

# The Relationship between COL5A1 rs12722 Polymorphism and Flexion-Extension Lumbar Spine Range of Motion and Soft Tissue Injuries

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## SUMMARY

**Background.** Genetics may play a critical role in soft tissue injuries by influencing the level of range of motion. To this end, the aim of the study was to investigate the relationship between the COL5A1 rs12722 gene polymorphism and flexion-extension lumbar spine range of motion and soft tissue injuries

**Methods.** A total of 100 male athletes from elite level bodybuilding, wrestling, artistic gymnastics and football sports branches were included in the present study. Blood samples were taken from athletes to analyze the COL5A1 rs12722 gene polymorphism. Then, with the help of a goniometer, flexion-extension lumbar spine range of motion levels of the athletes were measured. ANOVA, Pearson Chi-Square and Fisher Free-man Halton exact tests were used in the statistical analysis.

**Results.** As a result, it was seen that 30% of the athletes had CC, 46% had CT and 24% had TT genotype. In terms of allele distribution, 53% of athletes had the C allele and 47% had the T allele. There was a statistically significant difference between the COL5A1 rs12722 and flexion lumbar spine range of motion ( $p < 0.05$ ). On the other hand, there was no statistically significant difference in the other sub-dimensions ( $p > 0.05$ ).

**Conclusions.** In the study, it was concluded that the CC genotype and C allele of the COL5A1 rs12722 polymorphism may be associated with the increased level of range of motion in lumbar spine flexion. In conclusion, due to the increased level of movement, athletes may be significantly protected from soft tissue injuries.

## KEY WORDS

COL5A1 rs12722 polymorphism; lumbar spine; range of motion; soft tissue injury; sports.

## INTRODUCTION

Sporting performance is a complex phenomenon that is influenced by many factors. There are many factors that have an impact on this phenomenon. Genetics, which is a candidate to be one of these factors, may have a critical impact on athlete performance. Genetics is a multifactorial trait that involves athletic performance (1). Genetic traits possessed by athletes may have a key role for success in sports. When the success of the athletes was examined, it was observed that some of them could achieve the desired success with

3,000 hours of work and some with 10,000 hours of work. This may indicate that genetics may be an important marker in determining sporting success (2).

Athletes' hereditary conditions such as skeletal-muscle, respiratory, cardiovascular system efficiency and susceptibility to injuries may be critical in maintaining a healthy sports life. Sports injuries occur when the body's endurance limits are exceeded. The negativities caused by sports injuries may sometimes turn into an irreversible situation for athletes. Identifying the hereditary characteristics that cause

sports injuries can make great contributions to athletes and their coaches in terms of protection from injuries. Another dimension of sports injuries is their effects on the economies of the countries. The English Premier Football League is an example of this situation. In the Premier League, an average of £74.7 million was spent on sports injuries in a season, including medical fees and insurance costs (3). In this case, the abilities and physical development of the athletes may decline, and they may face an irreversible situation.

The injuries that athletes encounter during sports performance are mostly soft tissue injuries (4). Damage to tissues such as tendons, ligaments, muscles, etc., is known as soft tissue injuries. Although many factors are effective on soft tissue injuries, there may also be genetic factors that affect these injuries. To date, regarding soft tissue injuries in sports, *COL5A1*, *COL1A1*, *COL12A1*, *MMP1*, *MMP3*, *IGF2*, *EMILIN1*, *ESR1*, *SMAD6*, *TTN* and *TIMP2* gene variants have been identified (5-8). The *COL5A1* gene, which is assumed to be effective on collagen tissues, may be of great importance in soft tissue injuries.

The *COL5A1* gene has important effects on type V collagens (9). The *COL5A1* gene is responsible for the production of type V collagen which is called the Pro- $\alpha 1$  (V) chain. Collagens are rope-like procollagen structures consisting of three chains each. The combination of the two chains forms type V collagen. Three-stranded procollagen structures form mature collagen structures with the help of enzymes. These collagens turn into a thin and long structure with the help of type I collagen. Type V collagen regulates the range of these fibrils, that is, their thickness (10). The most common forms of type V collagen are heterotype chains consisting of 1  $\alpha 2$  propeptide and 2  $\alpha 1$  propeptide encoded by *COL5A1* and *COL5A2*, respectively (11).

The fact that collagen is structurally flexible and has a wide range of motion may protect athletes against soft tissue injuries. Flexibility is the ability of the muscle to contract, extend, be stimulated, transmit, and to expand the joints at an optimal level during movement (12). The joint range of motion, which has similar characteristics to flexibility, is an important skill in the development of physical fitness and sporting ability (13). Regardless of the sports branch,

improving joint range of motion may provide a number of benefits. These may be listed as improving athletic performance, protection from injuries and adaptation to activities (14, 15).

The joint range of motion level may be a trait controlled by hereditary factors. To this end, it is a trait that is influenced by both multifactorial phenotypes and genetic factors (16). For this reason, the *COL5A1* gene polymorphism may be an important biomarker in joint range of motion and soft tissue injuries (17-19, 21). The *COL5A1* gene is localized on the 9q34.3 long arm of chromosome 9 (**figure 1**).

In the study, male athletes from football, bodybuilding, gymnastics and wrestling branches were examined. This may explain due to have a higher injury rate male athletes than female athletes in these sports branches (22). The aim of the study was to investigate the relationship between the *COL5A1* rs12722 gene polymorphism and flexion-extension lumbar spine range of motion and soft tissue injuries. We think that the results of the study will make valuable contributions to sports science.

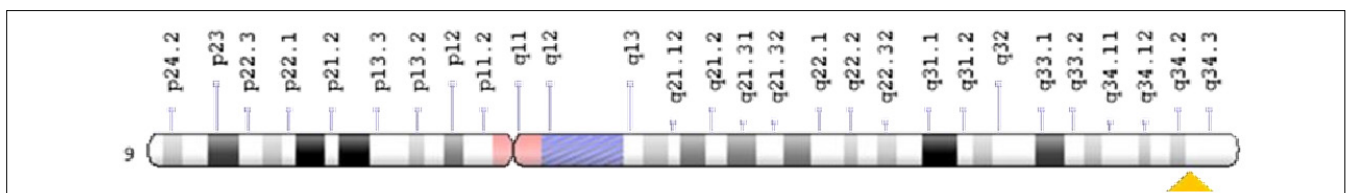
## MATERIALS AND METHODS

### The study group

The study group of the research consisted of a total of 100 athletes, 25 bodybuilders, 25 wrestlers, 25 artistic gymnasts and 25 footballers. Athletes were selected voluntarily and randomly for the study. The inclusion criteria for the study are presented in **table I**. The study was conducted in accordance with the Declaration of Helsinki. The study was approved by Ondokuz Mayıs University Clinical Research Ethics Committee, on February 26, 2021, with 2021/24 decision number. Additionally, permissions were obtained from the participants to be included in the study.

### The study design and data collection tools

The study was carried out in two parts. In the first part, the 10-question demographic information form was applied to the athletes by making the necessary explanations. Athletes were provided with the necessary time to answer each question.



**Figure 1.** *COL5A1* gene in genomic location.

**Table I.** Criteria for study participation.

Inclusion criteria
To be a male and Turkish athlete in the relevant sports branch over the age of 18.
To be active and regularly in elite level and related sports branches for at least 10 years.
To be a competitor at national and international level.
Not having any history of injury, especially in the lumbar spine region, before and during the measurements.
Not having any viral infectious diseases (COVID, hepatitis, diphtheria, dysentery, AIDS, tuberculosis, <i>etc.</i> ), bacterial diseases and continuous treatment.
Not having any genetic disease due to soft tissue damage. For example, Ehlers-Danlos Syndrome, <i>etc.</i>

Anthropometric characteristics of the athletes were measured at least twice, and the average of values were recorded. For height measurement, sensitivity  $\pm 1$  mm, device was used. Additionally, Xiaomi Mi Body Composition Scale 2 Model, sensitivity  $\pm 50$  g, digital scale was also used for weight measurement. Then, the athletes' Body Mass Indexes (B.M.I.) were calculated and recorded. Data obtained from athletes were presented by detailing in **table II**.

In the second part of the study, the flexion-extension lumbar spine range of motion levels of the participants were measured with a goniometer device. Before the measurements, the athletes were given general and special warm-up exercises, respectively. The athletes' flexion-extension lumbar spine range of motion levels were measured at least twice and the average results were recorded. The flexion-extension lumbar spine range of motion was measured by a manual goniometer with a length of 20 cm and a 360 degree rotation angle. Additionally, the goniometer measurements were performed by the test practitioner with the support of a doctor of physical therapy. This measurements were carried out with a similar technique and by the same person. The book, joint range of motion and muscle length testing, guided flexion-extension lumbar spine range of motion measurements (23).

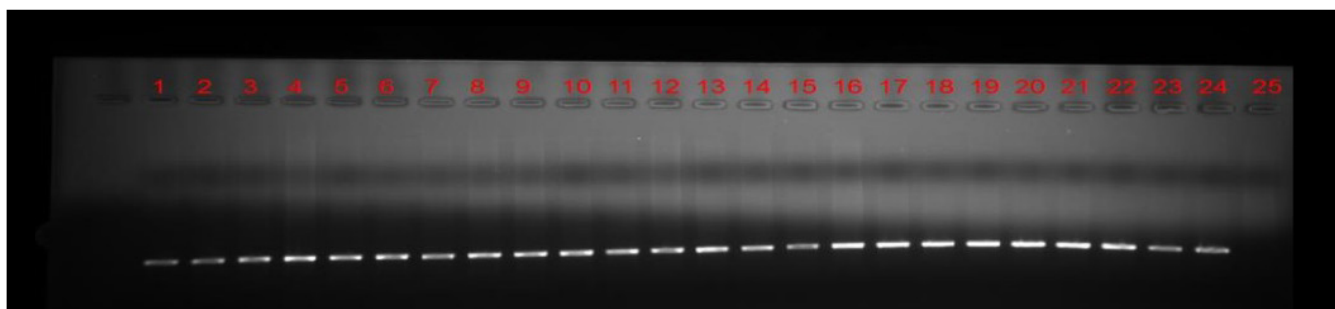
### Genotyping

In the present study, blood samples were taken by EDTA tubes. DNA isolation procedures were performed using DNA isolation kit from 100 blood samples. The isolated DNA samples were taken to the PCR reaction process to amplify the *COL5A1* 3'UTR gene regions. For the

**Table II.** Participant characteristics in study.

Variables	Groups	N	%
Age (years)	18-22	60	60
	23-28	15	15
	29-34	7	7
	35-40	7	7
	> 41	11	11
Height (cm)	160-165	6	5
	166-171	16	15
	172-177	38	37
	178-183	29	32
	>184	11	11
Weight (Kg)	50-65	32	32
	66-85	46	47
	86-100	16	15
	101-115	4	4
	>116	2	2
Body Mass Index Kg/m <sup>2</sup> )	18.5 and under	3	3
	19-24.9	57	57
	25-29.9	33	33
	30-34.9	3	3
	>35	4	4
Sports Branches	Bodybuilder	25	25
	Wrestler	25	25
	Artistic	25	25
	Gymnast	25	25
	Footballer	25	25
Soft tissue injury experienced for more than a month	Yes	36	36
	No	64	64
Soft tissue injury experienced for every year	Yes	14	14
	No	86	86
Total		100	100

*COL5A1* rs12722 (BstUI) region, 5'-GAAGACGGTCTTG-GAGACTG-3' was used as the forward primary and 5'-GAAGGCACCTGCAGAATGAC-3' was used as the reverse primer. New England M0285L Taq 5x Master Mix was used in the PCR reaction. Reaction conditions were prepared as master mix 5  $\mu$ l, forward primer 0.5  $\mu$ l, reverse primary 0.5  $\mu$ l, DNA 3  $\mu$ l, ddH<sub>2</sub>O 16  $\mu$ l total 25  $\mu$ l. PCR reactions were performed as 3-minute denaturation at 94 °C, 1 minute at 94 °C, 1 minute at 53 °C, 1 minute 35 cycle at 72 °C and 8 minute elongation reaction at 72 °C. The



**Figure 2.** Gel electrophoresis image of COL5A1 rs12722 polymorphism.

products obtained after PCR were processed in 2% agarose gel at 90 volts and 90 minutes. The Sanger Method was used for sequencing. (24). The sequence PCR program was performed in 25 cycles of 1 minute at 96° C, 10 seconds at 96 °C, 5 second at 50 °C and 4 minute at 60 °C. The samples were loaded into the ABI 3130 genetic analyser device and one-way sequencing was performed.

The gel electrophoresis image of the COL5A1 rs12722 polymorphism was shown in **figure 2**.

### Statistical evaluation

SPSS 22.0 package statistical program was used in the analysis of the data. In more than two group comparisons, the ANOVA test was used. Chi-square and Fisher Freeman halton exact tests were used to determine whether there is

a relationship between categorical independent variables. The statistical significance level was determined as  $p < 0.05$ . The Hardy-Weinberg Equilibrium was considered in the distribution of genes within the population (25). The data obtained from genotyping and another measurements were presented in the results.

### RESULTS

The findings obtained from the present study were shown below as both genotype and allele distribution. In order to facilitate the statistical process, the flexion-extension lumbar spine range of motion scores of the athletes were standardized and the average of their lower and upper performance ranges was taken as flexion  $<120/≥120$ , extension  $<60/≥60$ .

According to **table III**, 30% of the athletes had CC, 46% had CT and 24% had TT genotype. Additionally, 53% of athletes had C allele and 47% had T allele.

According to **table IV**, there was no statistically significant difference between genotypes of the COL5A1 rs12722 polymorphism and the anthropometric test results ( $p > 0.05$ ).

According to **table V**, COL5A1 rs12722 polymorphism CC, TT, and CT genotypes were in the Hardy-Weinberg Equi-

**Table III.** Genotype and allele distribution of the COL5A1 rs12722 polymorphism.

%/n	Genotype			Allele	
	CC	CT	TT	C	T
Total %	30%	46%	24%	53%	47%
Total n	30	46	24	106	94

**Table IV.** Test result of the COL5A1 rs12722 polymorphism and anthropometric variables.

Anthropometric Variables	Genotype			f	p
	CC	CT	TT		
Height	174.85±5.94	177.95±7.01	175.84±5.83	2.28	0.10
Weight	73.35±11.09	77.93±17.30	76.91±12.53	0.92	0.40
BMI	24.17±3.92	24.60±4.17	25±4.15	0.27	0.76

\*P-value < 0.05.

**Table V.** Test result of the *COL5A1* rs12722 polymorphism and sports branches.

Sports Branches	Genotype			X <sup>2</sup>	HWE	P-value	Allele		X <sup>2</sup>	P-value
	CC	TT	CT				C	T		
Body Building	4 (13.3%)	5 (0.8%)	16 (34.8%)	7.73	0.78	0.25	24 (22.6%)	26 (27.7%)	2.65	0.44
Wrestling	8 (26.7%)	9 (37.5%)	8 (17.4%)				24 (22.6%)	26 (27.7%)		
Artistic Gymnastic	10 (33.3%)	4 (16.7%)	11 (23.9%)				31 (29.2%)	19 (20.2%)		
Soccer	8 (26.7%)	6 (25%)	11 (23.9%)				27 (25.5%)	23 (24.5%)		
<b>Total</b>	<b>30</b> <b>(30%)</b>	<b>24</b> <b>(24%)</b>	<b>46</b> <b>(46%)</b>				<b>106</b> <b>(53%)</b>	<b>94</b> <b>(47%)</b>		

\*P-value < 0.05.

**Table VI.** Test result of extension lumbar spine range of motion and *COL5A1* rs12722 polymorphism.

Extension	Genotype			X <sup>2</sup>	P-value	Allele		X <sup>2</sup>	P-value
	CC	TT	CT			C	T		
< 60	16 (53.3%)	15 (62.5%)	32 (69.6%)	2.05	0.35	64 (60.4%)	62 (66%)	0.66	0.41
≥ 60	14 (46.7%)	9 (37.5%)	14 (30.4%)			42 (39.6%)	32 (34%)		
<b>Total</b>	<b>30</b> <b>(30%)</b>	<b>24</b> <b>(24%)</b>	<b>46</b> <b>(46%)</b>			<b>106</b> <b>(53%)</b>	<b>94</b> <b>(47%)</b>		

\*P-value < 0.05.

librium ( $p > 0.78$ ). There was no statistically significant difference between the bodybuilding, wrestling, artistic gymnastics and football sports branches and genotype and allele distribution of the *COL5A1* rs12722 polymorphism ( $p > 0.05$ ). It was observed that bodybuilder athletes had the highest genotype (CT genotype) distribution ratio. The highest allele distribution was found in artistic gymnasts (C allele).

According to **table VI**, there was no statistically significant difference between extension lumbar spine range of motion and the *COL5A1* rs12722 polymorphism ( $p > 0.05$ ). The highest genotype distribution was athletes with CT genotype and < 60 extension lumbar spine range of motion. The highest allele distribution was athletes with T allele and < 60 extension lumbar spine range of motion.

According to **table VII**, there was a statistically significant difference between flexion lumbar spine range of motion and the *COL5A1* rs12722 polymorphism ( $p < 0.05$ ). These differences were found in both genotype and allele distribution. The highest genotype distribution was athletes with TT genotype and < 120 flexion lumbar spine range of motion. The highest allele distribution was athletes with T allele and < 120 flexion lumbar spine range of motion.

## DISCUSSION

In the study, the *COL5A1* rs12722 polymorphism, which was thought to be an important risk factor on soft tissue injuries, was examined in detail. The obtained results were discussed and evaluated together with the scientific data in the relevant literature.

**Table VII.** Test result of flexion lumbar spine range of motion and COL5A1 rs12722 polymorphism.

Flexion	Genotype			X <sup>2</sup>	P-value	Allele		X <sup>2</sup>	P-value
	CC	TT	CT			C	T		
< 120	14 (46.7%)	20 (83.3%)	26 (56.5%)			54 (50.9%)	66 (70.2%)		
≥ 120	16 (53.3%)	4 (16.7%)	20 (43.5%)	7.89	0.019*	52 (49.1%)	28 (29.8%)	7.70	0.005*
<b>Total</b>	<b>30</b> <b>(30%)</b>	<b>24</b> <b>(24%)</b>	<b>46</b> <b>(46%)</b>			<b>106</b> <b>(53%)</b>	<b>94</b> <b>(47%)</b>		

\*P-value &lt; 0.05.

There was no significant difference between the sports branches and genotype and allele distribution of the COL5A1 rs12722 polymorphism ( $p > 0.05$ ). When the genotype and allele distribution results of the COL5A1 rs12722 polymorphism were examined, it was seen that the athletes had the most CT genotype and C allele. Bodybuilders had the highest genotype percentage for CT genotype of the COL5A1 rs12722 polymorphism. Gymnasts also had the highest allele percentage for C allele of the COL5A1 rs12722 polymorphism. Bodybuilders and gymnasts had the lowest genotype count of the COL5A1 rs12722 polymorphism. For this purpose, in study by Tringali *et al.* (26) was found that, when the rhythmic gymnasts were examined in terms of the COL5A1 rs12722 polymorphism distribution, 4 of the 42 athletes had CC genotypes, 13 had TT genotypes and 25 had CT genotypes. According to these results, the COL5A1 rs12722 polymorphism genotype distribution was not consistent with the present study. In the present study, there was no significant difference between the COL5A1 rs12722 polymorphism and extension lumbar spine range of motion ( $p > 0.05$ ). The fact that the spine has a mechanism that may protect the lumbar spine region from excessive extension may be effective on this result. Additionally, the spine's anatomy during the backward movements of the athletes may also have an effect on the extension lumbar spine range of motion measurement scores. This issue has to more research. According to the chi-square results, significant differences were found between COL5A1 rs12722 polymorphism and flexion lumbar spine range of motion ( $p < 0.05$ ). To this end, Petrillo *et al.* (27) concluded in their study that the COL5A1 rs12722 polymorphism CC genotype showed significant differences, in the passive external rotation, compared to the TT and CT genotypes. Collins *et al.* (28) concluded in their study that the COL5A1 rs12722 polymorphism may

be a genetic marker related to range of motion. In another study by Brown *et al.* (29) it was found that the COL5A1 rs12722 polymorphism may be related to range of motion. Lim *et al.* (30) reported that the COL5A1 CC genotype, in passive straight leg lift, had differed significantly compared to the CT and TT genotypes. These results should support that the COL5A1 rs12722 CC genotype may be associated with an increased level of range of motion. As CC genotype and the C allele of the COL5A1 rs12722 polymorphism produce irregular and sparse collagen, the collagens - which is encoded by this genotype and allele - may prevent athletes from soft tissue injuries. On the contrary, the fact that the TT genotype and the T allele produce denser and more regular collagen may affect the mechanical properties of connective tissues, stimulating a decrease in level of range of motion (31). For this reason, the genotype and allele of the COL5A1 rs12722 polymorphism may regulator structural integrity of soft tissues. To this end, Dines *et al.* (32) reported that the C allele of the COL5A1 rs12722 polymorphism may provide resistance to injury in runners. In another study, Hefferman *et al.* (33) reported that the the C alleles and CC genotypes of the COL5A1 rs12722 and rs3196378 polymorphisms had an inherited resistance in soft tissue injuries.

