS Ankle Hindfoot Score, ATRS Score, AOFAS Hallux MTP-IP Score. Patient is allowed to perform Heel Rises gradually after 6 weeks.

Patients were called for follow up at 3months and 6 months for assessing Heel Rise Height Index, Calf Circumference, AOFAS Ankle Hindfoot Score, ATRS Score, Modified RUPP Score and AOFAS Hallux MTP-IP Score.

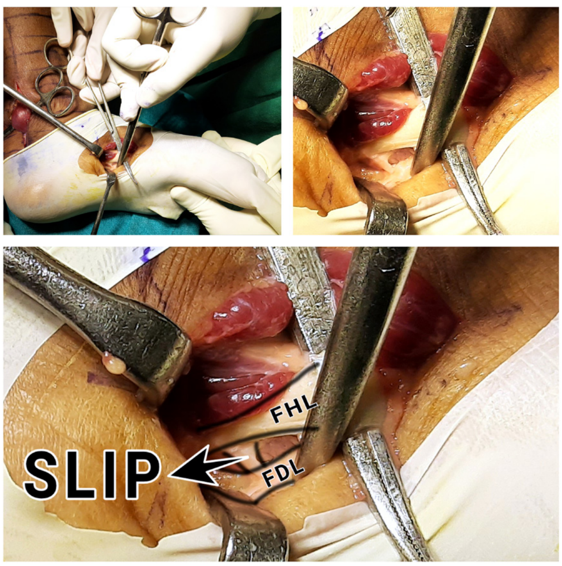

Figure 1. Soft tissue dissection and isolation of FHL tendon through 1st incision, Type I anatomical variation of Master Knot of Henry.

Statistical analysis

All the statistical analysis was done using SPSS (ver. 21.0) for Windows. Repeated measure ANOVA test was used to compare the values over subsequent follow-ups.

Result was considered statistically significant if P-value < 0.05. In this study the most important findings obtained are the significant improvement of Mean AOFAS Ankle-Hindfoot scores, Mean ATRS scores and Mean Modified RUPP Scores. The improvement of AOFAS Hallux MTP-IP Joint scores and Mean Heel Rise Height Index are also found to be significant. Type I variation in MKH was found in 90.9% of the patients while 9.1% patients showed Type II variation. There was only 1 patient who had infection at the heel site and no patients had any donor site morbidity.

RESULTS

This study had 22 patients who underwent FHL Tendon Transfer using 2 incision technique and followed up for 6 months postoperatively.

The mean age group of study population was 50.7 ± 11.1 years and having a male preponderance (63.6%). Left side was predominantly affected (63.6%). Majority of the patients were farmers (40.9%) by occupation and the most common mechanism of injury was slip and fall in the fields (72.7%). The mean delay in presentation following the injury was 18.5 ± 13.4 weeks and history of steroid injection was present in half of the study population (54.5%). The mean defect as measured in USG was 5.23 ± 1.34 cm.

The Heel rise height index (HRHI) which was defined as the Heel-rise height of affected side divided by the heel rise height of un-injured side showed significant improvement from 7.16 ± 6.93% to 63.36 ± 9.87% ($p < 0.0001$, repeated measure ANOVA test) and calf circumference on the injured side showed significant improvement ($p < 0.01$) at the end of 6 months follow-up. There was significant improvement in AOFAS ankle-hindfoot scores from 43.91 ± 4.63 pre-operatively to 89.68 ± 4.95 ($p < 0.0001$), ATRS Scores from 19.55 ± 2.81 preoperatively to 79.05 ± 2.95 ($p < 0.0001$), AOFAS hallux MTP-IP Scores from 65.18 ± 4.17 preoperatively to 96.27 ± 4.68 ($p < 0.0001$) at the end of 6th month follow-up. The improvement seen in Modified RUPP Scores were significant at the end of 6th month follow-up ($p = 0.008$, McNemar Test).

Regarding the intra-operative findings, the mean total duration of surgery was found to be 93.41 ± 13.92 mins and the mean time required to find Master Knot of Henry (MKH) and release was found to be 20.82 ± 5.88 mins. It was deduced that a mean of 22.13 ± 3.90% of the total duration of surgery is needed for finding and release of MKH. One of the patients had intra operative tourniquet malfunction, because of which the duration of surgery was way more than the mean due to obvious reason of not obtaining a relatively bloodless field to visualize, identify and work with the tendons. The mean height and width of the FHL tendon graft was found to be 8.09 ± 0.63 cm and 7.57 ± 0.54 cm respectively.

We could identify only 2 variations in the anatomy of MKH. Type I variation: single slip from FHL proximally to FDL was seen in 20 (90.9%) of the study population, while other 2 (9.1%) had Type II variation: 1 slip from FHL proximally to FHL and another slip from FDL proximally to FHL (6).

In this study the mean wound healing time found was 13.09 ± 3.49 days. One patient had wound complication of surgical site infection at the heel site, due to which the wound healing was delayed. This is the same patient who had intra operative tourniquet cuff malfunction, and a tag suture was applied with a gauze at the heel site as an additional reinforcement. This is the site which got infected on 10th post operative day, for which antibiotic bead insertion was done and the wound went on to heal well by 28th post operative day. This patient was also found to have comparatively decreased functional outcome compared to the other patients at last follow-up.

There were no re-ruptures throughout the follow-up period. There was no donor site morbidity, great toe deformities, or any paresthesia due to iatrogenic sural nerve injury. All the patients had absent flexion of IP (interphalangeal) joint of great toe, but this did not translate to any functional deficiencies as in walking or activities of daily living.

The mean Heel Floor Distance (HFD) was found to be 7.45 ± 1.53 cm on the normal side while on the injured side, it was found to be 0.59 ± 0.59 cm. The minimum and maximum HFD on the Normal side was 5 cm and 11 cm, respectively, while on the injured side it was 0 cm and 2 cm, respectively. The mean heel floor distance was 7.45 ± 1.53 cm with a minimum measurement of 5 cm and maximum of 11 cm on the normal side and 0.59 ± 0.59 cm with a mean range 0-2 cm on the injured side.

The heel rise height index (HRHI) was 7.16 ± 6.93% pre-operatively, 42.06 ± 9.72% at 3 months and 63.36 ± 9.87% at 6 months. The improvement was found to be significant with $p < 0.0001$ calculated by repeated measure ANOVA.

The mean calf circumference was 40.05 ± 1.3 cm in normal side and 39.2 ± 1.28 cm in affected side pre-operatively. The mean calf circumference on normal side was 40.02 ± 1.34 cm at 6 weeks, 40.10 ± 1.32 cm at 3 months and 40.2 ± 1.38 cm at 6 months. The Mean calf circumference on injured side was 39.27 ± 1.32 cm at 6 weeks, 39.44 ± 1.17 cm at 3 months and 39.61 ± 1.24 cm at 6 months (**table I**).

The calf circumference of the injured side as a percentage of the normal side was calculated and the mean was found to be 97.87 ± 1.3% pre-operatively, 98.16 ± 2.43% at 6 weeks, 98.38 ± 2.02% at 3 months and 98.55 ± 1.31%. This was found to be statistically insignificant with $p = 0.3$ by repeated measure ANOVA test.

The mean AOFAS Ankle-Hindfoot Scores improved from 43.91 ± 4.63 pre-operatively to 54.59 ± 7.2 at 6 weeks, 78.59 ± 5.4 at 3 months, to 89.68 ± 4.95 at 6 months (**figure 2**). This was found to be statistically significant with $p < 0.0001$ with repeated measure ANOVA Test.

The mean ATRS Scores improved from 19.55 ± 2.81 pre-operatively to 38.95 ± 3.12 at 6 weeks, 70.82 ± 3.55 at 3 months, to 79.05 ± 2.95 at 6 months (**table II**). This was found to be statistically significant with $p < 0.0001$ with Repeated Measure ANOVA test.

The mean AOFAS hallux MTP-IP scores improved from 65.18 ± 4.17 at 6 weeks to 83.18 ± 3.46 at 3 months and to 96.27 ± 4.68 at 6 months (**table III** and **figure 3**). This was found to be statistically significant with $p < 0.0001$ by repeated measure ANOVA test. There was no deformity

Table I. Calf circumference.

Calf circumference (cm)	Mean ± SD
Normal side Pre-Op	40.05 ± 1.30
Injured side Pre-Op	39.20 ± 1.28
Normal side at 6 weeks	40.02 ± 1.34
Injured side at 6 weeks	39.27 ± 1.32
Normal side at 3 months	40.10 ± 1.33
Injured side at 3 months	39.44 ± 1.17
Normal side at 6 months	40.20 ± 1.38
Injured side at 6 months	39.61 ± 1.24

Repeated Measure ANOVA; $p < 0.01$.

Table II. Comparison of ATRS Scores preoperatively and during follow up period.

ATRS Scores	Mean ± SD	Minimum	Maximum
Pre-Op	19.55 ± 2.81	15.00	25.00
6 weeks	38.95 ± 3.12	35.00	46.00
3 months	70.82 ± 3.55	66.00	78.00
6 months	79.05 ± 2.95	74.00	84.00

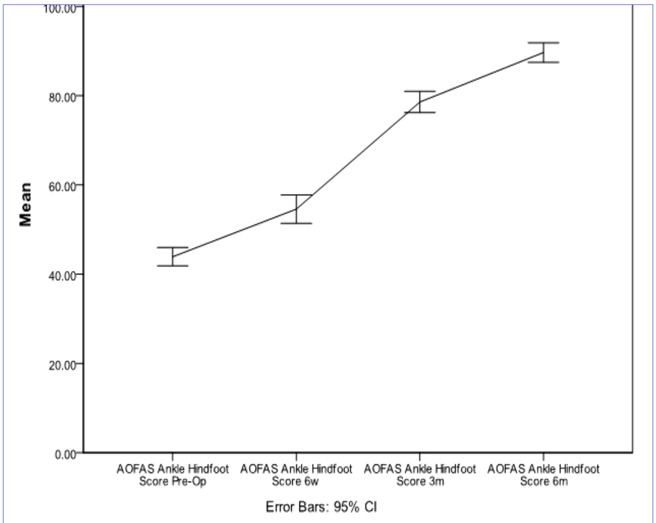

Figure 2. AOFAS Ankle-Hindfoot Scores.

seen in the great toe post operatively. Interphalangeal joint flexion was absent with presence of normal 1st MTP joint flexion in all the patients which did not translate into any clinical/functional weakness or any difficulties in performing activities of daily living and did not affect the satisfaction outcome of the patient.

Modified RUPP scores improved from poor at 3 months follow-up to fair at 6 months (**table IV**). 1 patient had scored fair at 3 months which improved to good at 6 months follow-up. At the end of 6 months follow-up, total of 13 patients (59.1%) had excellent scores (**table V**). The improvement from 3 months to 6 months was found to be statistically significant with p = 0.008 done using McNemar Test. In this study, the mean total duration of surgery was found to be 93.41 ± 13.92 mins while the mean time required to find MKH, and release was 20.82 ± 5.88 mins. The mean time required to find MKH, and release was found to be 22.13 ± 3.9% of the total duration of surgery. One of the surgeries took about 135 mins, the delay was attributable to the malfunctioned tourniquet cuff intra-op which led to difficulty in achieving a bloodless operative field.

The mean length of the FHL graft obtained was 8.09 ± 0.63 cm measured from the musculotendinous junction to the distal tip (**figure 4**). The mean thickness of the FHL graft obtained was 7.57 ± 0.54 cm as measured using graft sizer.

In this study, Type I variation of MKH: a single slip from FHL proximally to FDL distally was found in 20 patients (90.9%) and Type II variation: slip from FHL proximally to FDL distally and another slip from FDL proximally to FHL distally was seen in 2 patients (9.1%). There were no other variations found. The Mean Wound Healing time was found to be 13.09 ± 3.49 days with a minimum of 11 days and

Table III. AOFAS hallux MTP-IP Scores.

AOFAS Hallux MTP-IP Scores	Mean ± SD	Minimum	Maximum
6 weeks	65.18 ± 4.17	50.00	72.00
3 months	83.18 ± 3.46	74.00	87.00
6 months	96.27 ± 4.68	87.00	100.00

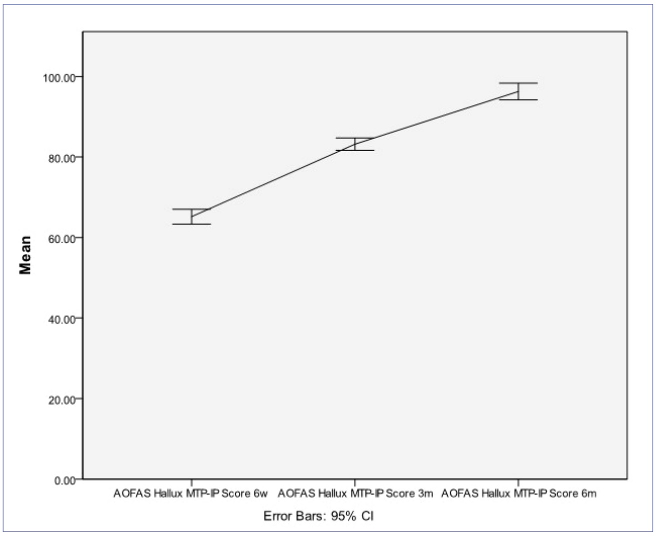

Figure 3. AOFAS Hallux MTP-IP Scores.

Table IV. Modified RUPP Scores.

Modified RUPP Scores	Count	Percentage (%)
3 months		
Excellent	8	36.4
Good	12	54.5
Fair	1	4.5
Poor	1	4.5
6 months		
Excellent	13	59.1
Good	8	36.4
Fair	1	4.5

Table V. Comparison and improvement of Modified RUPP Scores.

		Modified RUPP Scores 6 months				
		Excellent	Good	Fair	Poor	Total
Modified RUPP Scores 3 months	Excellent	8 (100%)	0(0.0%)	0 (0.0%)	0 (0.0%)	8 (36.4%)
	Good	5 (41.7%)	7 (58.3%)	0 (0.0%)	0 (0.0%)	12 (54.5%)
	Fair	0 (0.0%)	1 (100.0%)	0 (0.0%)	0 (0.0%)	1 (4.5%)
	Poor	0 (0.0%)	0 (0.0%)	1 (100.0%)	0 (0.0%)	1 (4.5%)
	Total	13 (59.1%)	8 (36.4%)	1 (4.5%)	0 (0.0%)	22

McNemar Test; p = 0.008.

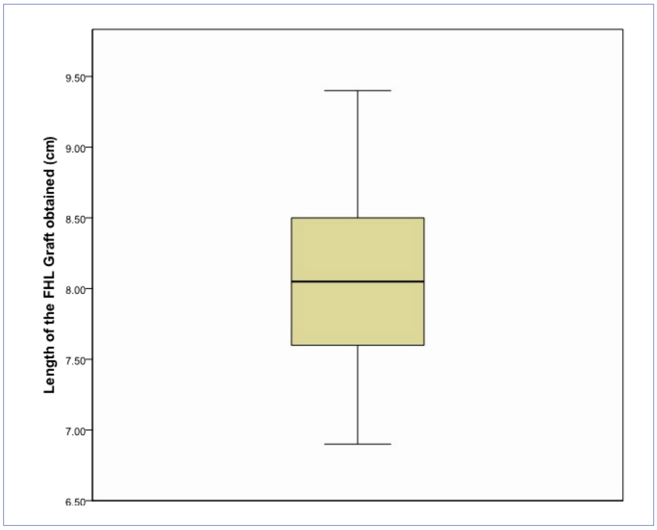

Figure 4. Length of FHL Graft obtained.

maximum of 28 days. One patient had Surgical Site Infection at Heel site due to which wound healing was delayed. 1 case (4.5%) had surgical site infection at the heel site, for which the corrective secondary procedure performed was antibiotic bead insertion following which the wound healed completely by 28 days. As a result, this patient had a comparatively decreased functional outcome at the last follow-up. There were no re-ruptures in the study throughout the follow-up of the patients. None of the patients had paresthesia in the operated side due to iatrogenic sural nerve injury.

DISCUSSION

There are various procedures documented for the management of chronic Tendoachilles tears and each of them yield satisfactory outcomes. In the most recent systematic review done, they concluded that both FHL and PB tendon transfers show good results for treatment of chronic TA tears and incorporated Visual Analogue Scale, AOFAS and ATRS scores (9).

In this study the procedure adopted is FHL tendon transfer using 2 incision technique, which differs slightly from most of the procedures done in various studies with respect to exposure of Tendoachilles. Tendoachilles was neither visualized nor debrided. There was no augmentation done in the form of suturing the FHL to the residual Tendoachilles while the other studies done documented suturing of FHL to the residual Tendoachilles. In one study, a minimally invasive 3 incision procedure was adopted in treating chronic TA tears using Peroneus brevis tendon where the gap was less than 6 cm (10). Another study shows good results for Chronic TA tears using Peroneus brevis in a minimally invasive surgical procedure with no complications (11). In our study of 22 patients, the mean age of patients was 50.7 ± 11.1 years, with majority of patients below the age of 50 years (40.9%). The study done by Mahajan and Dalal had slightly older patients with mean age of 70 years while that done by Nagakiran *et al*. had patients with a mean age of 52.3 years (12, 13). This study had a male preponderance with a total of 14 male patients (63.6%) and 8 female patients (36.4%). The study done by Nagakiran *et al*. also had male preponderance with 20 males (74%) and 7 females (26%) (13). However, the study done by Suttinark and Suebpongsiri had a female preponderance with 3 males (33.3%) and 9 females (66.7%) (14). This study population consisted predominantly of farmers (40.9%) followed by manual laborers (31.8%) and home makers (27.3%). The most common mechanism of injury in this study was found to be slip and fall (72.7%) attributable to field injuries and very commonly toilet seat injuries. This was described in the study by Dar TA *et al*. as the Indian commode is in level with the surrounding floor, making the foot easily slip into the commode following which the foot reflexively causes to go into plantar flexion when the patient tries to get out (15). During this, the taut Tendoachilles hits the toilet rim violently causing an injury/tear to the Tendoachilles. In this study, the mean time of presentation following the injury was 18.5 ± 13.4

weeks with majority (36.4%) of them presenting before 10 weeks. Similar results were reported in the study done by Mahajan and Dalal, which reported a delay in mean of 15 weeks from the injury to the time of surgery, while that done by Nagakiran *et al*. showed a mean delay of 5.6 weeks. In this study, left side was injured in 14 (63.6%) of the patients. The study done by Nagakiran *et al*. also showed similar observations. A study done by Chang *et al*. also had similar results, and they attributed this to right hand dominant individuals having a more frequent left foot push off (16). Despite this, other studies show a preponderance for right sided injuries. About 12 patients (54.5%) in our study give a history of receiving local steroid injection to the wound, a practice still persistent in the peripheral health centers, especially for Retrocalcaneal bursitis. Various studies show the greater incidence of TA tears in patients having history of local steroid infiltration. Mahajan and Dalal's study had 22% patients with a history of local steroid injection. A study done by Vallone shows the importance of using USG guidance for local steroid infiltration in their study of Complete TA tears after local infiltration of corticosteroids in the treatment of deep retrocalcaneal bursitis (17).

The mean defect as measured under USG guidance was 5.23 ± 1.34 cm in this study pre-operatively. The study done by Wegrzyn *et al*. reported 7.4 cm as the average defect in TA ruptures, while that done showed 6.00 ± 0.64 cm as the average gap after debridement and excision of fibrosis (18). The study done by Mubark *et al*. showed no significant correlation of the tendon gap as measured by USG to the final ATRS Scores (19). The patients in this study were almost unable to do heel rises on the affected side at presentation. The mean heel floor distance on the unaffected side was 7.45 ± 1.53 cm. The Heel Rise Height Index (HRHI) was calculated as heel rise in the affected side as a percentage of the uninjured side and the improvement of HRHI over follow-ups was found statistically significant in this study. At the last follow-up of 6 months, patients had a mean of 63.4 ± 9.87% in this study. Comparable results were reported in the study done by Carmont *et al*., where patients were followed up for 12 months at the end of which they obtained mean HRHI of 82 ± 16% (20). In this study, there was an overall very minimal increase in the mean calf circumference in the affected side, from 39.2 ± 1.28 cm to 39.61 ± 1.24 cm. These findings are consistent with the study done by Suttinark and Suebpongsiri in which they reported some calf hypertrophy in most of the patients (14). The study done by Daniel K. Wilcox *et al*. showed reduction of mean circumference to 96% of the normal side (21). In this study, calf circumference of the injured side was calculated as a percentage of the normal side, and the improvement in this percentage was found to be insignificant in this study.

The mean AOFAS Ankle-Hindfoot score in this improved from 43.91 ± 4.63, pre-operatively, to 89.68 ± 4.95 at the last follow-up, *i.e.*, 6 months. Similar results were reported in the study done by Nagakiran *et al*. which showed improvement from 39.79, Pre operatively, to 91.14 at 6 months follow-up (13). Similarly, the study done by Suttinark and Suebpongsiri showed improvement from 54.6 to 92.9, but this was at the end of 22 months of follow-up (14). Previous study showed improvement from a mean of 69 to 88 at end of 12 months (12). These minimal variations could also be attributable to the variation in the procedure of surgery followed in these various studies.

In this study, the mean ATRS scores improved from 19.55, pre-operatively, to 79.05 at the end of 6-month follow-up. This was comparable to the study done by Nagakiran *et al*. which showed improvement from 19.64 to 81.14 at the end of 6 months (13). A study done by Oksanen *et al*. showed that the mean ATRS score came to 70.3 following a mean follow-up of 27 months (22).

The improvement of mean AOFAS hallux MTP-IP scores seen in this study, from 65.18 preoperatively to 96.27 at 6 months follow-up was comparable to the study done by Coull *et al*. and others, where the mean AOFAS Hallux MTP-IP scores was found to be 97 at the end of mean follow-up of 43.6 months (23). The results were also consistent with another study done by Richardson *et al*. which showed the mean AOFAS Hallux MTP-IP score was 96.4 with a mean follow-up of 28 months (24). There was absent plantar flexion in interphalangeal joint of great toe in all the patients, while the plantar flexion of 1st MTP joint was preserved in all the cases in this study. This absence of IP joint flexion did not cause any clinical/functional deficiencies in the patient, nor was there any decrease in the patient satisfaction outcome in this study. They did not have any difficulty in walking as a result of the absent dorsiflexion of Interphalangeal joint. These reports are consistent with other studies which showed absent IP joint flexion which did not affect the gait of the patient.

A study done by Hahn *et al*. showed a significant reduction in the active flexion of IP and MTP joints of hallux and a slightly extended hallux in more than 35% of their cases (25). However, there was no such complication in this study. The modified RUPP Scores in this study showed statistically significant improvement from 3 months to 6 months and about 13 (59.1%) patients had excellent scores. This was comparable to those obtained in the study done by Tawari *et al*. where PB brevis was used, and they had about 50% patients had excellent scores (26).

The mean total duration of surgery was 93.41 mins, out of which the mean time required to find, isolate and release MKH was noted to be 20.82 mins. So, the mean percentage of total duration of surgery was found to be 22.13%. A study done by Rahm *et al.* showed similar results with mean of 99 mins where Modified Wapner technique was used (27). 2-incision technique was used in this study, and the mean length of the graft obtained was 8.09 ± 0.63 cm. This is comparable to the results in the study done on cadavers by Beger *et al.*, which had a mean length of 7.03 ± 0.86 cm obtained by the same 2-incision technique, while that obtained using single incision technique was 5.75 ± 0.63 cm (7).

In this study, the anatomical variation in the MKH had 20 (90.9%) Type I (Single slip from FHL proximally to FDL distally) and 9.1% had Type II (Slip from FHL proximally to FDL and another slip from FDL proximally to FHL). There were no other variations found. These findings were consistent with the study done on cadavers by Mao *et al.*, which had similar two variations only, *i.e.*, Type I found in 96.9% cadavers and Type II found in 3.1% cadavers with no other variations (6). All these studies have been done on cadavers, which allows for extensive dissection and better understanding of these variations. However, this work attempted to study these variations intra-operatively. This knowledge of variations is important for the surgeons to carry out the transfers and expect the functional outcome. In this study the mean wound healing time calculated by the post-operative day when suture removal was carried out was 13.09 ± 3.49 days. This study had only 1 patient who had wound complication at the heel site. This occurred in that same patient who had tourniquet cuff malfunction intra-operatively which subsequently led to increased duration of surgery because of a relatively bloody field of surgery. For this case, also due to unsatisfactory fixation in the calcaneal tunnel, tag suture was applied with a gauze at the heel site. This was the one which developed Infection at the heel site, and it gradually healed with the help of antibiotic bead insertion by the end of 28 days. Hence this experience also re-emphasizes the well-known fact that the shorter duration of surgery can also probably decrease the incidence of wound complications. There were no other complications noted in this study including re ruptures, paresthesia following iatrogenic nerve injury, deformities, or any donor site morbidities.

CONCLUSIONS

FHL tendon transfer using 2-incision technique had good functional outcome as detailed in this study. Though there are other autologous donor grafts like FDL and PB, FHL has the advantages of being isophasic, stronger than FDL and PB and has the same axis of contraction as that of Tendoachilles. The procedure of surgery done in our study is slightly different from those done in most of the other studies, wherein the procedure done in this study had no exposure of the Achilles tendon/muscle belly, which helps in further reducing the incidence of wound complications. This procedure is technically more demanding as thorough knowledge of the anatomy is essential for the surgeon, especially at the 2nd incision, required for harvesting the FHL graft, more so a longer one. An attempt was made to classify the anatomical variations in Master Knot of Henry intra-operatively, despite previous studies being done only in cadavers. Very minimal donor site morbidity (in the form of absent IP joint flexion in great toe) was noted with no clinical/functional deficiencies, residual deformities in the hallux, gait problems and patient satisfaction outcome, even though there was absent Hallux Interphalangeal joint flexion with preserved Hallux MTP joint flexion.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

SV: conceptualization, writing. AR: study execution. VCS: data collection, writing.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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ORIGINAL ARTICLE

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Peroneus Longus Tendon Autograft for Primary Arthroscopic Reconstruction of the Anterior Cruciate Ligament

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SUMMARY

Purpose. Peroneus longus tendon graft is not a popular first choice for ACL reconstruction. However, newer literature has shown good outcomes with its use. This study compares functional outcome and donor site morbidity of peroneus longus with hamstring tendon autograft to assess if it can be considered as one of the first choices for ACLR.

Methods. This prospective cohort study involves 54 patients who underwent arthroscopic single-bundle ACLR. 27 patients each were operated on with hamstring and peroneus longus autografts. At 2 years follow-up, functional outcome was compared between groups using International Knee Documentation Committee (IKDC), Modified Cincinnati, and Tegner-Lysholm scores. Donor site morbidity in the peroneus longus group was assessed using Foot and Ankle Disability Index (FADI) and The American Orthopaedic Foot and Ankle Society (AOFAS) scores.

Results. At 2 years follow-up, there was no statistically significant difference in the mean IKDC (77.26 *vs* 80.78), Modified Cincinnati (84.41 *vs* 89.07), and Tegner-Lysholm scores (85.19 *vs* 88.78) between the hamstring and peroneus groups respectively. Mean FADI and AOFAS scores at 2 years follow up were 96.11 and 91.67 respectively in the peroneus group suggesting no significant donor site morbidity as compared to preoperative scores.

Conclusions. Peroneus longus performs similar to hamstring grafts and can be considered as one of the first choices for arthroscopic ACL reconstruction.

KEY WORDS

ACL injury; autograft; donor site morbidity; hamstrings; peroneus longus tendon.

INTRODUCTION

Arthroscopic anterior cruciate ligament (ACL) reconstruction is the most accepted treatment for complete ACL injury worldwide. The most popular autograft choices are bone-patellar tendon-bone (BPTB) and quadrupled hamstring tendon graft. Peroneus longus graft is not a popular first choice for primary ACL reconstruction at most centers, however, in the last decade or so, there has been an increasing trend for its use. Multiple studies have compared the efficacy of peroneus longus tendon graft with hamstring

graft in primary ACL reconstruction (1-6). Although many studies show comparable and good clinical outcomes, there have been persisting concerns over donor site morbidity following peroneus longus grafting such as weakness of eversion-inversion and ankle instability (7).
The indications for peroneus longus graft which were earlier restricted to revision cases or multiligamentous reconstructions are now gradually expanding to primary ACL reconstructions. Due to limitations in both quality and quantity of studies, non-inferiority of peroneus longus to hamstring grafts is yet to be established substantially. In our study, we have prospectively compared two cohorts of patients who underwent arthroscopic ACL reconstruction with peroneus longus and hamstring graft, respectively. We aim to assess if the peroneus longus autograft is comparable to hamstring autograft in terms of functional outcome and donor site morbidity for primary arthroscopic ACL reconstruction, making it a safe alternative first choice.

METHODS

This was a prospective cohort study conducted in a tertiary referral center at Mangalore, India, following the approval by Institutional Ethics Committee (Protocol No.- KMCMLR 09-19/428 – Date of approval: September 25, 2019). Patients between the age of 18 to 50 years who were diagnosed to be having isolated complete ACL tear based on clinical and MRI evaluation and who underwent arthroscopic ACL reconstruction were included in the study by purposive (non-random) sampling. Patients who had a multi-ligamentous knee injury, intra-articular fractures, chondral injuries, meniscal injuries, arthritic changes or previous ankle lesions were excluded. All those patients who completed a minimum follow up of 2 years from September 2019 to December 2022 were included in the study. The sample size of 54 patients was selected with reference to a study by Rhatomy *et al*. in which they studied a total of 52 patients, (80% power at 5% level of significance) (2). The study population was divided into two groups of 27 each. Patients in group A received hamstring autograft and those in group B received peroneus longus autograft. To avoid selection bias, every consecutive patient was allotted alternatively between the two groups. Informed consent was taken from all the subjects in this study and the rights of participants were protected. Demographic data (age and gender) was collected from all patients. Preoperative anterior drawer and Lachman test results were documented for each patient. Preoperative American Orthopaedic Foot and Ankle Society (AOFAS) Ankle hindfoot score (8) and Foot and Ankle Disability Index (FADI) (9) were assessed in the peroneus longus group to be able to compare them postoperatively.

Surgical technique of single-bundle ACL reconstruction

All patients in both groups were operated on by the same surgical team. Surgery was done under spinal anesthesia and a high groin tourniquet was used in all patients. Initially, a thorough diagnostic arthroscopy was performed through standard anteromedial and anterolateral portals (10). After confirmation of ACL tear, autografts were harvested.

Harvesting peroneus longus graft

A longitudinal incision was made over the posterolateral aspect of the distal leg, just posterior to the lateral malleolus. After subcutaneous dissection, peroneus longus and brevis tendons were identified and tagged. Sural nerve was not encountered in the approach. Lesser saphenous vein and its tributaries were protected. Tenodesis was performed at their distal most aspect with polyester nonabsorbable braided suture. Following this, the peroneus longus tendon was whip stitched, cut distally, and harvested using an open tendon stripper. Stripper was carefully maintained just superficial fibula, while not extending into proximal 1/3rd of leg, in order to prevent injury to superficial and deep peroneal nerves. While harvesting the peroneus tendon graft, the ankle is maintained in plantar flexion to minimize the risk of sural nerve injury (11). The harvested graft was consistently between 24- 26 cm in length and after tripling had a diameter between 7.5 to 9 mm (**figure 1**).

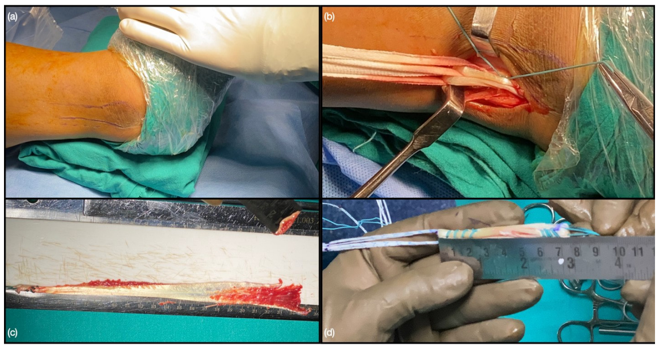

Figure 1. Steps of harvesting of peroneus longus autograft and preparation.

(a) Skin marking for incision; **(b)** Identification and isolation of peroneus longus and brevis along with their distal tenodesis; **(c)** Graft length measurement and preparation; **(d)** Tripled peroneus autograft.

Harvesting hamstring graft

An oblique 5 cm long incision was made over the anteromedial surface of the proximal third of the leg overlying the pes anserinus insertion. After subcutaneous dissection, sartorius fascia was identified and divided, following which semitendinosus was identified and tagged (**figure 2**). The tendon was whip stitched, cut distally, and harvested using an open tendon stripper. In 20 out of 27 cases, semitendinosus alone was insufficient for the desired graft thickness. Hence gracilis tendon was additionally harvested and the graft was quadrupled or tripled to attain optimal dimensions (8 cm ± 0.5 cm length and 8.5 mm ± 1 mm diameter). In both groups, the graft was wrapped with vancomycin-soaked gauze (12) and tensioned.

Figure 2. Harvesting hamstring autograft.

(a) Skin marking for standard knee arthroscopy portals and hamstring harvesting; **(b)** Isolation of semitendinosus graft after the division of sartorius fascia.

Tunnel preparation and graft fixation

Standard methods of femoral tunnel (trans-portal) and tibial tunnel preparation were adopted for both groups (13, 14). On the femoral side, the graft was fixed using Ultrabutton adjustable fixation device (UB; Smith and Nephew, Andover, Massachusetts, USA). The tibial side was fixed using a titanium RCI (reverse thread interference) screw (RCI; Smith and Nephew, Andover, Massachusetts, USA). Before putting the RCI screw on the tibial side, cycling of the knee was performed to tension the graft and assess graft impingement (**figure 3**).

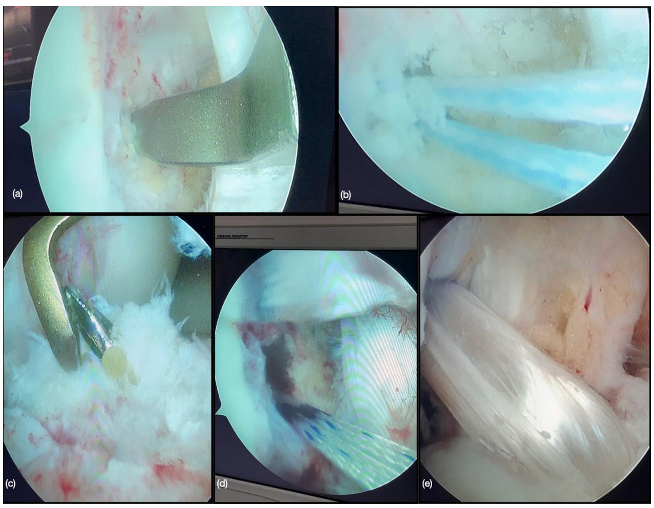

Figure 3. Steps of femoral and tibial tunnel preparation and graft passage.

(a) Marking femoral tunnel entry point; **(b)** Suture loop passed through femoral tunnel; **(c)** Placement of tibial tunnel through the footprint posterior to the anterior horn of lateral meniscus; **(d)** Passage of the adjustable loop with graft through the prepared tunnels; **(e)** Final graft position.

Rehabilitation

Postoperatively patients in both the groups underwent accelerated rehabilitation in 5 phases as described by Shelbourne *et al.* (15). Postoperative bracing was not used. Rehabilitation emphasized full knee extension on the first postoperative day and immediate weight-bearing as per the patient's tolerance. Patients were regularly followed up and periodic clinical and radiological assessments were done.

The functional outcome of both groups of patients was assessed at two-year follow-up along with donor site morbidity in the peroneal longus group. The functional outcome was quantified by questionnaire-based scoring systems like International Knee Documentation Committee (IKDC) (16), Modified Cincinnati (17), and Tegner-Lysholm (18) scores. Anterior drawer and Lachman tests were performed in both groups by the same team of surgeons. Donor site morbidity in the peroneus longus group was quantified using AOFAS Ankle hindfoot score and FADI.

Statistical analysis

The collected data were analyzed by descriptive and interferential statistical methods. Descriptive methods such as frequency and percentage were calculated to summarize categorical data. Mean and standard deviation (SD) were calculated to summarize the IKDC, Modified Cincinnati, Tegner-Lysholm, AOFAS, and FADI scores. Unpaired t-test was used to compare scores between the groups at two-year follow-up. The Chi-square test and Fischer's exact test were used to compare categorical parameters between the groups. Analysis was done using SPSS 25.0 software. The level of significance in this study was 5% (P-value less than 0.05).

RESULTS

In our study we included 54 patients who were divided subsequently into group A (hamstring) and group B (peroneus longus) of 27 each. In the hamstring group, the mean age of the patients was 32.11 ± 9.460 years of which 92.6% were males and 7.4% were females. In the peroneus longus group, the mean age of the patients was 31.74 ± 7.744 years of which 74.1% were males and 25.9% were females. Fischer's exact test revealed no significant statistical difference in age distribution between the two groups ($p = 0.297$). The Chi-square test revealed no statistical difference in gender distribution between the two groups ($p = 0.067$).

The anterior drawer test and Lachman test preoperatively in all the patients in both groups were positive (grade 3

Table I. Comparison of functional outcome at two-year follow-up in both groups of patients.

Scores (post-op)	Graft used	Sample size (n)	Mean	Standard deviation	t-test P-value
IKDC	Hamstring	27	77.26	7.209	0.085
	Peroneus longus	27	80.78	7.526	
Modified Cincinnati	Hamstring	27	84.41	15.445	0.169
	Peroneus longus	27	89.07	7.961	
Tegner-Lysholm	Hamstring	27	85.19	11.806	0.186
	Peroneus longus	27	88.78	7.418	

Table II. Comparison of donor site morbidity in the peroneus longus group.

Scores	Sample size (n)	Mean	Standard deviation	Mean difference	Standard deviation of the difference	Paired t-test P-value	
AOFAS Pre-op	27	100.00	0.000	4.333	6.367	0.198	NS
AOFAS Post-op	27	95.67	6.367				
FADI Pre-op	27	104.00	0.000	4.889	3.446	0.180	NS
FADI Post-op	27	99.11	3.446				

translation with a soft endpoint). At two-year postoperative follow-up, none of the patients showed clinical instability and all the patients showed Lachman grade 0 or 1 with a firm endpoint.

On comparison of two-year follow-up scores of both groups, there was no statistically significant difference noted in IKDC ($p = 0.085$), Modified Cincinnati ($p = 0.169$), and Tegner-Lysholm ($p = 0.186$) scores, implying that the peroneus longus group had an equally good functional outcome (**table I**).

To assess donor site morbidity in the peroneus longus group, the mean AOFAS ankle hindfoot score assessed at two-year follow-up was noted to be 95.67 ± 6.367 with a mean difference of 4.333 ± 6.367 from the preoperative scores. These differences were statistically not significant ($p = 0.198$). The mean FADI score at a two-year follow-up was 99.11 ± 3.446 with a mean difference of 4.889 ± 3.446 from preoperative scores which was also statistically not significant ($p = 0.180$) (**table II**). This implies there was no significant donor site morbidity in patients who underwent ACL reconstruction with peroneus longus autograft. No patients in the peroneus longus group showed adverse complications such as sural nerve injury.

DISCUSSION

Arthroscopic ACL reconstruction is a commonly performed surgery and has gained tremendous popularity in recent times, especially with the increasing exposure to contact sports. Currently, graft choices for primary ACL reconstruction (ACLR) are autologous hamstring semitendinosus gracilis (ST-G), quadriceps tendon, bone-patellar tendon bone (BPTB), peroneus longus autograft, allografts, and carbon filament-based synthetic grafts (19, 20).

Autografts are preferred for primary reconstruction of ACL due to ubiquitous availability, better biologic incorporation, no risk of disease transmission, and better biocompatibility. Allografts, on the contrary, have a higher risk of disease transmission, poor biocompatibility, poor graft incorporation, and face issues of unavailability in developing countries. However, they offer advantages over autografts such as reduced surgical time, no donor site morbidity, and abundance of graft material in multi-ligament reconstruction or revision cases (21, 22). Amongst autografts, BPTB graft has been considered the gold standard for the reconstruction of ACL. However, with the advent of hamstring (ST-G) autograft, the use of B-PT-B graft has declined due to the association of significant donor site morbidity (21, 22).