In the literature review, the studies were also found in which there was no relationship between the COL5A1 polymorphism and joint range of motion. For this purpose, Bertuzzi *et al.* (34) concluded in their study that the COL5A1 rs12722 polymorphism had no effect on the level of range of motion. Posthumus *et al.* (35) reported that there was no significant difference between the MMP3 rs679620 and the COL5A1 rs12722 polymorphisms and range of motion. O'connell *et al.* (36) reported there were no significant differences between COL3A1 rs1800255, COL6A1 rs35796750 and COL12A1 rs970547 gene variants and range of motion.



A mutation in the *COL5A1* gene polymorphism can have significant effects on both the range of motion and the level of flexibility. This is supported by clinical data. Classic Ehlers-Danlos syndrome (EDS) is an inherited connective tissue disease which is associated with joint hypermobility and excessive skin elasticity. In conclusion, it seems likely that the *COL5A1* gene may cause soft tissue injuries by affecting the level of range of motion.

## CONCLUSIONS

The present study concluded that the CC genotype and C allele of the *COL5A1* rs12722 polymorphism may be associated with the increased level of range of motion in lumbar spine flexion. As a result, due to the increased level range of motion, athletes may be significantly protected from soft tissue injuries. This may be explained by the fact that genetics has an indirect rather than direct effect on the range of motion.

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## DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

## CONTRIBUTIONS

SK: writing – original draft, data curation, conceptualization. ME: project administration, conceptualization.

## ACKNOWLEDGEMENTS

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## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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# No Influence of Menstrual Cycle on Muscle Strength and Flexibility in Women Practising Strength Training

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## SUMMARY

**Background.** The menstrual cycle (MC) is a natural process of the female reproductive system, characterized by fluctuations in the hormones estrogen and progesterone, which can affect physical performance, particularly strength and flexibility.

**Objective.** To analyze the influence of the MC on muscle strength and flexibility in individuals practicing strength training, identifying variations throughout the different phases of the cycle.

**Methods.** An exploratory study included 15 amenorrheic university students ( $22.50 \pm 5.11$  years) practicing strength training for at least 6 months, with a minimum of 3 weekly sessions. Participants with uncertain MC regularity, athletes, or those missing assessments were excluded. Sociodemographic, gynecological questionnaires, and the Menstrual Distress Questionnaire (MDQ) were administered. Muscle strength was measured via the 1-RM test for upper and lower limbs; flexibility by range of motion (goniometry) and the sit-and-reach test; subjective perception of exertion was recorded. Data were analyzed using ANOVA ( $p < 0.05$ ).

**Results.** A significant difference was observed ( $p = 0.001$ ) only in menstrual symptoms, with higher values during the menstrual phase and lower values in the postmenstrual phase ( $\Delta$ : 120%). No significant differences were found in the other variables between the phases of the MC.

**Conclusions.** This study found no significant differences in flexibility or muscle strength across MC phases. Despite more intense symptoms during menstruation, physical performance was unaffected. Future research should explore the relationship between the MC and physical performance in women, especially in strength training.

## KEY WORDS

*Menstrual cycle; strength; flexibility.*

## INTRODUCTION

The menstrual cycle (MC) is a natural biological process that occurs monthly in women, from menarche to menopause, and is associated with fluctuations in sex hormones, primarily estrogen and progesterone (1). These hormonal fluctuations follow a predictable pattern in average 28-day cycles (2). The MC is commonly divided into three phases: the follicular phase, the ovulatory phase, and the luteal phase. The follicular phase begins with menstruation and extends

until ovulation, being further subdivided into the menstrual and post-menstrual periods. During this phase, there is a decline in estrogen and progesterone levels, followed by a gradual increase in estrogen, which stimulates the development of a dominant follicle, preparing the body for ovulation (1, 3). During the ovulatory phase, which occurs right after the post-menstrual period of the follicular phase, the egg is released and transported toward the endometrium. This phase is characterized by high concentrations of estrogen

and progesterone. The ovulatory phase lasts an average of 24 to 48 hours and is followed by the luteal phase, which lasts approximately 14 days. The luteal phase is divided into two periods: the intermenstrual period (early luteal phase) and the premenstrual period (late luteal phase), which begins between the 23rd and 24th days after the onset of menstruation (4, 5). During the premenstrual period, estrogen and progesterone levels drop significantly due to the degeneration of the corpus luteum, in the absence of fertilization, preparing the body for the next MC (1, 6).

Female physical performance can vary throughout the phases of the MC. In the post-menstrual period, the gradual increase in estrogen levels promotes anabolic responses, including enhanced muscle strength. Additionally, there is an increase in norepinephrine production, which directly impacts physical capacity, boosting muscular performance during this period (7). As the cycle progresses to the ovulatory phase, physical performance begins to decline, albeit subtly. During the ovulatory phase, there is a reversal in hormonal concentrations, marked by a significant decrease in estrogen levels, which reduces anabolic capacity. This effect is exacerbated by the rise in progesterone, which promotes catabolism and prepares the body for the luteal phase (7-9). For this reason, Blagrove *et al.* (8) suggest that the intensity and volume of strength training be adjusted according to the muscular responses of each MC phase, tailoring training to the performance characteristics of each period.

Additionally, flexibility may also vary throughout the MC due to increased levels of relaxin, particularly during the premenstrual period. This hormonal rise affects joints and ligaments, enhancing their elasticity and, consequently, range of motion (RM) (10). Similarly, but through different physiological mechanisms, during the menstrual and post-menstrual periods, the increase in estrogen and progesterone stimulates collagen synthesis and the activity of metalloproteinases, leading to greater ligament laxity and reduced tendon stiffness, factors that influence flexibility and RM (11).

Thus, the present study aims to analyze the influence of the MC on muscle strength and flexibility in individuals engaged in strength training, seeking to identify potential variations throughout the cycle's phases. The objective is to understand the physical responses that women may experience during the MC, enabling the formulation of more precise recommendations for adjusting training parameters, optimizing the effectiveness of programs, and minimizing discomfort or injury risks associated with hormonal fluctuations.

## MATERIALS AND METHODS

### Study type and population

This is an exploratory research study (12), conducted at the Biodynamics Laboratory (LABIO) of the Superior School of Physical Education at the University of Pernambuco (ESEF-UPE). The study was approved by the Human Research Ethics Committee (date of approval: November 11, 2019) of UPE, under opinion no. 3.696.219, following the ethical guidelines established by Resolution 466/12, which regulates research involving human subjects.

The sample selection was conducted through in-person invitations to all classes at ESEF-UPE, where the study's objectives, inclusion and exclusion criteria, as well as the risks and benefits of participation were presented. University students over 18 years old, eumenorrheic, without dysmetabolic issues, who had been engaged in strength training for at least six months, with a minimum frequency of three training sessions per week, and who agreed to participate voluntarily in the study were included. Participants who reported uncertainties regarding their MC regularity, those who were athletes in specific sports, who presented any injury to the musculotendinous complex, or those who missed any study assessments were excluded.

Thus, 20 volunteers agreed to participate by signing the Informed Consent Form (ICF) and meeting the inclusion criteria. However, 5 were excluded for not attending one of the assessments, resulting in a final sample of 15 women.

### Study design

After accepting and signing the ICF, a session was scheduled for explaining and familiarizing participants with the tests, as well as administering the sociodemographic questionnaire and gynecological history, aimed at characterizing the sample.

The test battery was conducted at four distinct times: familiarization, menstrual period, post-menstrual period, and premenstrual period. The familiarization session was scheduled with a minimum interval of 72 hours before the expected date of menstruation, as reported by the volunteer. After familiarization, the volunteers were instructed to notify the researchers of the day their menstruation began for the first assessment, conducted during the menstrual period, specifically between the first and second day of menstruation. The second assessment occurred in the post-menstrual period, between the fourth and fifth day after the onset of menstruation, coinciding with the end of menstrual flow. Finally, the premenstrual assessment was conducted between the 23rd and 24th days after the onset of menstruation (4, 5).

During the familiarization session, a detailed explanation of the study was provided, according to the scheduled initial contact with each participant. At this time, body mass and height were measured, and the sociodemographic questionnaire and gynecological history were administered. Each volunteer was then subjected to an acclimatization session with the selected tests, starting with flexibility assessment, measured by RM using goniometry, considering shoulder and hip joint flexion and extension, with the right side as a reference (13). After the RM assessment, the flexibility of the posterior muscle chain was evaluated using the sit-and-reach test (SRT) with the Wells bench (5, 14, 15). Muscle strength was assessed using the one-repetition maximum (1-RM) test (5, 16), measuring the strength of the lower limbs (LL) and upper limbs (UP). At the end of the test battery, volunteers reported their effort using the scale subjective perception of exertion (SPE) (17).

After the familiarization phase, the same evaluations were conducted during the other three phases of the cycle (menstrual, post-menstrual, and premenstrual), with the addition of completing the Menstrual Distress Questionnaire (MDQ) (18) at the beginning of each assessment for the respective phase of the MC.

All assessments were conducted in the LABIO at ESEF-UPE, with temperature controlled at 22 degrees Celsius (71.6 degrees Fahrenheit) during the evaluations and without the presence of any ambient sounds, except for the commands for performing the tests. All assessments and reassessments were conducted by a single evaluator, using the same instruments and procedures throughout. The tests and retests were performed between 11:00 AM and 1:00 PM.

### Collection instruments

The sociodemographic questionnaire and gynecological history aimed to characterize the sample. The sociodemographic questionnaire assessed personal health conditions and lifestyle, specifying training history characteristics. The gynecological history investigated information regarding contraceptive use, obstetric history, and menstrual history. Menstrual symptomatology was assessed using an adapted version of the MDQ (18), consisting of 27 items that address the main symptoms associated with menstruation. Each item is scored on a scale from 0 to 4 points, where 0 = no symptom; 1 = mild symptom; 2 = moderate symptom; 3 = severe symptom; and 4 = unbearable symptom. A higher score indicates greater reported symptomatology. The MDQ was administered during the assessments in the menstrual, post-menstrual, and premenstrual periods.

RM was assessed using goniometry, with a universal acrylic goniometer from the Carci brand, to measure active flexion and extension of the shoulder and hip joints, using the right side as a reference. Shoulder flexion and extension were measured in the anatomical position, with the palm in a neutral position at 0 degrees of abduction, adduction, and rotation. Under the researcher's instruction, the participant actively performed the maximum possible RM in flexion, with the value verified and recorded in a data collection instrument. Next, the participant performed the extension movement, with the angle also noted. Hip RM was evaluated with the participant in a supine position for flexion and in a prone position for extension. In both positions, the movement started at 0 degrees of abduction, adduction, and rotation, and under the researcher's instruction, the participant performed the maximum RM, with the angle recorded in a data collection instrument (13). For this study, the average RM obtained in flexion and extension for each segment (shoulder and hip) was adopted, resulting in a single mean for each.

The flexibility of the posterior muscle chain was assessed using the SRT (5, 14, 15), which measures flexibility in the posterior region of the spine and lower limbs. A wooden Wells orthopedic box (Zapmédica brand, dimensions: 30.5 cm × 30.5 cm × 30.5 cm) was used. Participants were instructed to sit on their ischial tuberosities, barefoot, with their feet apart and soles resting on the base of the box, knees fully extended, and hands stacked with middle fingers aligned. In the initial position, participants were to take a deep breath, and upon exhaling, slide along the measuring line as far as possible, holding the position for approximately 3 seconds to validate the measurement. In each session, three attempts were made, and the average of the three results was included in the analysis. The zero point of the scale aligns with the foot support and advances approximately  $\pm 28$  cm toward the participant.

Muscle strength was assessed using the 1-RM test (5, 16). To evaluate the strength of the LL, a horizontal leg press machine was used, which primarily performs knee and hip extension actions. For the UP, a chest press machine was employed, which primarily facilitates horizontal shoulder adduction, scapular abduction, and elbow extension. Both machines were from the Movement brand and were equipped with fixed weight bars, cushioning, automatic counters, and timers.

Initially, on each machine, starting with the horizontal leg press, the participant performed a warm-up with full range of motion for the knee and hip, executing 12 repetitions at 40% to 60% of the maximum load estimated by

the participant. After 2 minutes, the load was adjusted to the maximum estimated weight. If the participant successfully completed the 1-RM (characterized by full range of motion during the exercise, specifically full extension of the knee and hip in the concentric phase of the movement), she rested for an additional 3 to 5 minutes, and the procedure was repeated for up to three attempts. If the participant was unable to complete the movement correctly, the test was terminated, and the load obtained from the last successful attempt was validated as the maximum load. The same procedure was followed for the chest press, with the participant performing the complete concentric movement of horizontal shoulder adduction, scapular abduction, and elbow extension.

Effort during the activities was measured using the SPE (17). At the end of the assessments for each respective period, participants rated their perceived level of effort for completing the tests on a scale of 1 to 10 (where 1 = very light activity; 2-3 = light activity; 4-6 = moderate activity; 7-8 = vigorous activity; 9 = very hard activity; and 10 = maximum effort). A higher score indicated greater perceived exertion.

### Data analysis and processing

All data were recorded in collection instrument forms, tabulated in electronic spreadsheets, and subsequently analyzed. For data treatment, exploratory inspections were conducted to identify extreme values (outliers), as well as to check for normality of distribution and homogeneity of data. Statistical analyses included descriptive and inferential techniques, either parametric or non-parametric, as necessary, and the characterization of the sample was presented. Repeated measures ANOVA was used to compare the menstrual, post-menstrual, and pre-menstrual periods. Statistical analysis was conducted using IBM SPSS Statistics for Windows, Version 20.0 (Armonk, NY: IBM Corp.). The significance level was set at  $p < 0.05$  for all analyses.

## RESULTS

The sample consisted of 15 volunteers, with an average age of  $22.50 (\pm 5.11)$  years. They had been practicing strength training for an average of  $3 (\pm 0.71)$  years, with an average weekly frequency of  $4 (\pm 0.97)$  days. Regarding gynecological conditions, menarche occurred at an average age of  $11 (\pm 1.16)$  years, and 20% of the participants reported using contraceptives. The characteristics of the sample are detailed in **table I**.

When analyzing the differences in flexibility (RM and flexibility of the posterior muscle chain), muscular strength, perceived exertion, and menstrual symptoms during the three phases of the MC (menstrual, post-menstrual, and pre-menstrual), significant differences ( $p < 0.001$ ) were observed only in menstrual symptoms. Using the MDQ, higher scores were found during the menstrual period (score:  $36.27 \pm 19.71$ ) and lower scores during the post-menstrual period (score:  $16.53 \pm 11.53$ ;  $\Delta$ : 120%) (**table II**).

When comparing the participants who used (80%) and did not use (20%) contraceptives, no significant differences ( $p > 0.05$ ) were observed in any of the measured variables (**figure 1**).

## DISCUSSION

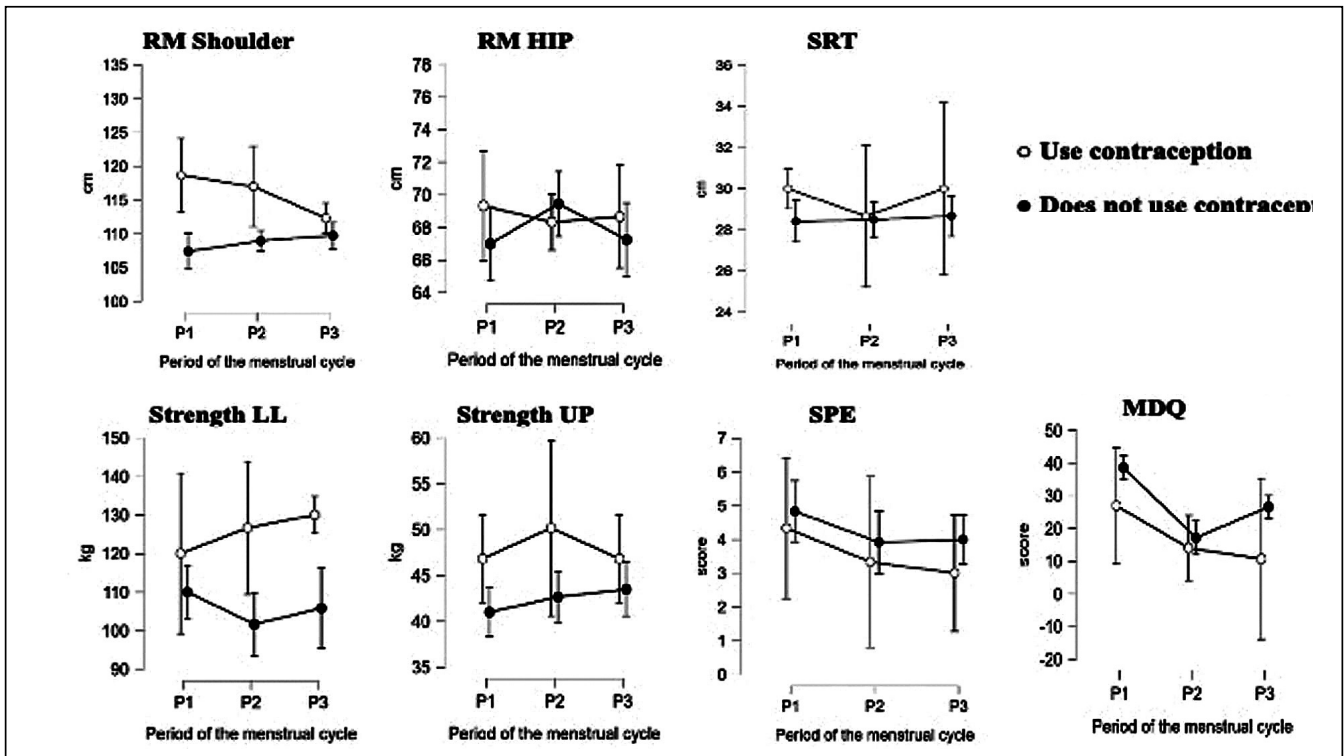
In this study, no significant differences were found in flexibility, muscle strength, or SPE between the phases of the MC (menstrual, post-menstrual, and pre-menstrual). The only significant variation observed was in the menstrual symptoms reported during the MC, with higher values during the menstrual phase ( $p < 0.001$ ), as assessed by the MDQ.

Variations in women's physical performance may be directly associated with the phases of the MC due to hormonal fluctuations, primarily of estrogen and progesterone (1, 6). The follicular phase is subdivided into two periods of the MC: menstrual and post-menstrual. The first four days of

**Table I.** Sample characterization (n = 15).

n = 15	Mean (Md) $\pm$ SD	Minimum	Maximum	P-value
Age (years)	22.50 (21.00) $\pm$ 5.11	19	40	<b>0.001*</b>
Mass (kg)	62.90 (65.40) $\pm$ 7.76	48.00	71.70	0.084
Height (cm)	163.00 (162) $\pm$ 5.08	155	171	0.709
BMI (kg/m <sup>2</sup> )	23.70 (24.0) $\pm$ 2.91	17.40	28.00	0.708

BMI: Body Mass Index; \* $p < 0.001$ : Significance value of the normality test (Shapiro-Wilk).



**Figure 1.** Comparison between periods (menstrual, post-menstrual and pre-menstrual) of volunteers who use and do not use contraceptives.

P1: Menstrual period; P2: Post-menstrual period; P3: Pre-menstrual period; RM: Range of motion; SRT: Sit and reach test; LL: Lower limbs; UP: Upper Limbs; SPE: Subjective perception of exertion; MDQ: Menstrual Distress Questionnaire.

**Table II.** Comparison between periods (menstrual, post-menstrual and pre-menstrual).

	Menstrual	Post-menstrual	Pre-menstrual	P-value
RM Shoulder (cm)	109.66 ± 13.25	110.56 ± 9.63	110.26 ± 10.25	0.833
RM Hip (cm)	67.47 ± 9.31	69.23 ± 9.42	67.53 ± 11.24	0.369
SRT (cm)	28.73 ± 13.68	28.53 ± 14.51	28.933 ± 13.30	0.823
Strength LL (kg)	112.00 ± 41.48	106.67 ± 43.93	110.67 ± 10.33	0.619
Strength UP (kg)	42.17 ± 9.15	44.17 ± 12.22	44.17 ± 10.10	0.456
SPE (score)	4.73 ± 1.87	3.80 ± 2.00	3.80 ± 1.82	0.170
MDQ (score)	36.27 ± 19.71	16.53 ± 11.53	23.40 ± 21.04	<b>0.001*</b>

RM: Range of motion; SRT: Sit and reach test; LL: Lower limbs; UP: Upper Limbs; SPE: Subjective perception of exertion; MDQ: Menstrual Distress Questionnaire; \*p < 0.001: Significant difference.

menstruation correspond to the flow phase, known as the menstrual period or early follicular phase. Next, we enter the late follicular phase or post-menstrual period, when the flow has ceased and the body transitions towards ovulation

(1). During the follicular phase (menstrual and post-menstrual periods), estrogen and progesterone levels increase, particularly in the early follicular phase (menstrual period), with concentrations rising as the late follicular phase



(post-menstrual period) approaches. The peak of these hormones marks the end of the late follicular phase and the transition to ovulation (3).

The ovulatory phase lasts an average of 24 to 48 hours, and after it concludes, the luteal phase begins, lasting approximately 14 days. This phase is divided into two periods: the intermenstrual period (early luteal phase) and the pre-menstrual period (late luteal phase), which starts at the end of the luteal phase, around the 23<sup>rd</sup> or 24<sup>th</sup> day after the onset of menstruation (4, 5). During this phase, there is a sharp drop in estrogen and progesterone levels due to the degeneration of the corpus luteum (in the absence of fertilization), preparing the body for the onset of the menstrual period (1, 6).

These hormonal fluctuations can trigger a variety of symptoms in women, affecting connective tissues and muscle function. This may influence joint stability (altering RM and muscle flexibility), muscle strength, and consequently the SPE during exercise, depending on the stage of the MC (11, 19, 20, 21), or even increase the incidence of injuries at the myotendinous junction, due to inefficient flexibility (22). The increase in estrogen and progesterone (menstrual and post-menstrual period) promotes collagen synthesis and the activity of enzymes like metalloproteinases, which degrade the extracellular matrix and lead to tissue remodeling. This can result in greater ligament laxity and decreased tendon stiffness, directly affecting flexibility and, as a consequence, RM (11). Regarding muscle strength, elevated levels of these hormones may influence neuromuscular transmission and excitation-contraction coupling, affecting muscle contraction efficiency and, consequently, strength and SPE (19, 20). The premenstrual period (late luteal phase) is characterized by a sharp decline in estrogen and progesterone, which induces a sedative effect on the activation of the muscular system by the central nervous system, directly impacting muscle strength. Additionally, this significant drop can lead to exacerbated sensory activations, contributing to pain, increased water retention, and edema, which may influence range of motion. Hormonal changes during this phase also affect neurotransmitters linked to the limbic system and prefrontal cortex, leading to mood changes and decision-making difficulties. This set of symptomatic conditions is known as premenstrual tension (PMT) and can cause physical performance alterations due to the psychophysical disturbances mentioned (23).

Although physiological conditions suggest potential changes in physical performance, this study did not observe any significant variation ( $p > 0.05$ ). Regarding muscle strength, some studies support this result. For instance, Pereira *et al.*

(5), comparing muscle strength across three phases of the MC in 20 women engaged in strength training using the 1-RM test, found no significant difference. Similarly, Thompson *et al.* (24) observed that muscle strength did not change throughout the MC in a study evaluating the muscle performance of 30 trained women. Furthermore, Romero-Moraleda *et al.* (25) found that 13 eumenorrheic trained women exhibited similar muscle strength performance across different MC phases. Likewise, Jonge *et al.* (26) did not identify any variations in muscle strength or fatigue (equivalent to SPE) when evaluating 19 trained women across the MC.

On the other hand, Rodrigues *et al.* (27) observed that in the late follicular phase (post-menstrual period), strength was greater than in the early follicular phase (menstrual period) when assessing muscle strength through the 1-RM test in 15 women who had been engaged in strength training for at least three years. These differences suggest that as physical performance improves with increased training duration, hormonal fluctuations may elicit different physical responses during various phases of the MC. This could be attributed to the fact that the authors evaluated women with a more extensive training history (over three years), unlike this study and others, such as Pereira *et al.* (5), which found no differences in women who had been training for at least six months, a criterion that was also used to include participants in this study's sample.

This hypothesis is supported by the studies of Pournasiri *et al.* (28), who assessed the muscle strength of 37 athletes from various sports with a minimum training history of three years, using isokinetic analysis of knee extensors and flexors. The results revealed that the athletes exhibited higher strength indices in the post-menstrual period compared to the menstrual and pre-menstrual periods.

Regarding flexibility, Ghangrekar *et al.* (29) corroborate the results of this study by not observing variations in joint instability across the three phases of the MC, assessing 90 women who had been exercising for at least three months. On the other hand, Miyazaki and Maeda (10), when correlating the MC with the flexibility of 16 young, healthy women who did not engage in sports or specific training involving strength or flexibility, observed, through knee extension using an isokinetic dynamometer, that passive stiffness decreased during the ovulatory and luteal phases, suggesting changes in the flexibility of the posterior muscular chain of the LL during these phases.

In contrast to this study, Pereira *et al.* (5), when assessing flexibility through the SRT in 20 trained women, found higher levels of flexibility in the post-menstrual period.

These differences may stem from secondary training practices, as in the study by Miyazaki and Maeda (10), the participants did not engage in strength or flexibility training, unlike in this study, where all participants practiced strength training, which may explain a lower susceptibility to performance changes related to hormonal fluctuations. In Pereira *et al.*'s (5) study, which also involved women engaged in strength training, it was not evaluated whether the participants engaged in additional training besides strength training. Depending on the specificity of the physical training performed, there may be a greater involvement of flexibility, making women more sensitive to variations in this capacity throughout the MC.

Regarding MC symptomatology, we observed that the highest sensitivity occurred during the menstrual period ( $p < 0.001$ ). These findings are related to the negative physical and emotional symptoms, measured by the MDQ, that some women experience during the late luteal phase and that tend to improve at the onset of menstruation, characteristics commonly associated with PMT. Although the exact mechanisms of PMT are not fully understood, Boboc and Oinonen (30) suggest that there is evidence indicating that hormonal sensitivity may contribute to symptoms not only during the premenstrual phase but throughout the luteal phase. Schmidt *et al.* (31) argue that the variations causing physical and emotional changes associated with PMT are not due to hormonal fluctuations but rather hypersensitivity to abrupt hormonal changes.

When considering physical performance and, consequently, sports performance, it is essential to recognize the influence of physical and emotional aspects on performance. PMT can lead to a reduction in performance throughout the MC due to the cyclical recurrence of symptoms that affect the behavioral dimension (fatigue, insomnia, dizziness, *etc.*), the psychological dimension (irritability, depressed mood, anxiety, restlessness, *etc.*), and the physical dimension (headaches, tenderness, swelling, muscle and joint pain, *etc.*), with these symptoms decreasing rapidly after the onset of menstruation (32).

Although this study identified relationships between negative symptoms and the MC, particularly during the menstrual period, no other variables were observed that could reflect the magnitude of the influence of these changes on performance. The study did not find significant differences in the evaluated capacities, such as strength and flexibility.

Another relevant point to discuss is the absence of significant differences between women who use and do not use contraceptives. Studies such as that of Romero-Moraleda *et al.* (25) indicate that contraceptives may minimize the natural

hormonal fluctuations of the MC, which could theoretically result in less variation in physical performance throughout the cycle. However, in this study, no significant variations were found between the groups. This suggests that, regardless of contraceptive use, other factors, such as the level and type of training, may play a more determining role in strength, flexibility, and perceived exertion performance. This finding reinforces the need for further studies specifically investigating the impact of contraceptives on physical performance in trained women to determine whether there is indeed an attenuation of the effects of the MC.

As limitations, the study could have explored other performance-related capacities, such as physical and emotional aspects. Additionally, the sample consisted predominantly of women with an average age of  $22.50 (\pm 5.11)$  years who practiced only strength training. Including women from varied age groups and those participating in other physical and sports modalities could provide a more comprehensive and accurate view of the variations in performance associated with PMT. Analyzing these additional variables could reveal direct relationships with the increased symptomatology reported during the menstrual period, offering a more complete understanding of the impact of PMT on physical and sports performance.

The findings of this study have important practical implications, especially for physical education professionals and coaches working with women. Although no significant differences were observed in physical performance variables during the different phases of the MC, it is advisable that training plans consider individual variability in menstrual symptoms. Continuous monitoring of the MC and SPE can be an effective strategy for adjusting training load as needed, without compromising performance. Additionally, it is crucial for athletes to be educated about the potential influences of the MC on performance, enabling them to adjust their physical and mental preparation according to their needs, thus fostering greater confidence in continuous training throughout the cycle.

## CONCLUSIONS

In this study, no significant variations were observed in flexibility and muscular strength throughout the different phases of the MC, and these variables had no impact on SPE. Although the literature documents physiological variations throughout the MC, the results obtained did not indicate significant changes in the performance of the assessed physical capacities.

The symptomatology, as expected, showed greater intensity

during the menstrual period. However, this manifestation did not seem to influence the performance in the analyzed capacities, suggesting that, despite the reported physical and emotional discomfort, it does not directly affect physical performance.

Given the importance of understanding possible variations in female physical performance throughout the MC to optimize training prescriptions and maximize sports performance, it is recommended that future studies include a more diverse sample, encompassing women of different ages and sports modalities. These studies could further investigate the influence of the MC on performance variables, providing more robust guidelines to enhance the performance of women, particularly among those engaged in strength training.

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## DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

## CONTRIBUTIONS

JPMS, WRS: investigation, data collection, writing – original draft. KBC, AFB, MCC, RCRL: writing – review & editing, formal analysis. TMSV, MSFC: formal and statistical analysis. WRS: supervision & editing. WRS, JPMS: funding acquisition.

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## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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# Association Between Primary Dysmenorrhea and Accelerometer-Measured Physical Activity Metrics in Nulliparous Women of the United Arab Emirates: A Cross-sectional Study

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## SUMMARY

**Background.** Dysmenorrhea and menstrual characteristics significantly impact physical activity patterns, yet few studies have objectively measured these associations using accelerometers. This study aimed to investigate the association between dysmenorrhea severity, menstrual characteristics, and accelerometer-measured physical activity levels in nulliparous women in the UAE.

**Methods.** An observational study was conducted among 46 women aged 18-45 years, with varying severity levels of primary dysmenorrhea (PD) classified by the Numeric Pain Rating Score (NPRS) and Working ability, Location, Intensity, Days of pain, Dysmenorrhea (WaLIDD) scores. Participants wore a Fibion triaxial accelerometer for three consecutive menstrual days to measure sitting time and light, moderate, and vigorous intensity physical activity times.

**Results.** Participants spent  $11.0 \pm 1.56$  hours/day sitting, with  $3.84 \pm 1.73$  hours in light-intensity activity,  $33.6 \pm 20.3$  minutes in moderate-intensity activity, and  $0.38 \pm 0.62$  minutes in vigorous-intensity activity during the menstrual days. Women with moderate-to-severe PD had lower light-intensity activity by 1.26 hours/day than those with mild PD ( $p = 0.030$ ). Women with heavier menstrual flow had lower vigorous-intensity activity by 0.75min compared to those with scanty menstrual flow ( $p < 0.050$ ). No significant associations were found between menstrual characteristics and sitting or moderate-intensity activity times.

**Conclusions.** Dysmenorrhea severity and menstrual flow were associated with physical activity times, particularly with reduced light and vigorous activity. Tailored interventions addressing these menstruation-related characteristics may improve physical activity levels and mitigate long-term health risks, enhancing the well-being of women with PD.

## KEY WORDS

*Accelerometer; dysmenorrhea; menstrual flow; physical activity; sedentary behavior.*



## INTRODUCTION

Physical inactivity is becoming a global burden as sedentary behaviors have increased over the last few years. The World Health Organization (WHO) 2020 physical activity guidelines highlighted the importance of moderate and vigorous activities and provided recommendations on the dose needed to achieve optimal health outcomes (1). However, these guidelines lack recommendations for the time spent doing light activity and being sedentary. Moreover, precise guidelines for managing sedentary behavior and improving the physical activity of individuals living with disabilities or chronic diseases are lacking as well (2).

Physical inactivity is a significant risk factor associated with an increase in non-communicable diseases (NCD) (3, 4), such as cardiovascular diseases (5, 6), diabetes, chronic respiratory conditions (7), *etc.* NCD is a leading cause of morbidity and mortality worldwide. It is considered the leading cause of 68% of deaths globally (8), with a noticeable increase in NCD risk factors like hypertension and obesity in adolescents (9, 10). Deaths due to physical inactivity might account for approximately 5.3 million per year (11).

Global decrease in physical activity levels persisted even with the implementation of campaigns to increase awareness about the importance of exercise. Approximately 27.5% of adults worldwide have an extremely low activity level (12). In the United Arab Emirates (UAE), the prevalence of regular physical activity among youth is dangerously low (13). A study was conducted on the young adult population in the UAE using the ActiGraph device, which reported that a quarter of the individuals are sedentary, around one-fifth are moderately active, and only about a quarter are engaged in intensive physical activities. The study also showed that young men (50%) and women (76.6%) had a high sedentary behaviour time for approximately 80% of waking hours. Moreover, female participants are more involved in light physical activities, while male participants are more engaged in moderate and vigorous physical activities (14).

Exploring the association between physical activity levels and menstrual pain (dysmenorrhea) in women is an area worthy of investigation. Dysmenorrhea is defined as pain associated with menstruation and can be categorized into primary dysmenorrhea (PD) or secondary dysmenorrhea. PD is one of the most common gynecological issues among young women (15). PD is a painful uterine contraction that usually starts a few days before menstruation and continues during the first 48-72 hours of menstruation without an obvious pelvic pathology. It usually starts 1-2 years after the onset of menarche and gradually decreases with ageing (16). PD prevalence ranges from 45% to 97% among women

worldwide, irrespective of socioeconomic status, and is one of the main causes of absenteeism at school and work, with reports of negative impact on academic performance (17-20). Specifically, the prevalence of PD among adults studying in the Kingdom of Bahrain was 90.7%; these data were taken from a population of 42.5% Bahrainis, 27.9% Saudis, 22.1% Kuwaitis, and 7.5% Omanis (21). Among the young adult females in the Kingdom of Saudi Arabia with a history of PD, 70% had moderate-to-severe PD, while the remaining 30% had mild PD (22). Furthermore, the prevalence of PD in adolescent females in Dubai has been reported to be 94.7%, leading to absenteeism at school, cessation of regular training, and a decrease in physical activity levels (23). The global burden of dysmenorrhea is high, as it has a profound negative impact on all aspects of life, including an effect on health (30%-50% reports of severe pain and up to one-third of adolescents reporting symptoms such as headaches, nausea, dizziness, and fatigue) (24). Social relationships (reporting poor relationships with friends and family as well as poor sports activities) (25, 26), and health-care/economic aspects (increased healthcare costs by  $\approx 2.2$  to 2.9 times higher than usual costs) (27). If the symptoms go untreated, then it increases the risk of chronic pelvic pain and general chronic pain over time (28, 29). However, another study negates this claim and states that women with chronic dysmenorrhea are more likely to develop central sensitivity syndromes rather than chronic pain (30).

Studies have yielded contradictory results to date, with some indicating an increase in PD-related menstrual pain with increased activity in women, while others suggest the opposite. A study comparing the difference in menstrual pain and premenstrual symptoms in athletes *versus* the sedentary population showed that the athletes had higher menstrual pain ( $6.15 \pm 2.85$ ) than the sedentary population ( $5.54 \pm 2.35$ ) on the numeric pain rating scale (range: 0-10) (31). However, other studies showed improvement of menstrual pain after adding aerobic exercises (32, 33). Previous studies have shown that increased activity of the posterior and anterior sling of muscles due to repetitive concentric and eccentric contractions could improve core muscle control and decrease low back problems (34, 35).

Various other risk factors have been linked to the presence of PD, including a maternal history of dysmenorrhea (36-38), skipping breakfast (39), poor dietary behaviors (40), and a menarche age of less than 12 years. Dysmenorrhea may be accompanied by other physical symptoms such as headaches, dizziness, nausea, diarrhea, changes in appetite, bloating, swelling in the legs, breast tenderness, and lethargy (41, 42).

Menstrual distress causes negative responses that might impair social activity, activities of daily living, and even working and school attendance (43). Nevertheless, the distress varies between different women depending on their nutritional intake and lifestyle. Most women who had menstrual distress also reported being active smokers, having high sugar and caffeine intake, and drinking alcohol (44, 45). A Working ability, Location, Intensity, Days of pain, Dysmenorrhea (WaLIDD) score was created to self-report the degree of menstrual pain and interference with activities of daily living, as it measures the working ability, number of painful locations during menstruation, intensity of pain, and days of pain during menstruation. A high WaLIDD score indicates increased severity of dysmenorrhea (46).

Very few studies have been conducted on the specific characteristics of menstruation (*e.g.*, menstrual flow heaviness and length of menstruation) and their relationship with physical activity. De Carvalho et al. (2023) analyzed physical performance and self-perception of menstrual symptoms during early menstruation and after menstruation. They found that women with heavier menstrual flow had shorter activity performance, and an increased perception of menstrual symptoms was correlated with a decrease in total time to exhaustion during activities (47). Another study compared physical activity avoiders and non-avoiders during menstruation; the avoiders group showed an increase in menstrual flow heaviness, a longer menstrual period, and a higher level of fatigue than non-avoiders (48). These results are similar to the results of another study that concluded that lifestyle modifications with the addition of physical activity decreased PD pain and menstrual flow (49). Additionally, the muscular stiffness is lower in women, and the tolerance for muscular stretching is higher in women than in men; therefore, light physical activity like mobility exercises might help ease pain during menstruation due to a reduction in muscular stiffness (50, 51).

An association between the addition of physical activity and change in menstrual pain rating in women with PD has been reported previously (52-54). Recent studies showed a reduction in the severity of PD after the prescription of 8 weeks of aerobic exercises (32, 55, 56). Another study showed that regular strengthening, stretching, jogging, and muscle relaxation reduced PD symptoms (57). Exercise has been hypothesized to reduce pain intensity in those with PD by acting as a non-specific analgesic by increasing the blood flow to the pelvis, disrupting the accumulation of prostaglandins and delaying the onset of pain (58, 59). Exercise also reduces stress and improves mood by reducing sympathetic nervous system activation and increasing endorphin

secretion, which in turn aids in reducing pain intensity in PD (60). Regular exercise before the onset of menarche and during menstruation has been claimed to be the strongest dysmenorrhea prevention measure (61), where brisk walking for 30 minutes, especially in the first 3 days of menstruation, has been reported to reduce the severity of PD (62). However, it is crucial to understand that the interaction between physical activity and anthropometric factors varies significantly during the pre-pubertal growth phase in females. This, in turn, affects the age of menarche and the onset of menstruation due to changes in body composition (63, 64).

Barriers to physical activity of women in the UAE ranged between cultural challenges such as difficulty in women joining the gym as there are few centers for women only, longer sitting hours in office jobs, presence of chronic illnesses, and other barriers like lack of time to incorporate physical activity in daily life, a belief that physical activity is not a social activity that can be done with friends or relatives, and boredom of exercise (65-67). The “walkability” of the city was also a major component influencing physical activity levels. This was determined by how the city is built and the perceived barriers that hinder the practice of physical activity, such as the physical attractions, street crossings, and sidewalk characteristics. Recent studies reported that Dubai, an Emirate in the United Arab Emirates, is not considered a highly “walkable” city due to the urban sprawl, lack of public transportation, roads being designed mainly for car usage, lack of shadows and sidewalks in many areas, and harsh weather (68, 69).

The effect of PD on physical activity has been studied using self-reported questionnaires in the UAE (14). One study reported the level of physical activity using hip-worn Acti-Graph accelerometer data in adult women (70). The latter research only reported physical activity as a percentage on days with and without menstrual pain. It did not specify individual differences in time duration for sitting, light, moderate, and vigorous activities (70). The hip-worn accelerometer only measured motions occurring in the vertical plane (walking and running) as it is an omnidirectional accelerometer. The study showed that the women without PD experienced mild menstrual pain with no significant decrease in physical activity levels, whilst women with moderate-to-severe PD showed a 40% decrease in physical activity compared to the control group (70).

In addition, a study investigated the differences in physical activity data between accelerometers and self-reported questionnaires. Self-reported data met 90% of the required physical activity recommendations, whilst according to the accelerometer data, only 70% were met (71). This indicates

that accelerometer-measured data can capture objective physical activity data while minimizing biases such as exaggeration or reduction of time spent in sedentary or physical activity from self-reported measures.

The present study aimed to investigate the association between dysmenorrhea status, menstrual period length, menstrual flow amount, and WaLIDD scores with accelerometer-measured sedentary (sitting) time and light, moderate, and vigorous intensity activity times in women with different severity levels of PD in the UAE. We hypothesized that the history and severity of dysmenorrhea and heavier menstrual flows are associated with increased sedentary time and reduced physical activity.

## MATERIALS AND METHODS

### Study design and setting

An observational study was conducted among nulliparous women in the emirates of Sharjah, Ajman, and Dubai in the United Arab Emirates. The study was reviewed and approved by the Research Ethics Committee, University of Sharjah (REC-22-10-10-S – approval date: October 10, 2022). Informed consent was obtained from all subjects involved in the study.

### Participants

Nulliparous women aged 18-45 years with regular menstrual cycles, with no, mild, or moderate-to-severe PD, who could read and understand English and had a normal body mass index ( $18.5\text{--}25\text{ kg/m}^2$ ) were included in the study. Those with menstrual pain of at least 4/10 on the Numeric Pain Rating Score (NPRS) for at least two consecutive periods were classified as having moderate-to-severe PD, while those with NPRS < 4/10 were classified as mild dysmenorrhea, and those with NPRS = 0 were classified as no dysmenorrhea (72-74).