The quest to find better autografts is a never ending one. Although present medical practice has embraced the use of hamstring tendons as the graft of choice, there are certain concerns that prompt us to look for better alternatives. Hamstring graft harvest bear the concern of weakening knee flexion and causing an imbalance in quadriceps-hamstring dynamics (23). Hamstrings being dynamic stabilizers on the medial side, there is a concern while choosing hamstring graft in patients with multi ligamentous injury, especially those with medial collateral ligament injury (23). Moreover, semitendinosus tendon is often found to have inadequate diameter as noticed in our study, thus requiring concomitant gracilis harvest with tripling or quadrupling of grafts. In females and chronic ACL deficient knees, one can anticipate further attenuation of hamstring tendons thus potentially compromising graft diameter. Lesser diameter of graft, especially below 7.5mm is known to increase risk of graft rupture and increases revision rate (24). Every 0.5 mm increase in graft diameter from 7 mm to 9 mm has been found to reduce revision rate by 0.82 times and also has a positive correlation with IKDC scores (25).

Since the pioneering study by a Turkish group in 2008, there have been numerous studies exploring the use of peroneus longus tendon as a graft for primary ACL reconstruction (26). Rhatomy *et al*. in their study used peroneus longus graft with tenodesis of the distal stump of peroneus longus to peroneus brevis. They noted the excellent functional outcome of the knee at 2 years follow-up without any significant ankle or foot disability (2). Cao *et al*. conducted a study on 35 patients using peroneus longus as a graft (1). At 15-months of follow-up, their Lysholm score was excellent in 25 patients, good in 6 patients, fair in 3 patients, and poor in 1 patient with an average score of 97.2 (range 60-100). KT-3000 evaluation was normal in 28, near normal in 4, abnormal in 2, and poor in 1. The average AOFAS score was 96.3 which was not statistically significant from preoperative scores. They concluded that peroneus longus is a good substitute for ACL reconstruction with no significant donor site morbidity. Mingguang *et al*. in 2018 compared the functional outcome of patients undergoing arthroscopic ACL reconstruction with the anterior part of peroneus longus and hamstring tendon (5). They concluded that the anterior part of the peroneus longus has a similar functional outcome as that of the hamstring tendon with satisfactory isokinetic muscle power and no donor site morbidity.

Using the peroneus longus tendon as the first choice for primary arthroscopic ACL reconstruction has also attracted skepticism regarding donor site morbidity and its *in vivo* biomechanical performance when compared to hamstring tendon graft. Angthon *et al*. in their study involving 24 patients, reported a significant decrease in isokinetic muscle strength (eversion and inversion) at 7-months follow-up as compared to the contralateral side. They reported the association of ankle instability in the early postoperative period and concluded that peroneus longus autograft is unfavorable for primary use (7). In contrast to these findings, Fu Dong Shi *et al*. found no statistical difference between peroneus longus and hamstring tendon groups while assessing inversion-eversion movements using a robotic dynamometer at 2 years postoperative period (4). Although Angthon *et al*. found inferior eversion muscle strength, interestingly they found no statistically significant donor site morbidity as assessed via American Orthopedic Foot-and-Ankle Society (AOFAS) for ankle-hindfoot score and Visual Analogue Score-Foot Ankle (VAS-FA) at an average 1-year follow-up (7). Similarly, a study on 16 patients conducted by Sasetyo *et al*. found no significant ankle or foot disability in patients undergoing ACL reconstruction with peroneus longus grafting at 6 months postoperative period (3).

Few studies have performed biomechanical tests to compare *in vitro* tensile strengths of hamstring *vs* peroneus longus tendons (4, 27). They have found no significant difference in strengths between the two graft options. Fu Dong Shi *et al.* in 2019 compared the biomechanical properties and functional outcome in patients undergoing arthroscopic ACL reconstruction with doubled peroneus longus tendon and quadrupled hamstring tendon (4). They found that by doubling the peroneus longus tendon, adequate length and thickness of graft could be attained. Whereas hamstring graft had to be quadrupled to achieve the same length and thickness. Also, biomechanically both tendons had similar *in vivo* stability, with no significant ankle donor site morbidity in the peroneus longus group. Concerns regarding the thickness of peroneus longus graft have been assessed in studies that have concluded satisfactory dimensions of graft on doubling or tripling (2, 4).

Some of the systematic reviews and meta-analysis have pointed out important conclusions to these various studies (23, 28). While most studies have found satisfactory clinical outcomes with peroneus longus autograft, there are only few studies which directly compare hamstring graft with peroneus longus graft using standardized tools and outcome measures (23). In such selected studies which compare the grafts, peroneus longus has found to give statistically higher scores of IKDC and Lysholm as compared to hamstring graft. Tegner activity scale has given statistically similar results. These meta-analyses have looked at donor morbidity to foot and ankle in terms of various parameters like AOFAS scores, FADI scores, strength assessment and hop tests. These have concluded that despite some biomechanical studies showing a reduced peak eversion torque, clinical parameters suggest no significant morbidity to foot and ankle (23). While these conclusions project non-inferiority of peroneus longus tendon, they also highlight the need for better studies to generate stronger evidence (28). Most studies have low sample size, lack of appropriate comparison, different grafting techniques (full thickness graft, anterior or posterior partial thickness graft), heterogenous surgical techniques (single bundle *vs* double bundle, anatomical *vs* non anatomical) and varied postop rehab. This heterogeneity potentially creates murkiness in the interpretation of results (23).

Hence, we designed our study as a prospective cohort type to add valuable evidence to this literature. We compared the difference in the functional outcome of peroneus longus graft to the hamstring graft in 54 subjects over two years, along with the assessment of any donor site morbidity in the peroneus longus group. Our results show comparable functional outcomes in the three scoring systems (IKDC, Modified Cincinnati, and Tegner Lysholm scores) with no statistically significant difference between both groups. This implies that the *in vivo* biomechanical performance of the peroneus longus autograft was comparable to hamstring autograft. The donor site morbidity in the peroneus longus group as assessed using AOFAS and FADI scores, showed that at two-year follow-up patients had excellent ankle function with no residual weakness or functional limitations. None of the patients had any adverse outcomes such as ankle instability, loss of movement, weakness, nerve injury. All patients had resumed back to their pre-injury activities satisfactorily.

In addition to this, we made few other important observations in favor of peroneus longus autograft. Firstly, the peroneus longus tendon was technically easier to identify and harvest. Peroneus brevis is deeper and muscular around the region, thus easily differentiating itself from superficial and tendinous peroneus longus. Secondly, the surgical time for harvest of peroneus longus graft was lesser than hamstring graft, which is beneficial economically and otherwise. Lack of fibrous attachments and vincula makes the harvest easier and reliably faster. Thirdly, we found peroneus longus to have a consistently thicker diameter and adequate length in all our cases (harvested graft was consistently between 24- 26 cm in length and after tripling had a diameter between 7.5 to 9 mm). On the contrary, our hamstring grafts commonly required quadrupling, and in most cases, we had to harvest both semitendinosus and gracilis.

This prospective cohort study adds strong evidence to the literature in favor of peroneus longus tendon autograft for ACL reconstruction. It disproves notions of donor site morbidity associated with it. We conclude that peroneus longus tendon autograft is non-inferior to hamstring autograft in single bundle arthroscopic ACL reconstructions and it may be considered as one of the first line autografts in primary ACL reconstruction. Our study bears the limitation of being conducted in a single-center catering to the local population with a limited sample size. Multicentric studies with larger sample sizes and longer follow-ups would give stronger evidence and validity to the above conclusions. Our study lacks the inclusion of professional athletes. Studies focusing on clinical outcomes and donor site morbidity in selected athletic populations can throw better light in this regard.

CONCLUSIONS

The results of our study suggest that peroneus longus can be used as one of the first choices of autografts for primary arthroscopic ACL reconstruction.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

SA, AH, BSR, PM, CS: conceptualization, design. SA, AH, BSR, PM, CS, ST, VK: intervention. AH, BSR: supervision. SA, ST, PMD, AN: data collection. AH, PM, CS, ST, VK: results analysis and interpretation. SA, AH, CS, VK, ST, PMD, AN: drafting. All authors: revision results, manuscript approval.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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ORIGINAL ARTICLE

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Arthroscopic Biceps Tenodesis: Midterm Clinical Results of a New Anchor Suture Technique in Patients with Single-Row Rotator Cuff Repair

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SUMMARY

Objective. This study evaluated the midterm clinical results of doing the arthroscopic proximal long head of the biceps tenodesis with an anchor suture of subscapularis or supraspinatus repair in patients with arthroscopic rotator cuff repair.

Methods. We evaluated the clinical results of long head of biceps tendon tenodesis in patients with single-row rotator cuff repair. They were all treated with our technique in which we did the tenodesis with anchor suture of rotator cuff repair in a manner that provides both bony and soft tissue attachment for the tendon. We evaluated the results of the long head of the biceps (LHB) tenodesis in all patients by looking for Popeye deformity, anterior shoulder tenderness, asking for anterior shoulder pain, and measuring elbow flexion and forearm supination force compared to the normal side as a primary goal, and compared results of LHB tenodesis with subscapularis or supraspinatus tendon suture as a secondary goal too.

Results. A number of 131 patients participated in the final follow-up: 34 patients had LHB tenodesis with subscapularis tendon suture and 95 patients with supraspinatus tendon suture. Mean of follow-up time was four years (24 to 71 months). Two patients had the Popeye deformity (1.5%), five patients had the anterior shoulder tenderness (3.8%), and seven patients suffered from anterior shoulder pain (5.3%). Elbow flexion and forearm supination forces were measured in the affected and non-affected limbs. There was no significant difference between the two limbs. Those who had LHB tenodesis with supraspinatus anchor suture had better results and less complications.

Conclusions. Arthroscopic tenodesis of the LHB tendon incorporated into single-row rotator cuff repair is a cost-efficient method, leading to better results for implant or soft tissue tenodesis too. Fixing to supraspinatus tendon seems to have better results and fewer complications compared to subscapularis tendon.

KEY WORDS

Biceps tenodesis; anchor suture technique; shoulder arthroscopy; rotator cuff repair.

INTRODUCTION

Disorders of the long head of the biceps (LHB) tendon have many pathological conditions, from inflammatory tendinitis to degenerative tendinosis (1, 2). The LHB tendon lesions are frequently associated with partial or complete rotator cuff tears, particularly in older adults (3-10). LHB tendon lesions such as biceps tear of more than 30%, subluxation, dislocation or a degenerative SLAP type II lesion can lead to chronic pain even after rotator cuff surgery (5, 11, 12). Therefore, treating them is recommended during rotator cuff surgery (10, 13-15).

The optimal method for surgical management of LHB tendon's pathology is still in debate (5). Two of the most common procedures are 1) biceps tenotomy and 2) biceps tenodesis. Biceps tenotomy is a recognized, successful procedure (1, 16). Arthroscopic biceps tenotomy is an easy and fast procedure with shorter surgery time and easier postoperative rehabilitation process (17, 18). However, there are always concerns of Popeye deformity or cramping pain and strength loss due to the tendon's distal migration (17). Its Popeye deformity rate is between 3% and 63% (17-21).

On the other hand, the purpose of biceps tenodesis is to keeping the length-tension relationship of the muscle, which may prevent muscle atrophy and help to save the normal contour of the biceps muscle (1). It is believed that biceps tenodesis should be used in younger, active patients (1). We can do tenodesis proximally with maintaining the LHBT in the bicipital groove (22, 23) or distally with removing the tendon from the groove (24, 25). Both proximal and distal tenodesis could be done with different fixation methods, including implant or soft tissue fixations.

In this research we used a cost-effective surgery technique for this procedure using an anchor suture of the rotator cuff repair. The primary goal of the research was to evaluate the overall result of this technique on all patients. The secondary goal was to compare the results of tenodesis by a limb of subscapularis repair suture *versus* supraspinatus repair suture. We believed that our technique could have had advantages for both soft tissue and implant tenodesis without the need for more implants.

METHODS

This cross-sectional study evaluated the clinical results of our different suture anchor technique for LHB tenodesis. The participants were patients who had referred to our center because of rotator cuff tear. All patients signed an informed consent before entering the study. The Ethics Committee of our University approved the study (IR.UMSHA.REC.1396.750 – Date of approval: February 14, 2018).

The inclusion criteria included: 1) being a patient with arthroscopic rotator cuff repair who requires biceps tenodesis because of (a) LHB tendon instability and (b) LHB tendinosis with more than 25% partial tear; 2) being treated with our method instead of any other method for biceps tenodesis.

The exclusion criteria were: 1) incomplete rotator cuff repair; 2) having any disorder in the operated or contralateral upper limb that could affect the pain or force of elbow flexion or supination; 3) revision surgery for rotator cuff tear; 4) not being available for the last follow up.

Surgical technique

Arthroscopy started in beach chair position with the arm in about 30° abduction and 60 forward elevation. Using a 30° scope from the posterior portal, we evaluated the glenohumeral joint for any pathology, including any rotator cuff tears, pulley integrity, and LHB tendon. Afterward, if subscapularis tendon tear needed to be repaired, during preparing subscapularis foot print, we prepared the proximal part of the intertubercular groove with shaver and arthroscopic rasp to make a fresh bony bed for LHB tendon. Then we repaired the subscapularis tendon from the anterolateral portal. However, the sutures were not cut and still left in the anterolateral portal. The suture strands of subscapularis repair passed from the intact LHB tendon. After making a loop around the tendon, the sutures were retrieved from the anterolateral portal again. Then the LHB tendon was cut, and the sutures were tied. If biceps tendon medial subluxation prevents subscapularis repair, first we passed a monofilament suture from LHBT and cut it to pull it out of the subscapularis footprint, then, after subscapularis tendon repair, monofilament suture was replaced by fiber wire of subscapularis repair (**figure 1**).

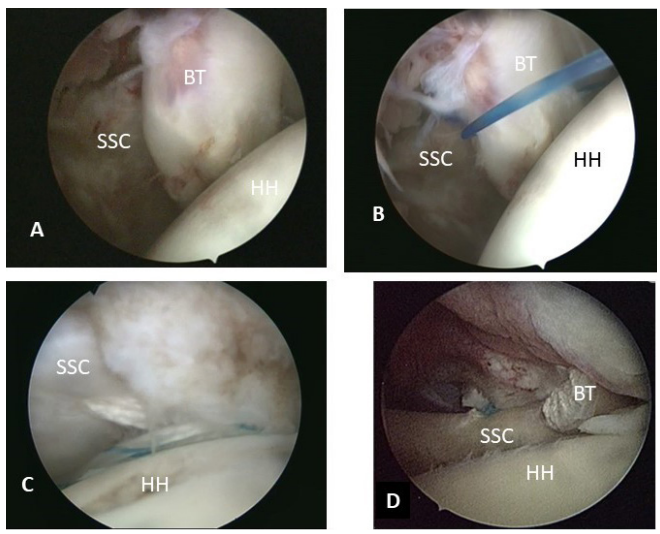

Figure 1. LHB tenodesis using subscapularis tendon suture.

(A) Posterior portal view, subscapularis tendon tear and medial subluxation of LHB tendon; **(B)** Passing a monofilament suture from LHB tendon; **(C)** Passing fiber wire suture of anchor suture from subscapularis tendon; **(D)** Final result of LHB tendon tenodesis after passing fiber wire of subscapularis tendon repair from LHB tendon and knot tying. SSC: subscapularis tendon; HH: Humeral head; BT: Biceps tendon.

If subscapularis tendon was intact, and supraspinatus tendon was torn so that the lateral restraint to the biceps' tendon stability failed, first a monofilament suture was passed through the biceps tendon with a 18-gauge needle. Then by retracting both sides of the monofilament suture from the supraspinatus tendon defect on humeral head and cutting the LHB tendon, we extracted the tendon from the gleno-humeral joint up to the subacromial space. Then we transferred the arthroscopic equipment to the subacromial space and after debridement of subacromial bursa, while preparing supraspinatus footprint, we prepared the proximal part of the inter tubercular groove with shaver and arthroscopic rasp to make a fresh bony bed for LHB tendon. The supraspinatus repair was done in a single row manner, but sutures of the anterolateral anchor were not cut. Finally, we finished tenodesis by passing sutures of supraspinatus repair from biceps tendon in the manner explained for subscapularis sutures. If supraspinatus tear is located anterior and LHB is easily visible from subacromial space, it is not necessary to cut it until fiber wire suture of supraspinatus anchor is passed from LHB (**figure 2**). The important point of this technique is attaching the proximal of the LHB tendon to the bursal side of subscapularis or supraspinatus tendon in a way that it does not disrupt the bone-tendon contact of rotator cuff, and also maintains contact of the LHB tendon to the prepared inter tubercular groove.

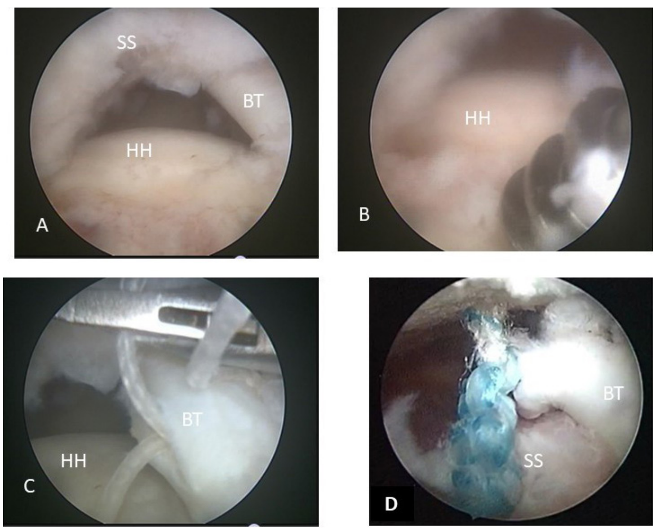

Figure 2. LHB tenodesis using supraspinatus tendon suture.

(A) Lateral portal view of sub acromial space; **(B)** Inserting anchor suture for supraspinatus repair; **(C)** Making a loop into and around LHB tendon using fiber wire suture of supraspinatus anchor suture; **(D)** Final result after knot tying, LHB tendon is attached to bursal side of supraspinatus tendon. SS: supraspinatus tendon; HH: humeral head; BT: biceps tendon.

The first author (HS) did all the surgeries with the same technique and the same suture management of all patients. The post-surgery instructions included four to six weeks of active shoulder motion restriction depending on the extent of rotator cuff tear. The elbow flexion started four weeks after surgery. Strengthening exercises were prohibited until 12 weeks after surgery.

The patients were evaluated by the two other authors who were not aware of the LHB tenodesis type. They recorded the anterior shoulder pain by asking the patients if they have pain at anterior of the operated shoulder, Popeye deformity by comparing two arms during extended and forcefully flexed arms, and anterior shoulder tenderness by palpation of anterior shoulder and bicipital grove while detecting reaction of patient for pain. They also measured the force of elbow flexion and forearm supination (Lafayette dynamometer, USA) and compared it to the normal healthy side. To compare patients who had LHB tenodesis with subscapularis repair sutures and those who had tenodesis with supraspinatus repair as a secondary goal, we divided our patients into two groups: subscapularis and supraspinatus groups. As the purpose of our study was evaluating results of our tenodesis technique in patients with single-row rotator cuff repair, the outcome scores were not evaluated as they can directly be influenced by results of rotator cuff repair.

Statistical analysis

We did all the statistical analyses with the statistical package for social sciences (SPSS) software version 21. Chi-square test and Fisher's exact test were used to compare the frequency of complications between two groups with different techniques.

Due to the normal distribution of data based on test Kolmogorov-Smirnov, Student t-test was used to compare the mean of elbow flexion and forearm supination forces in subscapularis and supraspinatus groups. P-value < 0.05 was considered significant.

RESULTS

Totally, 131 patients participated in the final follow up. **Table I** demonstrates demographic data of the patients. Their mean of age was 60.85 years old (27 to 78 years old). 48.8% of the patients were female and 51.1% male. LHBT tenodesis was performed in 95 patients with supraspinatus tendon suture and in 34 patients with subscapularis tendon suture. Mean age of the patients was not different between two groups, but they were significantly different in sex distribution. The mean of follow up time was four years (24 to 71 months).

First we evaluated clinical results of LHB by evaluating possible complications LHB tenodesis of our suture tech-

Table I. Demographic data of the patients.

	All patients	Supraspinatus group	Subscapularis group	P-value
Number	131	95	34	
Male	67 (51.1%)	45.3%	66.7%	< 0.05
Female	64 (48.8%)	54.7%	33.3%	< 0.05
Mean age	60.85	61.55	58.97	> 0.05

nique in all patients (**figure 2**). Two patients had Popeye deformity (1.5%), anterior shoulder tenderness in five patients (3.8%) and seven patients suffered from anterior shoulder pain (5.3%). There was not significant relationship ($p > 0.05$) between complication rate and sex (**table II**) or age (**table III**) of the patients.

Elbow flexion and forearm supination forces were measured in the affected and normal limbs (Lafayette dynamometer, USA). There was no significant difference ($p > 0.05$) between the two limbs in force of elbow flexion and forearm supination.

Then we compared results of the technique between two groups. **Figure 3** and **table IV** demonstrate comparison of complications between two groups. Two patients who had Popeye deformity, both were in the subscapularis group

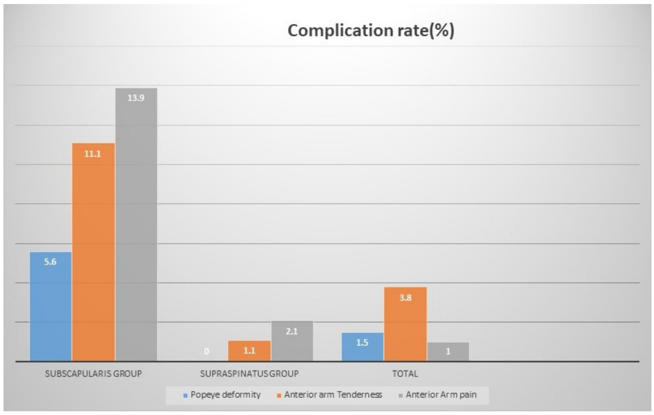

Figure 3. Complication rate (%) in all patients and both groups.

Table II. Dirtribution of complication of LHBT tenodesis by gender of patients.

Complication	Gender		P-value
	Fermale Number (%)	Male Number (%)	
Popeye deformity			
No	64 (100)	65 (97)	
Yes	0 (0)	2 (3)	0.496
Total	64 (100)	67 (100)	
Anterior arm tenderness			
No	63 (98.4)	61 (91)	
Yes	1 (1.6)	6 (9)	0.058
Total	64 (100)	67 (100)	
Anterior arm pain			
No	61 (95.3)	63 (94)	
Yes	3 (4.6)	4 (6)	0.116
Total	64 (100)	67 (100)	

Table III. Distribution of complications of LHBT tenodesis by age in all patients.

Complication	Age (year)		P-value
	No Mean ± SD	Yes Mean ± SD	
Popeye deformity	61.14 ± 8.37	42.00 ± 21.21	0.423
Anterior arm tenderness	61.29 ± 8.21	49.60 ± 16.18	0.182
Anterior arm pain	61.17 ± 8.20	55.14 ± 8.50	0.371

Table IV. Frequency of complications of LHBT tenodesis in each group.

Complication	Tenodesis method		Total	P-value
	SSC group Number (%)	SS group Number (%)		
Popeye deformity				
No	34 (93.4)	95 (100)	129 (98.5)	
Yes	2 (5.6)	0 (0)	2 (1.5)	0.074
Total	36 (100)	95 (100)	131 (100)	
Anterior Arm Tenderness				
No	32 (88.9)	90 (98.9)	126 (96.2)	
Yes	4 (11.1)	1 (1.1)	5 (3.8)	0.020
Total	36 (100)	91 (100)	131 (100)	
Anterior Arm Pain				
No	31 (86.1)	93 (97.9)	124 (94.7)	
Yes	5 (13.9)	2 (2.1)	7 (5.3)	0.017
Total	36 (100)	95 (100)	131 (100)	

Table V. Force (N) of elbow flexion and forearm supination of both limbs in supraspinatus and subscapularis groups.

Force	Subscapularis group Mean ± SD	Supraspinatus group Mean ± SD	P-value
Elbow flexion operated side	46.36 ± 18.62	52.14 ± 17.48	0.066
Elbow flexion normal side	48.92 ± 19.85	55.20 ± 19.26	0.100
Forearm supination operated side	36.6 ± 13.39	36.77 ± 14.46	0.726
Forearm supination normal side	38.11 ± 12.16	39.01 ± 13.43	0.538

(5.6%). We found no Popeye deformity in supraspinatus group ($p < 0.05$). Among five patients who had anterior shoulder tenderness, four patients (11.1%) were in the subscapularis group and one (1.1%) in supraspinatus group ($p < 0.05$). Among seven patients who had anterior shoulder pain without tenderness, five patient (13.9%) were in the subscapularis group and two (2.1%) in the supraspinatus group ($p < 0.05$).

Elbow flexion and forearm supination forces of affected and normal limbs, compared between two groups (**table V**). There was no significant difference ($p > 0.05$) between the two limbs in force of elbow flexion and forearm supination between supraspinatus and subscapularis group.

DISCUSSION

Treating LHB tendon lesions such as a biceps tear of more than 25%, degenerative SLAP type II lesion, subluxation or dislocation is recommended during rotator cuff surgery. This is because they can result in chronic pain even after a successful rotator cuff surgery (10-15).

The optimal surgical management of LHB tendon lesions is still controversial (5). The two most common procedures are biceps tenotomy and tenodesis. Although arthroscopic biceps tenotomy is an easy and fast procedure with shorter surgery time and easier postoperative rehabilitation process (17, 18), there are always concerns of Popeye deformity or cramping pain and strength loss due to the tendon's distal migration (1). Biceps tenodesis can maintain the length-tension relationship of the biceps muscle.

LHB tenodesis techniques vary according to the location and method of fixation. We can do biceps tenodesis proximally, in which LHB tendon is maintained within the bicipital groove, or distally so that it is removed from the groove (1). We can do the proximal fixation with an all-arthroscopic technique within the glenohumeral joint or sub deltoid space to the surrounding intact rotator cuff (25) or to the conjoint tendon (26) or just proximal within the bicipital groove. 90% to 100% biceps strength has been reported for different proximal fixation methods compared to the normal side (16, 27).

McCrum *et al.* studied 1,526 shoulders for complications of biceps tenodesis based on location, fixation, and indication (28). They were operated by 84 surgeons in 14 hospitals. This is the most comprehensive study that we have found about complications and results of LHB tenodesis. They defined "persistent" anterior shoulder pain as residual pain that does not resolve with biceps tenodesis, indicating that the procedure fails to alleviate anterior shoulder pain at the last follow-up. "New-onset" anterior shoulder pain was defined as pain that develops in the anterior shoulder after surgery in patients who do not have the anterior shoulder pain before surgery (28). As an indicator of procedure failure, there was Popeye deformity in 4.25% of soft tissue tenodesis and 4.77% of implant tenodesis (28).

In our study, we measured complication rate and force of elbow flexion and forearm supination in order to evaluate clinical results of our new anchor suture technique for LHB tenodesis. We did not measured shoulder function scores because we did LHB in patients who needed rotator cuff repair and shoulder function can be more determined by rotator cuff repair instead of biceps tenodesis. We found Popeye deformity in 1.5% of the patients. An explanation for these good results is probably that this technique has advantages for both soft tissue tenodesis (because of adhesion to the bursal side of the repaired rotator cuff in an early stage) and bony tenodesis (because of preparing the proximal of the bicipital groove for bony adhesion in a later stage after surgery).

Considering the anterior shoulder pain after LHB tenodesis, soft-tissue tenodesis can result in a significantly higher rate (11.9%) of new-onset anterior shoulder pain compared to implant tenodesis (2.6%) (28). In our study, we found seven patients with anterior shoulder pain (5.3%). Five of them were in the subscapularis group. Three of the five patients had persistent anterior shoulder pain. In other words, new-onset anterior shoulder pain was only 3% in our patients.

Although it is not possible to determine if anterior shoulder pain is due to LHB tenodesis or repair site of rotator cuff tear, we think that new onset anterior pain is more likely to be related to tenodesis.

McCrum *et al.* did not assess the anterior shoulder tenderness. However, we found five patients have this problem (3.8%), four of whom were in the subscapularis group (11.1%) and one (1.1%) in the supraspinatus group. Although we do not know if this tenderness is related to biceps tenodesis or rotator cuff repair site, its high rate in the subscapularis groove *vs* supraspinatus groove was notable. So, more studies to compare anterior shoulder tenderness in patient with and without LHB tenodesis with this technique is required to determine if high rate of anterior shoulder pain is related to tenodesis or subscapularis repair.

When comparing tenodesis techniques, many studies found out that soft-tissue tenodesis cases had a higher rate of subjective weakness than implant tenodesis cases (28-30). A possible explanation is that bony tenodesis may provide a more secure fixation, which may result in less change in the length-tension relationship over the course of healing, as under-tensioning of the biceps may result in early fatigue (31, 32).

We believe that subjective evaluation of weakness after biceps tenodesis and rotator cuff repair can be influenced by rotator cuff function. So, we measured the force of elbow flexion and supination instead of shoulder functional scores. We found no significant difference between both limbs of the participants. A reason can be that our method is secure enough to keep length tendon relationship over the course of healing.

Veenstra *et al.* evaluated 19 patients with proximal biceps tenodesis incorporated into supraspinatus repair for a mean of two years (33). Their technique incorporated LHB tendon into the articular side of rotator cuff. They did not prepare bicipital groove for bony attachment of biceps tendon. ASES score and visual analog score improved significantly. There was no change in elbow flexion and supination before surgery and at two years follow up. However, four patients had difference in arm contour compared to the non-operated side. We think that ASES and visual analog score could be deeply influenced by rotator cuff repair. Tenderness in the bicipital groove and evaluating Popeye deformity can directly evaluate results of LHB tenodesis.

Meghpara *et al.* evaluated the clinical outcomes of an all-arthroscopic biceps tenodesis using the anterolateral anchor during concomitant double-row rotator cuff repair with two years follow up (34). No patient developed deformity. Interestingly one patient who had LHB tenodesis incorporated into subscapularis tendon repair had persistent anterior shoulder pain. In our study we noticed more anterior shoulder pain, anterior shoulder tenderness and Popeye deformity in the subscapularis group. We did the tenodesis technique incorporated into single row rotator cuff repair and prepared proximal of bicipital groove for bony attachment of the tendon.

Limitation

The number of the participants who attended the final follow-up was limited. We could not determine whether new onset of anterior shoulder pain is related to LHB tendon or rotator cuff repair site, especially in subscapularis group, so more studies to evaluate anterior shoulder pain in patients with and without LHB tenodesis into subscapularis tendon repair is required. Although main goal of the study is evaluating results of the technique in all patients, comparison of two groups had some limitation. There is no homogeneity among the two groups in terms of number and gender due to low incidence rate of subscapularis tear compared to supraspinatus tear.

CONCLUSIONS

Doing arthroscopic tenodesis of LHB tendon using rotator cuff anchor suture is a cost-efficient method, leading to better results of bony or soft tissue tenodesis separately. Considering midterm follow up and number of patients of our study, fixation to supraspinatus tendon has better results and less complications compared with fixation to subscapularis tendon. Although, more studies are necessary to confirm this result.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

HS: study design, surgeries. AS: follow-up, data collection. AS, HS: writing. BH: discussion, editing. EK: data analysis.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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ORIGINAL ARTICLE

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Iliotibial Band Trigger Points and Plantar Heel Pain: A Cross-Sectional Study

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SUMMARY

Background. Plantar heel pain (PHP) is a degenerative plantar fascia syndrome that causes irritation under the heel and a functional deformity during weight bearing. Myofascial involvement, along with biomechanical changes due to tight fibrous connections, seems to contribute to this condition. As there is a fascial connection between plantar fascia, and iliotibial band, trigger points in the myofascial chain including iliotibial band can interfere with biomechanical modifications and aberrant lower limb functioning. The study aimed at establishing the associating iliotibial band (ITB) trigger points in plantar heel pain patients.

Methods. The study included 30 individuals with plantar heel pain of both genders. They were assessed by foot posture index (FPI) for the foot type and manually palpated for trigger points along the Iliotibial band on both the affected and unaffected side.

Results. The results revealed 73% prevalence of iliotibial band trigger points in plantar heel pain patients. And there was a significant association was found between trigger points and plantar heel pain ($p < 0.001$).

Conclusions. The current investigation found an association between the existence of iliotibial band trigger points and plantar heel pain. So, addressing the iliotibial band trigger points may help in reducing pain and discomfort in plantar heel pain individuals.

KEY WORDS

Fascia; foot; heel pain; IT band; trigger points.

INTRODUCTION

Plantar heel pain (PHP) is a degenerative disease of the plantar fascia caused by calcaneus trauma. It frequently radiates from the heel pad's center or the calcaneum medial tubercle and might extend through the plantar fascia into the medial longitudinal arch of the foot. Although the actual origin of PHP is uncertain, persons who have had excessive plantar fascia extension or micro-injuries have reported degenerative changes in the plantar fascia, with or without fibroblastic proliferation and without acute inflammation (1).

In contrast, the anatomical-histological characteristics of the PF, which has been considered merely an aponeurosis, have received scant research. According to some researchers, the embryological genesis of the PF involves its union with the Achilles tendon, and this union consists of a layer of periosteal fibers whose elasticity diminishes with age. The plantar fascia may perceive both the position of the foot and the state of contraction of the foot's intrinsic muscles. If these muscles contract excessively, the PF (which includes nerve endings) may be overstretched. The PF has also been examined extensively from a biomechanical standpoint. It plays a crucial function in the biomechanics of the foot by maintaining its medial longitudinal arch during gait or other loading circumstances. And it was also noticed that in individuals with pronated feet type the foot kinematic can get alter due to shortening of the iliotibial band (2).

Abnormal pronation at the subtalar joint may result in excessive internal rotation of the entire lower leg during weight-bearing, putting additional strain on the kinetic chain (1, 3). Excessive pronation increases ground response force on the medial aspect of the foot and the medial longitudinal arch. From acceleration until mid-swing, the ITB functions more efficiently to prevent tibial external rotation, causing ITB contraction and increased tension, resulting in ITB tightness (4, 5). This increased tension to the muscle fibers, or any muscle strain might cause the formation of trigger points.

A trigger point can be defined as a hyperirritable site in a perceptible taut band of skeletal muscle that, when compressed, causes referred discomfort and motor dysfunction (6-8). It has been argued that fascial limitations in one region of the body cause unnecessary tension in other parts of the body due to fascial continuity. This may put a strain on any structures encased, divided, or supported by fascia. As per the evidences, the plantar fascia, lateral leg muscles, and the iliotibial band all have single fascial interaction (9, 10).

According to the etiological perspective, there are multiple factors that contribute to plantar heel pain, and current research indicates that myofascial structural alterations are a major source of this pain (4, 6, 7, 9). Numerous studies sought to establish a connection between myofascial trigger points of leg and foot muscles and plantar heel pain, but despite of having the facial and biomechanical linkage none of those investigations have highlighted the significance of the iliotibial band in plantar heel pain. Therefore, the purpose of the present study was to examine the relationship between iliotibial band trigger points and plantar heel pain. The authors hypothesize that IT band trigger points would be positively associated with plantar heel pain.

MATERIALS AND METHODS

A cross-sectional study on 30 subjects with plantar heel pain was conducted after approval from the Institutional Ethical Committee of Srinivas College of Physiotherapy & Research Centre – Date of approval: April 09, 2019. All subjects provided written informed consent prior to participation. Subjects were chosen based on their ability to meet the criteria for selection and their willingness to participate.

The inclusion criteria were:

- Participants of both the genders with age between 20 to 50 years.
- Having unilateral or bilateral heel pain.
- Patients fulfilling diagnostic criteria for plantar fasciopathy (4, 6, 10).

The exclusion criteria were:

- Any previous history of knee and back pain.
- History of lower limb fracture, or ankle ligament damage in the previous 6 months.
- Impair sensation and/or pain perception related to diabetes, peripheral vascular disease, local infection, rheumatoid arthritis, and gout.
- Subjects undertaken any physical therapy sessions in the past three months.
- Complaining of acute fractures and sprains.
- Acute stage PIVD with intermittent claudication (4, 6, 10, 11).

Procedure

Subjects with plantar heel pain were screened using inclusion and exclusion criteria. The windlass test and the foot posture index (FPI) were used to measure the foot posture of all participants, and data was gathered (12). The demographic information was then acquired from all of the chosen respondents, and the data was analyzed.

ITB was evaluated manually and MTrPs were identified, while adhering to standard examination position and technique. Both the affected and unaffected sides of patients with plantar heel pain were palpated for comparison. The patient was positioned in side lying, with the examined side placed above the other for ITB. The therapist stands behind the limb being evaluated. The affected extremity should be draped appropriately and placed facing upwards, with knees slightly bent and pillows placed between the legs to relax the muscles. From the ASIS to the lateral femoral condyle, the IT band was palpated. By taking three finger breaths anterior to the greater trochanter of the femur, the trigger point was assessed using flat palpation (**figures 1, 2, 3**). The taut band and trigger point across the ITB were palpated

Figure 1. ITB trigger point palpation proximal part.

Figure 2. ITB trigger point palpation middle part.

Figure 3. ITB trigger point palpation distal part.

for jump signs, discomfort, twitch reaction, and transferred pain (8, 10, 11). Trigger points on both the affected and unaffected sides were palpated.

Statistical analysis

The data were analyzed using Windows-based SPSS 26 (Statistical Package for Social Sciences) software. The Kolmogrov-Smirnov test was used to find out the normality. The descriptive data were reported in mean and standard deviation of all variables. For inferential analysis, the Chi-Square test was used to find out the association of FPI, plantar heel pain, and ITB TrPs. The degree of association between the variables were rated using Phi Cramer's V criteria.
The level of significant value set as ($p < 0.05$). there was a significant association between IT band trigger points and plantar heel pain (Cramer's V 0.60) ($p < 0.05$) and similarly, there was even more a strong association was found between IT band trigger points and individuals with both plantar heel pain and pronated foot. (Cramer's V 0.82) ($p < 0.05$).

RESULTS

The current study included 30 people with plantar heel pain. There were an equal number of male and female participants. **Table I** shows the demographic information for the participants. The frequency distribution of their trigger point and foot features is shown in **table II**. According to FPI, 56% of PHP individuals had normal foot posture. Similarly, 33% of people had pronated feet. In addition, 73% of individuals had IT band trigger points. The study's findings demonstrated a strong relationship (Cramer's V 0.60) between IT band

Table I. Descriptive statistics for demographic data.

Variables	Values
Subjects (n)	30
Male/Female	15 (50%)/15 (50%)
Age (years)	34.4 (6.8)
Height (meters)	5.26 (0.4)
Weight (kg)	55.07 (5.8)
BMI kg/m^2	21.4 (4.3)

BMI: Body Mass Index; value reported as Mean (SD).

Table II. Frequency and percentage (%) of measurement variables.

Variables	Frequencies	Percentage (%)
Plantar heel pain (vas)		
5	5	16.1
6	8	25.8
7	12	38.7
8	4	12.9
9	1	3.2
FPI score		
Normal	17	56.7
Pronated	10	33.3
Supinated	3	10.0
Total	**30**	**100**
ITB TrPs (present/absent) in patient with PHP		
Absent	8	26.7
Present	22	73.3
Total	**30**	**100**

PHP: plantar heel pain; ITB TrPs: iliotibial band trigger points.

Table III. Interferential statistics for plantar heel pain and ITB TrPs.

Variables	Cramer's V	P-value
PHP-ITB TrPS	0.600	0.001
FPI-PHP-ITB TrPS	0.820	0.001

FPI: foot posture index; PHP: plantar heel pain; ITB TrPs: iliotibial band trigger points.

trigger point and plantar heel discomfort. Furthermore, an excellent relationship (Cramer's V 0.82) was discovered between IT band and participants with both plantar heel pain and pronated foot (**table III**,) showing that patients with plantar heel pain are more likely to have ITB TrPs.