Women were excluded from the study if they met the following criteria: a self-reported history of pregnancy, irregular menstrual periods, secondary dysmenorrhea (menstrual pain due to an underlying gynecological condition such as endometriosis or polycystic ovarian syndrome), menstrual cycles more than 35 days apart, hormonal therapy or an intrauterine birth control device, any recent history of pelvic, uterine, gynecological, or abdominal disease/surgery, and psychiatric disorders.

### Sample size estimation

Considering an effect size of 0.35, an  $\alpha$  value of 0.05, a

power of 0.80, and five independent variables to be included in multiple linear regression analysis, 43 participants are deemed adequate. We used the G\*Power 3.1.9.7 software to estimate sample size.

### Procedure

Women were contacted through adverts posted on social media websites and word of mouth. A custom-designed questionnaire asked questions regarding the history of PD and the absence of any exclusion criteria to ensure women's eligibility before enrolling them in the study. All eligible participants received a detailed description of the study procedure and were asked to sign an informed consent form before data collection. Sociodemographic data were recorded using a set of questions in the screening questionnaire.

Each participant received a Fibion device (Fibion Inc., Jyväskylä, Finland) on day 1 and was requested to wear the device throughout the day except when participating in water-based activities. The volunteers were asked to wear the device for the first 3 days of the menstrual cycle and fill out an NPRS score, where zero means no pain and 10 represents the worst pain possible. The Fibion device (20 g, L = 30 mm, W = 32 mm, T = 10 mm) was attached using hypoallergenic Hypafix® tapes on the right anterior upper thigh between the hip and knee joints. Participants were reminded to wear the device daily through text messages to their mobile phones throughout the data collection period. This device has proven valid and reliable for monitoring and measuring sedentary time and physical activities of daily living (75-78).

Fibion data processing techniques reported by the previous studies were employed in the current research to analyze sitting and upright posture/activity time (76). Fibion data were transferred to the manufacturer's website ([www.fibion.com/upload](http://www.fibion.com/upload)), and explicit reports on time spent sitting and different intensities of physical activity were obtained from the Fibion website. Intensities of physical activities were categorized as light-intensity (energy expenditure between 1.5 and 3 metabolic equivalents of task (MET)), moderate-intensity (between 3 and < 6 METs), and vigorous-intensity ( $\geq 6$  METs). Sedentary activity refers to energy expenditure of  $\leq 1.5$  METs.

Only participants who wore a device for  $\geq 10$  hours per day for the first three menstrual days were included. The participants were instructed to wear the Fibion device during waking hours as long as possible and remove it at night before sleeping to prevent conflation of night-time data with sitting and physical activity time (79). The accelerometer might record the reclining posture and consider it sitting time. Also, the device can interpret turning movements in

bed with side-lying posture (with the hips in flexion) as a different activity other than sleeping. For these reasons, we have asked our participants to remove the accelerometer before going to sleep to exclude night-time data before analyzing daytime sedentary and upright behavior. Additionally, to account for any variation between participants in wear time of the Fibion device, time spent in each activity was normalized to 16 hours of waking time per day (75). The intensity of menstrual symptoms was measured using the WaLIDD score questionnaire which assesses the working ability, anatomical location of pain, intensity of pain, and days of pain. The WaLIDD score has been reported to have good sensitivity and specificity of 63.7% and 56.9%, respectively, for detecting PD intensity rather than relying solely on NPRS (80).

Statistical analysis

Data normality was checked using the Shapiro-Wilk test. Data descriptive statistics were presented as mean and standard deviation (SD), or frequencies (with %). Multiple linear regression analyses were used to analyse the association between independent variables (PD intensity, length

Table I. Participant characteristics.

Variable	Value
Age (years)	22.60 ± 2.99
Weight (kg)	65.70 ± 8.59
Height (cm)	165 ± 6.98
BMI (kg/m²)	24.10 ± 2.19
Occupation	
Student	21 (45.7%)
Physiotherapist	9 (19.6%)
Personal trainer	7 (15.2%)
Research Assistant	5 (10.9%)
Clinical Dietitian	4 (8.7%)
Sedentary and physical activity times (per 16-h day)	
Sitting time (min)	660 ± 93.60
Light-intensity activity (min)	230.40 ± 103.80
Moderate-intensity activity (min)	33.60 ± 20.30
Vigorous-intensity activity (min)	0.38 ± 0.62

Table II. Menstruation-related information for all participants.

Variables related to menstruation		n (%)
Length of cycle (days)	≤ 21	2 (4.3%)
	22-28	40 (87%)
	≥ 29	4 (8.7%)
Length of menstruation (days)	< 5	2 (4.3%)
	5-7	40 (87%)
	≥ 8	4 (8.7%)
Amount of menstrual flow	Scanty	4 (8.7%)
	Normal	28 (60.9%)
	Heavy	14 (30.4%)
Menstrual pain in the last 3 menstruations	Yes	25 (54.3%)
	No	16 (34.8%)
	I don't know	5 (10.9%)
Frequency of presence of menstrual pain	Every menstruation	16 (34.8%)
	At intervals	15 (32.6%)
	Rarely	14 (30.4%)
	Never	1 (2.2%)
When is the menstrual pain experienced	Before menses start	10 (21.7%)
	During menstruation	22 (47.8%)
	Before and during menstruation	9 (19.6%)
	Not applicable	5 (10.9%)
Severity of dysmenorrhea	Mild primary dysmenorrhea (NPRS < 4/10)	23 (50%)
	Moderate-to-severe primary dysmenorrhea (NPRS ≥ 4/10)	23 (50%)

of menstrual period, amount of menstrual flow, WaLIDD score, presence of menstrual pain in the last three cycles) and dependent variables (sitting, light, moderate, and vigorous physical activity times per 16-h day). The level of significance was set at  $p < 0.05$ . The degree of multicollinearity of predictor variables was measured using the variance inflation factor (VIF), and all included independent variables in the model had a  $VIF < 3.0$ . Jamovi (Version 2.6) was used for all statistical analyses (81).

## RESULTS

Sixty healthy young women were enrolled in the study; four dropped out due to personal reasons, while 10 were excluded due to technical issues with the accelerometer data. Forty-six healthy young women with a mean age of  $22.6 \pm 2.99$  years and a mean BMI of  $24.1 \pm 2.19$  kg/m<sup>2</sup> were included in the analysis. Students comprised 45.7% of the population, while the remaining 54.3% were working women. **Table I** summarizes the demographic and anthropometric characteristics of participants. The median age of menarche was 13 and 12 in women with moder-

ate-to-severe PD and those with mild PD, respectively. All information related to menstruation is summarized in **table II**.

### Physical activity information

During the first three days of the menstrual cycle, participants spent most of their time sitting ( $11.00 \pm 1.56$  h). As for the physical activity, participants spent most of their time doing light-intensity activities ( $3.84 \pm 1.73$  h), followed by moderate-intensity activities ( $33.60 \pm 20.30$  min), and then very low durations of vigorous-intensity activities ( $0.38 \pm 0.62$  min).

### Sitting time

None of the variables of interest related to menstruation were significantly associated with the sitting time (**table III**).

### Light-intensity activity time

PD status was negatively associated with light-intensity activity time ( $p = 0.03$ ), with women in the moderate-to-severe PD group having light activity time shorter by 1.26 hours than the mild PD group (defined using

**Table III.** Variables associated with sitting time.

Variable	$\beta$ Coefficient	95%CI	P-value	Adjusted R <sup>2</sup>
Constant	9.5		< 0.001	0.095
PD status (moderate-to-severe <i>vs</i> mild)	0.94	(-0.034, 0.64)	0.077	
Length of menstrual period				
5-8 <i>vs</i> <5	0.65	(-1.22, 2.06)	0.609	
>8 <i>vs</i> <5	1.75	(-0.79, 3.04)	0.241	
Amount of menstrual flow				
Scanty <i>vs</i> heavy	0.39	(-1.03, 1.54)	0.694	
Moderate <i>vs</i> heavy	-0.26	(-1.07, 0.74)	0.715	
Presence of menstrual pain in last 3 menstruations.				
No <i>vs</i> Yes	-2.12	(-2.96, 0.23)	0.092	
IDK <i>vs</i> yes	-1.53	(-2.34, 0.38)	0.151	
WaLIDD score				
Mild PD <i>vs</i> severe PD	1.17	(-0.90, 2.41)	0.360	
Moderate <i>vs</i> severe PD	-0.10	(-0.99, 0.87)	0.891	

IDK: I don't know; PD: primay dysmenorrhea; WaLIDD: Working ability, Location, Intensity, Days of pain, Dysmenorrhea.



NPRS scores). The length of menstrual cycle, amount of menstrual flow, WaLIDD score, and presence of menstrual pain within the last three menstrual cycles were not significantly associated with light activity time (table IV).

Moderate-intensity activity time

None of the menstrual variables were significantly associated with moderate-intensity activity time (table V).

Vigorous-intensity activity time

The amount of menstrual flow was significantly associated with vigorous-intensity activity time. Vigorous-intensity activity time was longer by 0.75 minutes in participants with scanty menstrual flow than in participants with heavy menstrual flow (p = 0.031). Vigorous-intensity activity time was longer by 0.94 minutes in participants with moderate menstrual flow (p < 0.001) than those with heavy menstrual flow. Vigorous-intensity activity time was longer by 0.57 minutes in women with moderate PD than those with severe PD based on the WaLIDD scores (p = 0.025). On the other hand, the length of the menstrual cycle and the presence of menstrual pain within the last three menstrual cycles were not significantly associated with vigorous-intensity activity time (table VI).

DISCUSSION

A key finding of this study is the significant association between PD and light-intensity and vigorous-intensity activity durations. Our participants sat for an average of 11.0 ± 1.56 h per 16 hours daily. These levels are similar to the sedentary behavior of Emirati women employed in desk jobs (11.6 ± 1.1 h per 16-hour day) (66). It has also been shown that individuals who spent most of their working day sitting also spent longer outside work (82). These values indicate high sedentary activity times, as the sitting time was higher than the recommended seven hours of sedentary levels per day (83). Sitting hours equal to or exceeding 10 hours a day have been linked to a 34% increase in mortality rate (83). The increase in sitting time suggests that women with different levels of PD may be less likely to engage in activities like walking or light exercise, which in turn might contribute to an increase in various health issues like diabetes, hypertension, cardiovascular disorders, etc. (84-87). Our female participants showed a mean light activity of 3.84 ± 1.73 h per 16-hr day. Light-intensity activity durations were further shortened by 1.26 hours in women with moderate-to-severe PD than in those with mild PD. These differences might be linked to avoiding exercises or adapting them to be lighter by 34.3% of participants in another

Table IV. Variables associated with light-intensity activity time.

Variable	β Coefficient	95%CI	P-value	Adjusted R <sup>2</sup>
Constant	5.31		0.005	0.15
PD status (moderate-to-severe vs mild)	-1.26	(-0.69, -0.038)	0.030	
Length of menstrual period				
5-8 vs <5	-0.30	(-1.77, 1.42)	0.826	
>8 vs <5	-2.01	(-3.01, 0.69)	0.213	
Amount of menstrual flow				
Scanty vs heavy	0.18	(-1.14, 1.35)	0.868	
Moderate vs heavy	0.25	(-0.74, 1.02)	0.746	
WaLIDD score				
Mild PD vs severe PD	0.26	(-1.46, 1.75)	0.853	
Moderate vs severe PD	0.42	(-0.66, 1.14)	0.591	
Presence of menstrual pain in last 3 menstruations.				
No vs Yes	0.90	(-1.03, 2.07)	0.500	
IDK vs yes	1.47	(-0.47, 2.17)	0.199	

IDK: I don't know; PD: primary dysmenorrhea; WaLIDD: Working ability, Location, Intensity, Days of pain, Dysmenorrhea.

**Table V.** Variables associated with moderate-intensity activity time.

Variable	$\beta$ Coefficient	95%CI	P-value	Adjusted R <sup>2</sup>
Constant	18.2		0.433	-0.046
PD status (moderate-to-severe <i>vs</i> mild)	6.59	(-0.20, 0.53)	0.367	
Length of menstrual period				
5-8 <i>vs</i> <5	11.28	(-1.21, 2.32)	0.528	
>8 <i>vs</i> <5	9.59	(-1.59, 2.53)	0.645	
Amount of menstrual flow				
Scanty <i>vs</i> heavy	-8.05	(-1.78, 0.99)	0.565	
Moderate <i>vs</i> heavy	-8.77	(-1.41, 0.54)	0.375	
WaLIDD score				
Mild PD <i>vs</i> severe PD	-16.2	(-2.57, 0.98)	0.369	
Moderate <i>vs</i> severe PD	6.12	(-0.70, 1.30)	0.546	
Presence of menstrual pain in last 3 menstruations.				
No <i>vs</i> Yes	17.15	(-0.87, 2.56)	0.326	
IDK <i>vs</i> yes	-7.12	(-1.81, 1.11)	0.630	

IDK: I don't know; PD: primary dysmenorrhea; WaLIDD: Working ability, Location, Intensity, Days of pain, Dysmenorrhea.

**Table VI.** Variables associated with vigorous-intensity activity time.

Variable	$\beta$ Coefficient	95%CI	P-value	Adjusted R <sup>2</sup>
Constant	0.79		0.163	0.33
PD status (moderate-to-severe <i>vs</i> mild)	-0.32	(-0.55, 0.027)	0.074	
Length of menstrual period				
5-8 <i>vs</i> <5	0.58	(-0.48, 2.34)	0.189	
>8 <i>vs</i> <5	-0.45	(-2.37, 0.91)	0.375	
Amount of menstrual flow				
Scanty <i>vs</i> heavy	0.75	(0.12, 0.87)	0.031	
Moderate <i>vs</i> heavy	0.94	(0.74, 1.69)	< 0.001	
WaLIDD score				
Mild PD <i>vs</i> severe PD	0.69	(-0.30, 2.58)	0.118	
Moderate <i>vs</i> severe PD	0.57	(0.12, 1.72)	0.025	
Presence of menstrual pain in last 3 menstruations.				
No <i>vs</i> Yes	-0.35	(-1.94, 0.80)	0.406	
IDK <i>vs</i> yes	-0.49	(-1.96, 0.37)	0.175	

IDK: I don't know; PD: primary dysmenorrhea; WaLIDD: Working ability, Location, Intensity, Days of pain, Dysmenorrhea.

study due to increased menstrual pain, heavier menstrual flow, and/or increased fatigue (48). Light-intensity physical activity recommendations are currently not included in the WHO physical activity guidelines (1). However, the Canadian 24-hour movement guidelines recommend that “*adults should accumulate several hours of light physical activities, including standing daily*”. These recommendations were based on the reports showing that doubling the time spent doing light physical activities reduced the mortality rate by 29% (88, 89). Furthermore, shifting focus from isolating movement behaviors to integrating all movement behaviors of any intensity throughout the day is recommended to allow additional movement options for adults (89, 90). Moderate-intensity and vigorous-intensity activities timings of our participants were  $33.6 \pm 20.3$  min and  $0.376 \pm 0.618$  min per 16-hr day, respectively. These values fall very short of the WHO physical activity recommendations that recommend 150-300 minutes of moderate-intensity activities and at least 75-150 minutes of vigorous-intensity activities or an equivalent combination of both activities (1).

Vigorous-intensity activity duration is longer by 0.75 min in women with scanty menstrual flow than in those with heavy menstrual flow. In comparison, the duration of vigorous activity is longer, 0.94 min, in women with moderate menstrual flow than in those with heavy menstrual flow. Those women with scanty or moderate menstrual flow might be able to better participate in vigorous activities compared to their counterparts with heavy menstrual flow. The differences observed in vigorous activity between these subgroups were negligible ( $< 1$  min). Most studies combine moderate and vigorous-intensity activities as one variable; it is plausible that the values reported in previous literature were higher since they included a combination of moderate and vigorous-intensity times (90).

Although the vigorous activity timings are very low for all participants, they were shorter in participants with increased PD intensity, where vigorous activity duration is longer by 0.57 min in women with moderate-intensity PD than severe PD (classified using the WaLIDD score). The results in the current study are nearly similar to from the findings of Chantler *et al.* (2009), where the study concluded that there was a 40% decrease in all physical activities in participants with moderate to severe PD during the days of menstrual pain *versus* the non-menstrual days, whilst there was no significant difference in those with no dysmenorrhea (70). A previous study highlighted that the intensity of PD was reduced with the addition of 10-week high-intensity interval training; this change was mainly attributed

to hormonal modulation and a decrease in inflammatory proteins (89).

### Limitations and recommendations

To the best of our knowledge, this is the first study in the UAE to investigate the association of PD characteristics, physical activity intensities, and related information with objective sedentary and physical activity times measured by a triaxial (Fibion) accelerometer. In addition, we used the WaLIDD score to assess specific menstrual pain information and its effect on physical activity, whilst other studies measured menstrual pain only through NPRS.

Limitations of the current study include the lack of inclusion of sleep quality and other factors, such as smoking and dietary factors (40), that may be associated with PD. The accelerometer is not waterproof; therefore, no water-based activity can be measured. However, we have not received any complaints about the involvement of participants in water-based sports, mainly since such sports are not very commonly practiced by women during their menstruation. Future studies are warranted to explore the underlying mechanisms between physical activity and its effect on PD. Prospective longitudinal cohort studies are required to provide detailed insights into the cyclic nature and changes in menstrual cycle patterns/characteristics and their association with sedentary behavior and physical activity of women with and without PD. Finding the factors associated with physical activity times in women with PD would aid in developing more effective interventions to manage sedentary behavior and improve activity levels of women with PD.

### CONCLUSIONS

We found that women with moderate-to-severe PD had lower light-intensity activity time than women with mild PD. The severity of menstrual flow influences the duration of vigorous-intensity activities, and women with heavier menstrual flow had lower vigorous-intensity activity time than women with scanty menstrual flow. If these associations are confirmed in prospective longitudinal cohort studies, then tailored interventions to mitigate sedentary behavior and physical inactivity in women with dysmenorrhea could be delivered.

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## DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

## CONTRIBUTIONS

JA: conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing - original draft preparation, writing - review & editing, visualization, project administration. NM, FM: supervi-

sion, writing - original draft preparation, writing - review & editing. AA: conceptualization, methodology, software, validation, formal analysis, resources, data curation, writing - review & editing, visualization, supervision, project administration.

## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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# Management of Post-Traumatic Elbow Stiffness: A Systematic Review of Randomized Controlled Trials with Meta-Analysis

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## LEVEL OF EVIDENCE: 1

## SUMMARY

**Introduction.** This systematic review (SR) and meta-analysis aimed to assess the effectiveness of surgical and conservative treatments for post-traumatic elbow stiffness in improving pain, functionality, and quality of life.

**Methods.** A comprehensive search of PubMed, Scopus, Web of Science, and Cochrane Library databases was conducted for English-language studies up to April 2024. Randomized clinical trials (RCTs) focusing on surgical or conservative interventions for post-traumatic elbow stiffness were included. Primary outcomes were pain, functionality, and quality of life. Study quality and risk of bias were assessed using the Cochrane Risk of Bias 2 tool, while evidence certainty was evaluated with GRADE methodology.

**Results.** Twelve RCTs met the inclusion criteria. Surgical interventions, particularly open arthrolysis combined with early structured rehabilitation and intraoperative pain modulation, significantly improved long-term range of motion (ROM) compared to standard postoperative care, though evidence quality was low due to methodological limitations. Conservative treatments, such as muscle energy techniques (MET), provided short-term improvements in pain and functionality but lacked consistent long-term data.

**Conclusions.** Conservative treatments like MET are recommended for mild to moderate post-traumatic elbow stiffness. Severe cases or those unresponsive to conservative care benefit more from open arthrolysis followed by early rehabilitation and adjunct therapies. Further high-quality RCTs are needed to confirm these findings and refine treatment protocols.

## KEY WORDS

*Elbow; stiffness; surgery; rehabilitation; physiotherapy.*

## INTRODUCTION

The elbow plays a fundamental role in the upper limb's mobility, as it, along with the shoulder, ensures the correct positioning of the hand in space (1). Most activities of daily

living (ADL) are performed within a functional ROM of 100°, ranging from 30° of extension to 130° of flexion, as well as 100° of rotation, including 50° for pronation and 50° for supination (2). Reduced elbow mobility can lead

to difficulties in performing ADL to varying degrees and may restrict participation in work and social activities (3). After a traumatic event, there are multiple factors that can contribute to a reduction in the physiological ROM of the elbow (4). The complex anatomy and biomechanics make the elbow joint particularly prone to post-traumatic stiffness (5). Elbow stiffness is defined when the range of motion is 30°-120° in flexion-extension or less (6), or when pronation-supination is less than 50° (7). The incidence of post-traumatic stiffness is not well-defined in the literature, with Sojbjerg's 1996 study suggesting at least 5% (6), while a study by Zheng's group in 2018 found that more severe stiffness is associated with high-energy traumas (8).

Tissue changes that occur after a traumatic event can lead to the development of capsular fibrosis or heterotopic ossification processes (9). Post-traumatic capsular thickening leading to joint stiffness appears to be associated with a high presence of myofibroblasts, cytokine alterations, and disorganized collagen fiber production (10).

Among the classifications of post-traumatic elbow stiffness commonly used in the literature, there is Morrey's classification (11), which distinguishes types based on anatomical location: intrinsic, extrinsic, and combined. Intrinsic types involve the joint surface, such as misalignments or joint adhesions and loss of cartilaginous components. Extrinsic types include everything outside the joint, such as capsular contractures, ligament issues, heterotopic ossification, extra-articular misalignments, or fibrotic phenomena in soft tissues following burns. The most frequent category includes both intra and extra-articular elements and falls under combined types.

The multifactorial nature of stiffness necessitates a thorough clinical evaluation for proper assessment. It should encompass a comprehensive patient history with post-traumatic stiffness, seeking to identify the initial trauma and how it was managed up to the evaluation (12). Associated conditions such as neurological disorders, infections, or other traumas need to be considered for a correct diagnostic framework. Equally important are factors such as the timing of clinical manifestation, the characteristics and progression of symptoms, and the pre-morbid functional level, which influence the decision-making process. For example, stiffness detected in the mid-range of motion might indicate joint incongruity or an arthritic condition, while "end-range" stiffness could be attributed to an olecranon-humerus conflict (13). In the evaluation it is also important to consider psychosocial factors: patients with post-traumatic elbow stiffness may experience depression and anxiety (14), due to the impact that the pathology has on daily activities, therefore a transi-

tion from a purely biomedical framework to a bio-psycho-social one as already demonstrated for lateral elbow pain (15).

Treatment options for post-traumatic elbow stiffness can be surgical or conservative. The heterogeneity of clinical presentations has not yet provided a clear picture of which approach is more appropriate. In the absence of mechanical conflict causing stiffness due to poor healing, dislocations, or heterotopic ossification, conservative treatment is recommended (5). If signs and symptoms persist for at least 6-12 months, conservative treatment may not be recommended (9). Conservative treatment mainly consists of physiotherapy interventions, including manual therapy techniques, therapeutic exercise, and educational aspects. In the initial phases, treatments with static and dynamic braces have shown their effectiveness in both post-traumatic and post-operative stiffness (16, 17). The use of continuous passive motion (CPM) is highly controversial, despite its clinical use; Carpenter *et al.* have reported potential risks related to bleeding, edema, and possible ulnar nerve issues (18).

Surgical approaches have shown satisfactory outcomes after contracture release techniques (5). There are various described techniques that involve more or less extensive release, both open and arthroscopic, with or without the use of external fixators (19). The classification and decision-making algorithm proposed by Pederzini *et al.* published in 2024 (20) provide an updated framework for surgical planning in elbow stiffness, helping to distinguish between extrinsic and intrinsic forms and guide appropriate intervention strategies. Wang *et al.* (21) focused specifically on post-traumatic elbow stiffness associated with heterotopic ossification, supporting the efficacy of surgical excision combined with structured postoperative rehabilitation and prophylactic measures to prevent recurrence. Tedesco *et al.* (22) described a surgical technique for lateral ulnar collateral ligament (LUCL) repair in terrible triad injuries, a condition often resulting in significant post-traumatic elbow stiffness. Their method using a suture button contributes to restoring stability and facilitating early mobilization post-surgery. In the context of elbow release procedures, Xu *et al.* (23) explored the role of anterior ulnar nerve transposition in patients with post-traumatic elbow stiffness, concluding that this approach improves outcomes in symptomatic cases, while in situ release may be sufficient in the absence of neurological symptoms. Oliva *et al.* (24) systematically reviewed the surgical management of chronic distal triceps tendon rupture, an often-underdiagnosed condition that may coexist with or contribute to post-traumatic elbow stiffness. Recognizing and addressing these injuries is essential for optimizing functional recovery.

Currently, there are no secondary studies that have investigated through a SR whether there is a better approach, be it conservative or surgical, in terms of improving pain, function and quality of life for post-traumatic elbow stiffness. Therefore, the aim of this SR is to investigate potential differences in terms of improvement in pain, function and quality of life between different approaches in the treatment of post-traumatic elbow stiffness.

## MATERIALS AND METHODS

This SR was conducted following the methodological guidelines outlined in the PRISMA 2020 checklist (25). The review protocol has been registered in the PROSPERO system (CRD42023426417).

### Eligibility criteria

The study question was framed using the Population, Intervention, Comparison, and Outcome (PICO) model (26). The PICO question was composed by P: Adults with post-traumatic elbow stiffness; I: Conservative treatments; C: Surgical treatments; O: Pain, function, quality of life.

Articles that met the following inclusion criteria were included in this SR: 1. English written; 2. RCTs; 3. Adult population (age  $\geq 18$  years); 4. Patients with post-traumatic elbow stiffness; 5. Patients undergoing surgical treatment or conservative treatment; 6. Studies that measured outcomes in the domains of pain, function (*i.e.*, ROM variations, muscle strength, PROMs, *etc.*) and quality of life.

All types of post-traumatic elbow stiffness were included, whether treated conservatively or surgically. We therefore included RCTs that evaluated the effects of different conservative approaches on each other, the effects of different surgical approaches on each other, and studies that analyzed conservative *versus* surgical interventions. For conservative treatment is intended all physiotherapy approaches typically used for post-traumatic elbow stiffness such as manual therapy (*i.e.*, muscle energy techniques, mobilization with movement, passive mobilizations, manipulations, *etc.*) therapeutic exercise (active mobilizations, resistance training, aerobic training, *etc.*), splinting (static or dynamic) and CPM. We considered as surgical treatments: open release, arthroscopic release and open arthrolysis combined with or without external fixation, with or without concomitant distraction.

### Search strategy

A bibliographic search was conducted on April 2024, in the following databases: US National Library of Medicine

(PubMed/MEDLINE), SCOPUS, Web of Science (WOS), and the Cochrane Database of Systematic Reviews. No time limits were applied for article inclusion.

MeSH terms and keywords specific to each database consulted were used for the search string. Additionally, manual searches were performed. The search strings are available in **supplementary materials**. To improve the research itself, the reference lists of the included studies and the relevant reviews in the literature on the topic were also consulted.

### Selection process and data extraction

Duplicates were primarily detected and excluded through the Rayyan web app for systematic reviews (27). Two reviewers (FS, LDF) independently assessed the titles and abstracts for eligibility. The reviewers who selected the trials (FS and LDF) remained independent throughout the selection process. At the conclusion of this phase, the two reviewers (FS, LDF), independently assessed the full text of the articles to confirm they met the eligibility criteria. Once the studies for inclusion were selected, the data were extracted from the two reviewers (FS, LDF) independently. Any discrepancies or disagreements between the two reviewers identified were discussed and resolved with the assistance of a third reviewer (FM, EM, ML). For studies with incomplete data or data that were not directly accessible, an initial effort was made to reach out to the corresponding author for clarification. If there was no response or if additional data could not be provided, the articles were excluded from the study.

### Study risk of bias assessment

The methodological quality of the included studies was assessed by two independent reviewers (FS, LDF) and a third reviewer (FM, EM, ML) was consulted in case of disagreements to find a resolution. The Cochrane risk of bias tool (RoB2) (28) for randomized trials was used to assess the methodological quality of the included studies. The GRADE approach was used to rate the quality and strength of evidence as high, moderate, low, and very low regarding the main outcome (pain, function, and quality of life). Results summary tables were generated using GRADE pro Software.

### Statistical analysis

Effect estimates from continuous data were calculated as mean difference (MD) or standardized mean difference (SMD) depending on the measurement scales used in the studies. MD was used when the studies included reported the outcome using the same units (*e.g.*, ROM, VAS), while SMD was chosen for continuous outcomes with differ-



ent measurement units, according to section 10.5.1 of the Cochrane Handbook for systematic reviews (29). We used the ProMeta3 computer program to perform statistical analyses. We pooled data using random-effect models when large heterogeneity was assessed through I2 statistics (value greater than 50% was considered indicative of large heterogeneity) (30, 31).

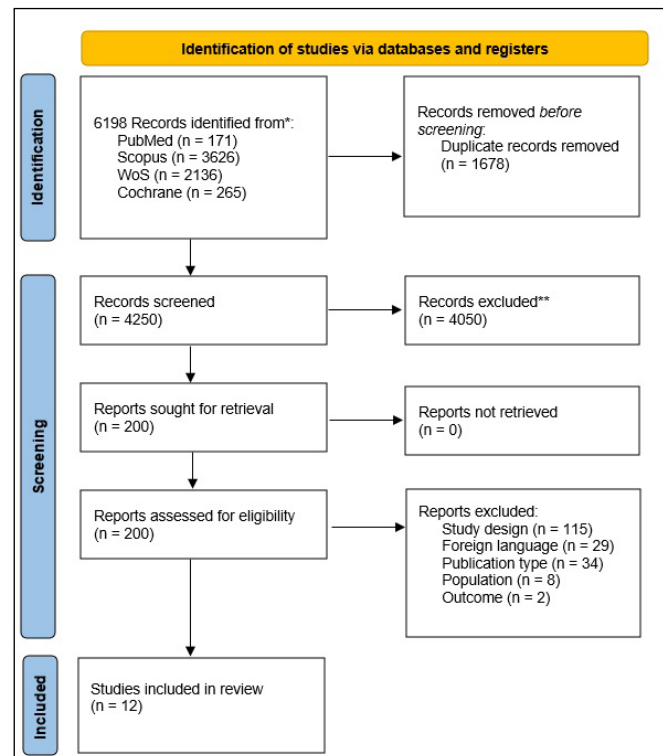
## RESULTS

### Study selection

Through the systematic search of online databases, 6,198 articles were included. The analysis of duplicates using the Rayyan software led to the exclusion of 1,678 articles considered duplicates. The first screening phase through the analysis of title, abstract and keywords led to the exclusion of 4,050 articles as they did not meet the inclusion criteria. 1,632 articles were excluded because the background of the article did not meet the inclusion criteria, 1,678 articles were eliminated due to the study design, 320 studies were excluded due to the type of publication, 420 for including a population different from the one investigated (adults with post-traumatic elbow stiffness). 200 remaining articles were then analyzed in detail to assess their eligibility. 115 articles were excluded because they did not meet the inclusion criteria regarding the study design, another 29 were excluded because they were written in a foreign language (not in English), 34 were excluded because the type of publication was not deemed appropriate (study protocols), 8 articles were excluded because they included a pediatric population (under 18 years of age) and 2 studies were excluded because the outcomes did not meet the PICO question and the inclusion criteria. Finally, 12 articles were included, all RCTs. The search process is summarized in **figure 1**.

### Study characteristics

A total of 12 RCTs published from 2008 to 2022 were included. The main characteristics were summarized in **table I**: author and year of publication, study design and purpose, participants, interventions, outcomes, and follow-up with the related results. The studies were conducted in different countries around the world: China (5), USA (1), India (1), Turkey (2), Brazil (1), Australia (1) and Hong Kong (1). The total sample of all participants included in the studies is 593 subjects who were enrolled in experimental or control groups. Each of them reported a diagnosis of post-traumatic elbow stiffness with limitation of ROM in flexion-extension. Only one study (32) compared the effects of conser-



**Figure 1.** PRISMA flowchart.

vative *versus* surgical treatment. The effects of conservative treatments were compared in six studies (33-38) while the remaining five RCTs (39-43) compared the effects of surgical treatments. **Table II** summarizes the interventions in the included RCTs. Regarding the methods of pain detection, one study (33) used the Numeric Pain Rating Scale (NPRS) at rest and in movement. The Visual Analogue Scale (VAS) at rest and in movement was used in nine studies (32, 34-36, 38, 40-43). With respect to the function domains, the ROM was detected in all studies using a goniometer, one study (35) used a digital goniometer and a dynamometer for muscles strength, while the others used a universal goniometer. The most used Patient-reported outcome measures (PROMs) were the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire (32-37) and the Mayo Elbow Performance Score (MEPS) (32, 39-41, 43).

### Risk of bias in studies

The methodological quality of the included RCTs was assessed using the Cochrane Risk of Bias tool Rob2 (28) (Review Manager RevMan) [Computer program] Version. In **figure 2** the items were summarized: randomization process, deviations from the intended interventions, miss-

**Table 1.** RCTS synthesis: author and year, design and scope, participants, intervention, outcome and follow-up, results.

Author (year)	Design and scope	Participants	Intervention	Outcome and Follow-up	Results
Bhosale (2022)	RCT, single-blind, Two-group. Effects of IASTM vs MET in patients with postoperative stiffness after elbow fracture.	Adults (>18) with post-operative elbow stiffness with loss of extension of $\geq 30^\circ$ and/or flexion $\leq 120^\circ$ at least 6-week post-surgery.	<b>Group A (13): IASTM and conventional treatment</b> Group B (13): MET and conventional treatment. Both groups received 3 weeks of supervised intervention, (twice a week), for a total of 6 sessions.	NPRS (at rest, at activity), ROM (universal goniometer), DASH, PFSE. Baseline e post-treatment.	Significant improvement (p<0.05) in both groups on all outcomes. Significant difference (p<0.05) in favor of IASTM in NPRS and PFSE.
Birinci (2019)	RCT, single-blind, two-group. Effects of PNF vs Static Stretching in patients with post-traumatic elbow stiffness.	Adults (18-55) who had sustained an elbow fracture and were treated at least 6 weeks either conservatively or surgically, with an elbow limitation in extension of flexion.	<b>PNF group (20): PNF and conventional treatment.</b> Static stretching group (20): passive stretching and conventional treatment. Twice a week for 6 weeks, for a total of 12 sessions.	DASH, AROM (universal goniometer), VAS (rest and activity), TSK, Short Form-12, GRCs. Baseline, post-treatment, 1 month follow-up.	Significant improvements in both groups. Higher PNF in DASH (p<0.03), VAS rest (p<0.03), VAS activity (p<0.01), AROM flex (p<0.04)
Birinci (2022)	RCT, single-blind, two group. GMI vs SE in patients with post-traumatic elbow stiffness following elbow fracture surgery.	Adults (20-55) at 4-8 weeks post-surgery with post-traumatic elbow stiffness (flex/ext joint deficit)	<b>GMI group (25): graded motor imagery and rehabilitation protocol. Home exercise in the follow-up period.</b> SE group (25): structured rehabilitation protocol. Home exercise in the follow-up period. Twice a week for 6 weeks, for a total of 12 sessions.	DASH, AROM (digital goniometer), VAS (rest, activity, and night), TSK, muscle strength (dynamometer), GRCs. Baseline, post-treatment, and 6 weeks follow-up	Improvements in both groups.
Cui (2019)	RCT, single-blind, two group. Effects of ERAS vs Conventional approach in patients with post-traumatic elbow stiffness candidates for open arthrolysis.	Adults ( $\geq 18$ years) with post-traumatic elbow stiffness (flex<120° and ext >30°)	<b>ERAS group (25): arthrolysis and Enhanced recovery after surgery.</b> Conventional Group (25): arthrolysis and mobilization encouragement.	VAS (rest and in motion), ROM, MEPS, complications. Baseline, 1 e 5 days post-surgery, 6 weeks, and 6 months follow-up.	VAS at rest and in motion better in ERAS (p<0.05) at 1- and 5-days post op then similar at 6 weeks and 6 months. Better ROM in ERAS (p<0.05). MEPS and similar complications.
Cui (2021)	RCT, double-blind, two group. efficacy of intravenous tranexamic acid (TXA) on post-surgery drainage, calculated blood loss, and early clinical outcomes in patients undergoing OEA	Adults ( $\geq 18$ years) with post-traumatic elbow stiffness (ROM $\leq 60^\circ$ according to Mansat and Morrey) candidates for OEA	<b>TXA group (48): arthrolysis and 1gr of TXA in 100 ml of intravenous saline solution and rehabilitation.</b> Placebo group (48): arthrolysis and 100 ml of intravenous saline solution and rehabilitation.	Post-surgery drainage, VAS (rest and in motion), blood loss, ROM, MEPS. Baseline, 1, 2, 3, 4 and 5 days after surgery, 6 weeks and 6 months follow-up.	Better short-term outcomes in the TXA group for pain, blood loss and drainage volume. After 6 weeks and 6 months there was no difference between the groups.

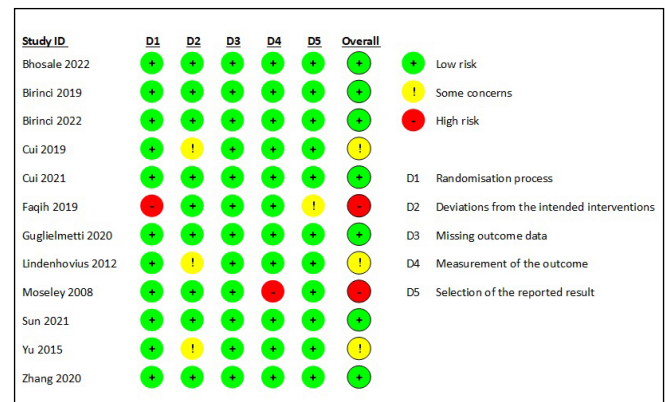
Author (year)	Design and scope	Participants	Intervention	Outcome and Follow-up	Results
Faqih (2019)	RCT, two group. Effects of METs immediately after immobilization or after one-week post-surgery for post-traumatic elbow stiffness.	Adults (18-50 years) post-surgery for post-traumatic elbow stiffness (intra- or extra-articular fractures of the elbow without ligament injuries)	<b>Early MET group (15): early MET and therapeutic exercise</b> Delayed MET group (15): the same protocol of early MET but one week later (upon removal of the immobilization) 6 a week for 3 weeks, for a total of 18 sessions.	VAS, ROM (goniometer), DASH. Baseline and post-treatment (3 weeks)	Better results in the Early MET group for pain, elbow ROM and function.
Guglielmetti (2020)	RCT, single blind, two group. Effects of conservative vs surgical treatment in post-traumatic elbow stiffness.	Adults (18-65 years) with trauma in the last 6 months with 4 months of conventional treatment failure (flex<100° east>30°).	<b>Surgical Group (15): surgical release with posterior approach and rehabilitation protocol like the conservative one.</b> Conservative Group (15): rehabilitation protocol, occupational therapy, CPM and static night orthoses.	Primary: elbow flex-est ROM. Secondary: MEPS, VAS, DASH, prone-sup elbow ROM, complications. Baseline, 6 weeks, 3 months, 6 months follow-up	Surgical group: greater ROM in flexion-extension, greater absolute and relative increase compared to rehabilitation alone at 6 months follow-up. The groups did not differ in clinical scores and complication rates.
Lindenhovius (2012)	RCT, two group. Effects of dynamic vs static orthoses in post-traumatic elbow stiffness.	Adults (>18 years) with post-traumatic stiffness (loss of >30° of flex-ext) without improvements in ROM in the last 4 weeks.	<b>Progressive static orthoses group (35): 3 times a day for 30 minutes + stretching exercises</b> <b>Dynamic orthoses group (31): 6-8 hours a day + stretching exercises</b>	ROM and DASH. Baseline, 3, 6 and 12-months follow-up.	Orthotics and exercise are effective at 6-12 months. No significant difference between the two groups.
Moseley (2008)	RCT single blind, two group. Differences between serial casting and positioning in elbow stiffness after brain trauma.	Adults with traumatic brain injury and post-traumatic elbow stiffness (at least 15 degrees of flexion deficit)	<b>Serial casting group (14): exercise protocol and 2 weeks of brace in stretching position with increase after 7 days.</b> Positioning group (12): exercise protocol and passive stretching by the physiotherapist for 2 weeks.	ROM, spasticity, TEMPA, VAS. Baseline, post-intervention (2 weeks), post-intervention + 1 day, after 4 weeks (follow-up).	In the short term, serial casting produces better effects than positioning. In follow-ups all effects are lost.
Sun (2021)	RCT, double-blind, two group. Effects of infiltrative therapy after arthrolysis for elbow stiffness compared to arthrolysis alone.	Adults (18-65 years) with post-traumatic elbow stiffness.	<b>PMOI group (28): arthrolysis, PMOI infiltration and rehabilitation protocol</b> Control group (31): arthrolysis and rehabilitation protocol	VAS (rest and in motion), ROM, blood loss, analgesic consumption. Baseline, all the first 7 post-operative days, follow-up at 3 months.	Infiltration group has greater reduction in post-operative pain and lower use of analgesics.

Author (year)	Design and scope	Participants	Intervention	Outcome and Follow-up	Results
Yu (2015)	RCT, single blind, two group. Effects of cryotherapy after arthrolysis for post-traumatic elbow stiffness.	Adults (18-70) with post-traumatic elbow stiffness.	<b>Cryotherapy group (31): arthrolysis, CryoCuff and rehabilitation protocol</b> Control group (28): arthrolysis and rehabilitation protocol	VAS, ROM, blood loss, MEPS, analgesic consumption. Baseline, all the first 7 post-operative days, follow-up at 3 months.	Cryotherapy effective in reducing pain and taking analgesics.
Zhang (2020)	RCT, two group. Effects of tranexamic acid in open arthrolysis for post-traumatic elbow stiffness.	Adults (>18 years) with post-traumatic elbow stiffness.	<b>TXA group (31): open arthrolysis, TXA and rehabilitation protocol</b> Control group (30): open arthrolysis, saline solution and rehabilitation protocol	Tourniquet time, intraoperative blood loss, postoperative drainage, ROM, MEPS Baseline, 1,2,3 post-surgery days, 6 weeks and 1 year follow-up.	Better results in the TXA group for intraoperative bleeding and reduction of blood loss.