DISCUSSION

PHP is frequently caused by tight or deconditioned trigger points in the leg muscles as a result of prolonged rest, a sudden increase in muscular activity, repeated micro-trauma to the muscle, and muscular injury caused by abrupt concentric/eccentric contractions. The association between ITB trigger points and plantar heel pain was investigated in a cross-sectional study of 30 participants. This study provides preliminary evidence for the role of the IT band in heel pain. People with plantar heel pain and pronated feet are more likely to have IT band trigger points. According to the study's findings, IT band trigger points were significantly associated with PHP (Cramer's V 0.60) ($p < 0.05$) and with both PHP and pronated feet (Cramer's V 0.82) ($p < 0.05$).

Previous research discovered that TrPs in the leg and foot musculature replicated pain feelings in persons with chronic plantar heel pain, and that the greater the number of trigger points, the greater the intensity of plantar heel pain. As a result, it suggests that TrPs may be a contributing factor to the severity of symptoms experienced by patients suffering from plantar heel pain. And the pain or discomfort are primarily because of diminution or loss of fascial sliding ability corresponds to the thickening and densification (7, 10, 11, 13).

According to the preceding statement, it is widely accepted that fasciae play a significant role in tissue preservation and repair via force transfer, facilitating mobility, stability, and proprioceptive communication throughout the body. If connective tissue is lost or its density is altered, the deep fascia and underlying muscle act abnormally. In many circumstances, this could be the cause of myofascial pain. Hyaluronic acid appears to be a significant factor in fascia density (2, 13).

It was found the hyaluronic acid has distinct responsibilities, including space filling, lubrication of joints, and water homeostasis, and it offers a substrate for the smooth gliding of different motor units between and within muscles. And hyaluronic acid production appears to be strongly associated with myofascial pain and mobility (13).

The authors propose that taut bands associated with TrPs may enhance muscular stiffness in the leg and foot, resulting in increased stress on the plantar fascia. It is also possible that motor disturbances associated with TrPs, such as muscular fatigue and faster fatigability, contributed to the reported muscle issues in these patients. All of these possibilities are consistent with previous research indicating that TrP treatment may be effective for alleviating plantar heel pain (10, 11, 14).

Evidence also suggests that people with generalized hypermobility, flat feet or ligamentous laxity of the feet prevent the symmetrical distribution of load on the soles of the feet, which causes a weight shift inward (due to the collapse of the medial arch) and an overload of the midfoot - modified foot biomechanics when walking in the push phase (15).

The different length-tension relationship of intrinsic and extrinsic foot muscles, such as a shorter hallucis and peroneus group and a longer peroneal group of muscles when compared to people with normal feet, causing some extra tension on the knee kinematics, including the IT band. Increased tibial and femoral internal rotation is also associated with increased foot pronation, resulting in an internal rotation moment at the knee. Internal knee rotation may cause the ITB and other structures surrounding the knee to stretch (14, 16). Furthermore, as revealed by recent studies, foot pronation can change hip kinematics, exerting load on the ITB via its proximal attachment. Stress, biomechanics, work ergonomics, posture, and exercise routines have all been implicated with PHP, according to several research (16). According to the author's hypothesis, the disturbed foot muscle kinetics and concurrent internal rotation of the tibia and femur caused by pronated feet place an excessive amount of demand on the proximal frontal plane kinetics, leading to internal rotation torque at the knee and IT band and thus the development of the trigger points.

A retrospective research revealed that patients with ITBS and IT band trigger points have decreased knee flexion and extensor torque. The study found that individuals with ITB triggers had poorer hip abductor strength. In order to control the coronal movement during the stance phase, sustained hip abductor torque is necessary via gluteus medius and, to a lesser extent, TFL. Weakness in the gluteus medius and TFL leads to poorer control of thigh abduction, and external rotation leads to increased internal rotation torque of the thigh, which increases tension in the IT band and puts greater strain on the fascial linings of the plantar fascia (4, 10, 12).

Other theories, such as fascial kinetics, contend that muscles influence tissues across the body via fascia-based links, regardless of what they accomplish individually. According to this view, the iliotibial band, which is the major structure in the lateral fascial chain, is physically and directly associated with the plantar fascia via its distal attachments. Similarly, the spiral chain fascial system, like this, has a direct connection between the iliotibial band and the plantar fascia through the peroneus longus muscle, and tightness of these structures can cause restricted ankle mobility (8, 9).

Because most trigger points were discovered when the ITB was palpated, it may be presumed that the majority of trigger points in PHP patients are located in the medial and distal ITB. According to previous research, there is a link between plantar heel discomfort and trigger points in the calf and foot muscle. The current study found a strong association between PHP trigger locations and ITB trigger locations. According to the study, few patients had ipsilateral TrPs and none had contralateral TrPs.

The study had a few drawbacks, the first being that the presence of ITB trigger points may also be associated with asymptomatic or impaired hip or knee motor control. As ITB control is closely associated with both proximal and distal kinematics and joint positions. In addition, the association between the ITB trigger point and the other types of foot postures as defined by the foot posture index (FPI) tool could not be established outside of the pronated group. Therefore, the authors urge that future research concentrate on evaluating uncontrolled proximal kinetics and determining the relationship between the trigger points and the various foot postures according to the FPI.

CONCLUSIONS

In the participants with plantar heel pain, the current investigation demonstrated a substantial association between the existence of iliotibial band trigger points. The Iliotibial Band Trigger Points and Foot Posture Index, however, did not associate well. Therefore, it is concluded that the clinical diagnosis of plantar heel pain can be extended to include the presence of iliotibial band trigger points as well.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

SSW: data curation, investigation, methodology, resources, validation, visualization, writing – original draft. DKP: conceptualization, formal analysis, project administration, software, writing – review & editing. PV: validation, writing – original draft, writing – review & editing. KS: resources, writing – review & editing.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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ORIGINAL ARTICLE

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Work-Related Risk Factors for Musculoskeletal Disorder among Nurses in Indian Hospitals

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SUMMARY

Background. Due to the difficulties of work-related musculoskeletal disorders (WMSD) that are common worldwide, medical personnel have been recognized as high-risk groups.

Objective. To evaluate the work-related risk factors that affect musculoskeletal disorder among nurses in Indian hospitals.

Methods. In this cross-sectional descriptive study, data were collected from 200 nursing staff working in Jawaharlal Nehru Medical College and Hospital in Aligarh Muslim University, Uttar Pradesh, India. A self-management modified musculoskeletal questionnaire (Nordic questionnaire) was used to assess the occurrence of WMSD in the past 12 months.

Results. Lower back pain (79%) followed by the right shoulder and neck (67%) and knee pain (63%) was highest among female nurses in past 12 months. The prevalence of MSD in past 12 months was highest in dentistry (81.25%), followed by orthopedics (62.5%) and surgery (57.78%) department. For tasks that require sitting, lower back pain is highest (49.4%, n = 45) followed by neck (40.6%, n = 37) and elbows (38.4%, n = 35). The lower back discomfort was highest who worked more than 6 hours (76.1%, n = 35), followed by neck (60.8%, n = 28) and right shoulder (56.5%, n = 26). Unexpectedly, 53.5% of nurses believed that the manual patient transfers leads to MSD on their body parts. In addition, 63.5% of nursing staff across all departments unexpectedly report that they agree they are under work pressure/stress and have experienced MSDs.

Conclusions. Nurses often have a high risk of WMSD in the lower back and neck; therefore, special measures should be taken to ensure that they work in an ergonomic setting, and appropriate body mechanics should be applied to limit the likelihoods of facing WMSD.

KEY WORDS

Work-related musculoskeletal disorders; nursing staff; work factors; psychosocial factors; Nordic Musculoskeletal Questionnaire.

INTRODUCTION

Healthcare organizations face many challenges due to aging employees, unemployment, increased patient acuity, number of patients and weight gain. Also, if the nurse is injured on the job, the cost of rehabilitation, absenteeism, and workplace accidents will also increase (1). A study shows that nurses are at seven time greater risk of serious injury than other occupations (2). Due to the occurrence of musculoskeletal disorder (MSD), many workers in various occupations are affected and have a significant impact on some organizations. Musculoskeletal disorders (MSDs) is a common work-related difficulty worldwide, and health care workers have been recognized as a high-risk group (3).

An increased risk of MSD has been recognized in occupations having repetitive tasks, hard work, uncomfortable postures, and lifting heavy objects (3, 4). Puagprakong *et al.* (5) investigating the effect of lower cross syndrome on the upper body posture of female office workers, it was found that different types of lower cross syndrome have different effects on upper body sitting posture, and poor sitting posture due to muscle imbalance leads to MSDs. In addition, it has been determined that physical requirements, work environment, and workplace will harm the physical and mental health of nursing staff (6). In addition, time constraints, low participation in decision-making, strict observation, lack of communication, unclear job occupations, and the time spent performing these tasks are all considered nurse situations (7).

Work-related MSDs are very common in medical institutions, with an annual prevalence ranging from 28% to 96% (8). Work-related illnesses have been found to be the leading cause of absenteeism in nursing facilities (9). Based on globally reported data, the prevalence of MSDs among nursing staff is reported to be high, *i.e.*, 89% in Portugal (10), 32.8% to 57.1% in Brazil (11), 10% to 50% in France (12), 85% in Macedonia (13), 78.6% in China (14), 88% in Iran (15) and 35.1% to 47% in the United States (16).

The occurrence of work-related MSD between nursing staff and related risk factors is important for health service decision makers and professionals to reduce the existence of problems. Therefore, it is important to adjust various risk factors in the manual patient care activities that nurses must perform to reduce the impact of WMSD. Manual patient handling is not safe for patients, impacts nurses, and can lead to risk of injury, pain, and adverse health effects (17). Therefore, among healthcare professionals, manual lifting of patients is considered to be the highest risk factor for illness, and increased obesity and age of nurses are also contributing factors (18). There is evidence that training alone is ineffective, and more and more people agree that the use of ergonomic interventions and equipment play an important role in reducing the risk of musculoskeletal disorders for nurses (19, 20). However, many accidents experienced by patients and nurses are caused by poor ergonomics (21).

A number of studies have shown that the various factors, namely posture, workload, duration of employment and gender, work stress and manual lifting, are factors that affect the risk of WMSD (3, 10, 11, 13, 15, 16, 22-24, 25). In addition, body mass index (BMI) is also related to MSD in various parts of the body, and there is a moderate correlation between high BMI (overweight and obesity) and increased incidence of musculoskeletal discomfort (26). In addition, Chen *et al*. (24) concluded that the influencing factors that lead to MSD include age, work experience, work content, working hours, standing, sitting and walking time at work, work stress level and exercise habits.

To the best of our knowledge, the prevalence of WMSD among nursing staff and related factors is of great importance to policy managers and health service professionals to reduce the occurrence of problems. Therefore, it is necessary to determine the multifactorial factors viz., work factors, employment durations, physiological factors, manual handling and exercise habit contributing WMSDs among nurses in last 12 months. In this study, a self-management modified musculoskeletal questionnaire (Nordic questionnaire) was used to assess the occurrence of WMSD among nursing staff. This study will serve as a benchmark for policymakers to apply recommended guidelines that reduce musculoskeletal discomfort in nurses and thus improve quality of care and performance.

METHODS

Study design

The study aims to investigate the factors affecting MSDs of nursing staff in Indian government hospital, and to assess the relationship between MSD and workload-related factors. The research protocol was approved by Ethical Review Committee of the Department (IRB: MED-21-0127-Date of approval: July 21, 2021) and with the 1964 Helsinki declaration. In this cross-sectional descriptive study, data were collected from nursing staff working in Jawaharlal Nehru Medical College and Hospital in Aligarh, Uttar Pradesh, India. In this survey, 227 participants who met the inclusion criteria were recruited voluntarily, and 27 participants did not complete the questionnaire were disqualified from the study. Therefore, finally 200 participants were selected in the study with the response rate of 80.97%. The study period is from August 2021 to October 2021.

Full-time nursing staff (100 men and 100 women) from seven different departments viz., general medicine, surgery, dentistry, gynecology, oncologist, orthopedic, and physiotherapy, voluntarily participate in this study (only those eligible for government benefits and report injuries during their work in the hospital, and receive compensation, treatment, or vacation). In addition, participants should: 1) a registered nurse, 2) minimum one year of working experience, 3) > 18 years of age, and 4) ready to participate in the research. However, those who were pregnant and have prior peripheral nerve disease, trauma and fracture sprains, and other musculoskeletal injuries were excluded from the study. Observed individuals with any missing information was also excluded from the survey.

Questionnaires

A self-management modified musculoskeletal questionnaire (Nordic questionnaire) was circulated among the nursing staff in two ways; first, it was sent by email, and second, it was physically submitted and collected thereafter. The questionnaire is separated into three parts: background information, job nature, work-related risk factors, physiological factors and its association on body part discomfort. Respondents were questioned to choose from 9 body parts (neck, shoulder, lower back, upper back, wrist, knee joint, elbow joint, lower extremity and upper extremity). Questionnaire comprise whether they have sensed discomfort in the past 12 months, which affected their capability to live or work (a "yes" answer is 1 point and a "no" answer is 0 points). The highest score for discomfort in each part is 3 points, and the lowest is 0 points. Due to the limited range of scores, the scores of discomfort in each part are further divided into "no" (0) and "yes" (1-3 points = 1). The questionnaire can recognize the dissimilarities in discomfort caused by different work factors, so as to more clearly define the MSD problem. Several studies have shown that the questionnaire has adequate consistency, reliability and validity (27, 28). A self-management modified musculoskeletal questionnaire (Nordic questionnaire) last 15 to 30 minutes.

RESULTS

Demographic characteristics

The results of demographic characteristics of all nursing staff in seven departments are shown in **table I**. Full-time nursing staff from seven different departments (100 men and 100 women), namely general medicine, surgery, dentistry, gynecology, oncology, orthopedics, and physiotherapy volunteered to participate in this study. The average age was 29.01 ± 9.46 years and 30.58 ± 12.03 years for women and men employees respectively. The average height was 157.3 ± 5.8 cm and 169.8 ± 3.2 cm for women and men employees respectively. In addition, the average BMI was 23.5 ± 3.8 kg/m² and 23.2 ± 4.2 kg/m² for women and men employees respectively. Most nurses (65% men and 57% women) had weights within the normal range. However, 24% of men and 26% of women are overweight and obese. The average duration of employment was 6.39 ± 4.73 years and 8.29 ± 6.12 years for women and men respectively. Most nurs-

Table I. Demographic characteristics of the participants.

Demographics	Male	Female
Number of respondent (n)	100	100
Age (yrs) (Mean ± SD)	30.58 ± 12.03	29.01 ± 9.46
Weight (Kg) (Mean ± SD)	66.8 ± 11.44	58.76 ± 10.48
Height (cm) (Mean ± SD)	169.8 ± 3.2	157.3 ± 5.8
BMI kg/m² (Mean ± SD)	23.2 ± 4.2	23.5 ± 3.8
Underweight	11 (11%)	17 (17%)
Normal	65 (65%)	57 (57%)
Overweight	18 (18%)	21 (21%)
Obese	6 (6%)	5 (5%)
Duration of employment (Mean ± SD)	8.29 ± 7.12	6.39 ± 4.73
Educational level		
High school/certificate course	15	14
Diploma	22	18
Bachelor's degree	47	62
Master/PhD	16	6

es have a bachelor degree (female n = 62, male n = 47), followed by a diploma (female n = 18, male n = 22) and a master/doctoral degree (female n = 16, male n = 6).

According to **table II**, in past 12 months, the highest incidence of MSD was in dentistry (81.25%), followed by orthopedics (62.5%), and then surgery (57.78%). It can be seen from all the valid respondents in the general medicine that most of the employees are male (n = 51), accounting for about 58.6% of the total number of employees, followed by 36 females (41.4%). However, 24 (47.1%) men and 18 (50.0%) females reported the incidence of MSD in past 12 months. Overall, the prevalence of MSD in all seven departments has been high (67%) in past 12 months.

In addition, the incidence of MSD in 9 parts of the body in the past 12 months is shown in **table III**. Feedback from various departments showed that the incidence of MSD in the lower back (LB) was the highest, 43.7% in orthopedics, 37.5% in dentistry, and 31.1% in surgery. In addition, the MSD of the right shoulder was 37.5%, the highest in the dental department, followed by the MSD of the elbow and upper back (31.5%). However, the highest prevalence of cervical MSD was reported in surgery (33.3%), followed by dentistry (25.0%). In addition, a total of 47 (23.5%) nurses reported that of all employees, the prevalence of MSD in the LB was the highest. However, the physical therapy and oncology departments did not report MSD on the right shoulder, neck, wrist, upper back, and knee. In addition, wrist MSD has the highest report rate in orthopedics (31.2%), followed by surgery (26.7%) and gynecology (21.1%).

Association of work factors and MSD

Table IV shows the pain frequency of 9 body parts in the work-related risk factors to determine its relationship with MSD. The work-related risk factors are distributed into posture, workload (time), and duration of employment. In addition, the influence of other associated factors, namely gender, work pressure, patient's physical handling and exercise habits on MSD was also evaluated.

Table II. The prevalence of MSD in each department in the past 12 months.

Department	Valid responded	Gender		MSD in last 12 Months		
		Male	Female	Male	Female	Total prevalence
General Medicine	87	51 (58.6)	36 (41.4)	24 (47.1)	18 (50.0)	42 (48.28)
Surgery	45	22 (48.9)	23 (51.1)	12 (54.5)	14 (60.8)	26 (57.78)
Dentistry	16	3 (18.7)	13 (81.2)	3 (100.0)	10 (76.9)	13 (81.25)
Gynecology	19	5 (26.3)	14 (73.7)	1 (20.0)	6 (42.8)	7 (36.84)
Oncologist	7	2 (28.6)	5 (71.4)	1 (50.0)	0 (0.0)	1 (14.28)
Orthopedic	16	12 (75.0)	4 (25.0)	7 (58.3)	3 (75.0)	10 (62.5)
Physiotherapy	10	5 (50.0)	5 (50.0)	2 (40.0)	3 (60.0)	5 (50.0)

Table III. The prevalence of MSD in 9 body parts in the past 12 months.

Body region	Department							
	All n (%)	G. Med. n (%)	Sur. n (%)	Dent. n (%)	Gyne. n (%)	Onco. n (%)	Ortho. n (%)	Physio. n (%)
Shoulder (left)	21 (10.5)	8 (9.2)	6 (13.3)	3 (18.7)	2 (10.5)	0 (0.0)	1 (6.3)	1 (10.0)
Shoulder (right)	28 (14.0)	10 (11.5)	6 (13.3)	6 (37.5)	3 (15.8)	0 (0.0)	3 (18.7)	0 (0.0)
Neck	33 (16.5)	10 (11.5)	15 (33.3)	4 (25.0)	2 (10.5)	0 (0.0)	2 (12.5)	0 (0.0)
Elbow	36 (18.0)	10 (11.5)	12 (26.7)	5 (31.2)	4 (21.1)	0 (0.0)	4 (25.0)	1 (10.0)
Wrist	36 (18.0)	12 (13.8)	12 (26.7)	3 (18.7)	4 (21.1)	0 (0.0)	5 (31.2)	0 (0.0)
Upper back	34 (17.0)	13 (14.9)	11 (24.4)	5 (31.2)	3 (15.8)	0 (0.0)	2 (12.5)	0 (0.0)
Lower back	47 (23.5)	15 (17.2)	14 (31.1)	6 (37.5)	4 (21.1)	0 (0.0)	7 (43.7)	1 (10.0)
Lower limb	32 (16.0)	11 (12.6)	9 (20.0)	3 (18.7)	4 (21.1)	1 (14.3)	3 (18.7)	1 (10.0)
Upper limb	27 (13.5)	8 (9.2)	9 (20.0)	4 (25.0)	4 (21.1)	1 (14.3)	1 (6.3)	0 (0.0)
Knee	36 (18.0)	15 (17.2)	11 (24.4)	3 (18.7)	5 (26.3)	0 (0.0)	2 (12.5)	0 (0.0)

Table IV. Association between MSD in 9 body parts with work and psychological factors during the last 12 months.

Independent variables	Shoulder		Neck	Elbow	Wrist	Upper back	Lower back	Lower limb	Upper limb	Knee
	Left	Right								
Posture										
Sitting (91)	20 (21.9)	24 (26.3)	37 (40.6)	35 (38.4)	23 (25.2)	24 (26.3)	45 (49.4)	14 (15.3)	24 (26.3)	28 (30.7)
Standing (96)	16 (16.6)	22 (22.9)	21 (21.8)	24 (25)	24 (25)	16 (16.6)	27 (28.1)	21 (21.8)	17 (17.7)	22 (22.9)
Walking (13)	1 (7.6)	3 (23.0)	4 (30.7)	0 (0)	1 (7.6)	3(23.1)	4 (30.7)	5 (38.4)	2 (15.3)	2 (15.3)
Workload (Time)										
< 4hr (4)	0 (0.0)	1 (25.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (25.0)	0 (0.0)	0(0.0)	0 (0.0)
4-6 hrs (16)	4 (25.0)	6 (37.5)	3 (18.7)	2 (12.5)	3 (18.7)	3 (18.7)	8 (50.0)	3 (18.7)	3 (18.7)	2 (12.5)
6-8 hrs (146)	68 (46.6)	87 (59.6)	72 (49.3)	45 (30.1)	29 (19.8)	56 (38.4)	98 (67.1)	43 (29.5)	39 (26.7)	47 (32.2)
> 8 hrs (46)	22 (47.8)	26 (56.5)	28 (60.8)	9 (19.5)	6 (13.0)	18 (39.1)	35 (76.1)	18 (39.1)	17 (36.9)	21 (45.6)
Employment duration										
< 2 yrs (81)	14 (17.2)	18 (22.2)	39 (48.1)	23 (28.3)	21 (25.9)	35 (43.2)	32 (39.5)	19 (23.4)	18 (22.2)	31 (38.3)
2-4 yrs (44)	16 (36.3)	16 (36.3)	23 (52.2)	17 (38.6)	18 (40.1)	19 (43.2)	14 (31.8)	17 (38.6)	10 (22.7)	18 (40.1)
5-10 yrs (52)	6 (11.5)	10 (19.2)	12 (23.1)	14 (26.9)	12 (23.1)	14 (26.9)	10 (19.2)	17 (32.6)	15 (28.8)	20 (38.4)
> 10 yrs (23)	3 (13.0)	4 (17.3)	5 (21.7)	4 (17.3)	2 (8.6)	5 (21.7)	4 (17.3)	2 (8.6)	4 (17.3)	2 (8.6)
Gender										
Female (100)	44 (44.0)	67 (67.0)	67 (67.0)	37 (37.0)	23 (23.0)	56 (56.0)	79 (79.0)	57 (57.0)	28 (28.0)	63 (63.0)
Male (100)	36 (36.0)	39 (39.0)	62 (62.0)	38 (38.0)	29 (29.0)	30 (30.0)	59 (59.0)	48 (48.0)	29 (29.0)	52 (52.0)
Work Stress										
Yes (127)	45 (35.4)	68 (53.5)	79 (62.2)	35 (27.5)	31 (24.4)	49 (38.6)	82 (64.5)	53 (41.7)	37 (29.1)	77 (60.1)
No (73)	7 (9.5)	10 (13.7)	11 (15.1)	13 (17.8)	13 (17.8)	15 (20.5)	16 (21.9)	14 (19.2)	9 (12.3)	13 (17.8)
Manual lifting										
Yes (107)	31 (28.9)	44 (41.1)	54 (50.4)	31 (28.9)	29 (27.1)	36 (33.6)	63 (58.9)	32 (29.9)	30 (28.0)	58 (54.2)
No (93)	7 (7.5)	11 (11.8)	13 (13.9)	15 (16.1)	15 (16.1)	12 (12.9)	18 (19.3)	10 (10.7)	14 (15.0)	10 (10.7)
Exercise Habit										
Frequently (73)	8 (10.9)	9 (12.3)	9 (12.3)	8 (10.9)	9 (12.3)	13 (17.8)	14 (19.1)	11 (15.0)	8 (10.9)	8 (10.9)
Sometimes (95)	19 (20)	21 (22.1)	28 (29.4)	25 (26.3)	26 (27.3)	27 (28.4)	34 (35.7)	26 (27.3)	25 (26.3)	29 (30.5)
Not at all (32)	8 (25)	10 (31.2)	14 (43.7)	13 (40.6)	13 (40.6)	12 (37.5)	14 (43.7)	10 (31.2)	12 (37.5)	13 (40.6)

Posture

According to **table IV**, for tasks involving sitting posture, the incidence of LB pain was the highest (49.4%, n = 45). For the same posture, the second highest reported discomfort occurred in the neck (40.6%, n = 37), followed by the elbows (38.4%, n = 35), knees (30.7%, n = 28), right shoulder and upper back (26.3%, n = 24). In addition, for tasks involving standing posture, the incidence of LB pain was the highest (28.1%, n = 27) followed by elbow and wrist (25.0%, n = 24). However, for tasks involving walking, the incidence of lower limb pain was the highest (38.4%, n = 5) followed by the LB and neck (30.7%, n = 4). In general, for all postures, nurses who report LB pain also indicated that they had MSD in their shoulders and neck. In addition, the sitting and awkward postures that involve lifting, forceful exertion, pushing, and pulling tasks place higher demands on body parts, leading to MSD.

Workload (time)

The relationship between MSD and workload (time) is usually determined based the workload, which is divided into four groups (**table IV**). The highest LB discomfort was reported by nursing staffs who worked more than 8 hours (76.1%, n = 35), followed by the neck (60.8%, n = 28) and right shoulder (56.5%, n = 26) discomfort. This was obvious for employees who work more than 8 hours and have an MSD prevalence of more than 50%. Similarly, 6 to 8 hours of work resulted in a 100% incidence, with the LB (67.1%, n = 98) having the highest prevalence, followed by the right shoulder (59.6%, n = 87) and the neck (49.3%, n = 72). In addition, for 4 to 6 hours of work, the highest reported MSD prevalence was in the LB (50.0%, n = 8), followed by shoulder MSD (37.5%, n = 6). Although, for workloads of less than 4 hours, few cases of body part-related pain has been reported. In short, the most common work-related risk factors with working hours longer than 4 hours were LB, neck and shoulder discomfort.

Employment duration

The results (**table IV**) of this study show that nursing staffs with employment duration less than two years had a MSD-related discomfort highest in neck (48.1%, n = 39) followed by upper back (43.2%, n = 35) and lower back (39.5%, n = 32). In addition, nursing staffs with employment duration of 2-4 years had a MSD-related discomfort highest in neck (52.2%, n = 23) followed by upper back (43.2%, n = 19), wrist and knee (40.1%, n = 18). However, compared to nurses with less than 4 years of service, nurses who have been employed for more than 5 years have a very low frequency of MSD-related complaints. Therefore, nurses with less than 4 years of experience have a higher incidence of MSD-related pain and the highest rate of neck discomfort, followed by upper back and knee disorders. This may be due to the job title and the employee's level of information of workstation safety. The current survey has no such impact, although in some cases it may be considered proportional to the number of years employees have worked in a particular department.

Association between other factors and MSD

Gender

The relationship between the MSD and gender shows (**table IV**) that female employees are at a greater risk of suffering from MSD. In this survey, 79% of female nurses reported LB pain followed by the right shoulder and neck (67%), and knee pain (63%). In contrast, male nurses reported the highest pain in the neck (62%), LB (59%), and knee (52%). Overall, compared to female nurses, male nurses have significantly fewer MSD symptoms in their body parts.

Work stress

The discomfort caused by MSD has a lot to do with work stress. 63.5% of nursing staff across all departments unexpectedly report that they agree they are under work pressure/stress, and also said their body parts have experienced MSDs (**table IV**). The highest prevalence of MSD report was at the LB (64.5%), followed by the neck (62.2%), knee (60.1%) and right shoulder (53.5%).

Manual lifting

Manual handling of patients is not safe for patients, has an impact on caregivers, and may have risks of injury, pain, and adverse health effects. Unexpectedly, 53.5% of nurses across all departments believed that the manually handling patient transfers leads to MSD in their body parts (**table IV**). The greatest discomfort reported was seen in LB (58.9%), followed by knees (54.2%) and neck (50.4%). In addition, nurses who did not use manual patient transfer reported much less discomfort to their body parts.

Exercise habit

The survey for this study showed that nurses with regular exercise habits (36.5%) reported a lower prevalence of MSDs compared to nurses who exercised irregularly (47.5%). However, nurses who do not have exercise habits have a high prevalence of MSD in the neck and LB (43.7%), followed by the elbows, wrists, and knees (40.6%) (**table IV**).

DISCUSSION

The study aims to investigate the factors affecting MSDs of nursing staff in Indian government hospital, and to assess the relationship between MSD and workload-related factors. The results of this study are not considerably different from those of other related studies. LB problems were the most prominent cause of discomfort reported by female (75%) and male (59%) nurses. Some nurses who have encountered this problem are unable to carry out normal activities and need to see a doctor for this situation. These findings were consistent with other studies (29-32). Furthermore, this survey confirms that the highest prevalence of MSDs was recorded in LB, followed by neck, shoulder, upper back, and knee problems. Although the studies reviewed reported the same issues, the exact order of the issues was not consistent. Neck and shoulder pain are also common musculoskeletal problems for nursing staff. According to the survey, compared to LB, the prevalence of work-related neck and shoulder MSDs in the past 12 months showed a higher rate of reported cases. Existing research shows that the three areas with the highest prevalence of MSD among nurses are the neck, shoulders, and LB, followed by the upper back, elbow/wrists, and knees (33). This in turn causes nurses to take sick leave, reduces their work efficiency, affects their mental state, and increases medical expenses due to additional workload and work stress. These findings are also consistent with the results of other studies (29, 34). Furthermore, Rai *et al*. (35) investigated the pre-COVID-19 and COVID-19 era impact on sonographer MSDS and reported shoulder pain ($p \leq 0.001$), neck pain ($p = 0.001$), low back pain ($p = 0.001$) and wrist pain ($p = 0.017$) were the most common symptoms.

The prevalence of work-related MSDs among nurses varies from study to study. Salama and Eleshenamie (36) reported that 99.0% of nurses were affected by MSD while studying risk factors for 300 nurses. Clari *et al*. (37) revealed one or more cases of upper limb disorders among 48.3% of nurses. Cheng *et al*. (38) used a standardized Nordic musculoskeletal questionnaire for 470 nurses with a prevalence of MSD at the LB (77.2%), neck (64.2%), and shoulders (58.7%). Similarly, Pakistani nurses also reported a high prevalence of musculoskeletal disorders (31.6%) over a 12-month period, with the most common site being the lower back (32%), followed by the shoulder (20%), upper back, and knees (10%) (39). Ahmad *et al*. (40) also reported that the back, neck and shoulder were the areas with the highest prevalence of complaints followed by the knee and wrist/hand. Chen *et al*. (22) conducted a survey of nurses' musculoskeletal discomfort at 793 health facility and reported neck discomfort (63.5%), shoulder discomfort (62.6%), and LB discomfort (59.3%). Furthermore, they concluded that there was a correlation between the amount of work done by the nurses and their satisfaction with their work and the amount of discomfort in their musculoskeletal system. Similarly, current surveys show that the LB pain (79%) was highest among female nurses, followed by the right shoulder and neck (67%) and knee pain (63%) in the past 12 months.

It was found that work tasks and psychosocial factors would increase the prevalence of MSD among nursing staff. The task characteristics of each department usually includes transferring patients from the gurney, transferring patients from the bedside to the other side, manipulating the different types of tools and machines, using surgical instruments, pushing/pulling the overhead vertical machine, hygiene care, wound care and working on the required computer workstation. Manual handling of patients is unsafe, impacts nurses, and may lead to risks of injury, pain, and adverse health effects. In present study, unexpectedly, 53.5% of nurses across all departments believed that the manually handling patient transfer's leads to MSD in their body parts. In addition, prolonged standing and sitting lead to a high incidence of LB and upper limb discomfort. Previous studies have uncovered the relationship between work posture and MSDs and concluded that prolonged sitting is linked to musculoskeletal symptoms in the shoulders, neck and LB (41-43). This may be due to workers holding a static posture for a long time to perform manual tasks, raising their arms and involving too many manual equipment (33). In addition, working postures with continuous or restricted postures, such as tasks that require upper limb movement, eventually force the neck and shoulders to awkwardly align, which may lead to the development of neck and shoulder musculoskeletal discomfort.

The prevalence of MSD is also related to other factors, such as gender, manual lifting, work stress, high mental pressure, and exercise habits (31, 43, 44). In addition, nurses who have been employed for more than 5 years have a very low incidence of MSD-related pain in their body parts. The reason may be due to the job position and employees' knowledge of workplace safety. This is consistent with a previous study conducted among nurses in rural Japan, which showed that the duration of employment has nothing to do with the prevalence of MSD (45). Additionally, high workload was found to have a significant impact on the prevalence of MSDs with working more than 2 hours (46). The current survey shows that for 4 to 6 hours of work, the highest reported MSD prevalence was in the LB (50.0%, $n = 8$), followed by shoulder MSDs (37.5%, $n = 6$). Although for workloads of less than 4 hours, there are few reported cases of body part-related pain. Yip (44) pointed out that designation, education level, and experience within working years are related to the incidence of LB pain. In terms of gender, most female nurses working across all seven departments have higher MSD symptoms than male. Overall, the prevalence of MSD across all seven departments has been high at 67% in the past 12 months. This may be due to the high physical requirements of manual handling tasks. In contrast, Esfahani *et al*. (47) concluded that their findings do not support the prevailing view that prolonged sitting at work as part of everyday life is necessarily associated with LB pain; rather, sitting posture, lower levels of physical fitness, and shorter duration of home activities may be associated with reduced extensor endurance in nonspecific chronic LB pain.

In this survey, most nurses (65% male and 57% female) were within the normal weight range and their BMI was unrelated to MSDs. However, 24% of men and 26% of women are overweight and obese; therefore, BMI may be closely related to MSD in these employees. This is consistent with the results of Attarchi *et al*. (48). However, Trinkoff *et al*. (49) stated an association of MSD between BMI and back/shoulder symptoms. Additionally, nurses with regular exercise habits (36.5%) reported a lower prevalence of MSDs than nurses who exercised irregularly (47.5%). However, nurses who lack exercise habits have a high prevalence of MSDs. Narayan *et al*. (50) also reported that physicians who participated in certain physical activities had lower MSD rates than physicians who did not engage in any physical activity. The most critical reason for this type of MSD may be the lack of training to understand relevant work-related situations. Intervention studies have shown that by reducing physical demands, good results have been achieved in the prevention of MSDs in nurses (49).

However, interventions aimed at reducing MSDs in hospitals must take into account not only ergonomics, but also the improvement of the organization of the working environment. Stavrianopoulos (51) reviewed the literature on safety culture development and paid more attention to the characteristics of safety culture development, as human factors affect perception and the implementation of cultural changes. Therefore, the healthcare industry should build a model that best meets their needs based on their assessments and can implement pilot programs to achieve this goal. Healthcare professionals can design different types of equipment to support different types of lifts and select equipment from different vendors to meet their assessment needs. In addition, the latest educational information should be communicated to nursing staff every year to help maintain the plan (52).

Recommendation and guideline for the policy makers

Policy makers may need to limit the number of hours nurses work per week. This attempts to limit the prevalence of MSD among nurses. In addition, the decision maker may emphasize rest when dismissing the task and stop when the nurses begin to experience pain during the task. Other policy improvements may attempt to completely redesign lifting operations to avoid movements that are considered high-risk factors. In addition, more policies are needed to increase awareness of workstation injuries, their importance, and consideration of prevention methods to minimize them. Basic training in work-related accidents, prevention policies and ergonomics will also help nursing staff. Practitioners can use these results to help nurses change their working conditions and implement preventive policies.

CONCLUSIONS

The findings of this study reconfirm the high prevalence of work-related MSDs among hospital nurses. In addition, current results indicate that healthcare professionals are at risk for MSD, especially in the LB, shoulders, neck, and knees. Work tasks and psychosocial factors were identified as the main reasons for employees' MSD. Therefore, ergonomic improvements to the work design and workspace are needed to reduce the risk of MSD and improve the patient care. In addition, medical institutions should invest in prevention programs, training, education, intervention policies, and organization of existing services.

Limitations and future scope

The main limitations of the present study were that the use of a questionnaire to collect data on the occurrence of musculoskeletal complaints was based on self-reported information provided by the participants, and no physiological tests were performed to confirm the diagnosis. Therefore, musculoskeletal complaints caused by factors other than work cannot be eliminated, which means that the prevalence of musculoskeletal complaints reported in this study may be overestimated. Second, the sample size reported in this study is smaller, and a larger sample size may provide a better and stronger support for results. Furthermore, this study only investigated demographic characteristics and job-related factors associated with musculoskeletal discomfort, ignoring other factors that may influence the development of the condition, such as burnout, resilience, satisfaction, and nurses' perceptions about how to deal the mobilizations when transferring patients. In addition, future research needs to assess the utmost effective way to prevent WMSD among nursing staffs. Currently, special referrals are made for certain cases with persistent musculoskeletal symptoms. Since working in the dentistry, orthopedics, surgery, and gynecology departments is considered to have a protective effect on back pain, follow-up will be conducted to determine which strategies the department uses and how to share these strategies with other departments in the hospital.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

MMA: conceptualization, design, writing. AMA: conceptualization, revision. SZ: analysis, drafting, revision. MR, MS, IA: data collection.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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REVIEW

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Night Splints in Plantar Fasciitis: A Systematic Review

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LEVEL OF EVIDENCE: 1

SUMMARY

Introduction. Plantar fasciitis (PF) is a subcalcaneal pain syndrome that affects 10-16% of the world's population. The use of foot and ankle splinting allows the talocrural joints to be in anatomical position, reducing the contracture and tension generated by pain and PF.

Objective. To review the literature on the effectiveness of night splinting in plantar fasciitis.

Materials and methods. Seven databases were used, and EndNote Web and Rayyan reference managers were employed. After exclusion of duplicate articles, Phase 1 - reading of titles and abstracts and Phase 2 - reading of the full texts according to the eligibility criteria by two blinded reviewers (R1 and R2) and discrepancies resolved by the third reviewer (R3). Risk of bias assessment was performed by blinded R1 and R2 with the Cochrane tool, Rob 2.

Results. The references of 258 studies were identified, 144 from the major databases and 114 from grey literature. Finally, three randomized clinical trials were included in this review. A high risk of overall bias was found in the 3 studies included in this review.

Conclusions. It is concluded that the use of the night splint improves pain and function in individuals with plantar fasciitis. However, due to the high risk of bias obtained, there is needed with such a statement, and more primary studies are needed.

Study registration. The project has been registered in PROSPERO under number CRD42021285287.

KEY WORDS

Rehabilitation; plantar fasciitis; foot orthoses; pain management; orthotic devices.

INTRODUCTION

During gait, the foot is responsible for absorbing impact and distributing body weight. At the beginning of the gait (support phase), most of the pressure is in the heel region and in the propulsion phase the pressure passes mostly to the forefoot region (1, 2). Many times, micro traumas in some of the regions with greater weight discharge can generate pain and/or discomfort, as is the case of plantar fasciitis (PF) (3-5).

A PF, also known erroneously as calcaneal spur, is a subcalcaneal pain syndrome common between 40 and 60 years of age, with about 15% of foot lesions in the population (4, 6). Within the affected population, the most frequent age is 40 to 70 years, and the most affected gender is male. Furthermore, athletes, especially runners, also report this orthopedic problem frequently, since during running the pressure distribution is altered (7-9).

The exact cause of this syndrome is unknown, it may result from inflammation in the region of the calcaneal origin of the plantar fascia, which is initiated by excessive traction (10). But it can also be associated with plantar fascia avulsion, stress fracture of the calcaneus, compressive neuropathy of the plantar nerves, plantar calcaneal spur, and plantar fat pad atrophy. The sum of these etiologies can cause pain for the patient (3, 8, 11, 12).

Many treatment techniques are based on decreasing symptoms, stretching, and releasing the triceps sural and fascia that become tensioned, because with the tension of the Achilles tendon and plantar fascia, functional risks are identified that limit dorsiflexion of the foot and toes (3, 13, 14). Treatments can be conservative or nonconservative (15); in most cases conservative treatment is already able to relieve the symptoms. Some treatments include foot orthoses (splint), corticosteroid injections, non-steroidal anti-inflammatory agents, therapeutic ultrasound, extracorporeal shockwaves, stretching exercises, night splints, bandages, and surgical intervention (14, 16-19).