The groups with the best results have been highlighted in bold; RCT: randomized controlled trial; IASTM: Instrument assisted soft tissue mobilization; MET: muscle energy technique; ROM: range of motion; NPRS: numeric pain rating scale; VAS: visual analogue scale; DASH: Disabilities of the Arm, Shoulder and Hand questionnaire; PFSF: Patient-Specific Functional Scale; PNF: proprioceptive neuromuscular facilitation; TSK: Tampa scale of kinesiophobia; GRCs: global rating of change scale; GMI: graded motor imagery; SE: structured exercise; ERAS: enhanced recovery after surgery; MEPS: mayo elbow performance scale; OEA: open elbow arthrolysis; TXA: tranexamic acid; CMP: continuous passive mobilization; PMDI: periarticular multimodal drug injection.

**Table II.** RCTS synthesis intervention

Author (year)	Conservative vs surgical	Conservative vs conservative	Surgical vs surgical
Bhosale (2022)		X	
Birinci (2019)		X	
Birinci (2022)		X	
Cui (2019)			X
Cui (2021)			X
Faqih (2019)		X	
Guglielmetti (2020)	X		
Lindenhovius (2012)		X	
Moseley (2008)		X	
Sun (2021)			X
Yu (2015)			X
Zhang (2020)			X

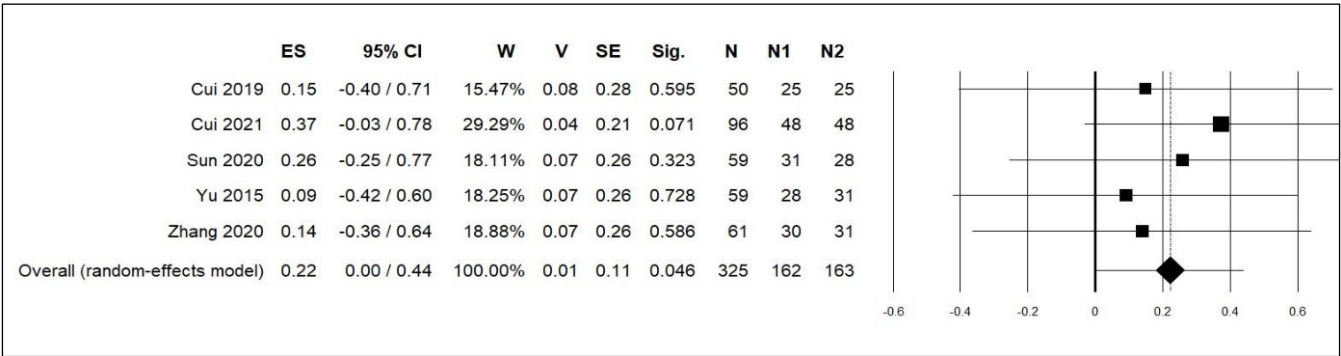


**Figure 2.** Risk of bias results (RoB2).

ing outcome data, measurement of the outcome, selection of the reported result.

Studies were rated as having a high, low, or unclear risk of bias for each component of the tool. Finally, an overall result was assigned which resulted in a low risk of bias in seven studies (32-35,39, 41, 42), some unclear elements in three studies (37, 40, 43) and a high risk of bias in two studies (36, 38) (figure 2).





**Figure 3.** Results of meta-analysis and forest plot of ROM improvement: control group N1 (left side) vs experimental group N2 (right side).

Results of synthesis

Despite the significant variability in interventions and follow-up periods, we were able to perform a meta-analysis using a random-effects model to evaluate the impact of various post-surgery treatments after open arthrolysis, compared to standard care, on the recovery of elbow joint ROM in flexion-extension for patients with post-traumatic

stiffness. We included 5 RCT studies (39-43) that compared conventional surgical treatment involving open arthrolysis with enhanced surgical approaches that incorporated innovative techniques during the procedure and post-operative care. Each study was structured with two groups: a control group and an experimental group. The ROM outcomes at baseline were compared to those at long-term follow-up

ARTHROLYSIS AND OTHER TREATMENTS COMPARED TO ARTHROLYSIS FOR IMPROVEMENT ROM IN POST-TRAUMATIC ELBOW STIFFNESS					
Patient or population: improvement ROM in post-traumatic elbow stiffness					
Setting: Hospital					
Intervention: arthrolysis and other treatments					
Comparison: arthrolysis					
Outcomes	N° of participants (studies) Follow-up	Certainty of evidence (GRADE) (95% CI)	Relative the effect	Anticipated absolute effects	
				Risk with arthrolysis	Risk difference with arthrolysis and other treatments
Long-term Range of Motion (ROM) assessed with: goniometer follow-up: mean 6 months	325 (5 RCTs)	⊕⊕○○ Low <sup>a,b</sup>	–	The mean long-term Range of Motion was 0	MD 0.22 higher (0 to 0.44 higher)
*The risk in the intervention group (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI). CI: confidence interval; MD: mean difference					
GRADE Working Group grades of evidence					
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.					
Moderate certainty: we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.					
Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.					
Very low certainty: we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.					

**Figure 4.** GRADE results: certainty of evidence for meta-analysis.



(averaging six months). All included studies used the same method for measuring ROM (universal goniometer). **Figure 3** presents the results alongside the forest plot, where the left column shows the control groups' outcomes (classical open arthrolysis, 162 patients), and the right column shows the experimental groups' outcomes (open arthrolysis with innovative elements, 163 patients). The forest plot illustrates the superior recovery of ROM in elbow flexion-extension in the experimental groups over the control groups at long-term follow-up. The overall effect size (ES) was 0.22, with a 95% confidence interval of 0.00 to 0.44, a two-tailed statistical significance (Sig.) of 0.046, a variance (V) of 0.01, and a standard error (SE) of 0.11.

### Certainty of evidence

The GRADE method applied to the 5 articles included in the meta-analysis conducted reported a low quality of evidence as two studies present some concerns in the domain of deviations from intended intervention due to the lack of blinding of the population, and the threshold value of 400 individuals analyzed between the experimental and control groups was not reached ( $n = 325$ ). **Figure 4** shows the results of the GRADE method using the GRADE pro Software.

## DISCUSSION

The aim of this SR was to analyze the effectiveness of different approaches in the management of post-traumatic elbow stiffness. To this end, RCTs were analyzed that verified the effectiveness of different conservative approaches, different surgical techniques and post-surgical rehabilitation protocols and conservative treatments *versus* surgical treatments. The first fact that emerged is the high heterogeneity of the proposed treatments, especially among conservative approaches. Only one study (32) has verified the effectiveness of conservative treatment *versus* a surgical one. Despite this, when analyzing the studies that investigated the effects of surgical approaches and different post-surgical protocols, it is interesting to note that open arthrolysis is the most used technique, confirming what is already present in the literature (44). Furthermore, as regards the studies that compared different surgical techniques with post-surgical rehabilitation protocols, it was also possible to compare the results from a quantitative point of view through the meta-analysis tool. The main finding from the meta-analysis is that the surgical approach with open arthrolysis followed by innovative elements appears to be superior to conventional open arthrolysis in the long-term recovery of elbow ROM in

flexion-extension. Analyzing the studies included in the meta-analysis in detail, various innovative elements were introduced by different authors to form the experimental group:

Cui *et al.* in 2019 (40) proposed an early and structured post-operative rehabilitation protocol called "enhanced recovery after surgery" (ERAS) as an alternative to the conventional approach. The ERAS group showed, compared to conventional group, better short-term outcome in the domain of pain at rest and in motion ( $p < 0.05$ ). Also, ROM was consistently better in the ERAS group ( $p < 0.05$ ). In 2021, the same author (41) suggested the administration of intravenous tranexamic acid just before the surgical incision, noting clear short-term improvement in pain on movement in the experimental group. Zhang (39) conducted a study with a similar approach but proposed the dual administration of tranexamic acid directly on the surgical incision just before wound closure.

Sun and colleagues (42) in their RCT proposed intravenous treatment with different drugs than the previous studies, a multimodal administration of Ketoprofen, Ropivacaine, and Epinephrine just before wound closure, observing an improvement in pain and ROM in the short term in the experimental group, while in the long term there were no substantial differences between the groups. Lastly, Yu (43) studied the effectiveness of cryotherapy in the immediate post-operative period after open arthrolysis with a reduction, in the first 7 post-surgery days, of VAS both at rest and in motion in the cryotherapy group and also a reduction in the intake of analgesic drugs. A rehabilitation protocol is present after each surgical procedure in all these studies (39-43), both in experimental and control groups, demonstrating how rehabilitation itself is considered important and effective. A recent update by Siemensma *et al.* (2023) (45) offers a structured, stepwise approach to the management of post-traumatic elbow stiffness in both adults and pediatric populations. Their emphasis on early mobilization, brace therapy, and surgical arthrolysis where indicated aligns well with the current treatment paradigms addressed in this review.

In all the studies with surgical approaches included in the meta-analysis, the experimental group (open arthrolysis and innovative elements) showed significant improvements compared to the control group (open arthrolysis and usual care or placebo). These results seem to be in line with what was reported in the non-systematic review by Akthar in 2021 (46), which highlights the effectiveness of open arthrolysis when followed by early rehabilitation involving therapeutic exercises, CPM, and orthoses. Experimental findings from Reiter *et al.* (47) using a rat model of elbow joint contracture

support the critical role of early and appropriately dosed physical therapy in preventing long-term stiffness, offering mechanistic insight into the importance of timing in rehabilitation protocols. Similar results are also confirmed by the recent overview by Siemensma (44), adding that open arthrolysis has a higher rate of complications and revisions compared to arthroscopic arthrolysis, which, on the other hand, has more limited indications. In this regard, the systematic review by Lanzerath in 2022 (48), suggests that, if indicated, arthroscopic arthrolysis should be preferred over open arthrolysis to reduce the risk of post-surgical complications. Additionally, a RCT (49), not included in this SR as it added both adult and pediatric patients, has highlighted the potential usefulness of combining continuous passive mobilizations with post-surgical rehabilitation after arthroscopic techniques.

It was not possible to conduct further meta-analyses on surgical approaches on other outcomes (pain and function) due to the heterogeneity in interventions, follow-ups and the unavailability of baseline values for pain (41). Attempts were made to contact the authors to obtain the data but without success.

RCTs that compared two different conservative treatment modalities presented heterogeneous elements that prevented a meta-analysis of the results. Nevertheless, it is possible to note that some techniques, although used with different frequencies and timing, have shown their clinical efficacy in reducing pain and improving ROM and function. An example is provided using Muscle Energy Techniques (MET) in the conservative management of post-traumatic elbow stiffness. The technique was used in two RCTs (33, 36) with different treatment frequencies: twice a week for three weeks (33), and six sessions a week for three weeks (36). Despite the high heterogeneity in treatment frequency, MET has proven to be effective in reducing short-term pain and improving ROM and function (33, 36). One study in 2018 (34) showed that stretching techniques based on the proprioceptive neuromuscular facilitation (PNF) appears superior to static stretching in improving pain, function and active ROM. It is interesting to note how there are similarities between PNF techniques and MET, despite using different frequencies and timing, they use the same principles of autogenic and reciprocal inhibition. The same author demonstrated in 2022 (35) how graded motor imagery (GMI) can have an important role among conservative treatments. Another promising conservative therapy is the one proposed by Bhosale in 2022 (33), known as instrument-assisted soft tissue mobilization (IASTM), which appears to offer similar effects to METs but with better results in reducing pain and

improving patient-specific functional scores.

Two RCTs (37, 38) have shown the efficacy of using static or dynamic orthoses in the conservative treatment of post-traumatic stiffness, although they showed contrasting long-term results. In this regard, Veltman's systematic review (50) on the effectiveness of conservative treatment with orthoses emphasizes that there are no differences between static and dynamic orthoses, and their use is recommended within 12 months of the onset of stiffness or when no further increases in ROM are observed.

Only one RCT, conducted by Guglielmetti and colleagues (32), studied the effects of a conservative treatment compared to a surgical one. The study included only patients with post-traumatic elbow stiffness who did not show improvement after four months of conservative treatment. Patients were divided into two groups: a conservative group that followed a rehabilitation protocol using static and dynamic orthoses and continuous passive mobilizations, and a surgical group that underwent a posterior release procedure previously described in the literature by the same authors (51), followed by a post-surgical rehabilitation protocol like the conservative one. The surgical approach followed by the rehabilitation protocol was more effective in terms of recovering ROM in flexion-extension at the six-month follow-up and did not differ in terms of complication rates and clinical scale results. This finding is in line with what is reported in the literature (5, 44, 46), which suggests that if stiffness persists after a period of conservative treatment, surgical intervention followed by early and structured post-operative rehabilitation is recommended.

Among the main limitations of the study, it is important to highlight the high heterogeneity among the different treatment approaches for post-traumatic elbow stiffness. Despite including 12 RCTs, only one of them evaluated the effects of surgical treatment compared to conservative treatment. Among the RCTs that assessed the effects of conservative treatments, there are differences in the frequency and duration of treatments, and two (36, 38) of them have a high risk of bias. Studies that analyzed open arthrolysis with usual care compared to open arthrolysis with innovative elements consistently reported improvements in ROM and pain in the experimental groups. Although it was possible to conduct a meta-analysis of the results using the random effects model, it is still important to highlight the high level of heterogeneity present in the innovative elements across the different studies in the experimental groups: some used accelerated rehabilitation protocols, others used cryotherapy, and even among those who employed infiltrative techniques for pain modulation and postoperative bleeding, there was high heterogeneity

in the choice of drug and the timing of administration.

The 12 RCTs included in this systematic review investigated various conservative and surgical approaches to post-traumatic elbow stiffness, often involving patients with heterogeneous etiologies and clinical profiles. This diversity, combined with differences in intervention protocols, treatment durations, and outcome measures, limited the possibility of conducting secondary analyses aimed at identifying the most effective treatment strategies for specific subgroups of patients.

Among these, only five studies met the criteria for inclusion in the meta-analysis. While this analysis provided valuable insights, especially regarding the potential superiority of open arthrolysis combined with innovative elements, several limitations emerged. Two of the five studies showed concerns related to deviations from intended interventions due to the lack of participant blinding. Additionally, the GRADE assessment led to a downgrading of the overall certainty of evidence to “low,” not only because of the aforementioned risks of bias and the clinical heterogeneity among studies, but also due to imprecision: the total sample size of the pooled studies did not reach the optimal information size (OIS) of 400 participants, a recognized threshold for robust estimation of treatment effects in meta-analyses. To overcome these limitations and strengthen the evidence base in this field, future research should focus on conducting adequately powered, multicenter randomized controlled trials. Standardization of intervention protocols and follow-up durations, along with the development of a core outcome set specific to post-traumatic elbow stiffness, would significantly improve comparability across studies. Moreover, stratification of patients according to key clinical characteristics, such as etiology (*e.g.*, presence of heterotopic ossification), chronicity, or prior treatment failures, could help identify the most effective treatment strategies for distinct patient populations.

## CONCLUSIONS

The treatment of post-traumatic elbow stiffness remains a

significant challenge for healthcare professionals. Conservative approaches are the first treatment option in less severe cases. There are various conservative techniques available, MET seem to offer better short-term results, but further studies are needed to draw conclusions. In cases where stiffness persists or in more severe cases, surgical approaches, whether arthroscopic or open, should be considered, considering the risk of complications and the patient's characteristics. The meta-analysis suggests that open arthrolysis, when followed by innovative elements such as early rehabilitation protocols, infiltrative therapy, or cryotherapy, appears to offer better long-term recovery of the elbow flexion-extension ROM compared to open arthrolysis followed by usual care. Future high-quality methodological RCTs comparing surgical treatment to conservative treatment, considering different types of post-traumatic stiffness, are needed.

## FUNDINGS

None.

## DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

## CONTRIBUTIONS

FS, LDF, EM, FM: conceptualization. FS, FM, LDF: methodology, investigation. FS: software. project administration. FS, FM, LR, LDF, GG, DP, AR, ML: validation. FS, FM, EM, ML, LR, AR: formal analysis. FS, FM: resources, writing – review & editing, visualization. FS, LDF: data curation. FS, FM, LR, LDF, GG, DP, AR, ML, EM: writing – original draft. FM, GG, LDF: supervision.

## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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# Anatomy of the Medial Patellofemoral Ligament: A Meta-Analysis

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## SUMMARY

**Purpose.** To consolidate the anatomical data on medial patellofemoral ligament's (MPFL) morphology and relationships with surrounding structures of the knee and contribute towards facilitating planning reconstruction surgeries.

**Methods.** Electronic databases were searched for articles containing quantitative data regarding MPFL's morphology and distances to surgically relevant radiographic and anatomic landmarks from inception to April 2025. To synthesize the results of the included studies, a random-effects model via the Comprehensive Meta-Analysis Version 4 software was employed.

**Results.** Initially, 7,263 articles underwent evaluation. Ultimately, 64 articles met the inclusion criteria and were included. When measured at its midline in 0° degrees of flexion, the length was 56.87 mm (95%CI 54.38-59.37 mm). MPFL was widest at patellar insertion (23.17 mm; 95%CI 20.99-25.35 mm) and narrowest at femoral insertion (11.96 mm; 95%CI 10.63-13.29 mm). Its thickness in the middle part measured 1.17 mm (95%CI 0.91-1.43 mm). The center of MPFL's femoral insertion was located on average 9.17 mm (95%CI 7.38-10.97 mm) distally, 10.81 mm (95%CI 8.54-13.08 mm) proximally, 6.82 mm (95%CI 0.94-12.07 mm) posteriorly and 2.22 mm (95%CI 1.45-2.99 mm) anteriorly in relation to adductor tendon tubercle and on average 6.21 mm (95%CI 4.18-8.23 mm) posteriorly, 9.03 mm (95%CI 6.79-11.27 mm) proximally, and 4.77 mm (95%CI -0.30-9.84 mm) anteriorly in relation to the medial femoral epicondyle.

**Conclusions.** The presented data facilitates graft harvesting and optimal femoral tunnel placement for reconstruction.

**Study registration.** This study has been registered at the International Prospective Register of Systematic Reviews (PROSPERO, No CRD42023488062).

## KEY WORDS

*Medial patellofemoral ligament; lateral patellar dislocation; anatomy; knee surgery.*

## INTRODUCTION

The medial patellofemoral ligament (MPFL) is a part of a medial patellofemoral complex (MPFC) that provides 50-60% of the restraining force against lateral patellar dislocation. Therefore, rupture of this ligament, typically at the femoral origin, is an essential lesion causing lateral transla-

tion of the patella. Although first-time lateral dislocation of the patella is usually treated non-operatively, patients with MRI-confirmed MPFL avulsions are at high risk for reinjury, and early surgical intervention should be considered (1). When determining which patients experiencing their first dislocation might benefit more from operative intervention,

it is important to take into account the patients' level of dysplasia and laxity (2).

Various surgical reconstruction techniques, typically with semitendinosus tendon, gracilis tendon, partial quadriceps tendon auto, or allografts or synthetic grafts, are being used, but a consensus regarding the most optimal method remains elusive. However, it is widely acknowledged that a clear understanding of the anatomy and morphology of the natural MPFL is crucial to achieving favorable surgical outcomes (3). Therefore, conducting a meta-analysis of MPFL anatomy and its relationship with surrounding structures is essential to guide more effective reconstructions. This is particularly important because an ideal MPFL graft should have anatomical and biomechanical similarities with the native ligament. A detailed meta-analysis of MPFL anatomy could help clinicians avoid significant discrepancies in the measurements and shape of the intact ligament and graft used for reconstruction, which can lead to complications such as patellar overload, medial patellofemoral arthritis, or even loss of postoperative movement (4). Another compelling reason to undertake a meta-analysis in this area is that the pivotal step during reconstruction is accurately identifying the ligament's origin of insertion. The femoral attachment site, which plays a critical role in ensuring proper isometry of the graft, remains controversial, as it has been described in several different locations (3-6). An additional justification for this research is that a thorough understanding of its anatomy is crucial, because placing the graft too proximally to the medial femoral epicondyle (MFE) can lead to a reconstructed MPFL being loose during extension and tight during flexion, potentially limiting knee flexion and causing excessive pressure, leading to chondral loss on the medial patellar facet. Conversely, positioning the femoral origin MPFL reconstruction too distally from the medial epicondyle can lead to tightness during extension and laxity during flexion lead to tightness during extension and laxity during flexion (5, 6).

Despite the current knowledge about MPFL being comprehensive, encompassing its anatomical structure, biomechanics, and clinical significance, there is no updated meta-analysis on this subject. In light of the previously discussed importance of detailed anatomical understanding for successful reconstructive surgery, the primary objective of this study was to integrate and consolidate the available anatomical data regarding its morphology and relationships with other structures of the knee. The anticipated outcomes of this meta-analysis are expected to contribute towards facilitating planning and performing surgeries on this anatomical entity and harvesting grafts with optimal properties for reconstruction.