The use of foot and ankle splinting allows the talocrural joint to remain in anatomical position, reducing the contracture and tension generated by pain and PF (20, 21). While the individual sleeps, the foot performs involuntary plantar flexion, resulting in contracture of the posterior leg muscle grouping. Therefore, the use of these orthoses (splints), by placing the joint in an anatomical position, results in a decrease in contracture (10, 21, 22). Therefore, during the night the splint keeps the lower extremity of the affected limb in dorsiflexion and the fingers in extension. The union of these positions allows the fascia to remain at its ideal length for a long period (22, 23). Despite the reports, there is a lack of secondary studies synthesizing the use of the night splint in these cases. Thus, the objective of this study was to review the literature on the effectiveness of night splinting in plantar fasciitis.

MATERIALS AND METHODS

Eligibility criteria

The acronym PICOS was used to formulate the question focused on this study: P – Population (individuals with chronic plantar fasciitis); I – Intervention (night splint); C – Comparison (control group or not using night splint); O – Outcomes: pain (Visual Analog Scale-VAS, which assesses pain changes from baseline to follow-up or the Numeric Rating Scale-NRS) and functionality (Foot Function Index, or other scales and questionnaires that assess pain or functional disability); and S – Study design (randomized clinical trials).

Inclusion criteria

Individuals with chronic plantar fasciitis, men and women, sedentary and athletes, with one or both symptomatic feet, with plantar fasciitis for at least 3 months, age > 18 years. Intervention of night splint use (night splint or orthosis) compared to placebo, simulated treatment, and no treatment, patients reporting plantar fasciitis, heel pain or symptoms (pain in the sole/ankle of the foot not due to other diseases) and pain at the time of recruitment, diagnosed by imaging (ultrasound, MRI) or clinical examination (*e.g.*, signs and symptoms).

Exclusion criteria

Individuals with other diagnoses (such as fascial plantar fibromatosis, plantar nerve injury, fracture, tumor, Morton's syndrome, diabetic diseases such as ulcers, osteoarthritis, rheumatic diseases, neurological diseases, acute or chronic infections, tarsal tunnel syndrome), surgical treatment, and pregnancy. Case studies, cohort studies, systematic reviews, literature reviews, editorials, and animal studies were also excluded.

Information sources

The initial search was conducted using keywords in the PubMed database, with the Medical Subject Headings (MeSH) system, descriptors defined in Health Sciences (DeCS), from the Virtual Health Library (VHL) site and also free terms. Individual search strategies were developed for the databases: PubMed, Embase, The Cochrane Library and The Physiotherapy Evidence Database (PEDro) and in the grey literature: Google scholar, Brazilian Library of Thesis and Dissertations and LIVIVO and at the end of the searches, which were carried out on July 02, 2022, the terms used were grouped in a table together with the number of references found in each base.

Study selection and data collection process

After exporting the databases to a folder named "searches", the references were imported into the EndNote Web reference manager for automatic and manual removal of duplicate articles. Then they were imported into Rayyan QCRI (Qatar Computing Research Institute, DOH, MQ), and again duplicate removal was performed by the first reviewer (AJPB). In this way, the studies that were included in Phase 1 were defined for reading of titles and abstracts, according to eligibility criteria, by two blinded reviewers (AJPB and MIGB). Studies that had a conflict were resolved by the third reviewer (MRB). The final selection, Phase 2, was based on the reading of the full texts by the two reviewers and similarly conflicts were resolved by the third reviewer.

Collected data

The main data collected according to the study characteristics (authors, year of publication, country), sample characteristics (size, mean age and sex), description of the intervention, results and conclusion.

Individual assessment of risk of bias in studies

The risk of bias assessment was performed by blinded reviewers R1 (AJPB) and R2 (MIGB) with the Cochrane tool, Rob 2. And disagreements were resolved by R3 (MRB).

Assessment of the risk of publication bias

Initially, to prevent publication bias, a comprehensive, sensitive search was performed, without restriction on period, language, and with a search of the gray literature. In this way, the risk of publication bias can be mitigated.

RESULTS

The following is a narrative synthesis of the results of the included studies structured around the reported results.

Study selection

All searches were conducted on a single day, December 02, 2021. References for 258 studies were identified, 144 from the major databases (PubMed n = 34, Embase n = 87, Lilacs n = 2, Cochrane n = 21 and Pedro n = 0) and 114 from the grey literature (Google Scholar n = 100, Brazilian Library of Thesis and Dissertations n = 0 and Livivo n = 14).

After removal of the duplicates, the remaining articles for Phase 1 were 102 titles and abstracts, according to the eligibility criteria, and for Phase 2, 23 studies were read in their entirety. Articles included in Phase 2 that did not meet the eligibility criteria were then excluded due to not finding the full article and the intervention not as expected. Three randomized clinical trials were selected and tabulated according to **table I**. **Figure 1** (PRISMA Flowchart 2020) summarizes the complete selection process.

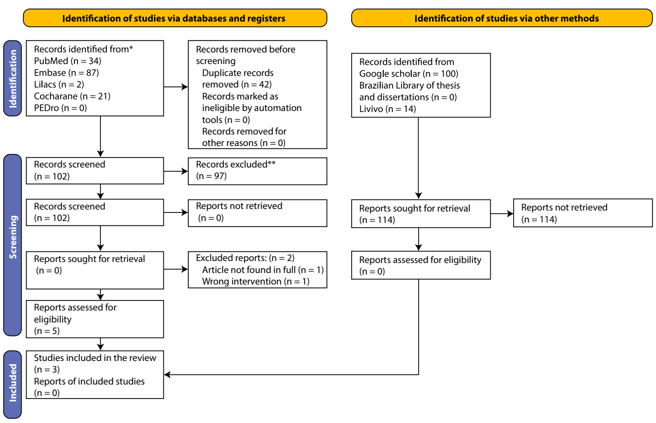

Figure 1. PRISMA 2020 flow chart for new systematic reviews that included searches of databases, registries, and other sources.

Characteristics of the studies

Three randomized clinical trials were included (24-26), one of them of the crossover type (24). The publication date was between 1998 and 2010. In all studies, the sample consisted of men and women with plantar fasciitis with a total of 105 sample units.

Individual study bias analysis

The Cochrane tool, Rob 2 was used for individual assessment of the risk of bias of the three included studies. **Figure 2** presents the results obtained in each of the five domains analyzed by the tool.

The randomization process domain showed two studies with moderate risk of bias (24, 26) and one with low risk of bias (25). The domain deviation from the intended interventions (25, 26) and one with moderate risk of bias (24). Regarding the missing outcome data domain, all three studies showed a low risk of bias (24-26). The domain measurement of missing outcomes showed two studies with low risk (24, 26) and one with moderate risk (25). And finally, in the selection of the reported results domain, all studies presented a high risk of bias (24-26).

Overall, the studies included and subjected to the risk of bias analysis had a high risk of bias.

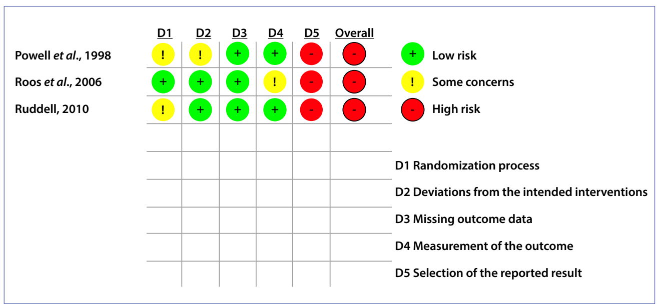

Figure 2. Analysis of the risk of individual bias.

Individual study results

Collection instruments

For measurement of the primary outcome, pain, the VAS scale was used in only one study (26). For the secondary outcome functionality, four different instruments were used: Mayo Clinical Scoring System and Ankle Hindfoot Rating Scale (AOFAS) in the study by Powell *et al.* (24); Foot and Ankle Outcome Score (FAOS) in the study by Roos *et al.* (25) and Foot Function Index (FFI) in the study by Ruddell (26).

Primary outcome – pain intensity

The study by Roos *et al.* (25) did not show significant difference for pain at any moment of evaluation for any of the

Table I. Summary description of the randomized clinical trials included in this review (n = 3).

<table>
<tr><th>Eligible studies (Country)</th><th>Sample description</th><th>Evaluation period</th><th>Outcome measure instrument</th><th colspan="10">Results</th><th>Conclusion</th></tr>
<tr><td rowspan="5">Powell et al., 1998 (United States) - RCT Crossover</td><td rowspan="5">-n = 37
M (n = 8)
F (n = 29)
-EG (n = 22) night splint month 1 and control month 2
-CG (n = 15) month 1 control and month 2 nights splint</td><td rowspan="5">T1: 1 month
T2: 2 months
T3: 6 months</td><td rowspan="5">-Mayo Clinical Scoring System (0-100)
-AOFAS (0-100)</td><td></td><td colspan="2">Mayo Clinical Scoring System</td><td colspan="2">AOFAS</td><td colspan="5"></td><td rowspan="5">Night splints for dorsiflexion provide relief from the symptoms of plantar fasciitis in most patients</td></tr>
<tr><td></td><td>EG</td><td>CG</td><td>EG</td><td>CG</td><td colspan="5"></td></tr>
<tr><td>T1</td><td>67</td><td>45</td><td>81</td><td>66</td><td colspan="5"></td></tr>
<tr><td>T2</td><td>69</td><td>67</td><td>84</td><td>76</td><td colspan="5"></td></tr>
<tr><td>T3</td><td>75</td><td>70</td><td>91</td><td>81</td><td colspan="5"></td></tr>
<tr><td rowspan="8">Roos et al., 2006 (Sweden) - RCT</td><td rowspan="8">-n = 43
M (n = 9)
F (n = 34)
-G1 (n =13) foot orthosis
-G2 (n =15) foot orthosis+night splint
-EG (n = 15) night splint</td><td rowspan="8">T0: Baseline
T1: 6 weeks
T2: 12 weeks
T3: 26 weeks
T4: 52 weeks</td><td rowspan="8">-FAOS (3 of 5 ratings)
-Pain (0-100)
-Symptoms onset (0-100)
-Functionality in sport and recreation (0-100)</td><td colspan="10">FAOS</td><td rowspan="8">The night splint+foot orthosis group had no significant improvement over the two groups that received treatments alone</td></tr>
<tr><td></td><td colspan="3">Pain</td><td colspan="3">Symptoms</td><td colspan="3">Functionality in sport and recreation</td></tr>
<tr><td></td><td>G1</td><td>G2</td><td>EG</td><td>G1</td><td>G2</td><td>EG</td><td>G1</td><td>G2</td><td>EG</td></tr>
<tr><td>T0</td><td>56 ± 12</td><td>50 ± 18</td><td>53 ± 15</td><td>70 ± 12</td><td>64 ± 22</td><td>63 ± 11</td><td>53 ± 25</td><td>35 ± 27</td><td>40 ± 19</td></tr>
<tr><td>T1</td><td>69 ± 19</td><td>68 ± 14</td><td>69 ± 18</td><td>74 ± 19</td><td>77 ± 20</td><td>75 ± 12</td><td>62 ± 30</td><td>57 ± 20</td><td>61 ± 19</td></tr>
<tr><td>T2</td><td>76 ± 26</td><td>76 ± 17</td><td>70 ± 15</td><td>76 ± 22</td><td>78 ± 14</td><td>76 ± 14</td><td>62 ± 32</td><td>59 ± 29</td><td>63 ± 20</td></tr>
<tr><td>T3</td><td>85 ± 13</td><td>77 ± 14</td><td>76 ± 18</td><td>87 ± 13</td><td>76 ± 25</td><td>80 ± 15</td><td>88 ± 17</td><td>69 ± 26</td><td>67 ± 26</td></tr>
<tr><td>T4</td><td>89 ± 16</td><td>82 ± 16</td><td>79 ± 20</td><td>90 ± 12</td><td>85 ± 14</td><td>82 ± 17</td><td>83 ± 22</td><td>78 ± 23</td><td>73 ± 26</td></tr>
<tr><td rowspan="14">Ruddell, 2010 (Canada) - RCT</td><td rowspan="14">-n = 25
M (n = 8)
F (n = 17)
-CG (n = 12) orthosis that kept the ankle in neutral position
-EG (n = 13) night splint that kept ankle in dorsiflexion</td><td rowspan="14">T0: baseline
T1: 1 month
Q2: 2 months
T3: 3 months</td><td rowspan="14">-VAS (0-10)
First steps of the morning
Activity of daily living (ADLs)
Exercise
-FFI (4 ratings)
Maximum Pain (0-90)
Maximum activity (0-50)
Modified Tegner activity scale (1-10)
Maximum disability (0-90)</td><td colspan="10">VAS</td><td rowspan="14">Both the neutral splint and the tension splint showed a similar change in pain level, with one not excelling over the other. The same was observed in the foot function index</td></tr>
<tr><td></td><td colspan="3">First steps of the morning</td><td colspan="3">Exercise</td><td colspan="3">DLA's</td></tr>
<tr><td></td><td>CG</td><td>EG</td><td></td><td>CG</td><td>EG</td><td></td><td>CG</td><td>EG</td><td></td></tr>
<tr><td>T0</td><td>8.5 ± 0.86</td><td>8.4 ± 0.79</td><td></td><td>7.0 ± 1.62</td><td>6.5 ± 2.80</td><td></td><td>6.0 ± 1.46</td><td>6.1 ± 2.37</td><td></td></tr>
<tr><td>T1</td><td>5.1 ± 2.63</td><td>3.4 ± 2.25</td><td></td><td>5.0 ± 2.82</td><td>4.0 ± 2.74</td><td></td><td>4.0 ± 2.46</td><td>3.2 ± 2.10</td><td></td></tr>
<tr><td>T2</td><td>3.3 ± 2.58</td><td>2.4 ± 1.73</td><td>p = 0.575</td><td>3.3 ± 2.73</td><td>2.8 ± 2.01</td><td>p = 0.960</td><td>2.9 ± 2.00</td><td>2.2 ± 1.78</td><td>p = 0.291</td></tr>
<tr><td>T3</td><td>1.5 ± 1.21</td><td>1.1 ± 1.22</td><td></td><td>1.9 ± 2.47</td><td>1.4 ± 1.40</td><td></td><td>1.9 ± 2.09</td><td>0.98 ± 1.01</td><td></td></tr>
<tr><td colspan="10">FFI</td></tr>
<tr><td></td><td colspan="2">Pain maximum</td><td colspan="2">Activity maximum</td><td colspan="2">Disability maximum</td><td colspan="3">Modified Tegner activity scale</td></tr>
<tr><td></td><td>CG</td><td>EG</td><td>CG</td><td>EG</td><td>CG</td><td>EG</td><td>CG</td><td>EG</td><td></td></tr>
<tr><td>T0</td><td>38.83 ± 13.66</td><td>43.90 ± 21.35</td><td>9.04 ± 7.88</td><td>10.65 ± 5.61</td><td>37.73 ± 21.66</td><td>49.88 ± 21.35</td><td>3.33 ± 1.97</td><td>3.69 ± 1.18</td><td></td></tr>
<tr><td>T1</td><td>36.69 ± 18.08</td><td>32.42 ± 17.88</td><td>4.70 ± 3.42</td><td>4.88 ± 4.83</td><td>31.23 ± 19.31</td><td>43.79 ± 25.89</td><td>3.33 ± 1.97</td><td>3.69 ± 1.18</td><td></td></tr>
<tr><td>T2</td><td>27.77 ± 18.66</td><td>24.94 ± 17.71</td><td>2.48 ± 2.70</td><td>3.63 ± 4.33</td><td>23.95 ± 23.61</td><td>17.54 ± 16.11</td><td>3.33 ± 1.97</td><td>3.69 ± 1.18</td><td></td></tr>
<tr><td>T3</td><td>24.05 ± 18.46</td><td>6.77 ± 13.74</td><td>4.55 ± 6.08</td><td>2.88 ± 5.04</td><td>17.80 ± 17.84</td><td>7.64 ± 10.95</td><td>3.33 ± 1.97</td><td>3.69 ± 1.18</td><td></td></tr>
</table>

RCT: randomized clinical trial; M: male; F: female; VAS: Visual Analog Scale; FAOS: Foot and Ankle Outcome Score; AOFAS: American Orthopaedic Foot and Ankle Society – ankle-hindfoot scale; FFI: Foot Function Index.

three groups. Similarly, Ruddell (26), also did not find significant differences regarding the participants' pain, and this was the only study that evaluated pain by means of the VAS. In contrast to Powell *et al*. (24), who analyzed the pain intensity using a pain domain within the Mayo Clinical Scoring System (MCSS) questionnaire and noted that significant differences were found between the groups and between assessment periods.

Secondary outcome – functionality

In the study carried out by Ruddell (26) the modified Tegner activity scale was used to assess the functionality of the individuals, and it was observed that there was no difference in any group in any of the evaluations. Roos *et al*. (25), applied the Foot and Ankle Outcome Score (FAOS) and found an improvement in functionality at all assessment times. Finally, Powell *et al*. (24), also found improvement in functionality.

Publication bias

Statistics-based analysis of publication bias was not performed due to only three articles being included in this systematic review (27).

DISCUSSION

The present review found, within the consulted databases, only three studies that fit the eligibility criteria stipulated in the published protocol. All included studies (24-26) were at high risk of bias when submitted to the Cochrane tool Rob 2.

The follow-up period ranged from 4 weeks, (one month) to 52 weeks and the only way to compare these evaluation periods would be with the corresponding time, that is, the evaluation with 12-week evaluation. Even so, the comparison would be unfeasible, since the collection instruments used to measure the outcomes analyzed (pain and functionality) presented a great variability, which made it difficult to compare the studies.

In terms of gender, there was a predominance of women (n = 80) compared to men (n = 25). Hill *et al*. (28), besides that, this study also found a relation between the increase in body weight and the manifestation of the symptoms of this syndrome, a fact that was also observed by Powell *et al*. (24). In this same study the authors observed that both the female and male groups had an average weight above the ideal body weight.

The study by Lim *et al*. (21) reported that nighttime dorsiflexion splints, as well as other non-invasive options, relieve the symptoms generated by plantar fasciitis syndrome. However, in the same study, it can be seen that there are other outpatient treatment options (extracorporeal shock waves and corticosteroids injections). Due to the individual response to interventions added to the wide variety of treatments available, it becomes unfeasible to develop a treatment protocol for plantar fasciitis syndrome.

Roos *et al*. (25) conducted a randomized clinical trial with groups receiving treatment alone (foot orthosis and night splint) and combined with other forms of conservative treatment. The group receiving the combined treatment did not show significant differences in the outcome of pain and function. Although the findings of a systematic review conducted in 2020 (29) stated otherwise. More recent studies show that the best treatment option for plantar fasciitis is the union of conservative techniques and the application of them not in isolation.

The only study that conducted a crossover randomized clinical trial to evaluate the benefits of pain and functionality was Powell *et al*. (24). In the one month, in which the experimental group (EG) used the night splint and the control group (CG) did not, there was a positive effect for EG and not for the CG. And in the last evaluation, at 6 months, it was possible to identify that the improvement was sustained even after the end of the splint use. On the contrary, some studies report that the symptoms of plantar fasciitis decrease spontaneously in some patients, and that is why the data collected in a very long follow-up should be carefully analyzed (30).

Through a randomized clinical trial, Turlik *et al*. (31) compared custom orthoses with generic orthoses and obtained positive results with the customized orthoses group. However, Ruddell's (26) study compared the tension splint group with the neutral splint group, and concluded that the maximum pain domain progressively decreased from baseline to the last assessment, the use of a night splint helps to reduce pain, and the dorsiflexion angulation is independent of this improvement. However, in association with the findings of Turlik *et al.* (31), it is considered the importance of verifying the degree of dorsiflexion angulation of the splints, once each individual has different range of motion in the ankle joint.

Due to the great diversity of instruments used for data collection and periods, there is difficulty in comparing studies, which made it impossible to perform meta-analysis. It is also pointed out that given the inclusion criteria, the studies by Batt *et al*. (32) and Probe *et al*. (33) were excluded because the comparator was not only a placebo or no treatment, that is, the use of medication or other forms of treatment - such as physiotherapy -, prevented the articles from entering the analysis.

Although the number of primary studies is small, the use of this conservative method for the treatment of plantar fasciitis showed promise. However, due to the high risk of bias presented in the analyzed studies, it is suggested that more primary studies be performed. And that these studies pay attention to fulfill domain 5 (Risk of bias in the selection of the reported result) of the Cochrane tool, Rob 2, for risk of bias, since the totality of the selected studies received high risk within this domain.

CONCLUSIONS

The use of the night splint shows itself as a useful tool for improves pain and function in individuals with plantar fasciitis.

FUNDINGS

This research received funding from the public sector agency, Fundação Araucária, through a scientific initiation scholarship.

DATA AVAILABILITY

The terms used for the initial search and the articles included in Phase 2 and then excluded - along with other data - are available under reasonable request to the corresponding author.

CONTRIBUTIONS

AJPB, MIGB, GRFB, ARC, CBD, MRBA: project conceptualizaion. AJPB, MIGB, MRBA: database search. AJPB, MIGB: studies analysis. AJPB, MIGB, GRFB, ARC, CBD, MRBA: bias risk analysis and meta-analysis. AJPB, MIGB: manuscript writing. GRFB, ARC, CBD, MRBA: critical revision of the manuscript.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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Muscle Mass Loss in Mechanically Ventilated Critically Ill Patients in Intensive Care Unit

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SUMMARY

Background. Muscle mass can be an important predictor for survival in critical illness, and there is no universally acknowledged approach for routinely assessing low muscularity at ICU admission. We aimed to identify patients with low muscularity and investigate whether ultrasound muscle mass measurements changed during the ICU stay.

Materials and methods. We performed a retrospective analysis of the ultrasound data of patients admitted with septic shock and sepsis in the ICU. We included patients who underwent ultrasound measurements of the quadriceps femoris muscle thickness including the rectus femoris and vastus intermedius. Weight and ultrasound measurements were performed on days 1, 3, 5, and 7 of the ICU stay.

Results. The study group comprised 61% (n = 14) males and 39% (n = 9) females with a mean age group of 63.74 ± 10.97 years. The mean APACHE score was 16.0 ± 2.38. The mean admission weight was 62.2 ± 16.6 and the recorded weight on day 7 was 59.4 ± 15.7 wherein the reduction in weight was statistically significant ($p < 0.01$). Muscle mass thickness measurements of rectus femoris reduced from 1.44 ± 0.34 cm on day 1 to 1.22 ± 0.33 cm on day 7 which was statistically significant ($p = 0.002$). Similarly, muscle mass measurements of the vastus intermedius reduced significantly from 1.23 ± 0.48 cm on day 1 to 0.97 ± 0.36 cm on day 7 with $p = 0.035$.

Conclusions. Ultrasound measurements of the quadriceps muscle layer thickness can be used to detect low and reduced muscularity. Strategies involving both adequacies of nutrition and timely rehabilitation and mobility can prove beneficial in lowering muscle loss in hospitalized critically ill patients.

KEY WORDS

Critically ill; mechanical ventilation; muscle mass; quadriceps; ultrasound.

INTRODUCTION

A systemic inflammatory response syndrome (SIRS) is a condition that triggers metabolic disorders in patients admitted to the intensive care unit (ICU). Bed rest, systemic inflammation, and pro-inflammatory response insulin resistance all contribute to muscle loss in critically ill patients (1, 2). Muscle wasting is one of many common outcomes that is faced by patients in ICU, and it contributes to muscle weakening (3, 4). Skeletal muscle is a component of lean body mass, and muscle loss has been linked to longer periods of mechanical ventilation (MV) as well as increased ICU and hospital mortality (5, 6). In recent years, there has been a greater knowledge of the science of muscle wasting and the diagnosis of prolonged functional impairment in survivors after critical illness (7-13). Even after 1 year of discharge complete physical function was not achieved and some patients suffered from physical impairments 5 years after the resolution of critical illness (14, 15). Loss of muscle mass, metabolic and physiological dysregulation of skeletal muscle, skeletal muscle architectural degeneration, and malfunctioning central and peripheral brain impulses all contribute to muscle weakness (7). Given the unstable and debilitated state of patients, obtaining objective and practicable measurements of muscle health at admission and during the course of critical illness is difficult; consequently, nonvolitional approaches and alternative measures are required to assess muscle health (16). The quadriceps muscles, which are a key weight-bearing muscle group, have been studied in most research to demonstrate the correlation between muscle mass and strength among hospitalized patients (17-19). Muscular quantifications that are sensitive enough to identify minor changes over short time periods may aid in the evaluation of therapies to combat muscle atrophy and weakness.

Calorie requirements among critically ill patients shift dramatically throughout their illness, putting them at risk of malnutrition or overfeeding. It's a known fact that malnutrition is linked to a loss of lean body mass (LBM), delayed wound healing, a higher risk of nosocomial infection, and weakened respiratory muscles. Many factors can influence resting energy expenditure (REE). The LBM is one of the most important drivers of REE. In critically ill patients, a measurement of muscle mass and changes in muscle mass could be used to establish an LBM index. According to recent Global Leadership Initiative on Malnutrition (GLIM) Guidelines, muscle mass is a new and unique metric of malnutrition (20). A number of techniques like muscle ultrasound, lean body mass via CT scan, and segmental bioelectrical impedance spectroscopy are now available to assess muscle mass, lean body mass (LBM), or Fat-Free Mass (FFM) in ICU patients at the bedside.

Non-invasive measurement of skeletal muscle mass as well as quality parameters of intramuscular glycogen content (IMGC), intramuscular adipose tissue (IMAT), and muscle size using a muscle-specific ultrasound-based technique have been proposed in recent studies (21). Muscle mass from ultrasound has been validated using gold standard procedures such as MRI/CT scan (22). In the ICU, a recent study found good inter-rater and intra-rater reliability for muscle mass ultrasound in critically ill patients (23). Furthermore, research has also indicated that enhanced ultrasound-guided muscle mass has been linked to improved functional handgrip strength following a focused ICU diet intervention (24). This enables a better understanding of the link between skeletal muscle amount and quality, as well as malnutrition and outcome risk (12, 13).

Evidence indicates that numerous factors may cause considerable daily fluctuations in energy expenditure amongst critically ill individuals (25, 26). Indirect calorimetry is a standard used to measure caloric needs in critically ill patients at the bedside, and its use has been strongly suggested by the European Society for Clinical Nutrition and Metabolism (ESPEN) and American Society for Parenteral and Enteral Nutrition (ASPEN) guidelines (27, 28) to optimize nutritional support for better clinical outcome. Despite the fact that measured LBM has been demonstrated to be an essential determinant of REE, no previous research has looked into the association between estimated LBM and REE using ultrasound-based muscle thickness measurement. This present study was taken up with the following objectives:

1. To study muscle mass loss in a period of 7 days from ICU admission in ventilated patients with sepsis and septic shock.
2. Relationship of weight and muscle mass loss.
3. Correlation with comorbidities.
4. Correlation with APACHE score.

MATERIALS AND METHODS

The study is taken up to retrospectively compare whether the body weight measurements correlated with muscle mass measured by ultrasound. Institutional Ethical Committee S. L. Raheja Hospital, Mumbai approval was obtained for the study (ECR/70/Inst/MH/2013/RR-19 – Date of approval: October 13, 2021).

We performed a retrospective observational study in mechanically ventilated critically ill septic shock patients receiving artificial nutrition at the tertiary care hospital. Patients were included and excluded from this study when they met the criteria as depicted in (**figure 1**). Informed consent is not applicable.

Measurement of body weight

The body weight of each patient was checked at admission and thereafter every alternate day to coincide with the measurements by the ultrasound. The weight of each of the patients was checked using a hospital bed using a Hill-Rom HR900 Accella™ bed with an inbuilt weighing scale.

Measurement of muscle mass

An ultrasound for skeletal muscle measurements was done using a Siemens ACUSON X300™ (Siemens Health Care, Germany) machine. Muscle thickness measurements were done using B-mode of USG using 5.0–13.0 MHz (megahertz) linear array probe. All measurements were taken by a doctor who was trained in using bedside USG in ICU and was certified. The measurements were done as per the method described by Gruther *et al.* (3). The thickness of the major muscles of the lower limbs, including the rectus femoris and vastus intermedius, was assessed. The patient was placed in a supine position with legs extended and toes facing the ceiling before the measurements were taken. Using a permanent marker pen, a straight line was drawn from the anterior inferior iliac spine to the superior border of the patella. A midpoint of this line was marked, and a linear probe was placed gently and absolutely perpendicular to the skin. A semicircle-shaped

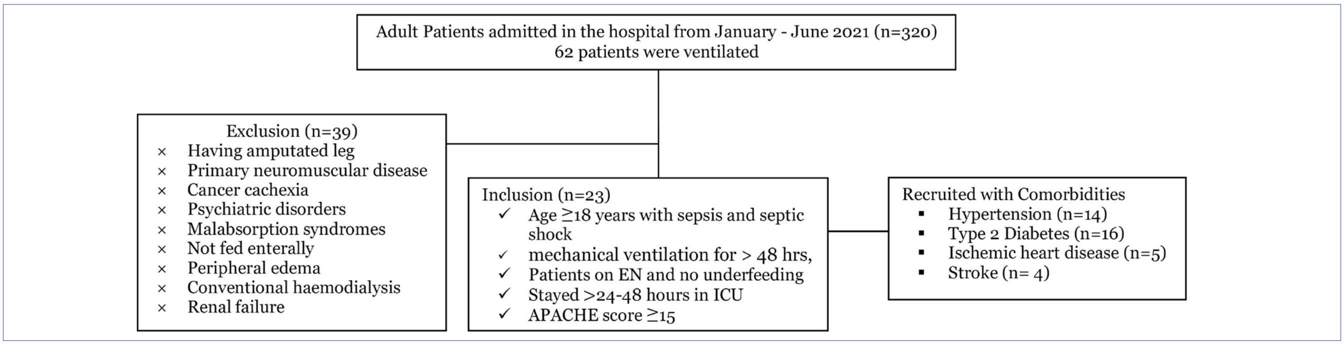

Figure 1. Patient enrolment criteria.

muscle observed in between the skin and subcutaneous tissue and femur bone indicated the rectus femoris muscle. A smaller muscle placed just above the bone and below the rectus femoris was the vastus intermedius (**figure 2**).

Measurements taken were as below:

1. Vertical distance of rectus femoris muscle.
2. Vertical distance of the vastus intermedius.
3. Distance between the upper border of the rectus femoris muscle and the upper border of the femur bone was taken to identify the quadriceps femoris muscle thickness.

Measurements were taken on days 1, 3, 5, and day 7 (**figure 3**). Energy estimations were performed by indirect calorimetry and continuous enteral feeds were planned accordingly. Patients were enterally fed within 24hrs after admission and the adequacy of protein and energy was maintained at 50-70% of the prescribed values from day 2.

Statistical analysis

The collected data were analyzed with IBM SPSS Statistics for Windows, Version 23.0. (Armonk, NY: IBM Corp). To describe the data descriptive statistics frequency analysis, percentage analysis was used for categorical variables, and the mean and SD were used for continuous variables. Normality of data was ascertained by plotting histograms. All the continuous data were normally distributed. Data were presented to find the significant difference between the bivariate samples in paired groups, the paired sample t-test was used. For the multivariate analysis, repeated measures of ANOVA were used with Bonferroni correction to control the type I error on multiple comparisons. Pearson correlation coefficients were determined to assess the correlation between muscle diameters and various other variables on admission. In all the above statistical tools the probability value 0.05 is considered a significant level.

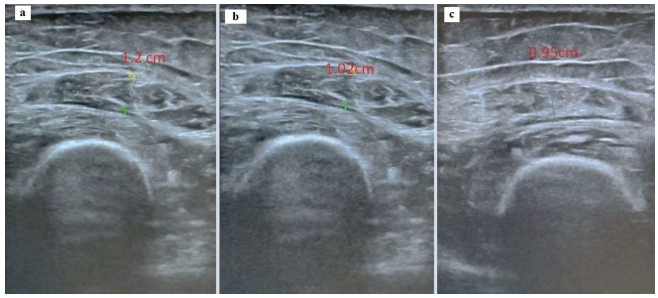

Figure 3. Representative ultrasound sonography image of muscle mass measurement.
(**a**) Day 1; (**b**) Day 5; (**c**) Day 7.

RESULTS

All hospitalized patients between January 2021 and June 2021, admitted to the ICU with sepsis and septic shock, were included in the study.

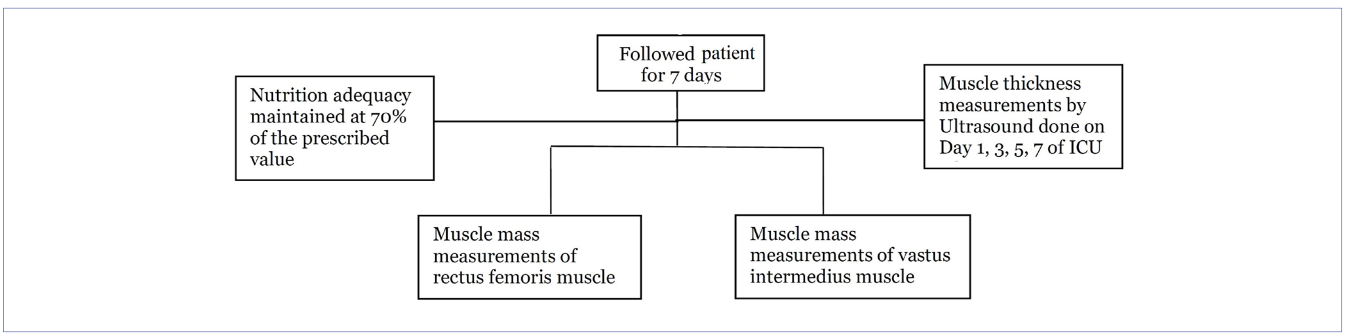

Figure 2. Muscle mass measurement timeline.

During the study period, 320 patients were admitted to the ICU. Of the 62 patients who were ventilated, of which 23 were eligible for inclusion with sepsis and septic shock, 39 were excluded. The study group consisted of 61% (n = 14) males and 39% (n = 9) females with a mean age group of 63.74 ± 10.97 years. Among the 23 patients with septic shock, 61% (n = 14) had hypertension, 70% (n = 16) had type 2 diabetes mellitus, 22% (n = 5) had ischemic heart disease, and 17% (n = 4) had a stroke. Among the patients included, 16 and 7 patients had 2 and 3 comorbidities respectively. The mean APACHE score was 16.04 ± 2.38. The mean weight at admission was 62.2 ± 16.6 and the recorded weight on day 7 was 59.4 ± 15.7 wherein the reduction in weight was statistically significant ($p < 0.01$) as depicted in **table I**.

The muscle mass thickness measurements of the rectus femoris (muscle mass 1) reduced from 1.44 ± 0.34 cm on day 1 to 1.22 ± 0.33 cm on day 7 which was statistically significant ($p = 0.002$) (**table I**). Similarly, the muscle mass measurements of the vastus intermedius (muscle mass 2) reduced significantly from 1.23 ± 0.48 cm on day 1 to 0.97 ± 0.36 cm on day 7 with $p = 0.035$ (**table I**). The comparison of rectus femoris muscle mass on day 1 and between days by repeated measures with ANOVA showed the F-value = 8.833 ($p = 0.002$) which indicates a statistically significant difference between muscle mass on day 1 and the following days. A similar comparison was done with the repeated measurements of the vastus intermedius muscle with F-value = 6.661 ($p = 0.010$) showing a statistically significant reduction in the thickness of the muscle. This reveals that critical illness leads to significant muscle loss, with the rectus femoris muscle loss of around 15% and the vastus intermedius loss of approximately 25% by day 7. There was no significant correlation between APACHE scores and the muscle mass thickness of rectus femoris, vastus intermediate, or both combined.

All the patients who were included in the study were also monitored for adequacy of energy and protein through enteral feeding.

Tables II and **III** demonstrate the correlation between various parameters with the diameter of rectus femoris and vastus intermedialis at different time periods. There was a significant positive correlation of only weight on admission with rectus femoris diameter on day 1 ($r = 0.811$, $p < 0.001$), day 5 ($r = 0.682$, $p = 0.001$), and day 7 ($r = 0.552$, $p = 0.022$). However, weight showed a significant positive correlation with vastus intermedialis diameter on day 1 only ($r = 0.725$, $p < 0.0001$). No other parameter showed a significant parameter with muscle diameter at any time point.

DISCUSSION

In this study on 23 critically ill patients with sepsis, we investigated whether ultrasound-based quadriceps muscle thickness reduced after admission to the ICU. This measurement is a good indicator of muscle mass. Our study revealed that the muscle mass thickness measurements of the quadriceps femoris reduced from 2.63 ± 0.80 cm on day 1 to 2.16 ± 0.62

Table I. Patients characteristics with weight and muscle mass measurements.

Variable	Day 1	Day 3	Day 5	Day 7	P-value
Age, mean ± SD, years	63.74 ± 10.97				
Male/Female, n (%)	14/9 (61/31%)				
Comorbidities present					
Hypertension, n (%)	14 (61)				
Type 2 Diabetes Mellitus, n (%)	16 (70)				
Ischemic Heart Disease, n (%)	5 (22)				
Stroke, n (%)	4 (17)				
Body Weight mean ± SD, Kg	62.2 ± 16.6	60.8 ± 16.5	60.0 ± 16.2	59.4 ± 15.7	0.0005
Height mean ± SD, cm	160.11 ± 7.73				
APACHE II score	16.04 ±2.38				
Serum creatinine mean ± SD, mg/dL	2.32 ± 1.89				
Muscle Ultrasound thickness					
Rectus femoris (centimetres), mean ± SD	1.44 ± 0.34	1.35 ± 0.34	1.29 ± 0.33	1.22 ± 0.33	0.002
Vastus intermedius (centimetres), mean ± SD	1.23 ± 0.44	1.11 ± 0.38	1.01 ± 0.34	0.97 ± 0.34	0.010
Total quadriceps femoris (centimetres), mean ± SD	2.63 ± 0.80	2.43 ± 0.59	2.28 ± 0.63	2.16 ± 0.62	0.016

Table II. Correlation of various parameters with rectus femoris diameter at different time periods.

Parameters	Day 1		Day 5		Day 7	
	Pearson correlation	P-value	Pearson correlation	P-value	Pearson correlation	P-value
Age (years)	-0.271	0.211	-0.232	0.286	-0.053	0.830
APACHE score	0.305	0.157	0.133	0.544	0.260	0.282
HTN	0.251	0.248	0.117	0.594	0.330	0.168
DM	0.094	0.669	-0.040	0.856	0.039	0.875
Stroke	0.262	0.227	0.236	0.278	0.259	0.285
Weight on admission	0.811	**< 0.0001**	0.682	**0.001**	0.552	**0.022**

Table III. Correlation of various parameters with vastus intermedius diameter at different time periods.

Parameters	Day 1		Day 5		Day 7	
	Pearson correlation	P-value	Pearson correlation	P-value	Pearson correlation	P-value
Age	-0.072	0.744	0.082	0.718	-0.007	0.977
APACHE score	0.119	0.588	0.020	0.930	-0.058	0.818
Hypertension	0.127	0.565	0.269	0.227	0.276	0.268
Diabetes	0.287	0.185	0.083	0.712	0.090	0.721
Stroke	-0.038	0.862	0.191	0.394	0.203	0.420
Weight on admission	0.725	**< 0.0001**	0.195	0.410	0.218	0.417

cm on day 7 which was statistically significant ($p = 0.016$). Studies have also indicated similar results that lower limb muscles are more prone to early atrophy than upper limb muscles, as evidenced by a greater decrease in thickness within the first five days of ICU admission (29). Secondly, few studies have investigated subject groups using ultrasound and set the standard values of the quadriceps muscle layer thickness at ICU admission. At ICU admission, a quadriceps muscle layer thickness of 2.0 cm can be set as a cut-off value indicating low muscularity (30). Although the patients' quadricep measurements indicated that it was above the cut-off on day 1 our study revealed a marked reduction by day 7. In critically ill patients, early enteral feeding and mobility are indicated, and individualized therapy could avoid additional muscle loss (31-33). Although early enteral nutrition was provided and adequacy of 70% of the prescribed goals was maintained, we did not track the functional impairments and methods of mobilization among the study population. Secondly, another limitation is that this was a *post-hoc* examination of discharged patients. As a result, prospective studies should be carried out to confirm these findings.

CONCLUSIONS

In conclusion, we looked retrospectively at how the quadricep muscle had changed over time and identified that ultrasound measurements of the quadriceps muscle layer thickness and the rectus femoris muscle can be used as indications of low muscularity.

Ultrasound muscle mass evaluation during ICU admission can be a useful tool for detecting reduced muscularity.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

SS: conceptualization, design. SS, RC, SR, AB, EM, KP: data acquisition, analysis, and interpretation. RC, SS: drafting. SS, RC, SR, AB, EM, KP: critical revision. All the authors have approved the final manuscript.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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Figure of Eight FiberTape Stabilization for Acute Posterior Sternoclavicular Joint Dislocation

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SUMMARY

Background. Acute posterior sternoclavicular joint dislocation is a rare, serious and difficult injury to diagnose and treat. Posteriorly dislocated clavicle may compress mediastinal structures making this injury an emergency requiring urgent reduction. There is no gold standard of treatment.

The purpose of this retrospective study is to demonstrate the treatment of acute posterior sternoclavicular joint dislocation with figure-of-eight FiberTape technique, its efficacy and mid-term outcomes.

Materials and methods. For this retrospective study, we recruited five patients who were treated for acute traumatic posterior sternoclavicular joint dislocation. Attempts of close reduction were unsuccessful in all cases. Open reduction and surgical fixation were therefore performed with figure- of-eight technique using FiberTape. Data concerning time from injury to surgical treatment, hospital stay time, preinjury sport activity level were analyzed. The median follow-up time was 12 months (range 10-26) which included clinical evaluations and the DASH and Oxford Shoulder score questionnaires.

Results. Open reduction and sternoclavicular joint fixation were successful in all subjects with no complications. The treatment functional results were very good. DASH scores were 0.8 (n = 2), 1.7, 2.5 and 3.3 and Oxford Shoulder scores 44, 44, 46, 46, 48. The durability of our fixation was confirmed when one of the patients had a subsequent bike accident 3 months after the procedure. The initial fixation was unaffected.

Conclusions. The presented technique allowed safe, effective, and durable results of the posterior sternoclavicular joint dislocations management.

KEY WORDS

Acute posterior sternoclavicular joint dislocation; FiberTape; open reduction and internal fixation; sternoclavicular injury; sternoclavicular reconstruction.

INTRODUCTION

The sternoclavicular joint (SCJ) is a saddle joint that makes the only true articulation between the upper limbs and the axial skeleton. SC joint lacks bone stability relying mostly on ligaments and capsule. The extrinsic structures such as the interclavicular ligament, costoclavicular ligament (CC), strong joint capsule and intraarticular disc ensure the stability and enable the clavicle to move. The injuries to the proximal clavicle are rare and the dislocations in this region are even more uncommon. The SCJ dislocation represent only 1% of all joints dislocations and about 3% of all upper limb dislocations (1). There are two main types of acute SCJ dislocation, anterior and posterior. Anterior dislocations are about nine times more common (2). They are less dangerous, mainly treated conservatively with good clinical outcomes (3). Posterior sternoclavicular joint dislocations (PSCJD) are, on the other hand, associated with serious life threating conditions due to the mediastinal compression (4). The diagnosis of PSCJD can be difficult, as standard X-ray projections can many times mislead the clinician and posterior dislocation can be omitted. Serendipity X-ray projection in 40-degree cephalic tilt might be used, but if there is a high suspicion of PSCDJ, CT scan is required for a proper evaluation (5). There is no specific PSCJD classification. Allman proposed SC injury classification. Complete ligamentous rupture with joint dislocation is grade III injury. Jaggard *et al*. introduced their classification proposal, making PSCJD type V sternoclavicular joint injury (6).

The PSCJD management is aimed at releasing the pressure of mediastinal structures by reduction of the dislocation. Closed reduction should be tried first at the emergency department. If it fails, reduction under general anesthesia should be performed. If closed reduction in not achievable, open reduction should be done. The operation should be performed in a multidisciplinary hospital with a thoracic surgeon back up (5).

During surgical intervention of acute dislocation soft tissue status, including intraarticular disc and joint capsule should be inspected. In case of major damage, joint should be stabilized (7). There are numerous techniques of reduction maneuvers and internal fixation methods (7-12). They are mainly described for chronic anterior dislocation, not for acute posterior. There is a limited literature about the condition involving big patient groups, therefore there isn't a gold standard of fixation. Metal implant-based methods, reconstructive graft techniques and artificial suture materials are used. To our best knowledge there are no publications reporting usage of FiberTape in this condition.

In this study we present 5 cases of acute posterior SCJ dislocation treated surgically with figure-of-eight FiberTape technique. We demonstrate our operation technique, patient outcome scores and mid-term follow-up results.

Aim of the study

The aim of this retrospective study is to demonstrate the treatment of acute posterior sternoclavicular joint dislocation with figure-of-eight FiberTape technique, its efficacy and mid-term outcomes.

MATERIALS AND METHODS

We reviewed five subjects for our study. They all sustained PSCJD and were treated in years between 2018 and 2020. Upon admission all patients underwent a detailed assessment, general medical history was taken, trauma mechanism and preinjury sport activity level were obtained. A meticulous physical examination was performed. Standard X-rays and CT scans were done before the procedure. All significant patient data (date of surgery, operated side, dominant hand side, hospital stay duration, complications) were gained retrospectively from medical records. All operations were carried out by single senior orthopedic surgeon. On follow-up visits all patients were informed about the study and agreed on publication of their anonymized photos and functional outcomes by signing an appropriate consents. The end-point of this study was a follow-up examination 10-26 months after surgery. Patients were asked to complete a DASH (disability of the arm, shoulder, and hand) and Oxford Shoulder score questionnaires.

Ethics

Bioethical committee approval was not required as the study is retrospective, and data analysed was concerning patients already operated.

Surgical technique and postoperative treatment

Failed closed reduction was an indication for an open procedure. All operations were performed under general anesthesia. Patients were positioned in the beach chair position. To facilitate easier reduction a gel pillow was put under patient's back between the scapulae. The patients were given muscle relaxant medications and a subsequent attempt of close reduction was performed. Traction of abducted upper limb was applied, then sterile tower clip was introduced to grasp the medial clavicle and direct forward traction was applied. Failed closed reduction in all 5 cases was an indication for the open procedure. A "L-shaped" incision of approximately 10 cm length (range from 7-11 cm) was made at the level of medial clavicle and sternal manubrium. The SC joint posterior dislocation was visually confirmed. Reduction was performed with help of pointed reduction clamps. A direct force to proximal end of the clavicle was applied. Proper reduction was confirmed using intraoperative fluoroscopy. Intraoperatively posterior capsule, intraarticular disc and ligaments were inspected, when seriously damaged, stabilization was indicated. To achieve fixation four 2.5 mm holes were drilled bicortically, two in medial end of clavicle and two in sternal manubrium. Fixation was performed using a figure-of-eight technique with a FiberTape suture (Arthrex, Naples, Florida). A detailed suture technique is shown in **figure 1**.

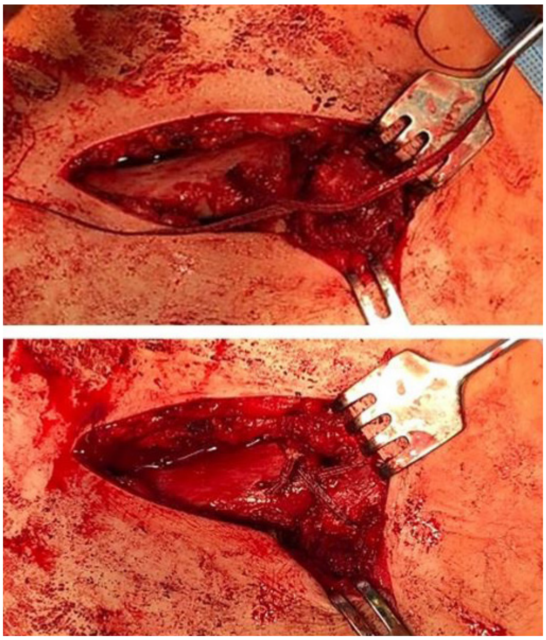

Figure 1. Surgical technique.

Postoperatively, patient's upper limb was immobilized in Dessault's sling for first 6 weeks. The time in the orthosis was intended to enable good ligamentous and soft tissue healing. Patients were instructed basic shoulder Codman Pendulum exercises. Moreover elbow, wrist and hand movements were encouraged. After 6 weeks sling was withdrawn, and conventional physiotherapy was started to regain full range of motion. Full active range of motion exercises and weight bearing were gradually allowed, according to clinical course. All patients completed a rehabilitation program with a physiotherapist. Patients were allowed to return to sport after minimum of 12 weeks after surgery.

The follow-up visits were performed at 6, 12 weeks and 10-12 months after operation, in accordance with existing standard trauma visits protocol. A detailed orthopedic examination was performed on each visit. At the last follow-up visit patients were asked to complete patient specific functional scale questionnaires.

RESULTS

Five patients suffered from PSCJD and underwent open reposition with figure-of-eight FiberTape fixation technique. Their main characteristics, age, gender, injury mechanism and concomitant injuries are shown in the **table I**.

All 5 patients presented with an acute injury, type III Allman (13) type V Jaggard (6). Three of them were referred to our center from smaller regional hospitals as they did not have a cardiothoracic surgeon back up. Two patients presented to the emergency department in our Center. All subjects experienced a bicycle accident. The main symptoms were pain in SCJ region. Patient 3 felt short of breath with normal blood saturation level. Patient 2 experienced pain on swallowing. None of the patients experienced other injuries. All patients were hemodynamically stable. None of the patients had signs of neurovascular structure damage. Therefore, none of the surgeries were urgent and could be properly planned for subsequent days. Patient 2 CT-scan is shown in **figure 2**. In all cases a primary closed reduction attempt was performed, without success. All 5 subjects were therefore qualified for reduction under general anesthesia. All dislocations were irreducible and open reduction was indicated and performed. In all cases joint capsule, intraarticular disc and ligaments were seriously damaged, making indication for stabilization (7).

Table I. General information.

Patient	Sex	Age	Side	Patient's dominant hand	Preinjury occupation and sport activity	Time from injury to surgery in days	Follow-up time in months
1	M	19	Left	Right	Student/minor physical activity	2	11
2	M	20	Right	Right	Student/Krav Mag competitor	2	12
3	F	41	Left	Right	Nurse/minor physical activity	1	10
4	M	43	Left	Right	Office worker/non-professional bike	5	24
5	M	27	Left	Right	Office worker/minor physical activity	7	26

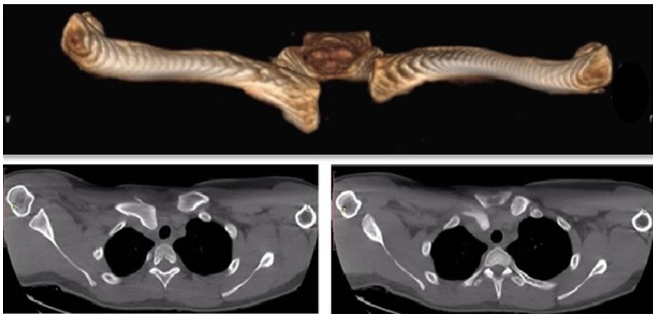

Figure 2. Patient 2 CT.

The median time from injury to operation was 2 days (range from 1 to 7). Median time of operation was 55 min (range from 42 to 70 min). There were no intraoperative complications. A thoracic surgeon was present in the operation theatre but was not asked for assistance. Blood loss was neglectable. The median hospital stay was 5 days (range from 4 to 7).

All compression symptoms in Patient 2 and 3 resigned after operation.

At the early follow-up visits (6, 12 weeks) no wound or neurovascular complications were observed.

Patient 1 experienced a second bicycle accident 3 months after procedure. He showed up at our hospital ED with shoulder pain. A physical examination, X-ray and CT scan were performed. Upon examination SCJ was stable. A CT scan confirmed proper clavicle position, without loosening of the fixation material. No injuries to SCJ region or shoulder region were observed. He was diagnosed with shoulder contusion and discharged with upper limb sparing recommendations.

At one year follow-up visit all patients reached pre-injury physical activity levels. The median DASH and Oxford scores were 1.7 and Oxford Shoulder score was 46. Detailed scores are presented in the **table II**.

There was no instability observed. All patients had a full range of motion of the upper extremity, the average shoulder abduction, forward elevation, external rotation in 90 degrees of abduction, and external rotation in adduction were 170° ± 15°, 165° ± 20°, 80° ± 15°, and 65° ± 25°, respectively. Patient 2 1-year range of motion is shown in **figure 3**.

Three of 5 patients reported some residual tenderness at the SCJ. Two patients experienced a minor deformity in the SCJ region without clinical significance. No patients reported any residual instability of the SCJ.

Table II. Patient specific scales 12-months results.

Patient	DASH score	Oxford Shoulder score
1	0.8	46
2	0.8	46
3	2.5	44
4	3.3	44
5	1.7	48

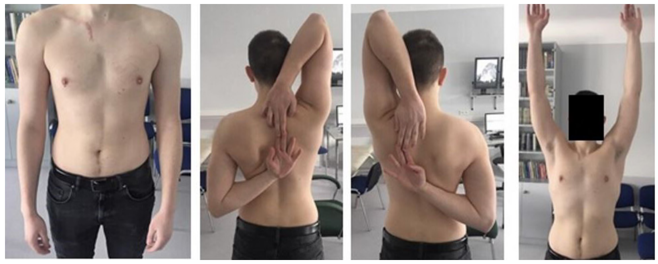

Figure 3. Patient 2 1-year functional outcomes/range of motion.

DISCUSSION

PSCJD is a rare, difficult to diagnose and dangerous condition. In our Clinic, a major trauma center for a whole region, we observed only 5 cases of PSCJD which we describe in this study. In the literature only around 120 cases have been reported (5). What is more, patients can be easily misdiagnosed, as standard X-ray projections may be misleading and posterior dislocation can be omitted (5). Therefore, in all our patients, when PSCJD was suspected, a CT scan was performed for a proper evaluation. The severity of the condition is described in many papers. Worman and Leagus reported that 16 of 60 patients had suffered complications involving the trachea, esophagus, or great vessel compression (14). Mark Fenig *et al.* reported a fatal case of brachiocephalic vein laceration in a 16-year-old boy (15). Therefore, any suspicion of posterior dislocation should be treated seriously, as an emergency. It is reported that about 60% of PSCJD are successfully treated by close reduction (6). In all our patients several attempts of close reduction were performed by many doctors. They were all unsuccessful.

There is limited literature on the condition, involving a sufficient number of patients. There is no consensus, whether surgically reduced dislocation should be anyhow stabilized. Kendal *et al.* in their systematic review of PSCJD recommend that in select acute cases with substantial ligament disruption, ligament reconstruction with Figure-of-eight autograft or augmentation of synthetic material is indicated (7). We believe that a thorough examination and inspection of capsule and intraarticular disc should be performed and based on damage severity the stabilization should be indicated. In all our cases the intraarticular disc was ruptured and surrounding tissues including joint capsule were seriously damaged.

There is no gold standard of fixation. We came across many fixation methods of sternoclavicular joint instability. They were mainly described for chronic anterior dislocation. The first was based on a metal implant (K-wires or plates) (16). K-wires stabilization was widely used in the past, but many serious complications have been reported. Lyons and Rockwood reported six major vascular injuries and eight deaths due to pin migration from SCJ (17). Janssens de Varebeke *et al*. reported the pulmonary artery main trunk perforation by Kirshner wire migration from right sternoclavicular joint (18). Therefore K-wires are now not recommended to use in SCJ region (16). Locking plate usage was described by Rongguang *et al*. in a case series of 5 patients with SCJ dislocation (16). They have shown good results in all patients, but all subjects had a subsequent operation for plate removal (17). We believe it is fundamental to consider the range of motion of the clavicle in the sternoclavicular joint. For every 10 degrees of forward flexion of the glenohumeral joint clavicle elevates about 4 degrees. Moreover, any complex movement of the upper extremity engages the sternoclavicular joint. The clavicle may rotate up to 40° along its longitudinal axis (19). These movements make rigid metal implants susceptible to migration and failure. In our clinical experience we observed plate failure after proximal clavicle fracture fixation, what is consistent with literature (8). Therefore, reconstructive techniques using grafts were introduced. Many grafting materials are described: semitendinosus, palmaris, plantaris, sternocleidomastoid, gracilis tendons or synthetic FiberWire or Rota-Lok (9, 12, 20). Moreover, many techniques have been reported, single loop (9), double figure-of-eight (11) or unicortical (21) reconstructions. Spencer and Kuhn compared 3 fixation techniques on cadaveric specimens. Figure-of-eight semitendinosus reconstruction was reported to have superior biomechanical properties (21). The downsides of all grafts are possible atrophy or elongation in time, causing lack of stability and recurrent instability (21). Moreover, the need of graft harvesting extends the operation to distant regions.

Taking into account all methods described above, we decided to stabilize SCJ with synthetic heavy suture FiberTape material. To our best knowledge there are no publications reporting usage of this material in this condition.

In all patients, we used FiberTape figure-of-eight fixation technique. We observed that this material and method offers a perfect combination of strength and flexibility of fixation. It provides a good replacement for the damaged joint stabilizing tissues, enabling their regeneration. Moreover, it does not use any autografts eliminating graft harvesting procedure and all downsides of it. Figure-of-8 technique enables movement in the joint, not limiting the upper extremity range of motion. We believe that bicortical drilling and fixation method enables proper stability, both posterior and anterior.

What is worth mentioning, is that Patient 1 experienced a second bicycle accident, falling on the shoulder and SCJ region. It did not cause any damage to the joint or fixation. This proves the durability of heavy suture tape and our technique.

The main limitations of our study are the small sample size, its retrospective character, lack of randomization and control group. All this is due to the rarity of the condition and need for open fixation. For proper evaluation of long-term results and incidents of joint arthrosis further investigations with large patients groups and randomization are needed.

CONCLUSIONS

The figure-of-eight FiberTape technique has proved to be safe and enabled good stability of SCJ. The midterm outcomes in all our patients were good. There were no major complications observed. Patient satisfaction with the treatment was high, all patients returned to the same physical activity level as preinjury. The durability of fixation was confirmed by a subsequent bicycle accident of one of the patients.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

PN: literature search, study design, data collection, analysis and interpretation, writing. PC: conceptualization, data interpretation, critical revision. DL: data analysis and interpretation. KB, PP: data analysis and interpretation, critical revision. PW: data interpretation, critical revision. KK: conceptualization, data analysis and interpretation, critical revision. All authors read and approved the final manuscript.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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Neck Muscles Sense of Force in Healthy Individuals and Subjects with Trigger Points of the Upper Trapezius Muscle

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LEVEL OF EVIDENCE: 3B

SUMMARY

Introduction. Trigger points can be the source of radiating pain and may interfere with normal muscle function. The aim of this study is to investigate the neck muscle's sense of force in subjects with trigger points of the upper trapezius muscle compared with healthy subjects.

Materials and methods. In a cross-sectional analytical study, in 40 young subjects with hidden trigger points of the upper trapezius muscle and 40 healthy young subjects, constant, absolute and variable error of sense of force of cervical muscles, range of motion of neck and pressure pain threshold of upper trapezius muscles in both groups were measured.

Results. The absolute and variable error of sense of force in the extensor and lateral flexor muscles of the neck were significantly different between two groups, and the subjects with hidden trigger points had higher errors. The pain threshold of both sides in subjects with hidden trigger points was significantly lower than healthy subjects. The range of motion wasn't significantly different between the two groups.

Discussion and conclusions. This study showed that the sense of force error was higher in subjects with trigger points. Also, the pressure pain threshold in subjects with trigger points were lower than healthy subjects. As a result, In the evaluation of neck pain patients, it is important to pay attention to sense of force error.

KEY WORDS

Force sense error; head and neck; proprioception; trigger points; upper trapezius muscle.

INTRODUCTION

Trigger points (TPs) (1) are tight, palpable, distinct and localized knots in skeletal muscles that cause refferal pain (1, 2). Different types of trigger points (TPs) include: cutaneous, fascial, ligamentous, periosteal, and myofascial, the most common of which is "myofascial" (1). Myofascial trigger point (MTrP) is a hypersensitive spot in skeletal muscles or fascia that it can be with taut band or not (3). MTrPs mostly occur in muscles that play a key role in controlling posture, such as levator scapula, upper trapezius (UT), sternocleidomastoid, scalene, erector spinae, quadratus lumborum and gluteal muscles (4). This disorder is more common in the upper quarter of the body, especially the UT muscle (5). Bad postures may cause TPs in upper quarter of the body muscles (6). The upper part of the trapezius muscle is one of the important postural and stabilizing muscles in head and neck area. Myofascial pain related to the presence of chronic TPs of the UT muscle can causes pain and disability in the neck region (4). The occurrence of TPs have prevalence ranging from 30% to 93%, especially in people who remain in improper and prolonged posture of head and neck (1, 7, 8). It is suggested that the occurrence of TPs can cause functional neck disorders, tension headaches, mechanical neck pain, reduced fascial elasticity and restircted range of motion (ROM) (9). Also, it may have harmful effects on social life and activity of daily living. Proprioception plays an important role in regulating the overall posture and balance of the body and consciously sensing movement and force (10). Proprioceptors include free nerve endings and mechanoreceptors in the skin, fascia, muscles, tendons, joint capsule and ligaments (11). Proprioception has the components for detecting the position and movement of body segments (called sense of position and movment respectively) and also the force or tension of muscles (called sense of force) (12-14).

Various factors such as neck pain, fatigue and inflammation may reduce proprioceptive input and imapir proprioception (10, 15-18). The presence of TPs can cause all the mentioned symptoms (11, 19, 20). Geist *et al*. reported that releasing trigger points of ankle muscles could improve proprioception in patients with lateral ankle sprain (21). The occurrence of inflammation in the muscle causes hypoxia, pain and fatigue, and these complications are directly related to the inefficiency of the muscle function and loss of proprioception (12, 22). Weerakkody *et al*. reported that muscle pain cause inhibitory effect on spinal motor neurons as a result, it may increase the force sense error (23).

TPs can cause pain in different mechanisms. They may cause long-term contarction and local spasm on sarcomeres while there may lead hypoxia and incresases pain sensitivity. All these events eventually create a faulty cycle of spasm-pain (1, 13, 24). Researches stated that existence of TPs causes disturbance in the range of motion and affect the kinematics of cervical spine which inturn can disturb proprioception (4, 25).

Considering the role of muscle receptors in the proprioception and the high density of these receptors in the muscles of the cervical area, neck proprioception plays a key role in controlling posture and movement. So it seems important to pay attention to the proprioception of neck and its evaluation and treatment in disorders of this area (11). Only one study was available to the researchers that examined the proprioception of subjects with head and neck TPs who suggested that patients with TPs have more position sense error in neck region (11).

On the other hand Dochetry *et al.*, Kim *et al.* and Niespodziński *et al.* did not observe a relationship between the sense of position and the sense of force in subjects with chronic ankle instability (26-28). So a disturbance in the sense of position will not necessarily lead to a disturbance in the sense of force (28). However researchers stated that head and neck TPs may disturb position sense of neck area (11), it is important to examine the sense of force error of neck region seperately. No published study has investigated the sense of force of neck muscles in people with trapezius muscle HTPs. Therefore, the aim of this study is to compare the sense of force of neck muscles between people with HTPs and healthy people. If a disturbance in the sense of force is observed in these people, while showing the necessity of paying attention to this aspect of proprioception in the evaluation of these people, perhaps future studies can improve the proprioception of this area by treating muscle TPs to decrease the risk of neck disorders.

MATERIALS AND METHODS

In this cross section analytical study, 40 subjects with HTPs of the UT muscle with an average age of 24.1 and 40 healthy subjects with an average age of 24.2, were recruited using a simple convenient nonprobability sampling method in Sardasht city. The inclusion criteria of subjects with TPs include: 1) age range between 18 and 30 years; 2) Inactive TPs in the UT muscle were diagnosed based on the examiner's clinical examination and having at least three of the following: a) Palpable taut bands in the muscle; b) Sensitive points in the form of nodules on taut bands; c) Referral pain after pressure or traction; d) Local contractile response following pressure; 3) Having pain equal to or greater than 3 on the visual analogue scale (VAS) by applying a force with an intensity of 2.25 kg/cm by the algometer device. Healthy subjects were recruited to study while they were at same age range and they must be free of TPs and pain by applying a force of 2.25 kg/cm (using an algometer) in the UT muscle. The subjects with active TPs in UT and other neck muscles, experience of surgery in head and neck, and head and neck trauma or neck pain in last six months were excluded.

The tools required for data collection were: 1) force sense measurement tool (dynamometer), 2) visual analogue scale for pain assessment, 3) universal goniometer and 4) pressure algometer.

Ethics

The Ethics Committee of Shahid Beheshti University of Medical Sciences approved this research by the following protocol number (SBMU.RETECH. REC.1397.1376 – Date of approval: March 17, 2019). Individuals signed the written consent form to participate in the research.

Test method

After recruiting the subjects based on inclusion and exclusion criteria, they signed an informed consent form before participating in the test. The demographic information of the subject also was recorded. For this purpose, the height and weight of the samples were measured using a scale and tape measure attached to the wall, and the body mass index (BMI) was calculated. The trigger points in upper trapezius muscles were inspected while subject sat on a chair whose height was proportional to the examiner's height so that the subject's head was placed in the mid line of the body, hands were on the thighs and the soles of the feet were completely in contact with the ground. The examiner looked for muscle taut bands from the occiput prominence to the acromion appendage with the thumb flat palpation (29-31). This method has good inter-examiner reliability for detecting TPs (24, 32). In the next step, the sensitive points were marked with a marker, and a force equal to 2.5 kg/cm^2 was applied to these points through a pressure algometer (made in Taiwan, model 5020) and the subject reported the perceived pain by number between zero and ten on visual analogue scale (VAS). If the reported number was more than 3, the subject met the criteria for entering the study as patient group and was prepared to perform the test.

In the next step, the subject sat on the chair in a relaxed position so that the back spine was protected by the back of the chair. Both hip joints were placed in 90-degree flexion. In order to prevent the feet from pressing on the ground during the contraction of the neck muscles, a tripod was used and it was placed under the rearfoot and forefoot was hang down. The knees were flexed at 30 degrees and the hands of subject were placed on the thighs during the test. In order to place the head and neck in neutral position, the sternal notch, chin and tip of the nose were placed in one line and parallel to the vertical axis of the body, and the line connecting the base of the nose and the occiput was placed at horizontal level. The examiner advised the subjects to relax their trunk and upper and lower limbs and try to apply force to the side and back of their head by pressing the head and neck only.

In order to evaluate the force sense error, a dynamometer with H3-C3 load cell by Zemic company from Netherlands was used, the validity and reliability of which was checked and confirmed in the research center of the rehabilitation faculty. The dynamometer was installed on the wall and its monitor was placed on a stand in front of the subjects. To introduce subjects with the test steps, before the test, a submaximal isometric contraction was taken from the specified muscles.Then the maximum voluntary isometric contraction (MVIC) was determined in the extensor and lateral flexor muscles of the head and neck. To evalualuate the head and neck extensor muscles, in sitting position the plate of dynamometer was placed behind the subject's head and its center was placed in front of the occiput bone and to evaluate the lateral flexor muscles of the head and neck, the subject was placed in a sitting position and laterally next to the plate installed on the wall. This plate was placed on the side of the head above the upper edge of the ear in front of the temporal bone.

The subjects were asked to press the dynamometer plate with maximum force 3 times with a one-minute interval, and during the effort, the same verbal feedback was given to encourage them. The individual's MVIC was recorded in kilograms during each of the three attempts and converted to Newtons. The maximum recorded value used as the MVIC value of the muscle. Then the 30% of this value was used as the target force. The target force is the force that the person must reproduce it without looking at the monitor of the dynamometer. The subject was asked to presse the dynamometer with the isometric contraction of the extensor and right and left lateral flexor muscle group to reach the target force value which is 30% of the MVIC of the defined muscle group and maintained this position for 30 seconds to remember the force. Then, while the monitor was moving away from the subject's sight, the subject tried to reproduce the target force by relying on the proprioception. This was repeated three times with an interval of 30 seconds between each trial, and the reproduced force was recorded each time. The difference between the target force and the reproduced force shows the amount of force sense error, and the average error of three repetitions was recorded as the force sense error of specified muscle group. The force sense error was calculated using three scales including: Absolute Error (AE) is defined as absoulute difference between the target force and the percieved or reproduced force, Constant Error (CE) (the amount of error including the direction of the difference between the two values) and Variable Error (VE) represents the variability of the errors between trials (calculated by standard deviation of the error in three trials) and indicates the cosistencey of proprioceptive performance (33).

The order of force sense error evaluation of muscle groups was randomly selected.

The range of right and left lateral flexion and extension of neck movements was evaluated by universal goniometer made by MSD company in Belgium in all of the subjects. Universal goniometer has been reported to have good reliability for measuring neck range of motion (ICC 0.73-0.89) (34, 35). To evaluate the active head and neck range of motion the subject sat on the chair with the foot on the floor and hands on the thighs. For neck extension, the center of the goniometer was placed on the soft part of the ear, and one of its arms was placed perpendicular to the ground and the other arm was placed on the base of the nose. The extension movement was performed by the subject. The result was recorded on the goniometer. To evaluate the neck left and right lateral flexion, the center of the goniometer was placed on the C7 spinous process, one of its arms perpendicular to the ground and the other parallel to the posterior and middle surface of the skull. The subject moved the head and neck twice, and the second time the obtained number was recorded on the goniometer (36).

Pain measurement using visual analogue scale

On a horizontal bar marked from 0 to 10, the number zero indicates the state without pain and the number 10 indicates the maximum possible pain (37). Previous studies have investigated the reliability and validity of this tool in measuring pain and have obtained acceptable values (38). The tape of the visual pain scale is 100 mm long, but in most cases, for ease of use, it is divided between the numbers zero to ten so that patients can use it more easily.

Algometry

Pressure algometer was used to evaluate pressure pain threshold in both groups. Algometer is a tool for measuring pain sensitivity and evaluating pain sensation. The device used in this study has measurement accuracy of 0.01 kg/cm^2. A metal piece with a diameter of 1 cm^2 is connected to the algometer and it records momentary force changes. The reliability of this tool in evaluating pain pressure treshold has been reported very well (ICC 0.75-0.89) (39, 40). In each subject, 3 points of the UT muscle were tested bilaterally. In order to check the pressure pain threshold, a gradually increasing force was applied in the sitting position until the pressure sensation changed to pain sensation and the obtained value was recorded. To check the intensity of pain, pressure pain equivalent to 2.5 kg/cm^2 was applied to the marked points and the pain intensity felt by the samples was reported on the visual analogue scale (VAS) (41). The tests were conducted by an examiner at an interval of 30 seconds. After evaluating all the variables in two groups of subjects with HTPs and healthy subjects, the data was analysed by SPSS (version 20) software. The Kolmogorov-Smirnov (K-S) test was used to check the normality of the distribution of variables, and according to the normal distribution of the variables, the parametric test of comparison of means (t-test for two independent groups) was used to compare the variables between two groups.

RESULTS

40 healthy women and 40 women with HTPs were evaluated. As shown in **table I**, there were no significant differences in demographic variables between the two groups.
Table II shows the force sense error values of different muscle groups in the healthy subjects group and subjects with HTPs group.
Based on the results of **table II**, no significant difference was determined between the HTPs and healthy groups in terms of the amount of constant error of head and neck extensor and right and left lateral flexor muscles, but in terms of absolute error and variable error of head and neck extensor and right and left lateral flexor muscles, the average scores of the subjects with HTPs group were significantly higher than the subjects in healthy group. The results of the comparison of the two groups in terms of pressure pain threshold indicate that there is a significant difference between the two groups in terms of the average pressure pain threshold on both the right and left UT muscle and the mean pressure pain threshold of the subjects with HTPs group was lower compared to the healthy group.
Based on **table III**, there is no significant difference between the two groups of HTPs and healthy group in extension and right and left lateral flexion range of motion.

Table I. Demographic characteristics of the samples examined in this study and checking the homogeneity of the two groups (n = 80).

Variables	Group	Number	Mean	SD	Min. score	Max. score	P-value
Weight	With HTPs	40	64.73	6.96	52	76	0.95
	Healthy	40	64.63	7.79	52	78	
Height	With HTPs	40	164.07	6.19	155	178	0.41
	Healthy	40	163.05	4.95	156	175	
Age	With HTPs	40	24.15	3.59	18	30	0.88
	Healthy	40	24.27	3.95	18	30	
BMI	With HTPs	40	24.07	2.55	19.13	30.02	0.60
	Healthy	40	24.43	3.71	17.99	31.24	

Table II. Comparison of force sense error values of different muscle groups and pressure pain threshold in subjects and controls.

Variables	Groups	Mean (n)	SD	P-value
Extension CE	With HTPS n = 40	4.12	183.2	0.98
	Healthy n = 40	3.66	60.3	
Extension AE	With HTPS	170.1	137.7	**0.001**
	Healthy	62.1	37.2	
Extension VE	With HTPS	168.3	112.1	**0.001**
	Healthy	56.1	34.7	
Rt. side flexion CE	With HTPS	-5.12	142.5	0.32
	Healthy	18.33	60	
Rt. side flexion AE	With HTPS	148.3	79.7	**0.0001**
	Healthy	61.5	25.7	
Rt. side flexion VE	With HTPS	127.4	74.6	**0.0001**
	Healthy	40.6	15.5	
Lt. side flexion CE	With HTPS	42.33	69.1	0.06
	Healthy	18.62	37.6	
Lt. side flexion AE	With HTPS	97.66	51.3	**0.0001**
	Healthy	61.54	21.8	
Lt. side flexion VE	With HTPS	90.39	66.7	**0.035**
	Healthy	65.91	27.4	
Rt. pressure pain threshold	With HTPS	4272.3	1024.4	**0.0001**
	Healthy	6584.4	1136.2	
Lt. pressure pain threshold	With HTPS	4772.1	992.9	**0.0001**
	Healthy	6581.5	1148.1	

CE: constant error; AE: absolute error; VE: variable error; SD: standard deviation; Rt: right; Lt: left.

Table III. Comparison of the range of motion of extension and lateral flexion to the right and left between the two groups.

Variables	Groups	Number	Mean (degree)	SD	St. error	P-value
Ext. ROM	With HTPs	40	66.8	4.7	0.74	0.69
	Healthy	40	67.2	5.3	0.83	
Rt. Lat. Flexion ROM	With HTPs	40	44.7	3.5	0.55	0.97
	Healthy	40	44.8	4.1	0.64	
Lt. lat. Flexion ROM	With HTPs	40	43.3	3.5	0.55	0.08
	Healthy	40	44.9	4.2	0.67	

Ext: extension; Rt: right; St: standard; Lat: lateral; Lt: left.

DISCUSSION

The results obtained from the analysis of statistical data showed that in the subjects with HTPs in the UT muscle, the sense of force is disturbed in all three movements of extension, right and left lateral flexion, and the absolute and variable error of the sense of force in all muscle groups of subjects with HTPs was more than healthy subjects.

Only one study was available to the researchers that investigated the cervical proprioception in subjects with TPs in head and neck muscles and reported that they have more position sense error in neck region (11). But in their study, only the sense of the position was investigated and the sense of force was not evaluated, while studies have shown that the sense of position and the sense of force evaluate the different aspects of proprioception and may not be related to each other (26-28). There was no available study to the researches that investigated the sense of force in these subjects, with which the results of the present study can be compared.

Researchers reported that the presence of TPs may increase pain and inflammation (42-45). Also, Proske *et al*. and Weerakkody *et al*. observed a relationship between pain and increased error of sense of force (13, 23). Geist *et al.* demonstrated that releasing TPs could improve proprioception in patients with lateral ankle sprain (21). Also, the disorder in the sense of force in different muscle groups of the neck can be justified in these subjects who have pain and inflammation, but this aspect of proprioception has not been previously investigated in these subjects**.** It is possible that the disorder in the sense of force in the cervical extensor and lateral flexor muscles cause that these muscles cannot apply the right amount of muscle force in neck movements which may cause damage in these muscle groups. So it is necessary to pay attention to the measurement of the sense of force in the evaluation and treatment of subjects with HTPs, and appropriate methods should be used to train and improve the sense of force in these subjects.

The results of this study did not show a significant difference between the range of motion of extension and right and left lateral flexion in the healthy subjects and subjects with HTPs group, which is different from the results of previous studies in this issue (31, 44, 46), which is probably due to the different methods and tools used in these studies. The results of this study also showed that the average pressure pain threshold in the group with HTPs is lower than the group without HTPs, which confirms the findings of the previous studies (13, 15, 23, 46). Shah *et al*. concluded that the presence of TPs in the UT muscles caused an increase in inflammatory substances and the occurrence of pain, and as a result, the pressure pain threshold in the mentioned group was lower than in the healthy group (42).

CONCLUSIONS

Based on the the results of this study, existence of HTPs in UT muscle could disturb the sense of force of extensor and lateral flexor muscles in cervical region. Due to the importance of this sense in the accurate application of muscle force, this defect in the sense of force may cause a disturbance in the precise application of force, which can lead to a defect in controlling the movement of the head and neck area. According to the results of this study, the assessment of the sense of force should be included in the clinical examinations of people with trigger points, and if a defect in the sense of force is observed, appropriate exercises should be prescribed to recover this sense to a normal state. Future studies should focus on investigating the effectiveness of different exercises in reducing force sense error and its effect on improving the symptoms of people with trigger points.

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None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

MKZ, MS: conceptualization. MKZ, MS, KKK: methodology. MS, DSK: investigation. AAB, MS: data analysis. MS, DSK: writing - original draft. MKZ, DSK, KKK: writing - review and editing.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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ORIGINAL ARTICLE

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Influence of Shoulder External Rotation Component on Median Nerve Neurodynamics in Neurogenic Cervicobrachial Pain Syndrome: A Cross-Sectional Study

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SUMMARY

Background. The upper limb neural tissue provocation test-1 (ULNTPT-1) is used for determining the neurogenic etiology of neck and arm pain. Biomechanical studies have primarily investigated *in vitro*, whereas *in vivo* examination is lacking.

Objective. The objective was to determine the effect of the shoulder external rotation (ER) component of ULNTPT-1 on the deficit in elbow extension range of motion (EEROM) and vibration threshold (VT) in participants with neurogenic cervicobrachial pain syndrome (CBPS).

Methods. Thirty-two patients were included in the study as per the inclusion criteria. ULNTPT-1 with/without shoulder external rotation was performed on symptomatic and asymptomatic side. Deficit in EEROM at the onset of muscle activation of biceps brachii (R1) and initial onset of pain (P1) along with VT in median nerve territory was recorded. One-way ANOVA was used to compare the difference and level of significance was $p < 0.05$.

Results. The effect of ULNTPT-1 with/without shoulder ER component on the deficit in EEROM at P1 & R1 was significant on symptomatic as well as on the asymptomatic side ($p < 0.001$). The difference was not significant on symptomatic ($p = 0.15$) and asymptomatic sides ($p = 0.31$) for the VT. The difference in value of responses obtained on each side with/without shoulder ER compared, showed no significant difference in all three outcomes P1, R1, and VT ($p = 0.219$; $p = 0.273$; $p = 0.145$).

Conclusions. There was greater deficit in EEROM with shoulder ER, which suggest that there is a heightened nerve mechanosensitivity with shoulder ER component of ULNTPT-1.

Study registration. Clinical Trial Registry India received a prospective registration for the trial with the number CTRI/2018/04/013383.

KEY WORDS

Cervicobrachial pain syndrome; median nerve; neurodynamics; neurogenic; upper limb neural tissue provocation test-1.

INTRODUCTION

A problem of the neck is one of the most common causes of musculoskeletal symptoms, with a lifetime frequency of 48.6%. The global burden of disease study ranks it fourth in terms of disability (1). Neck discomfort frequently radiates proximally into the head or distally toward the upper back or an upper limb. Cervicobrachial pain syndrome (CBPS) is one such condition, which is described as upper quarter discomfort with mechanosensitive neural tissue as the predominant feature (2-5). This syndrome is produced by abnormal mechanical tension in certain parts of the peripheral nervous system, resulting in atypical impulse-producing sites. When mechanical stress is applied along the length of the nerve, these locations are responsible for heightened sensitivity, which is known as mechanosensitivity (6). In the literature, a series of steps have been suggested for determining the heightened nerve mechanosensitivity (4, 5, 7).