## MATERIALS AND METHODS

This meta-analysis was conducted in accordance with the PRISMA™ (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) statement (7). In addition, this study has been registered at the International Prospective Register of Systematic Reviews (PROSPERO, No CRD42023488062). As this is a systematic review with meta-analysis with no direct reports of human and/or animal subjects data, conducting it required neither approval of an ethics committee nor participant informed consent.

### Search Strategy and Information Sources

Major online databases (PubMed, Web of Science, and Embase) were searched to gather relevant studies regarding the MPFL anatomy. The collection of data was carried out between November 2022 and April 2025 by three independent authors (MKCh, KS, JD). The Boolean technique was employed to conduct the search in PubMed, using the following search terms: "lateral patellar dislocation" OR "Medial Patellofemoral Ligament" OR "Medial patellar retinaculum". The search query for Embase and Web of Science databases followed the same general framework with regard to the specific syntactic needs of these search engines (all search queries are presented in **supplement 1**). The PICO (Person, Intervention, Comparison, Outcomes) algorithm that guided this search was as follows: the Person component focused on skeletally mature, adult individuals or cadavers. The Intervention involved the collection and analysis of anatomical data regarding the MPFL's morphology and its relationship with surrounding knee structures. For comparison, the study analyzed different anatomical measurements of the MPFL across various studies to establish a standardized reference for surgical planning. Finally, the Outcomes were the consolidation of anatomical data to facilitate optimal graft harvesting and femoral tunnel placement for MPFL reconstruction, ultimately improving surgical outcomes. Neither language, date, article type, nor text availability filters were applied. To ensure comprehensive data collection, a manual search through the references of the identified studies was performed. Throughout the study, the preferred reporting items for systematic reviews and meta-analyses (PRISMA) (7) were carefully followed.

### Eligibility Criteria

Three authors independently assessed the articles' eligibility. Only the studies that fulfilled the following criteria were included: 1) complete, unambiguous data regarding MPFL morphometry and/or its distances to anatomic and/or radiographic landmarks; 2) MRI, cadaveric, and/or radiographic;

3) studies performed on at least 5 knees; 4) subjects being skeletally mature. The following articles were excluded: 1) case reports and series performed on 4 and less knees, due to low statistical significance, review articles, unpublished manuscripts, letters to the editor, and studies carried out on 2) animals; 3) computer-simulated models of knees, and 4) pediatric populations (meaning less than 18 years of age). Records not meeting the criteria were ineligible because the results for the outcome were not measured or reported. Language was not an exclusion criterion; non-English reports were translated by medical professionals fluent in the language of the publication. These criteria were established based on the existing literature and our experience (8).

### Data extraction

Two reviewers (JD, KS.) independently screened titles and abstracts based on predefined inclusion and exclusion criteria, followed by a detailed analysis of the full texts of relevant publications. Studies that met the established criteria were included in the analysis. In cases of disagreement, a third reviewer (MKCh) was consulted to assist with the assessment.

Types of articles included in the study were original research articles conducted on 5 or more knees. Both cadaveric and radiographic studies were included. Qualitative data, such as year of publication, region of origin, gender of the subjects, and data collection methodology, were gathered. Quantitative data regarding sample size and its characteristics (age), prevalence among subjects, distances concerning surroundings (adductor tendon tubercle (ATT), medial femoral epicondyle (MFE), gastrocnemius tubercle (GT), perpendicular line posterior-most to Blumensaat line, posterior femur cortex line) of the MPFL, length at different degrees of flexion, width at patellar, vastus medialis oblique, vastus intermedius, and femoral insertion, width in the middle, thickness at femoral and patellar insertion, and thickness in the middle were collected.

### Quality assessment

In order to evaluate the quality, potential bias, and reliability of the studies included in the meta-analysis, the researchers used the Anatomical Quality Assessment (AQUA) tool (9). Reports underwent assessment in the following domains: 1) objectives and study characteristics; 2) sample design; 3) methodology characterization; 4) descriptive anatomy, and 5) reporting of results. Each domain was rated as having a high, low, or unclear risk of bias. Every record used was evaluated for the risk of bias by two reviewers who worked independently. Additionally, the Critical Appraisal Tool for

Anatomical Meta-Analysis (CATAM) was used to ensure the highest-quality finding (10).

### Statistical analysis

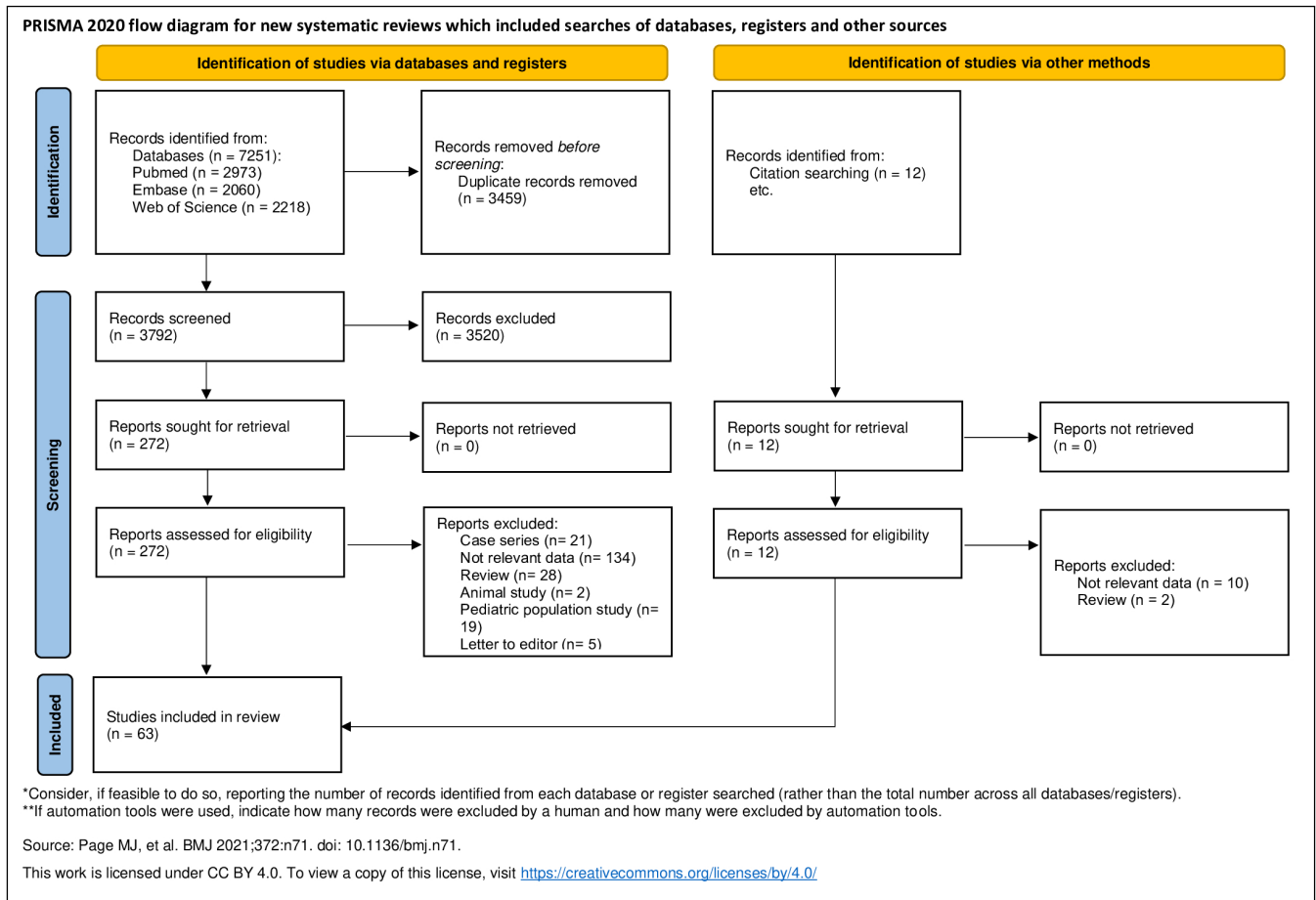
In synthesizing the results of the included studies, a random-effects model via the Comprehensive Meta-Analysis Version 4 (Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. Biostat, Englewood, NJ 2022) software was employed. The preliminary assessment of the studies indicated variability among the study outcomes, which could not have been attributed to sampling error. The random effects approach was deemed appropriate, as a certain degree of heterogeneity across the studies was anticipated. This model delivered a more conservative effect size estimate than the fixed-effects model.

To assess heterogeneity, the Q-tests and the I-squared statistics were employed. The Q-test provided the researchers with a test examining the possibility of all studies in the meta-analysis sharing a common effect size. Q P-value < 0.1 was considered significant. The I-squared statistic was used to determine whether the proportion of the total variation across studies was due to heterogeneity rather than chance. In relation to the I-squared statistic, the heterogeneity was found to “may not be significant” at values of 0-40%, “may indicate moderate heterogeneity” at 30-60%, “may indicate substantial heterogeneity” at 50-90%, and “may represent considerable heterogeneity” at 75-100%.

Furthermore, the tau and tau-squared statistics were employed to estimate the standard deviation of the underlying effects across studies. These were essential to understanding the distribution of the effect sizes and the degree of variability beyond sampling error.

## RESULTS

Initially, 7,263 articles underwent evaluation. A total of 7,251 records were identified from major electronic databases (PubMed, Embase, Web of Science); an additional 12 were found by citation searching. The duplicate removal process ruled out 3,459 records; the remaining 3,804 underwent the screening process. Of these, 284 records met all predefined inclusion criteria and were subsequently sought for retrieval for full-text assessment. All 284 records were successfully obtained and evaluated for eligibility. During the eligibility assessment, records were excluded based on the following criteria: 144 records were excluded due to incomplete or irrelevant data; 56 records were excluded due to inappropriate publication types, including 30 reviews, 21 case series, and 5 letters to the editor (these issues were



**Figure 1.** Flowchart of the meta-analysis.

not identifiable during abstract screening); 21 records were excluded due to an ineligible study population, comprising 19 studies involving pediatric populations and 2 animal studies, which could not be determined during the abstract screening phase. Ultimately, 64 (3, 4, 11-13, 15-17, 19, 24-33, 35, 40-83) articles met the inclusion criteria and were included in this meta-analysis. The studies that were included in this meta-analysis presented a low risk of bias in the AQUA score (9). Furthermore, all of the articles achieved at least 30 points in the CATAM (10) score, which is interpreted as “Good” or “Very Good” quality. A flow chart (**figure 1**) illustrates the process of data collection. A total of 2510 knees were included in this study. The characteristics of the included studies are depicted in **supplement 2**.

### Quality assessment

Based on the AQUA tool’s evaluation, the majority of the papers included in this meta-analysis showed a “low” risk

of bias in each of the five domains. The domain with the highest risk for bias was “objectives and study characteristics” because of the not clearly defined characteristics of the subjects studied. **Supplement 3** presents the results of the quality assessment.

### MPFL length

The MPFL is an extracapsular structure situated within layer II of the medial aspect of the knee. It consists of transverse fibers extending from the medial border of the patella and attaching to the area surrounding the adductor tubercle and medial epicondyle.

The length of MPFL was reported in the literature in three different ways. Measurements were made either at the superior edge of MPFL, at the inferior edge of MPFL, or in the middle of the ligament. Nevertheless, all studies reported the length of the MPFL as the distance between its patellar and femoral insertions. Moreover, MPFL lengths were

reported at different angles of knee flexion. When measured at the inferior margin of the MPFL, its length was 61.49 mm (95%CI 55.20-67.79 mm) at 0° of knee flexion; 61.02 mm (95%CI 55.02-67.02 mm) at 30°; 61.56 mm (95%CI 56.41-66.70 mm) at 60°; 60.47 mm (95%CI 52.34-68.60 mm) at 90°; and 58.51 mm (95%CI 46.53-70.49 mm) at 120° of knee flexion. MPFL measured at the superior margin in the same (0°, 30°, 60°, 90°, and 120°) knee flexion degrees was, respectively, 64.74 mm (95%CI 59.66-69.82 mm), 62.04 mm (95%CI 58.89-65.18 mm), 62.34 mm (95%CI 58.97-65.70 mm), 61.37 mm (95%CI 50.33-72.42 mm), and 59.19 mm (95%CI 42.60-75.78 mm) long. Majority of studies assessing the length (28 studies (4, 13, 15, 17, 18, 24, 25, 27, 30, 41-43, 45, 47, 51, 52, 54, 56-58, 62, 63, 66-68, 76, 79, 80)) reported MPFL length as measured throughout a line in the middle of the ligament. Such MPFL lengths were given for 0°, 20°, 30°, 45°, 60°, 90°, and 120° knee flexion degrees and measured 56.87 mm (95%CI 54.38-59.37 mm), 54.94 mm (95%CI 50.92-58.97 mm), 52.77 mm (95%CI 48.36-57.19 mm), 50.95 mm (95%CI 39.13-62.78 mm), 49.65 mm (95%CI 45.23-54.06 mm), 47.60 mm (95%CI 44.04-51.17 mm), and 41.86 mm (95%CI 38.52-45.20 mm), consequently. Specific data describing the length of MPFL is shown in **supplement 4**. **Figure 2** shows length changes of the superior, inferior margins, and middle of the ligament during motion.

### MPFL width

The authors provided data about MPFL's width at three different points: at its patellar insertion (23 studies (3, 4, 13, 16, 17, 24-26, 42, 45, 49, 51, 57, 60, 63-65, 70, 72-74, 76, 83)), femoral insertion (20 studies (3, 4, 13, 16, 17, 25, 42, 45, 46, 51, 54, 57, 64, 65, 70, 72, 75, 76, 78, 83)), and in the middle of the ligament (10 studies (3, 4, 16, 41, 42, 47, 50, 51, 68, 83)). MPFL was widest at its patellar insertion (23.17 mm; 95%CI 20.99-25.35 mm) and narrowest at its femoral insertion (11.96 mm; 95%CI 10.63-13.29 mm). The width of the middle part of the MPFL was 14.65 mm (95%CI 11.06-18.24 mm) (**supplement 5**).

### MPFL thickness

The analysis of nine studies provided data about the thickness of the MPFL in its middle part, which was 1.17 mm (95%CI 0.91-1.43 mm). Thickness of MPFL was also assessed at its patellar and femoral insertions by 6 (4, 51, 52, 54, 64, 67) and 5 (51, 52, 54, 67, 75) authors, respectively, and measured consequently at 1.45 mm (95%CI 0.95-1.96 mm) and 1.04 mm (95%CI 0.77-1.32 mm). Additional information about MPFL thickness can be found in **supplement 6**.

### Lengths of MPFL soft tissue attachments

Apart from the femoral bony insertion, part of MPFL's fibers end in the tendons of two muscles that constitute the medial part of the thigh: the vastus medialis oblique (VMO) muscle and the vastus intermedialis muscle (VIM). The analysis of 7 studies (16, 24, 26, 54, 68, 70, 77) revealed that the mean length of the MPFL insertion site at the VMO muscle is 28.46 mm (95%CI 20.50-36.42 mm). 3 studies (24, 26, 54) reported the mean length of the MPFL insertion site at the VIM, which was 21.37 mm (95%CI 11.51-31.24 mm). Detailed data regarding the length of these two insertions can be found in **supplement 7**.

### Distances to radiographic landmarks

The authors reported data regarding distances from MPFL's femoral insertion to the posterior femur cortex line (7 studies (31-33, 59, 61, 75, 81)), and a line perpendicular to the posterior-most aspect of Blumensaat line (5 studies (31, 33, 35, 59, 61)). The mean distances were as follows: 4.33 mm (95%CI 1.84-6.83 mm) anterior to posterior femur cortex line, and 2.51 mm proximal (95%CI 1.20-3.82 mm) to the perpendicular line to the posterior-most aspect of Blumensaat line (**supplement 8**).

### MPFL's relation to the ATT

The authors reported substantial variability regarding MPFL's relations to ATT. The center of MPFL's femoral insertion was described to be located distally (9 studies (3, 4, 16, 29, 33, 46, 61, 63, 75)), proximally (3 studies (46, 61, 83)), anteriorly (6 studies (3, 29, 46, 61, 63, 75)), and posteriorly (3 studies (16, 46, 83)) in relation to ATT. In respective studies, the center of MPFL's femoral insertion was located on average 9.17 mm (95%CI 7.38-10.97 mm) distally, 10.81 mm (95%CI 8.54-13.08 mm) proximally, 6.82 mm (95%CI 0.94-12.07 mm) posteriorly and 2.22 mm (95%CI 1.45-2.99 mm) anteriorly in relation to ATT. Twelve authors (11, 13, 29, 33, 48, 49, 58, 61, 64, 65, 70, 78) measured the distance between MPFL's femoral insertion and ATT in a straight line, which averaged 10.59 mm (95%CI 8.54-12.65 mm) (**supplement 9**).

### MPFL's relation to the MFE

8 studies (3, 16, 29, 32, 40, 63, 68, 75) observed the center of MPFL's femoral insertion posteriorly from MFE; 9 studies (3, 16, 29, 33, 46, 61, 63, 68, 75) reported its location proximally to MFE; and 3 studies (40, 46, 61) described the center of MPFL's femoral insertion as being anterior relative to MFE. In respective studies, the center of MPFL's femoral insertion was located on average 6.21 mm (95%CI 4.18-



8.23 mm) posteriorly, 9.03 mm (95%CI 6.79-11.27 mm) proximally and 4.77 mm (95%CI -0.30 to 9.84 mm) anteriorly in relation to MFE. 10 authors (13, 29, 33, 48, 49, 60, 61, 65, 68, 70) measured the distance between MPFL's femoral insertion and MFE in a straight line without specified directions, which averaged 11.21 mm (95%CI 9.18-13.23 mm) (**supplement 10**).

### MPFL's relation to the GT

The center of MPFL's femoral insertion was described to be located anteriorly (3 studies (29, 46, 61)) and proximally (4 studies (29, 33, 46, 61)) in relation to GT. In respective studies, the center of MPFL's femoral insertion was located on average 7.79 mm (95%CI 5.32-10.26 mm) anteriorly and/or 2.54 mm (95%CI 1.25-3.83 mm) proximally in relation to GT. Four authors (13, 29, 33, 61) measured the distance between MPFL's femoral insertion and GT in a straight line, which averaged 10.66 mm (95%CI 8.75-12.56 mm) (**supplement 11**).

### MPFL's insertion area

The area of MPFL's patellar insertion was reported by 4 studies (13, 51, 54, 61) and averaged 53.02 mm<sup>2</sup> (95%CI 40.93-65.12 mm<sup>2</sup>). Femoral insertion of MPFL (reported by 7 authors (11, 13, 27, 29, 40, 51, 61)) had a much smaller surface, being only 36.60 mm<sup>2</sup> (95%CI 26.67-46.54 mm<sup>2</sup>) (**supplement 12**).

## DISCUSSION

This meta-analysis focuses on anatomical features of the MPFL useful for proper graft harvesting and localizing original insertion sites.

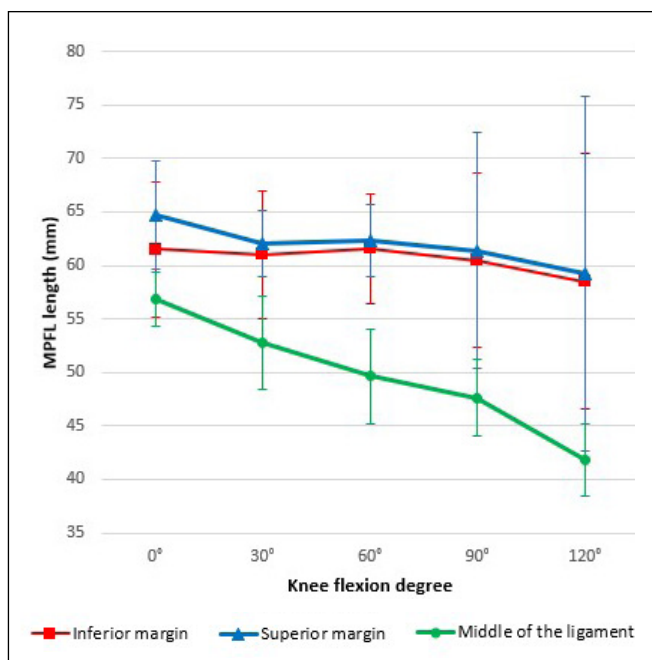
This study provides a detailed analysis of the length changes of the superior margin, inferior margin, and middle of the ligament at different knee angles. We observed a similarity in the length change pattern of the upper and lower ligament fibers, while the fibers of the middle part of the ligament shortened much more with the degree of knee flexion. MPFL's shape description varies among different studies, from being polygon-shaped (11), trapezoidal (12, 13), hourglass (14, 15), more triangular (3, 16), Y-shaped (17), or sail-like (3, 4) structure. Our study indicates that the ligament exhibits a sail-like, trapezoid shape, with its widest part at the patellar insertion, narrowing towards the middle, and being narrowest at the femoral insertion. Therefore, double-bundle (DB) grafts with anatomical anchoring are more anatomical and provide a better physiological stress distribution. In a study by Wang *et al.* (18), the DB tech-

nique scored greater than single-bundle (SB) in terms of Kujala Score and subjective questionnaire score.