Upper limb neural tissue provocation test-1 (ULNTPT-1) is a clinical test that is often used to diagnose CBPS-related heightened median nerve mechanosensitivity (8-11). The normal response to ULNTPT-1 in asymptomatic participants is reported as pain and paraesthesia in the distribution of a median nerve, stretch in the palmar aspect of hand/cubital fossa/shoulder area with an increase in response on adding cervical lateral flexion to the opposite side (11-14). A classic clinical indicator of heightened nerve mechanosensitivity is a decrease in Elbow Extension Range of Motion (EEROM) due to painful responses (P1) when the nerve is positioned into further position of strain (12, 15-19). To avoid further mechanical tension on the sensitive nerve and its mechanical interface, the central nervous system initiates the nociceptive-mediated flexor withdrawal response, which is usually associated with increased muscle activity (20-22). It has been postulated that the flexor withdrawal response (R1) occurs to prevent further mechanical strain on the sensitive nerve and surrounding tissue (20-22). The physical and physiological integrity of the peripheral nerves is required for normal sensory and motor functions. Vibration Threshold (VT), measures nerve physiological function, has excellent intra-rater reliability and is used in clinics to identify early signs of minor nerve dysfunction using the instruments like tuning fork and Biothesiometer (23-26). Vibration sense carried by the large Aβ fibers is one of the important aspects of the nervous system's diverse senses which is vulnerable to the blood supply reduction in case of heightened nerve mechanosensitivity (25, 26).

Shoulder abduction and External Rotation (ER), supination of the forearm with wrist and finger extension, and extension of the elbow constitute the ULNTPT-1. Interpretation of ULNTPT-1 depends on factors like speed, rhythm, through range perception of muscle activation and sequence of movement as they influence the neurodynamics (27). The therapist can tailor the base test to the individual patients by modifying the sequencing of the components based on the severity, irritability, and nature of symptoms, thereby increasing the test's sensitivity (2, 28). In cadaveric experiments, different ULNTPT-1 movement sequences resulted in varying mechanical strain on the nervous system (29-31). The impact of shoulder ER on median nerve neurodynamic tests is debatable in the literature (32). The ER of the shoulder in the sequence of ULNTPT-1 was reported to reduce strain in cords of the neck and arm plexus, with subsequent reduction in strain on the median nerve (32-34). Nevertheless, another argument in the literature suggests that it may influence neurodynamics physiologically (35). However, all the results are based on cadaver research, and shoulder external rotation influence has not been validated *in vivo* (35, 36).

ULNTPT-1 is an essential component in testing the neurogenic nature of CBPS (10). Knowing the differences in responses when completing ULNTPT-1 with and without shoulder ER will help us decide whether the shoulder ER component should be added or removed from ULNTPT-1. The response of median nerve neurodynamics testing with and without shoulder ER in CBPS with heightened nerve mechanosensitivity is lacking in the literature. The primary objective of this study was to evaluate how the shoulder ER component of ULNTPT-1 affect P1, R1, and VT in neurogenic CBPS on each symptomatic/asymptomatic side. The secondary objective was to find out the difference in the values of P1, R1 and VT obtained on each side separately when ULNTPT-1 was performed with/without shoulder ER and further to compare the obtained values between symptomatic/asymptomatic side.

MATERIALS AND METHODS

Study design

In order to compare the response of the ULNTPT 1 performed with and without shoulder ER, an observational cross-sectional study was carried out. This study adhered with the Declaration of Helsinki and strengthened the reporting of observational studies in epidemiology (STROBE) requirements (37, 38). The Institutional Ethics Committee granted ethical approval (IEC No. 80/2018 – Date of approval: February 14, 2018).

Setting and sample size calculation

The study was carried out between July 2018 and January 2019 in the physiotherapy outpatient unit at Kasturba

Hospital in Manipal, Karnataka, India. Written consent was obtained from eligible participants after they received comprehensive information about the study's methods. Standard recommendations were followed to determine the sample size (39). To determine the necessary sample size for this study, the mean and standard deviation of EEROM variable obtained from the previous study, was used. Using the confidence interval of 95% and test power of 80%, thirty two participants were recruited.

Inclusion and exclusion criteria

Following the detailed explanation of the procedure, informed consent was obtained from the participants before proceeding with the screening. One hundred and seventy-five (n = 175) participants with a complaint of neck pain radiating to unilateral arm were screened by a researcher pursuing a post-graduate degree in physiotherapy with orthopedics as a specialization. The neurogenic character of pain was evaluated in either gender aged 18 to 65 years with a complaint of acute or subacute (≤ 12 weeks) neck and unilateral arm pain. Participants were considered to have neurogenic cervicobrachial pain syndrome if their complaints were consistent and contained all of the following physical symptoms (7): 1) active movements of the neck (either side lateral flexion, extension, and same side rotation) and shoulder abduction reproducing the participant symptoms, 2) similar movement restrictions on the passive movement of neck and arm as obtained during active movement examination, 3) increase in mechanosensitivity on the symptomatic side with reproduction of participant symptoms during the performance of ULNTPT-1 and differentiating maneuver (wrist flexion for proximal symptoms, while same side cervical lateral flexion for distal symptoms) confirms the involvement of neural tissue, 4) elicitation of symptoms on palpation of a nerve root in the neck and median nerve in the medial arm or cubital fossa or carpal tunnel on the symptomatic side, and 5) evidence of a related pathology (example: positive Spurling's test). The previously mentioned indications and symptoms have been suggested and characterized as indicators of CBPS being neurogenic (4, 7, 39). The participants fulfilling all the above mentioned criteria were included. The participants who were not able to comprehend the research protocol, had non-neurogenic pain, limited shoulder motion, diabetic peripheral neuropathy and thoracic outlet syndrome were excluded from the study.

Outcome measures and rationale

Upper limb neural tissue provocation test-1 (ULNTPT-1)

In patients with neurogenic neck pain radiating to arm, ULNTPT-1 can be used reliably in the clinics with a difference of > 7 degrees can be considered as a meaningful change in the prognosis of the condition (15). In the symptomatic population with nerve related neck and arm pain, there exists moderate inter-tester reliability for assessing the mechanosensitivity of nerve on neural tissue palpation and tension testing (19).

Initial onset of pain (P1) and onset of muscle activity (R1)

Nerve throughout its course is surrounded by different connective tissue considered as nerve bed. Injury to the nerve increase the sensitivity of the nerve in response muscle gets overactive to offload the nerve to prevent undue stress on the nerve allowing symptom to get resolve (40). To examine the onset of muscle activity the initial disturbance in the flat line suggesting muscle activation, wireless surface EMG (Delsys Trigno wireless EMG system, AD Instruments, USA 2016) was used. Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) recommendations was used to position the electrode over the biceps brachii (20, 22, 43, 53). The elbow range at the point of onset of muscle activity (R1) can be measured using Electromyography (EMG), but low inter-tester reliability for perceiving the through range resistance in testing has been described in the literature (16). In the asymptomatic population, it was demonstrated good intra-rater reliability for R1 but fair inter-tester reliability (41). In a normal person with variation in neural extensibility have demonstrated an increase in muscle activity in a less extensible group (20). The response of the nerve to ULNTPT-1 in the asymptomatic population has shown an increase in the contraction of trapezius much earlier in the range in relation to initial onset of pain (P1) (42). Pain receptors and movement receptors send the afferent impulses resulting in an increase in resistance prior to the onset of pain (P1) with increased in the torque at the onset of pain response (22).

Measurement of Elbow Extension Range of Motion (EEROM)

Measurement of EEROM is a common procedure to estimate the mechanosensitivity of ULNTPT-1. The universal goniometer was used to measure EEROM. The intra-rater reliability intraclass correlation coefficient ranged from 0.45 to 0.99, the inter-rater reliability ranged from intraclass correlation coefficient 0.53-0.97, in the measurement of elbow range of motion using universal goniometer (43).

Vibration threshold (VT)

Measurements of vibration sensitivity are used both for detection and monitoring dysfunctions (44, 45). The test targets the Ab fibres - which mediate the sensation of vibration and are sensitive to ischemia. For example, vibration perception has been shown to be the first sensation to be lost in patients with diabetic neuropathies (46). In manual therapy, measurements of vibration thresholds (VTs) identified the existence of minor neuropathies (as exemplified by raised VTs in the Median and Ulnar nerves) associated with computer usage (47). These findings suggest that manual therapists could utilize vibration perception outcome measures for monitoring and managing such conditions (47). The vibration threshold has been measured using the standardized procedure (23). The intra-rater reliability for the median nerve, when tested over 2nd metacarpal head over the palmar surface of the hand, was reported as 0.922 (48).

Set-up, familiarization and procedure

After getting the consent, the demographics including age, gender, weight, height, hand dominance, symptomatic side and duration of symptoms of each participant were recorded. Participants were asked to lie down on a firm plinth (without pillow). Considering the sensory supply of the median nerve on the palmar aspect of the hand, vibration thresholds were recorded on the palmar aspect of the head of the second metacarpal (48). Before starting the procedure, participants were familiarized with vibration sense at the head of the second metacarpal bone on the hand's palmar surface. The participants were explained to say "started" with the initial perception of vibration and to say "stopped" when they stop perceiving it (23, 49). The laptop and EMG device was placed at the head end of the participants (to prevent any feedback to the participant) which can be seen by the examiner to look for the point at which the flat line (muscle is in relaxed state) show initial disturbance (indicating muscle activation) through the range of elbow extension movement as a protective response. The EMG electrode was placed over the belly of biceps brachii. To ensure constant shoulder depression pressure during the procedure, a biofeedback device inflated to 40 mmHg was placed on the superior aspect of the shoulder girdle. The asymptomatic side was assessed first. On the asymptomatic side, participants were given five minutes of rest between sequences (with or without shoulder ER). The sequence performed was shoulder depression (40 mmHg), shoulder abduction to 90°, forearm supination, wrist, and finger extension, with or without shoulder ER to 90° (as per randomization; flipping a coin; head, with shoulder ER and tail, without shoulder ER), followed by elbow extension. Investigator number 1 performed the sequence while investigator number 2 recorded the outcomes. During the performance of the sequence, the point at which EMG flat line showed the disturbance indicating onset of muscle activity (R1) and the point at which participants complained of onset of pain (P1), deficit in EEROM was recorded using a universal goniometer by investigator 2. While performing ULNTPT-1 with shoulder ER fulcrum of the goniometer was placed at humerus medial epicondyle, stationary arm parallel to the long axis of the shaft of humerus, while stationary arm pointing to the ulnar styloid. When ULNTPT-1 was performed without the shoulder external rotation component from the sequence, the lateral epicondyle was used as a fulcrum with a stationary arm parallel to the shaft of the humerus and a moving arm pointing towards the radial styloid (50). Participants were blinded from reading while recording. Five degrees short of the P1 range, the vibration of gradually increasing intensity was applied using Biothesiometer (VibrothermDx) to establish the vibration threshold. Vibration perception threshold (VPT) was recorded at which the participants first became aware of the sensation of vibration. The intensity was then increased by 50% and gradually reduced to establish the vibration discrimination threshold (VDT). When the participants were no longer able to perceive the fading vibration stimuli, VDT was recorded. Measurement of perception and discrimination thresholds were repeated thrice. No clues in any form (verbal or non-verbal) were provided to prevent inaccurate recordings. VT was calculated as a factor of the mean of the perception and discrimination thresholds. Participants were blinded from reading while recording. After completing the procedure on the asymptomatic side, a 5-minute rest period was given before repeating the process on the symptomatic side.

Statistical method

The data was analyzed using version 16 of the Statistical Package for the Social Sciences (IBM SPSS Modeler 16.0) software. Descriptive analysis was used to examine demographic data. Lewen's test for homogeneity of variance was used to assess for data homogeneity. One-way ANOVA for outcomes (P1, R1, and VT) both on symptomatic and asymptomatic sides for testing with and without shoulder external rotation. One-way ANOVA for outcomes (P1, R1, and VT) with the standard sequence between symptomatic and asymptomatic side. One-way ANOVA to compare the difference in the values of P1, R1 and VT obtained on each side separately when ULNTPT-1 was performed with/without shoulder ER.

RESULTS

Participants

Of the 175 participants screened, 34 were recruited. Due to technical error, data of 2 participants were not included in the analysis of the final results. The participants flow chart can be seen in the **figure 1**.

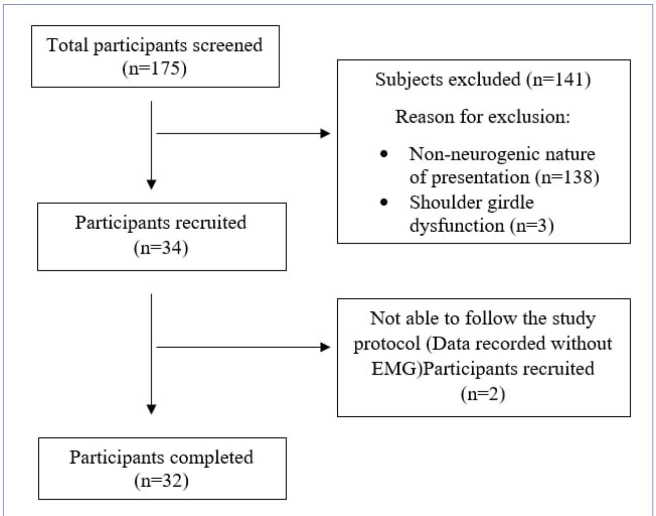

Figure 1. Participants flowchart.

The mean age of the participants (n = 32) was 38.91 ± 10.25 years. The demographic details of the participants provided in **table I**.

Lewen's test for homogeneity of variance showed that data was homogenous. Results of the comparison of responses on the symptomatic side with/without shoulder ER (**table II**) showed that R1 and P1 responses occurred earlier in the range when ULNTPT-1 was performed with standard sequence on the symptomatic side. Mean difference of more than 10 degrees were found for R1 and P1 responses between two sequences of ULNTPT-1. The VT response, however, did not differ between the sequences.

Results of the comparison of responses on the asymptomatic side with/without ER (**table III**) showed that R1 and P1 responses occurred earlier in the range when ULNTPT-1 was performed with standard sequence on the asymptomatic side. Mean difference of more than 10 degrees were found for R1 and P1 responses between two sequences of ULNTPT-1. The VT response, however, did not differ between the sequences.

When the difference in the value of responses of each outcome measure obtained with/without shoulder ER on the symptomatic and asymptomatic sides was compared (example: symptomatic side P1/R1/VT with shoulder ER minus symptomatic side P1/R1/VT without shoulder ER and asymptomatic side P1/R1/VT with shoulder ER minus asymptomatic side response P1/R1/VT without shoulder ER), none of the outcome were significantly different indicating that the shoulder ER component has impacted both sides equally (**table IV**).

Table I. Demographic characteristics of the participants.

Parameters	Mean ± Standard deviation
Male/Female, n (%)	13 (40.6%)/19 (59.4%)
Age (year)	38.91 ± 10.25
Weight (kg)	67.73 ± 9.07
Height (cm)	162.20 ± 9.28
Hand dominance right/left n (%)	32 (100%) / 0
Symptomatic side right/left n (%)	16 (50%)/16 (50%)
Duration of symptoms (weeks)	5.62 ± 3.43

Table II. Symptomatic side - comparison of the initial onset of pain (P1) in degrees of deficit in Elbow Extension Range of Motion (EEROM), onset of muscle activity (R1) in degrees of deficit in EEROM and Vibration Thresholds (VT).

Symptomatic side		Mean (SD)	Mean difference ± SE	95%CI of the difference	F	P-value
P1	With shoulder ER	51.50 (13.10)	12.65 ± 3.20	6.25, 19.05	15.61	0.001*
	Without shoulder ER	38.84 (12.51)				
R1	With shoulder ER	61.71 (12.45)	12.43 ± 2.89	6.65, 18.21	18.49	0.001*
	Without shoulder ER	49.28 (10.61)				
VT	With shoulder ER	4.49 (0.93)	0.32 ± 0.22	- 0.12, 0.76	2.10	0.15
	Without shoulder ER	4.17 (0.85)				

Measurements five-degrees short of P1 in volts obtained on the symptomatic side when ULNTPT-1 was performed with and without shoulder ER (n = 32). *Significant difference ($p \leq 0.05$).

Table III. Asymptomatic side - comparison of the initial onset of pain (P1) in degrees of deficit in Elbow Extension Range of Motion (EEROM), onset of muscle activity (R1) in degrees of deficit in EEROM and Vibration Thresholds (VT).

Asymptomatic side	Mean (SD)	Mean difference ± SE	95%CI of the difference	F	P-value
P1 With shoulder ER	27.34 (10.08)	9.68 ± 2.54	4.60, 14.76	14.53	0.001*
Without shoulder ER	17.65 (10.24)				
R1 With shoulder ER	37.12 (9.59)	10.06 ± 2.36	5.33, 14.78	18.10	0.001*
Without shoulder ER	27.06 (9.32)				
VT With shoulder ER	3.58 (0.72)	0.18 ± 0.17	-0.17, 0.53	1.05	0.31
Without shoulder ER	3.40 (0.69)				

Measurements five-degrees short of P1 in volts obtained on the asymptomatic side when ULNTPT-1 was performed with and without shoulder ER (n = 32). *Significant difference (p ≤ 0.05).

Table IV. Effect of shoulder ER when the difference of responses is compared between the asymptomatic and symptomatic side (n = 32).

Between sides comparison of difference value of each response	Mean difference ± SE	95%CI of difference	F	P-value
P1 Difference	2.96 ± 2.38	-1.80, 7.74	1.54	0.219
R1 difference	2.37 ± 2.14	-1.91, 6.66	1.22	0.273
VT difference	0.20 ± 0.14	-0.07, 0.48	2.18	0.145

No significant difference (p ≤ 0.05); P1 and R1 in degrees and VT in volts.

DISCUSSION

The primary objective was to determine the effect of the shoulder ER component of ULNTPT-1 on P1, R1 and VT in participants with neurogenic CBPS. We observed that the shoulder ER component of ULNTPT-1 for the symptomatic and asymptomatic sides resulted in a statistically significant effect on P1 and R1 as shown by more deficit in EEROM suggesting it caused more nerve mechanosensitivity. However, the shoulder ER component had no significant effect on VT.

The mechanosensitivity of the median nerve was higher when ULNTPT-1 was performed with a standard sequence (10, 27, 31). This may suggest that shoulder ER induces more nerve strain which could account for the reduction in range of motion at the elbow during ULNTPT-1. Controversy exists in the literature from several authors' works on the cadavers concerning the role of shoulder ER component in ULNTPT-1 testing. It was suggested that the shoulder ER component could be excluded (32-34). We disagree with the argument that exists with respect to the shoulder ER component, as our findings show that when ULNTPT-1 was performed with the standard sequence, an earlier increase in mechanosensitivity occurred. The reason for different results could be that during the performance of ULNTPT-1 *in vivo*, various mechanical events like strain, sliding and pressure, as well as physiological events like reduced blood flow and inflammation, may have influenced the mechanosensitivity of the nerve. In this current study, we attribute the mechanosensitivity to be resulting from physiological events in addition to mechanical events (2, 9). Hence our findings disagree with the argument to discard the shoulder ER component from the standard sequence of ULNTPT-1.

The nerve, throughout its course, is surrounded by different connective tissue, considered as nerve bed. With increased strain in the nerve, protective muscle activity occurs, which prevents the sensitized nerve from further elongation (20-22, 40). Evidence suggests low to fair inter-tester reliability with good intra-rater reliability for perceiving them through range resistance R1 (16, 51). Neural tissues are protected from stretch not solely by pain, but also by muscle activity, noted with an increase in EMG activity in muscles before pain onset (15, 20-22, 42, 52). Our study findings align with existing literature, as there was an increase in EMG activity of biceps brachii R1 earlier to the onset of pain. Biceps brachii was chosen for recording as it is one of the muscles involved in antalgic posture protecting the strain on the median nerve. It gets activated to prevent further elongation with elbow extension at the final component. Early dysfunction of a nerve can be identified reliably with a valid method of determining VT (23, 25, 26). We found no significant effect of the shoulder ER component of ULNTPT-1 on VT. Even though we put forward that both physiological and mechanical events in and around the nerve may influence the mechanosensitivity. We did not find any significant effect because of the methodology we adopted, as VT was measured 5 degrees short of P1. As the VT testing procedure is time-consuming, maintaining the position at the onset of mechanosensitivity was not opted in the current study as sustained strains & physiological events could lead to an increase in mechanosensitivity. As the participants in this study were symptomatic, we offloaded the nerve and recorded the VT, because of which we would not have found the disputed result in terms of vibration.

The secondary objective was to determine the effect of the shoulder ER component of ULNTPT-1 between symptomatic and asymptomatic sides. Although the mechanosensitivity was significantly early on the symptomatic side than on the asymptomatic side, we found that the difference in the magnitude of response of P1, R1 and VT to the shoulder ER component was similar when compared between the symptomatic and asymptomatic sides - suggesting that the shoulder ER component had impacted both the sides equally.

Clinical implications

In our study, we found that without the shoulder ER component, the mechanosensitivity of the nerve occurs relatively later in range for both sides. Thus, in participants with limited shoulder ER where the standard procedure of ULNTPT-1 testing could not be performed, we can use the response to compare what we get without shoulder ER. However, the same testing procedure should be used throughout follow up visits to assess for change in degrees of range of motion at which P1 and R1 occurred. Use the same procedure to compare between sides even if need to modify the test in that way.

Limitations

The speed with which elbow extension was performed is not quantified. However, care was taken to perform elbow extension with a constant slow speed and rhythm. The R1 was considered at the point where deflection can be seen on the EMG. However, deflection strength was not considered/quantified while recording. Also, during the recording of the responses no structural differentiation was performed.

Future recommendations

In future studies, different shoulder girdle muscles can be chosen for recording EMG activity during the testing, along with the quantification of the elbow flexor resistive torque. The R1 can be measured at the specific strength of deflection, and also the structural differentiation can be performed while during the recording of the responses.

CONCLUSIONS

There was greater deficit in EEROM with shoulder ER, which may suggest that there is a heightened nerve mechanosensitivity with shoulder ER component of ULNTPT-1. The practitioner can use the results acquired without a shoulder ER in cases where the patient's shoulder has limited range of motion.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

PK, RG, AP: study design. PK: writing - original draft. PK, RG: material preparation. PK: data collection. PK, RG, AP statistical analysis. All authors: writing - review and editing, final approval.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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The Effect of Contraction Type and Training Volume in Unilateral Exercises on Cross-Education: A Narrative Review Study

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SUMMARY

Objective. The effect of unilateral exercises on the untrained limb, usually called "cross-education," can help treat immobility. Review studies in 2017 have shown that type of contraction, volume, and intensity of training are effective on the rate of cross-education. Therefore, this review study aimed at the kind of contraction and the volume of training on crossed education.

Methods. In this review, we searched PubMed, Science Direct, Google Scholar, Scopus, and Web of Science databases from 2017 to December 2022. We used the keywords ("cross-education" OR "cross-transfer" OR "cross-training" OR "interlimb transfer" OR "strength transfer") AND ("unilateral strength training" OR "contralateral strength training" OR "resistance training" OR "strength training").

Results. Of the 391 studies, 22 articles were selected for final evaluation. Out of 22 studies, five studies compared the effect of eccentric and concentric contractions. Six studies examined the effect of mixed exercise. Four studies examined the effect of coupled eccentric/concentric contractions, one study examined the effect of only eccentric exercises, two studies investigated the effect of concentric contraction on cross-education, three studies examined the effect of only isometric contraction, and two studies evaluated the effects of isokinetic contraction on cross-education. The results of these studies showed that coupled contractions have a more significant effect on cross-education (8.6%-69%). Isokinetic contraction had the most negligible effect on the cross-education. The evaluation of BURST has shown more significant cross-education than the evaluation of the contralateral side.

Conclusions. Combined effect of concentric and eccentric contractions could cause the most cross-education effect, as much as 8.6%-69%. BURST evaluation showed more significant effects on cross-education than contralateral limb evaluation.

KEY WORDS

Contraction; training; resistance; exercise; cross-education.

INTRODUCTION

Unilateral training, commonly referred to as "cross-education," has piqued the curiosity of researchers in recent years (1). Several terms have been used to refer to this phenomenon: cross-transfer, cross-effect, cross-training, contralateral-learning, or inter-limb transfer (2, 3). However, according to Davis (4), the most common term in this field is cross-education. The term of "cross-education" is used to express the theory that the effects of practice on one side of body are transferred to the unpracticed side (4).

During unilateral immobility (non-use/orthopedic injury), cross-education (increasing the strength of contralateral and ipsilateral limb, homologous, and heterologous muscles) (5) can be used as a helpful method (6-8). The effects of cross-education are often evaluated either as a change in the strength or skill of the untrained limb (contralateral and ipsilateral limb) compared to the trained limb (as a percentage of the beneficial effects of the trained limb) or evaluated as a percentage of strength increase in the untrained limb relative to early condition (8, 9). Cross-education is limited to the homologous and heterologous muscles (5) of the untrained limb because the effect of cross-education requires the neural contributions of the trained muscles responsible for maintaining cross-education (10).

While there is much evidence about cross-education, in recent years, most studies have shown that different training protocols created varied cross-education results (1, 11-25). It has shown that the rate of increase in strength of the untrained limb varied from 45.2% (26), 30% (15), and 11% (16) to 5% (12) in the untrained limb. It has been indicated that to optimize the improvement of strength of the untrained limb, training plans should include concentric and eccentric exercises with moderate to high volume and enough rest intervals (27). In this regard, also, Manca *et al.* showed that the size of cross-education in the untrained limb had a proportional relationship with the type of contraction (28). They reported that the rate of cross-education of the isometric exercise isometric was (8.2%), concentric (11.3%), eccentric (17.7%), and isotonic dynamic (15.9%) in the untrained limb (28). Cirer-Sastre *et al.* reported that strength training programs with isometric, concentric, eccentric, or mixed contractions significantly affected cross-education; however, eccentric exercises had the highest effect on cross-education (27).

According to the results of mentioned studies in 2017, the occurrence and amount of cross-education in the untrained limb depends on the type of contraction (27, 28). In addition, the specific effects of cross-education are essential for clinicians who wish to use cross-education as a rehabilitation method. So, the specificity of contraction type in unilateral exercise raises concerns about the incidence and rate of cross-education because it hints at the control and adaptation of the brain on movement (29).

Regarding the different protocols of unilateral exercise, including the type of contraction and volume of exercises (number of sets, sessions, frequency, and repetitions of training), two meta-analyses conducted in 2017 showed that the type of contractions and the volume of exercises can affect the occurrence and rate of cross-education (27, 28). On the other hand, studies published from 2017 until now have used different training volumes with contradictory results about the rate and occurrence of cross-education (1, 11-25). Some studies used ten weeks of training in 20 repetitions (26), and some used 4 to 6 weeks of training in 5 to 8 repetitions (12, 15, 30) or several days of training (11) in their training protocol. It appeared that studies about the rate and occurrence of cross-education used different protocols in their training programs yielded contradictory results (1, 11-25). Combining and investigating the results of these studies can help us deduce the best conclusion about the effect of type of contraction and volume of training in cross-education. This review aimed to conclude which unilateral strength training volume (duration, frequency, intensity, and type of contraction) would optimize the strength increase in the untrained limb.

MATERIALS AND METHODS

In this review, based on the PICO method, we searched the database from January 2017 to December 2022 according to the last review studies carried out in 2017(27, 28). We used the keywords: ("cross-education" OR "cross-transfer" OR "cross-training" OR "interlimb transfer" OR "strength transfer") AND ("unilateral strength training" OR "contralateral strength training" OR "resistance training" OR "strength training") in PubMed, Science Direct, Google Scholar, Scopus, Web of Science databases. We included randomized trials in the English language that had a full text. The search strategy for each database is indicated in **appendix 1**.

Studies were selected for review that did not apply any restrictions on the gender of the sample. They used healthy individuals who had not suffered an injury the year before the intervention. The intervention used in these studies was one-sided exercise programs including concentric, eccentric, isometric resistance, and mixed exercises. The studies which used children and people with stroke, orthopedic disease, and surgical injuries were excluded. The studies that used the dominant and non-dominant limbs, homologous and heterologous muscles, as the target of the investigation were excluded. Moreover, articles that used electrical stimulation, transcranial magnetic or direct electrical stimulation, acupuncture, drugs or nutritional supplements, aquatic exercise, mirror therapy, whole-body vibration, immobilization, and stretching exercise were excluded.

The dependent variable in the selected studies was the strength recorded for the untrained limb (contralateral and ipsilateral limb) *versus* the trained limb. Studies were included that mentioned the average power based on MVIC (maximum voluntary isometric contraction), MVC (maximum voluntary contraction), the amount of power, torque, one-repetition maximum (1 RM), and its standard deviation before and after the intervention for both experimental and control groups. Studies that mentioned EMG as an outcome measure were excluded.

RESULTS

Characteristics of the studies

A total of 440 studies were identified (Web of Science: 95, PubMed: 72, Scopus: 99, Google Scholar: 36, and Science Direct: 136). These studies were screened for duplications based on the title and abstract. Of the 255 selected studies, 221 were excluded based on title and inclusion exclusion criteria. Twelve articles excluded based on methodological investigation. So, the final sample of 22 studies was used to conduct a narrative review (**figure 1**).

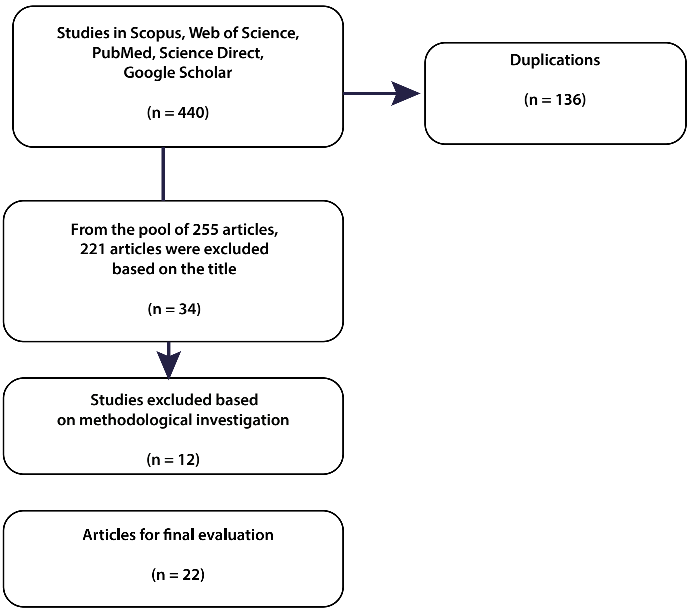

Figure 1. Flowchart of literature search showing the final 22 studies entered into this narrative review.

The results of this review are outlined in **table I**. In this review, the results divided into six parts based on contraction type into: studies with mixed exercise (studies that used aerobic, endurance, and global training as training protocol; the type of contraction is not clarified), compared contractions (studies that compared two contractions such as eccentric *vs* concentric), combined or coupled contraction (studies that added two contractions in one protocol such as eccentric with concentric), isolated eccentric contraction, isolated isometric contraction, isolated concentric contraction, and isolated isokinetic contraction.

Table I. Summary of 22 studies that investigated cross education.

Authors	Participants	Intervention group	Control group	Task/Contraction	load	Week/set/session/repetition	Outcome measure	% cross-education on the untrained side
Sumona Mandal 2022 (21)	-34 - Healthy inactive adult participants -Intervention group: (11 women, 9 men; age: 20.7 ± 1.3, height: 166.2 ± 7.3 cm; weight: 62.8 ± 16.3 kg) -Control group: (8 women, 7 men; age: 21.4 ± 1.8 y; height: 164.4 ± 8.3 cm; weight: 61.5 ± 14.0 kg)	-n = 20 -Calf raises group	-n=14 -Without intervention	-Calf raises -Mixed exercise	70-80% MVC	8/24/3/12	-Concentric and eccentric peak torque and strength via isokinetic in 30°/s and 120°/s	-Strength = 23/4% - Power = 14/6%

Authors	Participants	Intervention group	Control group	Task/Contraction	load	Week/set/session/ repetition	Outcome measure	% cross-education on the untrained side
Coratella 2022 (18)	-60 (Age: 22 ± 4 years, body mass: 60.2 ± 4.3 kg, and stature: 1.64 ± 0.06m) - The participants were not engaged in systematic resistance training for the previous six months	-Unilateral concentric-only (CONC) (n = 15) -Unilateral eccentric-only (ECC) (n = 15) - Concentric– eccentric (TRAD) (n = 15)	-n = 15 -No training	Unilateral strength grip -Concentric -Eccentric -Concentric/Eccentric	- 85%1 RM - 120%1- RM - 90%1 RM	8/6/16/7 -8/5/16/6 -8/4/16/5	Knee extensors isokinetic concentric, eccentric, and isometric peak torque	-CONC: concentric peak torque (9.2%) -ECC: concentric peak torque (11%), Eccentric peak torque (15%), Isometric peak torque (11.3%) -TRAD: concentric peak torque (8.5%), Eccentric peak torque (5.5%), Isometric peak torque(8.6%) -
Bartolomei 2022 (31)	-30 - Participants had a minimum of 2 years of resistance training experience (mean 6 SD, age: 26.4 6 3.3 years, body mass: 76.9 6 6.3 kg, and height: 177.6 ± 5.2 cm) -counterbalanced crossover study	n = 19 -High-intensity group = Bench press -Power group = bench press throw	-n = 11 -Stand quietly for 15 minutes, equal to the time required to perform the experimental protocol	-Bench press - Mixed exercise	-90% 1 RM in 15 minutes, rest 3 min -30%1 RM in 15 minutes with maximum explosive intent, rest 2 minutes	-5set/1 rep -5 set/one rep	-Bench press 1 RM in the post-activation performance enhancement -leg extension force	There was no significant difference between the two types of intervention in leg press extension in the untrained limb.
Aman 2022 (17)	-34 -Thirty-four middle-aged female volunteers (56.05 ± 5.21 years old; 66.88 ± 7.62 kg; 27.70 ± 2.77 kg/m²)	-n = 22 - MRT - DRT	-n = 12 -n = 0 Training	-Lower limb proprioceptive, balance, agility, and resistance exercise -Mixed exercise	10–15 RM	-12/36/60 minutes -12/60/60 minutes	-MVC quadriceps, hamstring, biceps, and trunk muscle	-BURST in hand (biceps) DRT= 45.1% MRT=33.4%
Martinez 2021 (15)	-36 - Men, -Moderately physically active -(Age 21.2 ± 2.76, lean mass 51.49 ± 2.48, height,20.53 ± 2.01)	-1-EG6s n = 12 -2-EG3s n = 11	-n = 13 -No training	-Single-leg decline squat -Eccentric	80%1 RM	6/3/8	-Knee extensor Peak torques (isometric, concentric, eccentric) -1 RM eccentric single-leg decline squat	-Concentric and eccentric peak torques - EG6s :30% - EG3s :21% -Isometric peak torque -EG6s=18% -EG3s=14%
Mendonca 2021 (32)	-30 -Normal body mass index (18.5–24.5 kg/ m²) -Normal blood pressure -Normal fasting glucose levels -normal blood lipids	-HIBFR=dynamic plantar-flexion training interventions (n = 15) - LIBFR with (calf-rotary machine) (n = 15)	-n = 0	-Plantar flexion -2 s concentric/2 s eccentric -1 s concentric/1s eccentric (combined)	-75% of 1 RM -20% of 1 RM	-4/20/4/10 -4/20/4/30+15+15+15	-MVC -Rate of torque development	-MVC=both groups not significant -Rate of torque development = both group (12-26%)

Authors	Participants	Intervention group	Control group	Task/Contraction	load	Week/set/session/ repetition	Outcome measure	% cross-education on the untrained side
Magdi 2021 (26)	-69 -(40 men: 20.1 ± 2.2 ys, 76.1 ± 7.8kg, 178.9 ± 5.7c 29 women: 20.4 ± 2.0yys, 60.2 ± 7.1 kg 165.1 ± 5.6cm. -Physically active individuals engaged in 6–8 h of physical activity per week.	-Accentually unilateral leg press group (n = 46)	-n = 23 -No training	-Accentually unilateral leg press -Coupled concentric combined eccentric contraction (combined)	-Concentric:30%1 RM -Eccentric:105%1 RM	10/4/20/8	-Unilateral leg press and unilateral elbow flexion (1 RM) -MAVIC -Unilateral muscle power at 40, 60, and 80% 1 RM	-Unilateral muscle power at 40, 60, and 80% 1 RM (45.2% in women, (69%) in men) -MVIC (18/2% in women, 32.8% in men) (BURST)
Sato 2021 (19)	32 -Healthy university students -EXT group (age: 20.7 _ 0.9 year; height: 167.1 _ 9.0 cm; body mass: 60.9 _ 11.4 kg) - FLE group (age: 21.4 _ 1.4 year; height: 165.7 _7.5 cm; body mass: 58.8_9.9 kg) -Control group (age: 21.1_0.6 year; height: 164.3_6.6 cm; body mass: 57.2_7.9 kg).	-Extended joint training (0°–50°; EXT) with Dumbbell lifting (n = 12) -Flexed joint training (80°–130°; FLE) with Dumbbell lifting (n = 12)	-n = 8 -No training	-Elbow flex/ext - concentric	From 30% (1st session) to 50% (2nd and 3rd sessions), 70% (4th and 5th sessions), 80% (6th and 7th sessions), 90% (8th and 9th sessions), and 100% (10th session) of the MVC-ISO torque at 50° for the EXT, and at 90° for the FLE group	5/10/30	-MVC-ISO -MVC-CON -MVC-ECC	Extension group: -MVC-ISO (15.9 ± 14.8%) -MVC-CON (16.7 ± 20.0%)
Sato 2021 (20)	-31 -Healthy university students - Eccentric training group (5 males, 4 females, age: 21.1 ± 0.9 y, height: 165.9 ± 7.7 cm, body mass: 58.4 ± 8.2 kg) - concentric training group (5 males, 4 females, 20.9 ± 0.6 y, 167.2 ± 7.7 cm, 63.3 ± 10.8 kg) and control group (7 males, 6 females, 20.9 ± 1.9 y, 166.4 ± 8.9 cm, 57.8 ± 7.9 kg).	-Unilateral progressive eccentric training (n = 8) -Unilateral progressive concentric training (n = 8)	-n = 8 -No training	-Elbow flexors With Dum bell -Resistance concentric -Resistance eccentric	-Training load was increased each week from 10 % (week 1), 30 % (week 2), 50 % (week 3), 80 % (week 4), and 100 % (week 5) of MVIC torque for the trained arm.	5/6/10/5	-1 RM of concentric Dum bell curl -MVIC of elbow flexors	-MVIC eccentric training *vs* concentric training (22.7 ± 17.9 % *vs* 12.2 ± 10.2 %) and 1 RM (19.9 ± 14.6 % *vs* 24.0 ± 10.6 %) -MVIC cross-body effect eccentric training *vs* concentric training (90.9 ± 46.7 %) *vs* (49.0 ± 30.0 %).
Pellet 2021 (23)	-50 -Healthy and right-handed participants -26 women, 24 men, aged 19–41 years	-G80=Group 80%+40% 1 RM (n = 16) -G40=Group 40% 1 RM (n = 16)	-n = 16 -No training	-Dumbbell Scott curl -3 seconds Concentric and 3 seconds eccentric (combined)	-80% 1 RM,40% 1 RM -40% 1 RM	4/12/	-Elbow flexion 1 RM in week1 and week4 -MVIC in week1 and week4	-1 RM week 1 = G80(18%) G40 (8.6%) in week1 -1 RM wee4=- Both G80& G40 showed CE -MVIC = there was no significant data (6.67% *vs* 4.12%)

Authors	Participants	Intervention group	Control group	Task/Contraction	load	Week/set/session/ repetition	Outcome measure	% cross-education on the untrained side
Maroto-isquirdo 2021 (33)	-40 -Physically active university students -(EM100:21.3 ± 1.1 y; 76.8 ± 8.2 kg; 180.0 ± 4.6 cm) -(EM150: 21.1 ± 0.6 y; 74.8 ± 6.6 kg; 179.1 ± 6.0 cm) -(FW: 21.4 ± 2.2 y; 75.1 ± 8.9 kg; 175.8 ± 5.9 cm) -Control: 22.7 ± 3.4 y,76.7 ± 11.1 kg, 175.3 ± 5.1 cm)	- Unilateral squat using electric-motor a device with 100% eccentric phase velocity (EM100) (n = 10) - Unilateral squat using electric-motor a device with 150% (EM150) of eccentric phase velocity(n = 10) -Unilateral squat using a conventional flywheel device (FW) (n = 10)	-n = 10 -No training	-Isoinertial squat training -Eccentric/concentric	Isoinertial load (0.05 kg/m^2) with 100% velocity and 150 % velocity in the eccentric and concentric phase	6/4/12/7	- Unilateral leg-press 1 RM - Muscle power at 40-80% 1 RM	-Leg press 1 RM strength increased in all training groups (22%-27.8%) -Muscle power in 40% 1 RM in EM150 (6.8%)
Colomer-Poveda 2020 (12)	-42 -Active men 21.8 ± 2.4 yr -Recreational activities included 2-3 h/wk of sports (mostly team sports) or aerobic training -LLF: (20.8 ± 1.3y) -HLLF: (21.4 ± 1.4y) -HLNF:(21.8 ± 1.5y)	-LLF (n = 11) -HLLF (n = 11) -HLNF (n = 11)	-n = 9 -Daily habits activity	-Unilateral knee extension -concentric	-25%1 RM -75%1 RM -75%1 RM	-4/3/5 -4/3/5 -4/6/5	-1 RM -MVIC in knee extensor	-1 RM -HLLF: 5% - HLNF: 6 % in
Hill 2020 (34)	-36 - College-aged women (mean age ± SD = 22 ± 2 yrs; height = 166.0 ± 5.7 cm; body mass = 64.2 ± 6.3 kg)	-Ecc-BFR (n = 12) - Con-BFR (n = 12)	-n = 12 -No intervention	-Forearm flexion -Resistance eccentric isokinetic -Resistance concentric isokinetic	75 eccentric and concentric isokinetic at 120. s -1	4/12/4 /75	-Eccentric peak torque -concentric peak torque -Maximal voluntary isometric contraction torque -Muscle activation in the second and forth weeks	Ecc-BFR: 13% increase in muscle strength in the forth week & 4.9% in the second week
Carr 2019 (35)	-20 -Participants had not engaged in programmed resistance training for at least three months before enrollment -Intervention group:(Three female, two left-hand dominants; age = 23.0 ± 2.0 years, stature = 175.9 ± 10.2 cm, mass = 74.3 ± 10.1 kg) -Control group:(three females, Two left-hand dominants; age = 25 ± 3 years, stature =177.2 ± 0.4 cm, mass= 3.2 ± 15.3 kg)	-Unilateral elbow flexors Strength training (n = 10)	-n = 10 -Without training	-Unilateral elbow flexion -Isometric	80% MVC	4/5/11/5	-MVC strength	-MVC –Strength in week 4 = 49.2% - MVC –Strength in week 2 = 22.3%

Authors	Participants	Intervention group	Control group	Task/Contraction	load	Week/set/session/ repetition	Outcome measure	% cross-education on the untrained side
Tseng 2019 (16)	-48 -healthy men who had not performed any structured regular resistance, aerobic, or flexibility training in the past 1 yr, and who did not carry heavy objects frequently in their daily activities and had no musculoskeletal injuries of the upper extremities -23.2 ± 2.5 yr, 172.6 ± 4.6 cm, 69.4 ± 8.2 kg	-Ipsilateral elbow flexor training at 10%, 30%, 50%, 80%, and 100% of MVC 1-Eccentric training (n = 12) 2-progressive concentric training (n = 12) 3- Il-RB (n = 12) 4-Cl-RB (n = 12)	-The average of the two groups (IL-RB) and (CL-RB)	-Elbow flexion -Eccentric -Concentric	10% to 100% of MVC, followed by 30 maximal eccentric contractions (30maxec) of the untrained elbow flexor one week later	5/5/ 5/6	MVC	MVC -Eccentric (11%) -Concentric (5%)
Farinas 2019 (13)	-35 21-38 years -Traditional group = (24 ± 5 yr, 173 ± 8 cm,3women; 8 men) -Cluster group: (24 ± 2yr,175 ± 9 cm, 4 women; 8 men) -Control group: (23 ± yr,173 ± 10 cm, 5 women; 7 men)	-Traditional training (n = 12) -Cluster training (n = 11)	-n =12 - No training	-Biceps curl -Mixed exercise	-10RM pre-test load	5/5 /10/6/135s rest 5/5/10/30/18.5s rest	-1 RM - (n10RM), -MVC	1 RM -Traditional training:(7.3%) -Cluster training: (6.5%)
Pietrangelon 2019 (36)	-31 - Healthy male (71.77 ± 4.06 years, 80.47 ± 12.09 kg, 1.67 ± 0.08 m) -Reporting current physical inactivity	-Endurance training, vigorous-intensity aerobic activity (n = 10) -Resistance training, leg-press, and leg-extension machines (n = 11)	-n = 10 -No training	-Leg press and leg extension -Mixed exercise	-Endurance training: 0.6– 0.7 of HRtr (1st–4th week, 30' pedaling; 5th–8th week: 40' pedaling) or 0.8 of HRtr (9th–12th week: 40' pedaling) -Resistance training: 1 RM: 1st–4th week, 12 repetitions at 60% 1 RM; 5th–8th week, 10 repetitions at 70–75% RM; 9th–12th week, 6–8 repetitions at 80% RM	-20 min on three days each week -12 / / 6-12	-MVC in leg extension -Hand grip strength	-HS in endurance training (20%) -MVC in resistance training (10%) (BURST)
Neltner 2019 (37)	-27 -Right hand dominant and had no shoulder pathology within the last year - Age: 21.37 ± 2.02 years; height: 167.85 ± 7.63 cm; mass: 74.42 ± 16.73 kg	- Right arm unilateral training (n = 13)	-n = 14 -No training	-Shoulder internal and external rotation -Isokinetic 60, 180, and 300° /s, w	- 10 maximal concentric repetitions of internal/external shoulder rotation	2/4/3/30	Average power in the left arm	There is no significant increase in the untrained limb

Authors	Participants	Intervention group	Control group	Task/Contraction	load	Week/set/session/ repetition	Outcome measure	% cross-education on the untrained side
May 2018 (38)	-24 -Recreationally active young men -BFR (22.6 ± 3.3, 177.6 ± 9.5, 73.0 ± 13.6) -Non-BFR -(22.1 ± 2.5,174.1 ± 6.7,72.4 ± 11.2)	-BFR resistance training group (n = 12)	-n = 12 -Non-BFR training	-Unilateral bicep curls followed by bilateral knee extension and bilateral knee flexion exercise – Mixed exercise	50% 1 RM, then in bilateral knee extension and flexion exercises 30% 1 RM.	7/20/3/10 rep in 50% 1 RM and 30 rep in 30% 1 RM, followed by three sets of 15 rep	1 RM strength using bilateral leg exercises and unilateral bicep curls	There is no significant increase in the untrained limb
Brass 2017 (11)	-20 -Participants had previous experience with resistance training but was instructed not to begin or change their physical activity for the duration of the study -Traditional group:(6 female; 5 male, 24.0 ± 3.0 years, 169.5 ± 10.5 cm, 70.6 ± 14.5 kg) -Daily training:(2 female; 6 male, 22.5 ± 3.5 years, 175.6 ± 9.4 cm, 76.8 ± 14.3 kg)	1-Traditional handgrip training group (n = 11) 2-Daily unilateral handgrip training (n = 8)	-n = 0	-Handgrip -Isometric	Maximum 100% 1 RM	-6/5/3/5 -18 day/5/18/5	-MVC in wrist extensors and flexors -Muscular activation (EMG) in wrist extensors and flexors	-TT: Peak handgrip force (12.5%) -DT: Peak handgrip force 7.8%) -TT: Peak wrist extension and flexion: 32/6/%/ 19/2% TT: Average muscle activity: for FCR (5/2%) and ECR (9/2%)
Boyes 2017 (25)	-19 -Young, healthy adults -Right-handed participant -HF:(age ,24.9 ± 3.9, weight,75.6 ± 13.7, height,174.7 ± 9.2) -LF: (age ,24.6 ± 6.3, weight,74.4 ± 10.2, height,171.5 ± 9.1)	-High Frequency (n = 10) - Low Frequency (n = 9)	-n = 0	-Right-hand Handgrip -Isometric	-90%–100% handgrip MVIC	-4/2 set *6 repetitions 10 times per week =120 -4/5 set *8 repetitions three times per week = 120	- Left-hand grip MVIC -MVC wrist flexion	-HF hand grip: 8.4% in the left limb -LF: hand grip 9.0% in the left limb
Hedayatpour 2017 (39)	-30 -Healthy male subjects (age, mean ± SD, 24.2 ± 1.9 yr., body mass 71.3 ± 10.5 kg, height 1.75 ± 0.05 m) with no history of knee injury or trauma	-High load-low repetition eccentric group (n = 15) -Low load-high repetition concentric group (n = 15)	-n = 0	-Leg press -Eccentric -Concentric	-120% 1 RM -60% 1 RM	-12/3/5 -12/3/10	MVIC in quadriceps	-27% -17%

BFR: blood flow restriction; BURST: Bottom–Up Rise Strength Transfer; CON: concentric; CONC: concentric; (CL-RB): contralateral repeated boot DRT: distributed resistance training; DT: daily training; EMG: electromyography; EG3 s: eccentric group hold of contraction 3 seconds; EG6 s: eccentric group hold of contraction 6 seconds; ECC: eccentric; EM: electric motor; FW: flywheel device; HR tr: Heart rate training; HLF: high load resistance training to failure; HLNF: high load resistance training not to failure; (IL-RB): ipsilateral repeated bout; ISO: isometric; LBFR: low-intensity blood-flow restricted; LLF: low load resistance training to failure; n: number MVIC: maximum voluntary isometric contraction; MRT: massed resistance training; 1 RM: 1 repetition maximum; TRAD: traditional.

Mixed exercise

Out of 22 studies, six studies evaluated the effects of mixed exercise (not clarified the type of contraction) in the form of resistance or non-resistance contraction (13, 17, 21, 31, 36, 38). Exercises in this group could induce significant cross-education in volume: (5-12 weeks, 5 sets, 10-60 sessions, 5-30 repetitions, 70% 1 RM-100% 1 RM or 70-100% MVC or 10-15 10 RM). In other words, training load with high intensity if applied in low volume (*i.e.*, 90% 1 RM in 5 set/1 repetitions) could not create a significant cross-education (12, 31). Aman *et al.* showed that the training protocol distributed in weekly sessions could produce more cross-education than mass training (17). In line with this result, Farinas *et al*. reported that if the rest time between repetitions increases, the cross-education will be increased (13). Pietrangelo demonstrated that resistance training with a volume above 60% 1 RM could produce cross-education in MVC of the untrained side (36). In contrast, May *et al*. showed that training volume with 50% 1 RM in seven weeks and 20 sessions could not produce a contralateral effect on the untrained side (38). The range of induced cross-education was between 6.5-45%. Of course, two studies in this section (17, 36) investigated Bottom-Up Rise Strength Transfer (BURST) that has increased the rate of cross-education (28). We discussed more about BURST in following sections.

Compared contractions

Five studies compared eccentric and concentric exercises (16, 18, 20, 33, 39). The training volume was between 5-12 weeks,5-16 sessions, 5-10 repetitions, and 10-100% 1 RM for concentric and10-120% 1 RM for eccentric contraction. The range of created CE via eccentric exercise was between 11%-27%. The range of created cross-education via concentric exercise was between 5-27%. Corotella *et al*. compared eccentric and concentric contractions with an intensity of 85% 1 RM for concentric contraction and 120% 1 RM for eccentric contraction, and 90% 1 RM for traditional eccentric/concentric contractions (18). They reported that eccentric contraction was the most effective in improving peak torque in the form of concentric, eccentric, and isometric torques (18). In line with these results, other studies (16, 20, 39) also reported that eccentric contraction is more effective than concentric contraction in cross-education. Tseng *et al.* showed ipsilateral elbow flexor training at 10%, 30%, 50%, 80%, and 100% of MVC in four group eccentric training, progressive concentric, ipsilateral-repeated bout, and contralateral repeated bout at volume of training in 5 weeks, 5 sets, 5 session, and 6 repetitions, could produce cross-education as much as 11% in only eccentric contraction group (16). Sato *et al.* showed unilateral progressive eccentric training in form of elbow flexion at weekly increased load from 10% (week 1), 30% (week 2), 50% (week 3), 80% (week 4), and 100% (week 5) of MVIC for the trained arm at a volume of training in 5 weeks, 6 sets, 10 sessions and 5 repetitions could produce cross-education in MVIC as much as 22% *vs* 12% than concentric training group (20). Of course, this rate is lower in eccentric contraction group than concentric contraction group in 1 RM concentric elbow curl measures (19% *vs* 24%) (20). Hedayatpour *et al.* showed high load-low repetition eccentric contraction in 12 weeks, 3 sets, and 5 repetitions in 120% 1 RM could produce more cross-education than concentric training group at 60% 1 RM intensity, 12 weeks, 5 sets, and 10 repetitions (39). Maroto-isquirdo *et al.* reported that eccentric contractions that carried out with squat using electric-motor at 100% and 150% eccentric phase velocity, in each phase of concentric and eccentric contraction, in form of unilateral squat training, are effective in induced cross-education to the same extent (33).

Coupled contraction

Four studies investigated coupled eccentric and concentric contraction (23, 26, 32, 33). Mendonca *et al.* reported that combined eccentric and concentric contraction at either high or low intensity (80 *vs* 20% 1 RM) during four weeks could not produce cross-education in MVIC, but could produce cross-education in the rate of torque development as much as 12-26% (32). Magdi *et al*. reported that combined eccentric/concentric contraction with an intensity of 30% 1 RM and 105% 1 RM in the lower limb could produce cross-education as much as 45.2% and 69% in the power of women and men regularly. Also, they reported that this increment in MVIC was as much as 18.2% in women, and 32.8% in men, regularly (26). Maroto-isquirdo also reported that a combination of eccentric/concentric contraction could produce cross-education as extent as eccentric-only training (33). The training volume was between 5-12 weeks,10-36 sessions, 5-8 repetitions, 10-105%1 RM intensity (33). Pelet *et al.* reported dumbbell Scott Curl in 3 seconds concentric and 3 seconds eccentric contraction at 40+80% 1 RM intensity could produce more cross-education in 1 RM measures than 40% 1 RM training group in week 1 of training (18% *vs* 8.6%) (23). This rate was similar in both group in week 4 of training in 1 RM measure (23). On the other hand, Pelet *et al.* showed MVIC measures did not differ between two groups in term of cross-education (23) The range of created cross-education via combined exercise was between 8.6%-69%.

It is important to notice the new phenomena in this section. Four studies investigated the lower to upper effects of unilateral training (17, 20, 26, 36). These studies investigated the cross-education in the form of Bottom-Up Rise Strength Transfer (BURST). It was reported that the rate of BURST is more than contralateral effects. Sato *et al.* reported training load that was increased each week from 10% (week 1), 30% (week 2), 50% (week 3), 80% (week 4), and 100% (week 5) of MVIC for the trained arm in volume of 5 weeks, 6 sets,10 sessions, and 5 repetitions could produce BURST as much as 90.9% in eccentric training *vs* 49.0% in concentric training group (20). Magdi *et al.* reported accentually unilateral leg press in form of coupled concentric (30% RM) combined eccentric (105% 1 RM) contraction in 10 weeks, 4 sets, 20 sessions and 8 repetitions could produce the induced BURST in 1 RM as much as 45.2% in women, 69% in men and induced BURST in MVIC as much as 18.2% in women, 32.8% in men (26). Pietrangelo *et al.* reported the endurance training with intensity 0.6-0.7 of target heart rate (1^{st}-4^{th} week: 30' pedaling; 5^{th}-8^{th} week: 40' pedaling) or 0.8 of target heart rate (9^{th}-12^{th} week: 40' pedaling) could produce BURST in hand strength as much as 20% and resistance training with intensity, 1^{st}-4^{th} week, 12 repetitions at 60% 1 RM; 5^{th}-8^{th} week, 10 repetitions at 70-75% RM; 9^{th}-12^{th} week, 6-8 repetitions at 80% RM could induced BURST as much as 10% in MVIC measures (36). Aman *et al.* reported the lower limb proprioceptive, balance, agility, and resistance exercise with intensity 10-15 1 RM, in 12 weeks, 60 sessions in 60 minute (distributed resistance training) could produce more cross-education (45.1%) than massed resistance training that carried out in 36 sessions (33.4%) (17).

Eccentric contraction

Studies in this section overlap with the above section because many studies compared eccentric exercise with eccentric or combined eccentric with concentric exercises. Only one study investigated eccentric contraction (15). Martinez *et al.* showed single leg decline squat at 80% 1 RM in eccentric contraction, 6 weeks,3 sets, and 8 repetitions could produce more cross-education in 6 seconds holding contraction time than 3 seconds holding contraction time (15). The range of induced cross-education was between 18-30%.

Concentric contraction

Such as above (only eccentric contraction group) the studies in this section have overlap with compared contraction section studies. Only two studies investigated concentric contraction on cross-education (12, 19). Colomer-Poveda *et al.* showed unilateral knee extension with 75% 1 RM intensity group in 4 weeks, 3 or 6 sets, and 5 repetitions could produce cross-education more than 25% 1 RM intensity load group (12). This rate is significant in 1 RM measures of cross-education, not in MVIC measures (12). According to Sato *et al.*, cross-education was only produced by the elbow extension group, reaching as high as 15.9% in MVIC-isometric and 16.7% in MVIC-concentric (19) when the load was incrementally increased from 30% to 100% MVIC-isometric over the course of five weeks, ten sessions, and thirty repetitions.

Isometric contraction

Three studies evaluated the effect of isometric contraction on cross-education (11, 25, 35). Carr *et al.* reported that unilateral elbow flexion with 80% 1 RM could produce cross-education as much as 22.3% in the second week of 4 weeks of training and 49% in the fourth week of training protocol (35). Barss *et al.* showed, however handgrip training in 100% 1 RM in 6 weeks could induce cross-education as much as 12.5%, but could induce a lesser amount of cross-education in 18 days of training with 100% 1 RM (7.8%) (11). Boys *et al.* reported handgrip isometric training in 80-100% 1 RM in high and low training frequency (10 times a week *vs* three times a week) could make cross-education in MVIC hand grip alike (8.2% *vs* 9%) (25). The amount of isometric training volume in these studies was 18 days, 6 weeks, five sets, 15-120 sessions, and 5-8 repetitions. The range of cross-education in this group was between 5.9%-49%.

Isokinetic contraction

Out of 22 studies, two investigated isokinetic contraction in the form of isokinetic concentric or isokinetic eccentric contraction (34, 37). Neltner *et al.* reported that concentric exercise in the form of isokinetic could not induce cross-education (37). On the other hand, Hill *et al.* stated that eccentric contraction in the form of isokinetic could induce cross-education; in contrast, concentric contraction in the form of isokinetic could not induce cross-education (34). Isokinetic eccentric contractions in 4 weeks, 12 sessions, four sets, and 75 repetitions could induce cross-education as much as 4.9%-13%.

DISCUSSION

This review aimed to infer which volume of unilateral strength training (duration, frequency, intensity, sets, and sessions) and type of contraction optimizes the increase in strength on the untrained limb. Our results indicated that the organization of training content interacts with the increase in strength observed on the untrained side. The result showed that the combination of the eccentric and concentric exercise was the most effective type of contraction, and eccentric, isometric, mixed, concentric, and isokinetic contractions were effective regularly. Besides, the eval-

uation of BURST showed more significant cross-education than the evaluation on the contralateral side.
In addition, the results indicated that training volumes with more than four weeks, distributed sessions, and more rest between repetitions could assist in producing more cross-education. This review suggests that type of contraction has priority over the volume of training on cross-education because the studies that investigated isokinetic contraction have used approximately similar volume to studies that investigated isometric contraction but showed a lower rate of cross-education than isometric group (4.9%-13% *vs* 5.9%-49%).

Mixed exercise

This review showed mixed exercise in the form of traditional, cluster, or other types of exercises in an intensity range (705% 1 RM-100% 1 RM) could produce cross-education as much as 6.5-45% (13, 17, 21, 31, 36, 38). This review has also shown that if exercises are applied with a high intensity, such as 90% 1 RM, but in low volume (5 set/1 rep), could not significantly produce cross-education (31). Then, it seems the multiplying training intensity by the training volume in cross-education could not assist cross-education. Nevertheless, it has been shown that exercises with higher intensity and higher volume could produce a significant cross-education (27) because the higher intensity and volume of training can activate the same hemisphere (40, 41) and reduce the inhibition between the two hemispheres (40). On the other hand, low-intensity exercises usually cannot create a stimulus for the ipsilateral hemisphere, so it affects cross-education rarely (40, 41).

Eccentric *vs* concentric contraction

This review demonstrated that eccentric contraction was more effective than concentric contraction in cross-education size. The range of cross-education effects created via this training protocol was eccentric (11-27%) compared to concentric exercise (5-27%) exercise (16, 18, 20, 33, 39). In addition, in section of only eccentric contractions and only concentric contraction, the rate of induced cross-education in eccentric contraction (18%-30%) (15) is more than only concentric contraction section (5%-16.7%) (12, 19). In agreement with these results, two review studies demonstrated that eccentric contraction was more effective than concentric contraction in cross-education (27, 28). The reason for this may be related to neuromuscular adaptations (42), mutual effects of more intra-cortical facilitation, and reduction of intra-cortical inhibition that eccentric exercise produces (43, 44). It was reported that following eccentric-only *vs* concentric-only training, corticospinal excitability increased more during the eccentric peak torque, with no change observed during the concentric peak torque (44). Additionally, corticospinal and intra-cortical inhibition was overall reduced following eccentric-only, but not concentric-only training (44). Interestingly, performing maximal eccentric actions was also shown to increase the activity of the central nervous system (45), so it is plausible that more significant inter-hemispheric stimuli occurred (10).

Coupled contraction

One of the remarkable points in this review is the combined effect of concentric and eccentric contractions on cross-education, which caused cross-education to 12%-69% (23, 26, 32, 33). Of course, a high increment in the rate of cross-education was only observed in the Magdi's *et al*. study because they evaluated the effects of accentuated unilateral leg training (concentric and eccentric) with an intensity of 30+105% 1 RM on the ipsilateral non-trained arm, not on the untrained leg (26). Otherwise, Mendonca *et al*. and Maroto-isquirdo *et al*. investigated the contralateral side of the trained limb (32, 33). It has been reported that the magnitude of the cross-education gains largely depends on those obtained ipsilaterally rather than contralaterally (28). It has been also showed that BURST induced neural changes in the strength of the untrained side and other untrained areas of the body (26). Moreover, accentuated eccentric loading exercises increase the secretion of insulin-like growth factors, testosterone, and anabolic regulatory factors, which can cause a general effect on the whole body, especially the untrained side, and improve cross-education (46).
According to these findings, Sato *et al.* (20), Pietrangelo *et al.* (36), and Aman *et al.* (17) also examined BURST in their studies in addition to Magdi *et al.* (26). They also reported a high amount of cross-education in BURST (90% in Sato *et al*., 45% in Aman *et al*., and 18-69% in Magdi *et al.*). Pietrangelo *et al*. reported an amount of BURST as much as 20%, which was lower than other studies (36). Because they used endurance training to induce cross-education and resistance training in different intensities (from 60% 1 RM, to 80% 1 RM in 8^{th}-12^{th} weeks), as we expressed earlier, training with lower than 70% 1 RM cannot induce cross-education effectively.

Isometric contraction

This review showed that the range of cross-education via isometric contraction protocols was between 5.9%-49% (11, 25, 35). There is a large amount of cross-education (49%) in Carr *et al.* study (35). One of the reasons for the higher amount of cross-education in the Carr's *et al*. study is that the non-dominant side was trained, and the dominant side was investigated (35). Studies have shown that exercises on the dominant side can be more effective than on the non-dominant side in cross-education (47, 48). In Carr's *et al*. study, also, cross-education was reported in the second week of 4 weeks of training and measured weekly, which creates an additional motor learning stimulus (35). It was reported that the measure of cross-education at an earlier time of intervention could be a factor in increasing the amount of crossed education (47, 48). Furthermore, Barss *et al.* showed that isometric contractions at 100% 1 RM intensity at six weeks of training protocols in 18 sessions had a few more effects on the cross-education than 18 days of training in 18 sessions (7.8 *vs* 12.5%) (11). In this regard, Boys *et al.* reported that both high and low-frequency isometric training with 90-100% 1 RM could produce approximately similar cross-education (8.4% *vs* 9%) (25). Boys *et al.* and Barss *et al.* results contradict the mentioned results in the mixed contraction group that higher intensity and volume of exercise create more cross-education than low-intensity and low-volume exercise. These contradictory results may originate from physiological and biomechanical differences between isometric and dynamic movements. In dynamic movements, cross-bridges have a greater connection (49, 50) and a higher discharge rate for motor units (51, 52) compared with isometric movements. In dynamic movement, also, antagonists are activated (53), while in isometric movement, the agonist is predominantly recruited, and the antagonist plays a minimal role (54). This suggests that the mechanisms which contribute to enhanced cross-education of dynamic strength seem unrelated to the mechanisms which contribute to enhanced cross-education of isometric strength.

Suggestion for future research

It suggested that future studies compare two sex (male or female), since, according to Magdi *et al.*, effect of cross-education varied between men and women (26). Moreover, future studies can be conducted at varied ages (youth or children *vs* adults) since according to Chaouachi *et al.* (55), children or youth people differently reacted to cross-education. Future research should also be conducted to separate the type of contraction in outcome measures of testing protocols.

CONCLUSIONS

This review showed that organized exercises in a more significant number of sessions and higher intensity of 1 RM (above 70% 1 RM) training could increase the strength of the untrained limb. The effects of contraction type in a combination of contractions (concentric+eccentric) on cross-education (8.6%-69%) had more effect on cross-education than isometric (5.9%-49%), mixed (6.5%-45%), eccentric (18%-30%), and concentric contractions (5-16.7%). Evaluation of BURST has indicated more significant amounts of ipsilateral untrained limb effects than only contralateral effects. Effects of training on the strength of ipsilateral untrained limb showed more significant increase than contralateral limb. In the other word, If we want to improve the strength of the untrained limb, it is better to train the limb on the immobile side by combining eccentric and concentric contractions.

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DATA AVAILABILITY

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CONTRIBUTIONS

MMR: conceptualization. MM, MMR, PS: methodology. MM, AD: investigation. MM, PS: data analysis. MM, AD, MMR: writing - original draft. MM, AD: writing - review and editing.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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SUPPLEMENTS

Appendix 1. Search strategy for each database.

PubMed: 72

Search: (((((“cross-education”[Title/Abstract]) OR (“cross-transfer”[Title/Abstract])) OR (“cross-training”[Title/Abstract])) OR (“interlimb transfer”[Title/Abstract])) OR (“strength transfer”[Title/Abstract])) AND ((((“unilateral strength training”[Title/Abstract]) OR (“contralateral strength training”[Title/Abstract])) OR (“resistance training”[Title/Abstract])) OR (“strength training”[Title/Abstract])) Filters: from 2017/1/1 - 2022/12/1 =72

Scopus: 99

(TITLE-ABS-KEY(“unilateral strength training”) OR TITLE-ABS-KEY(“contralateral strength training”) OR TITLE-ABS-KEY(“strength training”) OR TITLE-ABS-KEY(“resistance training”)) AND (TITLE-ABS-KEY(“strength transfer”) OR TITLE-ABS-KEY(“interlimb transfer”) OR TITLE-ABS-KEY(“cross-education”) OR TITLE-ABS-KEY(“cross-training”) OR TITLE-ABS-KEY(“cross-transfer”)) AND (LIMIT-TO (PUBYEAR,2022) OR LIMIT-TO (PUBYEAR,2021) OR LIMIT-TO (PUBYEAR,2020) OR LIMIT-TO (PUBYEAR,2019) OR LIMIT-TO (PUBYEAR,2018) OR LIMIT-TO (PUBYEAR,2017))=99

Web of Science: 94

(((TS=(“cross-transfer”)) OR TS=(“interlimb transfer”)) OR TS=(“cross-education”)) OR TS=(“cross-training”) AND (((TS=(“contralateral strength training”)) OR TS=(“unilateral strength training”)) OR TS=(“strength training”)) OR TS=(“resistance training”) AND 2022 or 2021 or 2020 or 2019 or 2018 or 2017

Science Direct: 136

(“cross-transfer” OR “interlimb transfer” OR “cross-education” OR “cross-training”) AND (“contralateral strength training OR “unilateral strength training” OR “strength training” OR “resistance training”), year: 2017-2022

Google Scholar: 39

(“cross-transfer” OR “interlimb transfer” OR “cross-education” OR “cross-training”) AND (“contralateral strength training OR “unilateral strength training” OR “strength training” OR “resistance training”), year: 2017-2022

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Reliability of Nonlinear Kinematic Analysis in Patients with Functional Ankle Instability During Dual-Task Walking

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SUMMARY

Objective. This study aimed to determine the intrasession reliability of nonlinear gait kinematic analysis under single and dual-task conditions in individuals with and without Functional ankle instability (FAI).

Methods. Individuals with FAI and healthy subjects completed a walking task on a treadmill, with or without performing an auditory Stroop task. The gait kinematic parameters, including the LyE of hip, knee, and ankle angles in three planes, were recorded. Cognitive task performance was analyzed using error ratio and average reaction time. The intraclass correlation coefficient (ICC) was utilized to determine the intrasession reliability of kinematic and cognitive outcome measures.

Results. ICCs for the FAI group in dual and single-task conditions ranged between 0.53 to 0.85 and 0.62 to 0.96, respectively. ICCs for healthy groups in dual and single-task conditions ranged between 0.47 to 0.89 and 0.86 to 0.95, respectively. Lower ICC values were mainly related to the hip and knee transverse planes ranging from 0.47 to 0.68. ICC values of the auditory Stroop task were higher in the reaction time variable (FAI (0.95), control (0.84)) than in the error ratio (FAI (-0.01), control (0.43)).

Conclusions. LyE of gait kinematics had moderate to very high reliability in participants with and without FAI in both single and dual-task conditions, and it might be helpful for clinical evaluation. The low intrasession reliability in hip and knee transverse planes must be interpreted cautiously.

KEY WORDS

Functional ankle instability; dual-task; gait; reliability; Lyapunov exponent; motion analysis; kinematics.

INTRODUCTION

Functional ankle instability (FAI) is one of the most prevalent musculoskeletal ailments, closely followed by lateral ankle sprains (1). Although individuals with FAI exhibit no signs of ligament laxity, they experience impaired function and recurrent ankle sprains due to their ankles frequently giving way (2). Proprioceptive impairment, weakness deficiencies, poor muscle recruitment, decreased ankle range of motion, and altered neuromuscular function may influence postural control and gait patterns in individuals with FAI (3-8).

Individuals with FAI have altered gait patterns during functional tasks, such as walking, which is the most common task in daily activities (9). Gait analysis under single-task conditions may restrict the validity of research and conceal changes in movement patterns under demanding situations (10). The effect of FAI on gait stability has been examined in relation to the dual task explained by performing two tasks concurrently. In managing posture and walking, cognitive factors play a crucial role. However, a literature study reveals that the role of cognitive factors in walking is typically neglected (11). According to research on several populations with balance issues, gait stability may be compromised during dual-tasking, diminishing balance control while walking. Thus, the dual-task paradigm can detect gait deficits that would otherwise remain hidden during normal walking (12, 13). In addition, since a behavior consists of three components - cognition, emotions, and executive functions - and sufficient evidence exists for the role of cognition in the central processing of information, dysfunction of executive functions, which is one of the components of behavior, can directly affect cognitive functions (14). Therefore, patients with FAI with difficulty in executive functions such as postural control should not be surprised to see cognitive impairments such as inattention. Siu *et al.* revealed that the performance of a cognitive task in the form of verbal reaction time declined as the difficulty level of the gait rose (15). Such research may imply that environmental degradation may influence the functionality of the central information processing system, even if it does not cause structural damage to information processing centers.

Even though human gait is a cyclic action, there is always a degree of variation in irregular fluctuations throughout time. Although linear statistics such as standard deviation and coefficient of variation are widely used to explain gait variability and estimate its magnitude, evidence has challenged the idea of linear dynamics (16, 17). This viewpoint is limited in disregarding the hidden temporal structure within the signal, which does not allow for a conclusive assessment of the dynamic features of the balancing control system. Examining the system's behavior over an extended period offers more accurate information. In contrast, the temporal pattern of gait variability or how gait evolves is crucial in measures derived from nonlinear statistics, indicating the interplay between the various locomotor and balance control system components (18). Using both types of linear and nonlinear analysis may be necessary to fully understand the behavior of a complex dynamical system, obtain a better interpretation of the characteristics of the locomotor system, and reach a more comprehensive result. The Lyapunov exponent (LyE) was employed to explore the present study's nonlinear dynamic behavior of postural oscillation. This technique examines gait stability and the dynamic system's susceptibility to disturbances (10, 19).

The intrinsic variability in gait patterns can affect the reliability and validity of kinematic outcomes. One of the criteria for choosing a parameter for evaluation, treatment, and biomechanical issues is its reliability. Reliability tells us how much relative error the test has in measurement. Although studies have investigated the reliability of gait kinematics measured with linear tools on healthy and clinical populations (20-23), little attention has been paid to the reliability of the nonlinear analysis. It is necessary to establish the reliability of LyE in various musculoskeletal disorders, including FAI, and in different experimental conditions, especially with a cognitive task. The cognitive-motor dual-task situation seems to increase the complexity of the task and extract more accurate information regarding gait kinematics than normal walking.

To the author's best knowledge, no study has been conducted to examine the reliability of the LyE of the hip, knee, and ankle angles in sagittal, frontal, and transverse planes in FAI. Since the lower extremity is a kinetic chain and functions as a unit, anything that affects the ankle is thought to affect the knee and hip as well. Additionally, in people with FAI, the fibula in the sprained ankle is positioned more anteriorly than the contralateral ankle, which may lead to rotary instability in the talocrural joint (24, 25). This finding suggests that researchers should pay attention to sagittal and transverse plane motions in FAI. Therefore, this study investigated the reliability of the LyE of the hip, knee, and ankle angles in three planes under single and dual-task walking in FAI and healthy adults. We hypothesized that the reliability of the LyE for lower limb kinematics would be acceptable under single and dual-task walking.

MATERIALS AND METHODS

Participants

Ethical approval was obtained from the Institutional Ethics Committee of Shahid Beheshti University (IR.SBMU.RETECH.REC.1400118 – Date of approval: June 18, 2021). Ten patients suffering from FAI (10 males) and ten healthy individuals (10 males) aged 18 to 40 participated in the study and signed the written consent form to participate in the research.

Participants in the FAI group had at least one significant ankle sprain occurring over the last 12 months that required protected weight-bearing for at least three days resulting in pain, swelling, and at least two episodes of "ankle giving way" in the past year. They were identified in the study using a Functional Ankle Ability Measure (FAAM) questionnaire to evaluate their performance, including the subscale of activities of daily living (ADL) and sports. They were excluded if they scored > 90% in the FAAM ADL score or > 80% in the FAAM sports score. Inclusion criteria for healthy subjects were free from a history of lateral ankle sprains. Both groups were free from visual and hearing disorders, dizziness, pain, and lower extremity surgery within the last six months before testing.

Procedure

The gait data on a treadmill was recorded by a 3D motion-capture system (Vicon Motion System Ltd®, Oxford, UK) with eight cameras placed at the height of 270 cm from the ground. The frame rate was also set to 100 Hz. Thirty-eight markers were attached to bony landmarks based on the Cluster algorithm. The markers were bilaterally attached to the superior anterior iliac spine, superior posterior iliac spine, femoral condyles of knee joints, malleoli, head area of the second metatarsus, the base area of the five metatarsi, the most prominent part of the heel area, and ten markers called cluster markers (4 markers in corner and one marker in the center) in the lower third and outside of the shank and the outer half of the thigh.

The experiment involved the immediate test-retest reliability accomplished in one day. The tested ankle of healthy subjects was defined by matching their leg dominance to the involved ankle of the FAI subjects. For example, if the injured ankle of the FAI subject was a non-dominant limb, the non-dominant limb of the healthy subject was determined for evaluation. The leg used for kicking a ball was defined as the dominant leg (26). All participants were familiarized with the testing procedure that contained barefoot treadmill walking at a self-selected speed. It lasted 6 minutes to ensure that subjects had similar gait patterns with over-ground walking (17). The reason for using the treadmill for walking is that a large amount of continuous data (*i.e.*, long time series) is needed to calculate the LyE. The participants walked on a treadmill for 95 seconds and completed two randomized conditions (three trials per condition), including 1) normal walking and 2) normal walking while performing a cognitive task.

In a dual-task condition, individuals were trained to pay enough attention to both walking and auditory Stroop task to avoid the effect of the task's priority. The auditory Stroop task is a modified version of the Stroop task usually used in the dual-task paradigm. The test was carried out in which two words, "high" and "low," were spoken in either high or low pitch. In the original auditory Stroop task (15), the respondents were asked to name the pitch of the sound. However, in the present study, the participants were instructed to recognize the pitch of the sound independent from the spoken word, reverse the answer, and say it as quickly as possible to increase the cognitive task difficulty. The stimulus was heard through a wireless headset (Rapoo, VH150). The auditory Stroop task was implemented using a custom program written in MATLAB (MATLAB R2021a) and was synchronized with the Vicon Motion System so that auditory signals played as soon as the participants started walking.

The LyE of the hip, knee, and ankle angles in three planes was used to measure gait kinematics. Error ratio (number of incorrect responses divided by the total number of stimuli) and average reaction time (the time required to respond to each auditory signal) were also used as two separate variables to measure cognitive performance.

Data processing

3D angles of lower limb joints have been extracted by a Cardan XYZ (flexion/extension-lateral bend-axial twist) rotation sequence. The flexion/extension angles were selected in this study for further analysis. The Cardan rotation sequence XYZ involves three steps: first, rotation about the laterally directed axis (X (flexion/extension)); second, rotation about the anteriorly directed axis (Y (lateral bend)); and third, rotation about the vertical axis (Z (axial twist)). After LCS (Local Coordinate System) computation for each segment, the resulting orientation matrix was used for extracting 3D angles. The angles for the XYZ sequence are designated α (alpha) for the first rotation, β (beta) for the second rotation, and ϒ (gamma) for the third rotation. The rotation matrix R and α angle for an XYZ rotation sequence are as follows:

$$R = \begin{bmatrix} \cos\gamma\cos\beta & \cos\gamma\sin\beta\sin\alpha + \sin\gamma\cos\alpha & \sin\gamma\sin\alpha - \cos\gamma\sin\beta\cos\alpha \\ -\sin\gamma\cos\beta & \cos\alpha\cos\gamma - \sin\gamma\sin\beta\sin\alpha & \sin\gamma\sin\beta\cos\alpha + \cos\gamma\sin\alpha \\ \sin\beta & \cos\beta\sin\alpha & \cos\beta\cos\alpha \end{bmatrix}$$

$$\alpha = \tan^{-1}\left(\frac{-R_{32}}{R_{33}}\right)$$

The LyE was calculated using the custom code in MATLAB software to examine joint angles in three planes. The LyE quantifies the separation rate of infinitesimally close trajectories. The LyE for sagittal angular hip, knee, and ankle angles displacement of time series was calculated using the algorithm presented by Wolf *et al.* (27). The LyE is zero for periodic data where there is no divergence in the trajectories. In other words, the trajectories overlap rather than diverge in the phase space. Five embedded dimensions were found for the present calculation. The LyE is relatively large for random noise when trajectories in the phase space have considerable divergence. We did not filter the joint kinematics to have a precise image of the variability during mentioned trials.

Statistical analysis

All calculations were performed using SPSS 26. Descriptive data were used to report the demographic characteristics. A two-way random model of intraclass correlation coefficient (ICC) was used to analyze the relative reliability of intrasession. For each ICC, a 95% confidence interval (CI) was reported to highlight the estimates' accuracy and to account for variance among the subjects. The relative reliability was classified based on Munro's classification. Munro determined the degrees of relative reliability based on ICC values: 0 to 0.25 little, 0.26 to 0.49 low, 0.50 to 0.69 moderate, 0.70 to 0.89 high, and 0.90 to 100 very high correlation (26).

For assessing absolute reliability, the standard error of measurement (SEM) was estimated as the square root of the mean square error term extracted from variance analysis. The minimal metrically detectable change (MMDC) was utilized to evaluate changes caused by error measurements and calculated as 95%CI of SEM of kinematic variables (SEM*1.96) (28).

RESULTS

There are no statistical differences based on demographic characteristics between groups ($p \geq 0.05$) (**table I**). Intrasession reliability results included the values of ICC, a 95%CI, SEM, and MMDC of the ankle, knee, and hip joints in three planes for two groups presented in **tables II**, **III**, and **IV**, respectively.

Table I. Demographic characteristics of participants with FAI and healthy controls.

Variables	FAI (n = 10)		Healthy (n = 10)		P-value
	Mean	SD	Mean	SD	
Age (year)	24.80	4.23	26.10	4.90	0.272
Body mass index (kg/m2)	24.59	5.31	26.47	3.60	0.333
Sports activity level*	2.00	0.66	1.90	0.73	0.865

P-values refer to the statistical significance of the chi-square test. SD: standard deviation; FAI: Functional Ankle Instability; *1: beginner; 2: semiprofessional; 3: professional.

Table II. Intrasession reliability of ankle Lyapunov exponent (LyE) during the single task and dual-task conditions in participants with FAI and healthy controls.

Conditions	Variables	Healthy					FAI				
		ICC	SEM	MMDC	95%CI for ICC		ICC	SEM	MMDC	95%CI for ICC	
					Lower	Upper				Lower	Upper
Single-task	AnkleX	0.91	0.06	0.16	0.78	0.97	0.92	0.05	0.16	0.79	0.97
Single-task	AnkleY	0.91	0.07	0.20	0.76	0.97	0.75	0.06	0.19	0.45	0.92
Single-task	AnkleZ	0.90	0.07	0.20	0.76	0.97	**0.62**	0.08	0.24	0.26	0.87
Dual-task	AnkleX	0.79	0.11	0.30	0.52	0.93	0.81	0.08	0.24	0.55	0.94
Dual-task	AnkleY	0.90	0.07	0.21	0.74	0.97	0.85	0.07	0.21	0.63	0.95
Dual-task	AnkleZ	0.90	0.07	0.21	0.75	0.97	0.84	0.07	0.21	0.62	0.95

X: Sagittal plane (dorsiflexion-plantarflexion); Y: Frontal plane (inversion, eversion); Z: Transverse plane (abduction, adduction); FAI: Functional Ankle Instability; ICC: Intraclass Correlation Coefficient; SEM: Standard Error of Measurement; MMDC: Minimal Metrically Detectable Change; CI: Confidence Interval; highlighted values show ICC < 0.7.

Table III. Intrasession reliability of knee Lyapunov exponent (LyE) during the single task and dual-task conditions in participants with FAI and healthy controls.

Conditions	Variables	Healthy					FAI				
		ICC	SEM	MMDC	95%CI for ICC		ICC	SEM	MMDC	95%CI for ICC	
					Lower	Upper				Lower	Upper
Single-task	KneeX	0.87	0.08	0.22	0.68	0.96	0.79	0.08	0.22	0.52	0.93
Single-task	KneeY	0.92	0.05	0.15	0.78	0.97	0.92	0.07	0.19	0.79	0.97
Single-task	KneeZ	0.94	0.04	0.12	0.84	0.98	0.84	0.11	0.31	0.61	0.95
Dual-task	KneeX	0.89	0.08	0.22	0.73	0.97	0.74	0.09	0.27	0.44	0.92
Dual-task	KneeY	0.81	0.10	0.28	0.55	0.94	0.77	0.11	0.30	0.48	0.93
Dual-task	KneeZ	**0.68**	0.26	0.72	0.34	0.90	**0.53**	0.25	0.70	0.14	0.83

X: Sagittal plane (flexion-extension); Y: Frontal plane (abduction, adduction); Z: Transverse plane (internal rotation, external rotation); FAI: Functional Ankle Instability; ICC: Intraclass Correlation Coefficient; SEM: Standard Error of Measurement; MMDC: Minimal Metrically Detectable Change; CI: Confidence Interval; highlighted values show ICC < 0.7.

Table IV. Intrasession reliability of hip Lyapunov exponent (LyE) during the single task and dual-task conditions in participants with FAI and healthy controls.

Conditions	Variables	Healthy					FAI				
		ICC	SEM	MMDC	95%CI for ICC		ICC	SEM	MMDC	95%CI for ICC	
					Lower	Upper				Lower	Upper
Single-task	HipX	0.86	0.07	0.20	0.66	0.96	**0.63**	0.09	0.25	0.27	0.88
Single-task	HipY	0.95	0.05	0.14	0.86	0.98	0.87	0.04	0.12	0.67	0.96
Single-task	HipZ	0.90	0.05	0.14	0.74	0.97	0.96	0.08	0.22	0.91	0.99
Dual-task	HipX	0.83	0.10	0.29	0.60	0.95	0.74	0.08	0.24	0.43	0.92
Dual-task	HipY	0.86	0.11	0.30	0.66	0.96	**0.58**	0.05	0.15	0.20	0.85
Dual-task	HipZ	**0.47**	0.18	0.51	0.07	0.80	**0.61**	0.29	0.82	0.24	0.87

X: Sagittal plane (flexion-extension); Y: Frontal plane (abduction, adduction); Z: Transverse plane (internal rotation, external rotation); FAI: Functional Ankle Instability; ICC: Intraclass Correlation Coefficient; SEM: Standard Error of Measurement; MMDC: Minimal Metrically Detectable Change; CI: Confidence Interval; highlighted values show ICC < 0.7.

Kinematic variables

In examining the reliability of the two groups, different values were obtained according to the test's conditions. For ankle joints, healthy individuals in both single and dual-task conditions at three planes had high and very high ICC values ranging from 0.79 to 0.91, respectively. FAI group had the same ICC values in both single and dual-task (0.75-0.92), except for the LyE in the transverse plane during the cognitive task with a moderate ICC value of 0.62.

Knee joints in healthy participants showed high and very high values in ICC in a single task ranging from 0.87 to 0.94. For the dual task, the LyE in the transverse plane had a moderate ICC value of 0.68, but the other two kinematic planes indicated high reliability (0.81 and 0.89). In the FAI group, all individuals in both walking conditions had high and very high ICC values ranging between 0.74 and 0.92, except for the LyE in the frontal plane with a cognitive task that showed moderate ICC values of 0.53.

For hip joints, healthy participants indicated high and very high ICC values in both conditions ranging from 0.83 to 0.95, except for the LyE in the transverse plane with dual-task, which had a low ICC value of 0.47. People with FAI showed moderate ICC values in the sagittal plane (0.63), high and very high values in the frontal plane, and transverse plane in a single task, respectively (0.87 and 0.96). For dual-task, the ICC value in the sagittal plane was high (0.74), and in the frontal plane (0.58) and transverse plane (0.61) were moderate.

In general, ICC values of 5 out of 18 (27%) variables were lower than 0.70 in individuals with FAI. In the healthy group, these values were 2 out of 18 (11%). In healthy individuals, ICC values in single-task conditions ranged from 0.86 to 0.95, and in dual-task conditions ranged from 0.47 to 0.89. The ICC values for people with FAI in single-task ranged from 0.62 to 0.96, and in dual-task ranged from 0.53 to 0.85.

Cognitive task variables

The reliability of the two variables of the cognitive task is shown in **table V**. The ICC values for average reaction time in healthy and FAI groups were 0.84 and 0.95, respectively. The ICC values for the error ratio in healthy and FAI groups were 0.43 and -0.01, respectively. Negative ICC values indicated poor reliability due to the highly variable data for the error ratio.

Table V. Intrasession reliability of error ratio and averaged reaction time during the dual-task condition in participants with FAI and healthy controls.

Variables	Healthy					FAI				
	ICC	SEM	MMDC	95%CI for ICC		ICC	SEM	MMDC	95%CI for ICC	
				Lower	Upper				Lower	Upper
Error ratio	**0.43**	8.10	22.47	0.03	0.78	**-0.01**	5.39	14.95	-0.29	0.45
Average reaction time	0.84	0.01	0.03	0.61	0.95	0.95	0.01	0.03	0.87	0.98

FAI: Functional Ankle Instability; ICC: Intraclass Correlation Coefficient; SEM: Standard Error of Measurement; MMDC: Minimal Metrically Detectable Change; CI: Confidence Interval; highlighted values show ICC < 0.7.

DISCUSSION

Conducting research on reliability is a valuable method to ensure that measurement error is lower than the treatment effect. In other words, the higher correlation among different trials to examine the reliability can minimize the risk of type II error, thereby increasing the power of variable measures (26). In the present study, intrasession relative reliability in the FAI group was high to very high in 13 out of 18 variables. We found five variables with moderate ICC values, three under dual-task conditions. We also discovered that 16 out of 18 variables in healthy subjects demonstrated high to very high relative reliability. Two variables with low and moderate ICC values were when the dual-task was applied. The ICCs in dual-task walking - while slightly lower than the ICCs in normal walking, probably due to greater task complexity - represent moderate to very high reliability. Regardless of the effect of cognitive load, intrasession reliability in healthy subjects was generally higher than in subjects with FAI. In agreement with this result, previous studies have shown gait variability to be less reliable in people with postural instability (29) and dementia (30) compared to healthy individuals. Gait impairments and fluctuation of motor performance may result in less reliable estimates of gait variability.

The results of absolute reliability based on kinematic measures agree with the results of the relative reliability of intrasession, in which the higher the SEM, the lower the reliability of the test and the less precision in measurement. The cognitive perturbations can provoke gait dynamics, so SEM and MMDC values were generally higher across dual-task conditions. In contrast, Hamacher's investigation revealed that the reliability of the trunk parameter LyE was similar during normal treadmill walking and walking while texting (10). The differences in ICC values might result from different walking tasks analyzed. The study of Hamacher *et al*. (10) analyzed walking with a predetermined walking speed, whereas we analyzed gait kinematics with a preferred walking speed.

Based on the results, the variability in an individual's walking pattern is mainly reflected in the transverse plane motions. While applying a cognitive task could not affect the reliability of LyE in the ankle joint, the LyE of hip and knee joints in both groups in the transverse plane had lower reliability in dual-task than in other planes. This finding is consistent with a systematic review by McGinley *et al*. It is not surprising as the lowest reliability and highest error frequently occurred in the hip and knee transverse planes (< 0.60) due to the limited range of movement (28). Specifically, McGinley *et al*. identified hip rotation angles susceptible to the highest error. The small ranges of movement in the plane angles can compromise the signal-to-noise ratios of these angles and, thus, compromise their reliability (31). In agreement with this result, another study examined the absolute reliability of gait parameters in healthy subjects and found the highest measurement errors in the transverse plane (32). The use of marker clusters in our study appears to improve the reliability of non-sagittal plane kinematic data as opposed to mentioned studies, which could be partly due to reduced skin movement artifact (33).

Regardless of the plane effect, the reliability of LyE of the knee and hip joint was lower than the ankle joint, particularly with the cognitive tasks. This result may be related to the joint angle changes and flexibility of the two joint muscles crossing the hip and knee joints, causing the instantaneous position of the hip and knee joint centers to be more variable than the ankle joint center (34). Also, previous research shows that proximal joints increase variability to prevent damage to distal joints (35). The sensory-perceptual impairments associated with patients with FAI may underlie this protective movement strategy to redistribute the impact from the unstable distal joint (*e.g*., ankle) to more stable proximal joints (*e.g*., knee and hip) due to mechanical advantages of the proximal joints (*e.g*., longer muscle fibers, greater muscle volume, and strength) during dynamic tasks (36).

According to our outcome, which is consistent with the finding of a systematic review (28), the reliability of sagittal and frontal planes was typically higher than 0.80 and 0.70 in most studies, respectively. Nazary-Moghadam *et al*. studied the reliability of knee flexion-extension LyE in people with and without anterior cruciate ligament deficiency under single and dual-task walking (37). Similar to the present study, the knee flexion-extension LyE had high intrasession reliability, with ICC values above 0.70.

The relative intrasession reliability of the auditory Stroop task showed that average reaction times were higher than error ratios in both groups. Some studies used auditory Stroop concurrently with postural tasks. Similarly, all these studies concluded that average reaction time is a more appropriate measure than error ratio (38-40).

The LyE is considered a useful measure in estimating the ability to withstand perturbations in human walking. Several studies (10, 37, 41, 42) have demonstrated lower LyE values of the lower limb joint angles during challenging situations and postural task difficulty in the clinical population compared with those of healthy individuals. Because all these studies were conducted in one session, their findings may be comparable with those of the present study. Moderate to very high intrasession relative reliability in both the FAI and healthy groups indicates that measurement error might be less than the variability between participants; consequently, the possibility of error type II would be limited. An essential point in this study is that the LyE of gait kinematics seems to be a sufficiently reliable measurement when comparisons between the FAI and healthy patient groups are obtained in one session.

The current study had some limitations. First, the findings could be generalized only to males with FAI. Future studies remain to assess the reliability of the LyE of gait kinematics in females with FAI and other groups with a varying history of injury during different motor/cognitive tasks. The other limitation was the small sample size. It suggests performing future research with a larger sample size to have a more precise estimation of the reliability of kinematic measures in subjects with and without FAI. Also, gait testing took place within one session in the present study. Future investigations should also consider evaluating the intersession reliability between sessions to reach a more comprehensive result.

CONCLUSIONS

In normal and dual-task walking, outcomes were comparable and indicated moderate to very high reliability, making it potentially helpful in detecting gait pathology. The low reliability in the hip and knee transverse plane requires consideration in data interpretation.

CONTRIBUTIONS

SSN: conceptualization. TB, SSN: methodology. MY, Z.E: investigation. TB: data analysis. TB, AD, SSN: writing – original draft. TB, AD, SSN: writing – review and editing.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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ORIGINAL ARTICLE

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Shoulder Function in Swimmers with and without Scapular Dyskinesia

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SUMMARY

Background and purpose. Considering the importance of the effect of scapular dyskinesia on movement patterns and performance in swimmers, it conducted this study to investigate shoulder function in swimmers with and without scapular dyskinesia.

Materials and methods. The present study was cross-sectional and included sixty professional male swimmers between 18 and 30 years old with and without scapular dyskinesia. McClure's test was used to identify people with scapular dyskinesia. It took a caliber test to measure the brachial scapular rhythm. SPSS 23 software was used for analysis. Independent t-test was used to examine the difference between groups at a significance level of 0.05.

Results. The results showed a significant difference between the feeling of shoulder joint position at 45 and 135-degree angles in swimmers with and without scapular dyskinesia ($p < 0.05$). There is a significant difference between the functional stability of the upper limbs of swimmers with and without scapular dyskinesia ($p < 0.05$). Also, there is a significant difference between the perception of shoulder joint strength of swimmers with and without scapular dyskinesia ($p < 0.05$).

Conclusions. Identifying the effects of dyskinesia on the sense of shoulder joint position, functional stability, and sense of force perception as one of the risk factors and as a target point for prevention and preventing the risk of chronic injuries in these people.

KEY WORDS

Shoulder; function; swimmers; dyskinesia; scapular.

INTRODUCTION

The shoulder complex is designed to achieve the greatest range of motion (ROM) with the most significant degrees of freedom of any joint system in the body (1). Hypermobility of the shoulder at the glenohumeral and scapulothoracic joints is balanced by the stability of the acromioclavicular and sternoclavicular joints. A complex ligamentous system contributes to primary stability at the glenohumeral joint, and a complex muscular ligamentous system acts as a secondary stabilizer. This support mechanism allows the shoulder to withstand large external forces while providing sufficient mobility for the upper extremity to perform complex movement patterns (2). A superb example of balance between shoulder mobility and stability occurs in sports that require overhead movements. Many overhead sports, such as throwing, racquets, and volleyball, require two or three overhead movement patterns (3).

Conversely, swimming requires multiple overhead movement patterns that include continuous clockwise and counterclockwise rotation of the arm. A competitive swimmer typically performs more than 4,000 strokes per shoulder in a single workout, making the sport a common source of shoulder pathology, and shoulder pain is the most common musculoskeletal complaint in swimming (4, 5).

With sports development and people's tendency towards championship sports, sports injuries have increased, making researchers focus on discovering the causes of injuries (6). A good posture requires the coordination of different body parts, and one of the parts that play an essential role in maintaining a good posture is the scapula. Improper movement of the scapula during shoulder movement is called scapular dyskinesia and is a neglected cause of pain and dysfunction. Scapular dyskinesia can be clinically characterized by medial or infero-medial ridge protrusion, scapular elevation or initial (earlier) elevation during arm elevation, or rapid downward rotation during arm abduct (7). Scapular dyskinesia was reported in 68% of patients with rotator cuff problems, 94% of patients with glenoid injury, and 100% of patients with glenohumeral instability (8). Scapular dyskinesia syndrome means (days: changes, kens: movement) changes in the movement and position of the scapula, which can be associated with shoulder syndrome. The only bone stabilizer of the scapula is the clavicle, and the proper functioning of the muscles plays an essential role in the stability of the scapula. Significant clinical findings have shown that changes in the position and movements of the scapula cause the scapula to become prominent concerning the trunk during movement or rest. A muscle imbalance between the upper trapezius and serratus anterior muscles mainly causes scapular dyskinesia (9-11). The scapula is a vital part of the upper extremity kinematic chain and a critical component of the glenohumeral rhythm, a significant determinant of upper extremity efficiency. Overhead athletes are at a higher risk of developing scapular dyskinesia. Although swimming is considered an overhead sport, information on scapular dyskinesia in these athletes is limited (12, 13). Considering the critical role of the shoulder in every aspect of shoulder movements, its natural position, and placement on the chest in both static and dynamic states is essential to performing arm movements and preventing shoulder injuries in swimmers (14). The research shows that most sports injuries in swimmers occur in the upper limbs and especially in the shoulder joint. One of the most common injuries in this area in these people is the swimmer's shoulder syndrome, which is the result of tissue entrapment in the subarachnoid area, and one of the risk factors for this injury is scapular dyskinesia syndrome (15). The anterior dentate muscle is a stabilizing and moving muscle in this area. The lower and middle parts of the anterior dentate muscle, with the front and enamel parts of the trapezius muscle form a power couple that controls the rotation and coordination in the movements of the scapula. As the arm moves into abduction, the scapula rotates upward to provide adequate space for the structures under the occipital arch (11, 16, 17). Suppose scapular dyskinesia is related to the disorder of scapular muscle strength due to scapular instability. In that case, changes in scapular movement in people with scapular dyskinesia are permanent, or these changes increase as the load on it increases (18). Swimmers are constantly exposed to shoulder and back injuries, so applying unnatural forces to overcome the water resistance is known to be one of the possible causes of this injury. The high prevalence of shoulder injuries in swimmers and the alarming consequences show the necessity of knowing the risk factors and the exact mechanisms of this injury, as well as identifying people at risk and applying preventive measures (19). Recent research has shown the pivotal role of the scapula in shoulder function, shoulder injury, and shoulder rehabilitation. This knowledge helps the physician provide more comprehensive care for the athlete. Usually, swimming represents a competitive sport. However, the current literature on the prevalence of scapular dyskinesia in swimming is limited. The majority of shoulder pain among competitive swimmers is high, but there are no guidelines for reducing shoulder injuries. Elucidating the differences between swimmers with and without shoulder pain can be a basis for developing a program to prevent shoulder injuries that may lead to pain and impaired performance (20). Due to the importance of injury risk factors such as scapular dyskinesia on movement patterns, it is necessary to identify the impact of this defect on the ability of swimmers so that by identifying it as one of the risk factors, it can be placed as a target point for prevention exercises and the risk of injuries prevent chronic disease in these people. Considering that defects in movement patterns can cause changes in the movement chain and potentially lead to injuries, it is important to identify and address these issues early on. This can help prevent more serious injuries from occurring, such as swimmers' shoulder injuries. By identifying these issues in an athlete's movement patterns and taking appropriate measures to address them, can coaches and health professionals prevent injuries before they occur?

MATERIALS AND METHODS

The current cross-sectional study was conducted on 60 professional male swimmers (a professional athlete is someone who must devote at least three hours to her/his specialized training during the day) (n = 30) with scapular dyskinesia and (n = 30) without scapular dyskinesia, 18-30 years old (1). The criteria for entering the study included having a continuous 3-year experience in swimming, having a Body Mass Index (BMI) (kg/m^2) of 18.5 to 25, not having any abnormalities affecting the research process (such as kyphosis, scoliosis, reclined back, uneven shoulder), and completing the consent form to participate in the research. The exclusion criteria for the participants were an age group higher than the purpose of the study, lack of consent to cooperate in the research process, and causing any pain during the work process.

The Ethical Committee of Hamadan University of Medical Sciences approved the study (IR.UMSHA.REC.1401.218 – Date of approval: May 21, 2022).

Data collection

After completing the consent form by the research subjects in the Tehran University gym club, swimmers warm up period before identifying the scapular dyskinesia. McClure's test was taken from the issues to identify scapular dyskinesia (percentage of agreement McClure's test was between 75% and 82%, and ϰw ranged from 0.48 to 0.61 (21)) in such a way that the researcher placed two dumbbells weighing 1.5 kg in both hands of the subjects. The person was asked first to raise his arms from zero degrees of flexion to 180 degrees of arm extension and after a 3-second pause, return his hands to the first position. At this time, the researcher stood behind the subject and observed the movement of the athlete's shoulder (the athlete did not have any clothes on his shoulder). If the athlete has scapular dyskinesia, the inner edge of the scapula is separated from the trunk, and the scapula has undergone internal rotation. Then the Kibler test was taken from the athletes to measure the brachial scapular rhythm. This test was performed in three positions of 0, 45, and 90 degrees of the arm, and based on the modified method, the distance from the lower angle of the scapula to the nearest vertebral spinous process was measured in each of the tips of the arm. By subtracting the 45 and 90 curves from the zero-degree angle in the measurements, a difference of more than 1.5 mm was recorded as external rotation, and a difference of less than 1 mm was recorded as internal rotation.

Kibler *et al*. were pioneers in the classification of scapular dyskinesia. Up to today, the 4-type classification is the most commonly used method in scientific studies to determine if participants display scapular dyskinesia or not. The 4-type classification has been evaluated regarding its reliability by the author himself. They found intra-rater reliability of k = 0.5 and inter-rater reliability of k = 0.4. This means that this method is moderately reliable (22, 23).

Then the subjects were asked to fill DASH questionnaire and the Nordic questionnaire.

The upper body Y test was used to quantitatively evaluate the ability of a person to perform this test. The person was asked to complete the reach operation with the free hand while the other was in a weight-bearing position in internal, inferior-external, and superior-external directions. The stability of the supporting hand was evaluated, while the mobility of the trunk and reach was assessed. During each exercise, shoulder stability and mobility, trunk rotation, and blind area stability were involved. A person needs more balance, proprioception, strength, and range of motion to reach an area outside the surface of the remote support. For normalization in the upper body test, the person was asked to abduct the arm to 90 degrees, and then the distance between c7 and the tip of the person's middle finger was calculated using a tape (KOMELON company) measure. The score in each direction was calculated based on the average of three successful attempts that were normalized. First, the more significant normalized score in each order obtained from three repetitions was summed to calculate the combined score. Then the more essential efforts in all three principles were added together. And divided by three and multiplied by 100, the individual's combined score was extracted to determine the individual's overall performance in this test.

To measure functional isometric strength, all tests were performed with a prone position on the floor using a 4 cm foam block with the person's forehead resting on it. And data analysis was done. In Test I, the shoulder was in full abduction (in line with the body), the forearm was in pronation, and the heel of the hand acted as the main point of contact with the force plane. In the Y-test and the T-test, the arm was 135 degrees and 90 degrees in shoulder abduction, respectively. In all tests, the elbow was fully extended (**figure 1**).

After a standard warm-up consisting of two submaximal efforts from 0% to 90% in each test position, subjects

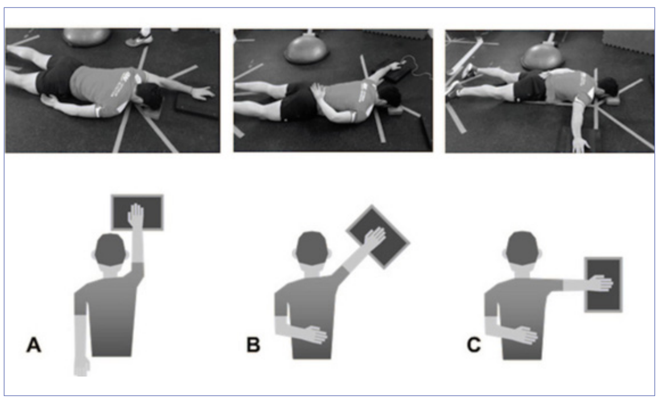

Figure 1. Measurement of functional isometric strength.

performed three attempts in three different places on the same limb. Then this procedure was repeated with the opposite limb. For the Y and T-tests, the opposite arm was placed behind the back so that the elbow does not touch the floor or cause trunk rotation. But in Test I, the arm was allowed to remain at the subject's side due to lower body rotational forces.

Data analysis

The statistical method used in this research included descriptive and inferential statistics. We were considering the normality of data distribution to compare two groups, independent t-test was used at a significance level of 0.05. All statistical analysis was performed using SPSS version 24.

RESULTS

Descriptive information related to the age, height and weight of the subjects is shown in **table I**.

Descriptive information related to research variables is shown in **table II**.

The Kolmogorov-Smirnov test was used to determine the normality of data distribution. Based on this test, the distribution is expected when the P-value is greater than the critical number at the 0.05 level. The results of this test showed that the distribution of all research variables was normal. To compare the feeling of the shoulder joint position in swimmers with and without scapular dyskinesia, an independent t-test was used, the results of which are presented in **table III**.

According to the statistics and the significance level of the independent t-test between the feeling of the shoulder joint position at angles of 45, There is a significant difference between 135 degrees of swimmers with and without scapular dyskinesia ($p > 0.05$). This means a significant difference exists between swimmers' sense of shoulder joint position with and without scapular dyskinesia. An Independent t-test was used to compare the perception of shoulder joint force in swimmers with and without scapular dyskinesia. According to the statistics and significance level of the independent t-test ($t = -3.24$ and $p = 0.002$), it was determined that there is a significant difference between the feeling of shoulder joint strength of swimmers with and without scapular dyskinesia. To compare the functional stability of the upper limb in swimmers with and without scapular dyskinesia, an independent t-test was used. According to the statistics and significance level of the independent t-test ($t = 2.27$ and $p = 0.026$), it was found that there is a significant difference between the functional stability of the upper limbs of swimmers with

Table I. Distribution of mean and standard deviation of age, height, and weight in different groups.

Variable	Group	Number	Mean ± SD
Age	Swimmers without scapular dyskinesia	30	22.80 ± 3.39
	Swimmers with scapular dyskinesia	30	24.10 ± 3.85
Weight	Swimmers without scapular dyskinesia	30	59.36 ± 6.69
	Swimmers with scapular dyskinesia	30	59.73 ± 4.73
Height	Swimmers without scapular dyskinesia	30	165.30 ± 10.39
	Swimmers with scapular dyskinesia	30	164.23 ± 10.17

Table II. Average distribution and standard deviation of research variables in different groups.

Variables	Group	Mean ± SD	
Sense of the position of the shoulder joint	45 dg	Swimmers without scapular dyskinesia	3.76 ± 1.85
		Swimmers with scapular dyskinesia	5.63 ± 2.20
	135 dg	Swimmers without scapular dyskinesia	4.73 ± 2.06
		Swimmers with scapular dyskinesia	6.70 ± 1.80
Sense of shoulder joint strength		Swimmers without scapular dyskinesia	6.43 ± 2.73
		Swimmers with scapular dyskinesia	8.93 ± 3.20
Functional stability of the upper limb		Swimmers without scapular dyskinesia	83.17 ± 5.85
		Swimmers with scapular dyskinesia	80.00 ± 4.88

Table III. Independent t-test results on the sense of position and perception of force in the shoulder joint and functional stability of the upper extremity of swimmers with and without dyskinesia.

Variable	Levene's Test		Independent *t*-test			
	F	p	Mean difference	t	Degrees of freedom	p
45 dg	1.070	0.303	-1.86	-3.55	58	0.001
135 dg	0.780	0.380	-1.96	-3.92	58	< 0.001
Understanding force	0.780	0.380	-2.50	-3.24	58	0.002
Performance Stability	0.820	0.368	3.16	2.27	58	0.026

and without scapular dyskinesia. The mentioned items are shown in **table III**.

DISCUSSION

This study investigated shoulder function in swimmers with and without scapular dyskinesia. Results of studies on whether scapular dyskinesia is a cause or a symptom of shoulder functional pathology vary, but it is believed to be a risk factor for further injury (24). The role of the scapula in upper extremity function has received considerable interest in recent years as our knowledge of the shoulder and surrounding structures has increased. The scapula plays several roles in facilitating optimal shoulder function when scapular anatomy and biomechanics interact to produce efficient movement. In normal upper-quarter function, the scapula provides a stable base from which glenohumeral mobility occurs. Stability at the scapulothoracic joint depends on the surrounding musculature. The scapular muscles must dynamically position the glenoid so that efficient glenohumeral movement can occur. When weakness or dysfunction is present in the scapular musculature, normal scapular positioning and mechanics may become altered. When the scapula fails to perform its stabilization role, shoulder function is inefficient, which can result not only in decreased neuromuscular performance but also may predispose the individual to shoulder injury. Clinical identification focuses on visual observation and examination procedures. It is thought to be more common in overhead athletes due to their reliance on unilateral upper extremity function, but its incidence has been unknown. According to the obtained results, as expected, we found a significant difference between the sense of shoulder joint position of swimmers with and without scapular dyskinesia (25).

In Matthew *et al.*'s systematic study, twelve studies including 1,401 athletes (1,257 overhead and 144 non-overhead; average age 24.4 ± 7.1 years; 78% male) were analyzed. They reported Scapular dyskinesis was found to have a greater reported prevalence (61%) in overhead athletes compared with non-overhead athletes (33%) (26).

In Jacopo *et al.*'s study, to determine the prevalence of scapular dyskinesia in asymptomatic young and elite swimmers, a total of 661 asymptomatic elite swimmers were examined for scapular dyskinesia, using a dynamic test consisting of examining the shoulder blades throughout the forward bending movement at the same time. The sagittal plane was evaluated and considered as present or absent. Scapular dyskinesia was diagnosed in 56 participants (8.5%). Type I scapular dyskinesia was the most common (46.5%). Male participants were twice as likely as female participants to have scapular dyskinesia, and no association was found between the dominant limb and the affected side (p = 0.258). Instead, a correlation was found between the breathing side and the affected side, such that swimmers with a preferred breathing side were more prone to develop scapular dyskinesia in the opposite shoulder (p < 0.05). Swimmers participating in long-distance events were found to be at higher risk of developing scapular dyskinesia (p = 0.01). Their results showed that scapular dyskinesia may be an asymptomatic condition in young elite swimmers and are present in 8.5% of these athletes. Early diagnosis may be useful for asymptomatic athletes with scapular dyskinesia and prevent its possible evolution into a symptomatic disease, which is in line with the aim of our study (12). In this regard, Tate *et al*. in one study, a sample of 142 collegiate athletes (National Collegiate Athletic Association Division I and Division III) participating in sports that required the use of the arm was rated and 66 of them underwent 3D. The kinematic data of both groups were evaluated through multivariate analysis of variance with *post-hoc* test and using the least significant difference method to compare the relationship between symptoms and scapular dyskinesia with odds ratio. The difference between the two groups of normal and overt dyskinesia was determined. Participants with overt dyskinesia showed higher scapular rotation (p < 0.001), lower clavicle height (p < 0.001), and greater clavicle extension (p = 0.044). The presence of shoulder symptoms did not differ between normal and overt dyskinesia volunteers (OR 0.79, 95% CI 0.33-

1.89). Subjects with scapular dyskinesia had less upward rotation during shoulder abduction and also reported a greater increase in an anterior tilt. In the present study, it was found that after performing interventional exercises, shoulder rotation increases and anterior tilt decreases in people with dyskinesia (27). In this connection, Huang *et al*. studied kinematics and muscle activity in people with scapular dyskinesia. A vision-based method was used to evaluate participating athletes with unilateral shoulder pain. Scapular movements during raising/lowering of arms as a single abnormal pattern (inferior angle protrusion - pattern I; medial edge protrusion - pattern II; excessive/insufficient scapular extension or upward rotation - pattern III), mixed patterns. They are classified as abnormal or normal patterns (fourth pattern). Scapular kinematics and related muscle activation were investigated with an electromagnetic motion recording system and surface electromyography. The results showed that the internal rotation of the scapula was observed more in people of pattern II and mixed pattern I than in control people when lowering the arm. The posterior tip of the degree was less in model I during the abduction of the arm. Upper trapezius activity was observed in individuals with pattern II during arm lowering. In addition, inferior trapezius and anterior serratus activity were lower in subjects with a brief pattern I and II during arm lowering. Specific changes in scapular muscle activation and kinematics were observed in different patterns of scapular dyskinesia. These findings also support using a comprehensive classification test to assess scapular dyskinesia, especially in the adduction phase (28). Another study, the results of which can be considered consistent with this study, is the study by Ou *et al*., in the study of scapular kinematic changes and related muscle activation in people with scapular dyskinesia. To investigate whether people with symptomatic scapular dyskinesia can achieve optimal movements and related muscle activities through conscious control, this research was conducted on 60 subjects with scapular dyskinesia (16 lower angles pattern I, 16 internal border pattern II and 28 mixed patterns) performed three selected exercises (arm elevation, lateral elevation, and passive external rotation) with and without conscious control. Three-dimensional electromagnetics and electromyography recorded scapular kinematics and muscle activation during the exercises. became. For scapular kinematics, a significant increase in scapular external rotation with conscious control during arm elevation and lateral arm elevation was observed in three groups. A significant increase in the activation of the middle and lower trapezius with conscious control was observed in the three exercises among the dyskinesia group. Increased serratus activation was found in the concentric phase of lateral external rotation in the pattern I and I+II groups. Conscious control of the scapula can improve scapular orientation and activation of the middle and lower trapezius and serratus during three selective exercises in subjects with symptomatic dyskinesis. To change, specifically, conscious control during external limbic rotation can increase serratus activity in the pattern I and I+II dyskinesias (29). In a study, Zandi *et al*. compared the functional stability of dominant and non-dominant shoulders in female volleyball players with and without anterior shoulder instability using YBT-UQ. In this study, the upper fourth balance test (YBT-UQ) was used to measure the functional stability of the dominant and non-dominant shoulders. After examination, the YBT-UQ composite score was higher in the non-dominant shoulder and the dominant shoulder of the healthy group and the non-dominant shoulder and the dominant (damaged) shoulder of shoulder instability, respectively. No significant difference was observed between the healthy group's functional stability of both shoulders ($p = 0.144$). In contrast, the functional stability of the non-dominant shoulders of the instability group was significantly higher than the unstable dominant shoulders ($p = 0.001$). The functional stability results of the unstable shoulders of the injured group were significantly lower than the results of the dominant shoulders of the healthy group, while on the non-dominant side, all directions except the supernumerary direction showed a significant difference. According to the results of this study, the functional stability of the unstable shoulder of university female volleyball players is lower than the functional stability of their non-dominant side or the functional stability of healthy people (30). In their study, Khaki *et al*. (31) found that athletes had a significant difference in the range of internal rotation ($p = 0.00$), less external rotation ($p = 0.02$), and more external rotation ($p = 0.02$) in the dominant shoulder compared to the non-dominant shoulder and compared to non-athletes ($p = 0.00$). The study also investigated the changes in range of motion in the rehabilitation of joint injuries and how it changes before shoulder injuries in throwing athletes, as well as the challenges of post-injury rehabilitation. The results showed that the range of shoulder rotation of throwers is shifted towards more external rotation and less internal rotation due to microtrauma caused by repeated throwing. These changes, which are not related to the type of throwing (upper arm or underarm), are one of the causes of shoulder pain in athletes (31). However, these findings are not consistent with the results of our study. In another study by Kibler *et al*., the role of scapular dyskinesia on the glenohumeral was investigated. The exact role and function of the scapula can be understood in many clinical situations. This lack of awareness is often interpreted as an incomplete assessment and diagnosis of shoulder problems. In addition, shoulder rehabilitation is often overlooked. However, recent research has shown the pivotal role of the scapula in shoulder function, shoulder injury, and shoulder rehabilitation (32). Optimal shoulder function is an integral component of optimal shoulder function. Multiple roles of the scapula have been identified in arm function and throwing, while scapular dysfunction continues to be associated with various shoulder pathologies. Although scapular motion changes may be common in overhead athletes, various reports have shown that identification and change management can lead to improved rehabilitation and functional outcomes. Since arm throwing movements in swimming occur due to integrated, multipart, sequential joint movement and muscle activation in the kinetic chain, function and dysfunction in the kinetic chain must be understood. Additionally, the scapula is a key link in the chain through its function of maximizing scapular rhythm and efficient throwing mechanics (33).

Therefore, assessment and management starting with the shoulder can lead to improved outcomes associated with shoulder pathology in swimmers. Although rehabilitation programs follow principles, they must be individualized based on the patient's presentation and return-to-sport needs. This study discusses scapular dyskinesia as a functional disorder associated with throwing injuries and altered performance and the relevance of the diseases to develop appropriate treatment in the future. This knowledge helps doctors to take more comprehensive care of the athlete. The evidence has shown that with the corrective method of controlling people with symptoms of scapular dyskinesia, they have recovered their correct posture, which is accompanied by a decrease in pain and an increase in the range of motion in the shoulder girdle. Swimmer's shoulder is a condition that may be identified with proper pre-season screening to identify disorders and training errors that may lead to symptoms. Suppose the swimmer becomes symptomatic during the season. In that case, the health and pathology specialist should identify the most likely disorders or training errors and investigate any significant tissue pathology requiring referral to an orthopedist. A comprehensive rehabilitation program usually includes strengthening the rotator cuff and scapular stabilizers, stretching the pectoralis anterior muscles that may be shortened, and applying activity modifications so that the athlete can continue to participate in sports. Future research should focus on addressing specific injuries before the season can reduce the incidence of a swimmer's shoulder and evaluate which injuries are the most significant risk factors. The results of the present research showed a significant difference in the performance of the scapula between people with dyskinesia and healthy individuals. This finding suggests that coaches and professional athletes, by repeating and practicing extensively on one side, may inadvertently cause problems on the opposite side, which can significantly impact the athlete's performance. On the other hand, paying attention to the condition of the involved body part and correcting any dyskinesia before training, can be very effective in improving the athlete's performance. According to the research results, it is suggested to classify people with dyskinesia based on the disease before starting sports and the disease as a result of exercise and compare the performance of the scapula to those without dyskinesia.

CONCLUSIONS

Swimmer's shoulder is a musculoskeletal condition that results in symptoms in the area of the anterior lateral aspect of the shoulder, sometimes confined to the subacromial region. The onset of symptoms may be associated with impaired posture, glenohumeral joint mobility, neuromuscular control, or muscle performance. Additionally, training errors such as overuse, misuse, or abuse may also contribute to this condition. In extreme cases, patients with swimmer's shoulder may have soft tissue pathology of the rotator cuff, long head of the biceps, or glenoid labrum. Physical therapists involved in the treatment of competitive swimmers should focus on prevention and early treatment, addressing the impairments associated with this condition, and analyzing training methods. Considering the importance of injury risk factors, such as scapular dyskinesia, on movement patterns, it is necessary to consider the impact of this defect on swimmers to identify it as one of the risk factors as a target point for prevention. Prevent the risk of chronic injuries in these people.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

MK: study design. HN: data collection. HN, SHB: writing. HN: editing and revision. RNV: data analysis., MK: discussion section improvement.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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