We confirmed that MPFL is an anisometric ligament with the biggest mean length at full extension of the knee and shows a relative isometry between 30° and 90° of motion for the superior and inferior margins. It did not demonstrate isometry when measured at its midline. Although the ligament should be reconstructed in the position where it is subjected to the highest strain-according to our study at 0° flexion-fixation in full extension is challenging due to the lack of proper guidance of the patella by the trochlear groove (19, 20). Failure to sustain an optimal graft length can result in complications such as patellofemoral overload, medial patellofemoral arthritis, persistent lateral instability, and loss of postoperative movement (20). When employing a DB technique for reconstruction, the focus is on reconstructing the portions of the ligament that demonstrate near-isometric behavior within the range of 30° to 90° of flexion. Moreover, considering the fact that the patella is most susceptible to subluxation at 30° of flexion (20), this range of angle could be considered optimal to prevent ligament laxity during this critical phase of patellar tracking.

This study found that the thickness of native MPFL in its middle part was 1.17 mm, and at its patellar and femoral insertions measured accordingly at 1.45 mm and 1.04 mm. Although Wong *et al.* (21) found no correlation between postoperative pain, arthritis, graft failure, and graft thickness, Elias *et al.* (22) noted that even though graft properties are not detrimental when they are positioned properly, graft sources that closely mimic the intact MPFL can minimize the risk of overloading the medial cartilage after reconstruction. Hamstring tendon grafts could be too thick and necessitate a fixation with a bony procedure at the patella, which can be a source for patellar fracture and violation of the anterior cortex or chondral surface of the patella (23).

Anatomical data regarding the length of the MPFL's insertion sites on the VMO and the VIM was compiled. The MPFL adheres to the inferior surface of the VMO, proximal to the patellar insertion (24). Ji *et al.* (24) distinguished two anatomic functional regions of the MPFL fibers: the overlap region, where VMO's and MPFL's fibers overlaid each other, and the non-overlapping region, proposing that only the injuries of the overlap region can be cured with nonsurgical treatment. In a study published by Panagiotopoulos *et al.* (25), strong "meshing" of the fibers of the VMO and MPFL was described. These results correspond with this study's findings regarding a wide insertion site of 28.46 mm to the VMO, which might indicate its substantial role in strengthening and dynamizing the ligament during early flexion. There-



**Figure 2.** Graph presenting the length changes of the MPFL according to the degree of the knee flexion.

fore, the authors of this study advocate that whenever grafts are being used for reconstruction of the ruptured MPFL, “meshing” to the VMO should be restored. The MPFL insertion to the VIM is at the medial margin of its tendon (26). Studies (26, 27) present varying findings on how tightly the ligament is attached to these muscles, possibly due to different dissection techniques. It’s widely recognized that nearly 90% of MPFL tears happen at the femoral insertion (24). This study confirms that this could be because the attachment to the patella is broader, and tension is spread out due to wide insertion and overlapping areas with these muscles. Recent anatomical studies report that the MPFL is situated in a groove between the ATT and the MFE. However, this location is difficult to palpate (28, 29), making it challenging to locate during surgery. Consequently, several articles propose using radiographic landmarks to identify the MPFL instead (30). This study details the MPFL relationship to the projected radiographic lines, which allows for more consistent radiographic assessments of anatomic repairs and reconstructions. This paper confirms that the mean distance from the femoral attachment was 2.51 mm distal to the perpendicular line at the posterior-most aspect of the Blumensaat line. This line is reported to be easier to identify (31) than the landmarks initially described by Shottle *et al.* (32), which included the posterior cortical extension line

and a perpendicular line intersecting the posterior origin of the medial femoral condyle for guiding femoral tunnel placement. This study concludes that the MPFL femoral origin is 4.33 mm anterior to the posterior femoral cortical line. Therefore, quantitative differences between the findings of this meta-analysis and studies that describe radiographic landmarks used for identifying femoral attachment (31-33) were found. In the study by Schottle *et al.* (32), this attachment was reported to be located 1.3 mm anterior to the posterior femoral cortex line and 5.5 mm proximal to the perpendicular line at the posterior-most aspect of the Blumensaat line. According to the results of this meta-analysis, the most accurate location could be combining Barnett’s (6.31) point distance of 3.8 mm anterior to posterior femoral cortical line and Wijdick’s (33) point of 2.6 mm proximal to the posterior-most aspect of the Blumensaat line.

Despite numerous studies suggesting that radiographic landmarks could effectively pinpoint the femoral attachment of the MPFL, Sanchis-Alonso *et al.* (34) found only 36.7% and 25.5% overlap in the anatomical tunnel area using Schottle’s (32) or Stephen’s (35) methods, respectively. These differences may stem from challenges in obtaining a true lateral radiograph or variations in trochlear morphology. Balcerak *et al.* (36) reported that a deviation as small as 5° from the true lateral fluoroscopic view might lead to a critical shift of approximately 5 mm from the native femoral insertion point in reconstruction surgery.

Few studies focus on femoral tunnel malpositioning and its correlation to clinical outcomes after MPFL reconstruction. Hopper *et al.* (37) demonstrated that Kujala and Lysholm scores significantly improved when the femoral tunnel was positioned within 10 mm of the MPFL’s anatomical insertion point. In contrast, Servien *et al.* (38) and McCarthy *et al.* (39) did not find any connection between femoral tunnel misplacement and poor clinical outcomes, despite their femoral tunnels being located 7 mm and 9 mm away from the anatomical MPFL center, respectively. These varying findings may result from the fact that most biomechanical studies define the center of the anatomical origin as the “functional” point of the MPFL (40). This research study revealed that the MPFL femoral insertion area spans 36.6 mm<sup>2</sup>, suggesting that femoral tunnel placement may be somewhat forgiving as long as it falls within this region.

The ATT is sometimes described in the literature as the “lighthouse of the medial knee” because once it is found, it enables surgeons to find all the other landmarks (30). This study reports that the center of MPFL’s femoral insertion was located on average 9.17 mm distally, 10.81 mm proximally, 6.82 mm posteriorly, and 2.22 mm anteriorly to ATT.

While Chen *et al.* (28) described a broad, easily detectable sulcus between the MFE and ATT, where the MPFL is usually located, prior studies have shown poor accuracy of palpation as a method to localize femoral tunnel placement (29). This meta-analysis provides detailed measurements of the distances from the center of the MPFL to MFE, AT, and GT in both the proximal-distal and anterior-posterior axes. Kernkamp *et al.* (30) demonstrated that adjusting the femoral attachments in the proximal-distal direction significantly affected length changes, while adjustments in the anterior-posterior axis had a smaller but still significant impact. Stephen *et al.* (35) noted that even small errors of 5 mm in the proximal-distal axis from the anatomical MPFL center during femoral tunnel placement resulted in increased peak and mean medial patellar contact pressures. Furthermore, shifts of the femoral attachment point by 5 mm in the proximal-distal axis significantly altered MPFL length, whereas shifts in the anterior or posterior directions of the same magnitude did not have significant effects on length changes (41). Considering the risks associated with inaccuracies in estimating the femoral attachment point of the MPFL and the center of the anatomic attachment on the femur being the most isometric position for the femoral tunnel placement, the findings of this study could be valuable for planning reconstruction surgery by providing a detailed description of the ligament's anatomy. Authors of this paper advocate for femoral tunnel placement localization with ATT, which is sometimes a palpable osseous anatomic landmark, followed by a confirmation with a true lateral radiograph.

This current study unquestionably has limitations. Potential bias may be present, as the accuracy of data compiled from various publications limits the outcomes of this meta-analysis. Some analyses could not be conducted by the authors due to a lack of consistent data availability. The limitations of this study include the mean age of subjects much greater than the age of the typical patient experiencing lateral dislocation (42). Consequently, there is a possibility that degenerative changes have influenced the results of the analyzed studies. Another limitation is the fact that some studies report the native location of the MPFL attachments in normal knees, which might not fully apply to individuals experiencing lateral patellar dislocation or recurrent instability. Moreover, if a procedure alters the knee's anatomy, such as a tibial tubercle osteotomy or trochleoplasty, the original location of the femoral attachment may no longer be suitable for graft attachment. Patients with patellar dislocation often exhibit various abnormal anatomical features, such as patella alta,

increased Q-angle, rotational deformities, and trochlear dysplasia, which could impact the accuracy of included studies that detail the MPFL insertion site anatomy (41). Anatomical differences between sexes were not taken into account. Biometrics, such as subjects' height, patella size, and limb length, were not available for most of the studies. The nature of data collection also generated a high level of heterogeneity among the studies. The review pooled studies employing cadaveric observation, MRI, X-ray, and CT scans as methods of measurement. Considering the available data on this subject were varied in terms of sources and observation methods, the results were pooled, and averages were presented. While this method is not ideal for a review of this type, statistically significant results could not have been generated if the studies reviewed had been segmented. The random effects model aids this somewhat as each study is weighted inversely proportional to its variance, where less varied studies have more influence on the overall effect size.

Subgroup and sensitivity analyses, such as leave-one-out analyses would generally aid the robustness of the conclusions. A meta-regression could have been useful to isolate certain characteristics of the studies that significantly contribute to the difference in effect size.

## CONCLUSIONS

A better understanding of the anatomy of MPFL is necessary among physicians in treating patients with lateral patellar dislocation, especially those who perform reconstruction surgeries. With consideration to the findings of this meta-analysis, the authors conclude that DB technique with anatomical anchoring allows for the recreation of the "fan-shaped" or "sail-like" shape and biomechanics of the original ligament. Authors advocate for the "meshing" of the MPFL grafts with VIM and VMO to restore its natural soft tissue insertions and provide enhanced support. Proper knowledge of MPFL's morphology and its relationship to surrounding structures enables proper graft harvesting and both femoral and patellar tunnel placements.

## FUNDINGS

None.

## DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

## CONTRIBUTIONS

MKC: conceptualization, project administration, data curation, writing – original draft. JD: data curation. KS: data curation, formal analysis, data management, writing – original draft. FP: formal analysis, writing – original draft. JS: data management, writing – review & editing.

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## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

- A. Descriptive and dynamic study of the medial patellofemoral ligament (MPFL). *Surg Radiol Anat.* 2019;41(7):763-74. doi: 10.1007/s00276-019-02234-7.
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# J-Stroke Myofascial Release Offers Greater Pain Relief than Foam Rolling in Patients with Plantar Fasciopathy: A Randomized Clinical Trial

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## SUMMARY

**Background.** In plantar fascia and nearby muscles, trigger points can reduce the pain threshold, causing increased sensitivity and discomfort in individuals with plantar fasciitis that lies superficial to plantar muscles of foot usually causes pain in inferior medial region of calcaneus during first few steps in the morning.

**Objective.** The purpose of this study was to compare the effects of foam roller and J-stroke myofascial release on pain intensity, pain threshold, range of motion and functional disability in patients with plantar fasciitis.

**Methods.** A total of 44 patients with plantar fasciitis were randomly allocated into two of the intervention groups, a Foam roller (n = 22) and J-Stroke myofascial release (n = 22) through computer-generated random number table. Outcomes were assessed through visual analogue scale (VAS) for pain intensity, pressure algometry for pressure pain threshold (PPT), weight bearing lunge test (WBLT) for dorsiflexion ROM at ankle joint and Urdu version of Foot and Ankle Disability index (FADI-U) for functional disability at the beginning of the session (baseline first session) and 4 weeks after completing the treatment sessions. The parametric test was used as data was found normally distributed by Shapiro-Wilk test. The independent t-test is used for intra-group analysis and paired t-test was used for intergroup analysis.

**Results.** The independent t-test for between the group analysis was not significant ( $p > 0.05$ ) for post VAS and post PPT (Plantar fasciitis) whereas post WBLT, PPT (Gastrocnemius and soleus) and post FADI were significant ( $p < 0.05$ ). The paired t-test value within the group analysis for both groups were found statistically significant ( $p < 0.05$ ) for all outcome measures except for group FR (Foam roller) in WBLT was not significant ( $p > 0.05$ ).

**Conclusions.** This study concluded that J-stroke myofascial release intervention provided clinically relevant results and was found statistically significant as the effect size was large and high mean difference was reported in comparison to foam roller intervention for all the outcome measures in reducing pain intensity, pain pressure threshold, disability and range of motion.

**Study registration.** The clinical trial was prospectively registered in the WHO-Iranian registry of clinical trials (Trial registration number: IRCT20190717044238N9, trial registration date: 09/11/2023).

## KEY WORDS

*Myofascial release; plantar fasciitis; pain threshold; trigger points; visual analogue scale.*

## INTRODUCTION

Plantar fascia is a wide band of connective tissue made of dense and fibrous connective tissue that supports the foot arch originating proximally from the medial calcaneal tubercle and extends distally to split into five digital bands that attach to the metatarsal heads and the proximal phalanx of each toe (1). Due to the deterioration of the plantar fascia, plantar fasciitis (PF) is considered the most common cause of sub-calcaneal pain associated with discomfort in the calcaneus (2). Approximately 15% of the heel pain are reported to health care professionals annually are due to plantar fasciitis and moreover in athletes it accounts for 8% cases of injuries related to running (3).

Obesity, pes planus, pes cavus, limited ankle dorsiflexion range, and tense calf muscles are intrinsic factors related to the patient. Examples of extrinsic factors *i.e.*, training and environmental factors include jogging on hard surfaces, suddenly increasing running volume or intensity, walking barefoot, and prolonged standing (4). Flatfoot has been linked to various ailments, including musculoskeletal disorders that affect the foot and ankle, like plantar fasciitis (5). While most plantar fasciitis cases improve with conservative treatment and time, about 1% of patients will need surgery. Age and sex are non-modifiable risk factors (6). Ultrasonography is accurate, reliable and inexpensive imaging technique in comparison to MRI for evaluating plantar fasciitis. To rule out bony lesions in heel plain radiography is suggested (7, 8). Physical examination reveals tenderness to palpation at proximal region of plantar fascia on the calcaneal tubercle. Windlass test will also be helpful in ruling out other potential causes of pain in heel region. Plantar fasciitis is often associated with gastrocnemius tightness that can also be felt during the physical examination (9).

Myofascial release is a technique used for mobilizing adhesions and breaking down restrictions in soft tissues (10). It has the best results if given for a chronic condition; the symptoms will worsen if the illness is acute. Two or three fingers are used to apply a stroke myofascial release, which creates some torque at the end of the stroke. The release is administered in the direction of the limitation. The heel of the hand applies counter pressure (11). Several studies report that myofascial release improves flexibility of hamstrings, shoulder ROM and jaw mobility proving the significance of technique in increasing ROM (12). Foam rolling is a type of self-myofascial release (SMR) technique where a person exerts pressure by using their own body weight. This subjects the soft tissues to direct and sweeping pressure, thus rupturing adhesions by improving the fascial layer's lubricity and promoting tissue extensibility (13). It is

supposed to improve fascial remodeling, increase elasticity, hydration and proprioception (14, 15).

Data gathered from the preliminary literature review showed that myofascial release techniques were found to be more effective than the conventional physical therapy intervention for plantar fasciitis (16). A few RCTs also reported the effectiveness of foam roller intervention in treatment of plantar fasciitis and declared that foam roller more effective in reducing pain, in terms of increasing range by weight bearing lunge test (17), pressure pain threshold at gastrocnemius and soleus (18), muscular power, agility of muscles and also boosts dynamic flexibility (19).

While physiotherapy treatments for plantar fasciitis are well-established, the effectiveness of specific techniques, such as foam rolling and J-stroke myofascial release, remains unclear, particularly in comparative studies. Both approaches aim to alleviate soft tissue restrictions and reduce pain, but they operate via different mechanisms. Foam rolling utilizes a self-administered approach to apply pressure to the fascia, potentially improving tissue extensibility and function, while J-stroke myofascial release is a manual technique that targets specific adhesions within the fascia to enhance mobility and reduce tension.

Despite evidence supporting the efficacy of both techniques in improving flexibility and reducing pain, direct comparisons between foam rolling and J-stroke release for plantar fasciitis have not been fully explored. Understanding how these techniques affect pain intensity, pain threshold, range of motion, and functional disability could provide valuable insights for clinicians and guide treatment decisions. This gap in the literature presents an opportunity to evaluate and compare these interventions in a systematic way, ultimately contributing to more effective management strategies for individuals suffering from plantar fasciitis. Hence, the objective of this study was to compare the effects of foam roller and J-stroke myofascial release on pain intensity, pain threshold, range of motion and functional disability in patients with plantar fasciitis.

## METHODS

### Ethical approval and consent to participate

This study was approved by the Institutional Review Board of the Riphah International University, Lahore, Pakistan (REC/RCR & AHS/23/0140 - approval date: August 03, 2023). All the participants provided written informed consent before taking part in the study. All methods were carried out in accordance with guidelines outlined in the declaration of Helsinki and CONSORT guidelines.

## Study design

This study was single blinded, randomized clinical trial conducted over 6 months from 1<sup>st</sup> July to 30<sup>th</sup> December 2023. In this study, 44 patients (14 males and 30 females) aged between 25 and 55 years with plantar fasciitis. The disease was pre-diagnosed or referred by orthopedic surgeon with heel pain in the morning on first step and heel pain focused over plantar aspect. Patients diagnosed with unilateral plantar fasciitis since last 6 weeks. These patients were recruited from outpatient physical therapy department of Public Sector Hospital, Pakistan. The sample did not include the patients who were reported with inflammatory and degenerative joint disorder, impaired blood circulation, ankle and foot bone fracture, patients with skin diseases *i.e.*, dermatitis or any infective disorder, metal implants and post-surgical, altered sensation in lower extremity, patients with history of corticosteroid injection in heel in last 3 months, diagnosed malignancy, diabetic foot. Informed consent in written form was taken from each participant prior to the inclusion in study. Patients fulfilling the selection criteria and willing to participate were recruited in the study, duly approved by Institutional Review Board (IRB). The demographic details such as height, weight, body mass index (BMI) and affected side were also recorded.

## Assessment

The assessments were done at baseline and after 12 treatment sessions for 4 weeks consecutively. Both assessments were performed by an assessor (qualified and trained physical therapist with 5 years' experience) dealing with musculoskeletal disorders patients. The patients were assessed for pain intensity, pain threshold, ankle dorsiflexion ROM and functional disability.

## Outcome measures

The primary outcomes of this study were pain intensity, pain threshold, ankle dorsiflexion ROM and functional disability.

### Visual analogue scale (VAS)

VAS was represented by a 10-cm-long line which showed no pain at one extreme end and worst pain possible at the other extreme of the line. The VAS has very good internal consistency (ICC = 0.96-0.98) and the test-retest reliability was excellent (20).

### Pressure pain thresholds (PPT)

PPT were assessed through pressure algometry. It measures minimum pressure required to produce pain. The algometry has high reliability reported (ICC = 0.91; 95% CI 0.82-0.96) (21).

### Ankle dorsiflexion with weight bearing lunge test (WBLT)

A tape measure was positioned on the floor perpendicular to the wall in order to measure the straight distance between the tip of the big toe and the wall. The participants were instructed to place their big toe and heel on the tape while standing on it. For improved balance, the patient was permitted to lean against the wall. To make contact with the wall without elevating the heel, participants were told to lunge towards it with their knees. Without raising the heel, the foot gradually glides in either direction towards or away from the wall until the ankle's maximal range of motion is reached. An additional physiotherapist measured patients both prior to and right after the intervention. This test has high inter-rater and intra-rater reliabilities for ROM assessment. [Intra-rater ICC = 0.97-0.98; Inter-rater ICC = 0.97(angle) and 0.99 (distance) (22, 23).

### Urdu version of Foot and Ankle disability index (FADI-U)

This tool, which is self-contained, measures functional limitations linked to foot and ankle diseases. There are two subscales comprising of total of 26 items: 22 items of the activity subscale and 4 items of the pain subscale. The Cronbach alpha coefficient (0.96-0.97) value showed excellent internal consistency (24).

## Randomization

44 patients fulfilling the inclusion and exclusion criteria were found eligible for the study. These participants were randomized by computer-generated random number table through simple random sampling. Those numbers were sealed in envelopes opened by main investigator to assign the allocated treatment. The participants were allocated to foam roller group and j-stroke group. Informed consent in written form was taken from each participant prior to the inclusion in study and the participants were fully aware about the treatment intervention techniques, risks and potential benefits as well as their right to withdraw at any time from the study.

## Blinding

This study was a single-blinded, randomized clinical trial. The outcome assessor (specialized in musculoskeletal physical therapy and had more than 5 years of experience) was blinded to the allocation of patients to the groups.

## Interventions

Patients agreeing to participate in study were recruited by convenient sampling technique and randomly assigned to one of the two groups. In group FR participants received treat-





**Figure 1.** Pressure pain threshold assessment using pressure algometer.

ment by a foam roller along with conventional physical therapy. The participants in group JS received J-stroke myofascial release with conventional physical therapy. The total duration of treatment was per week three sessions on alternate days for four weeks' time period. Assessment of the patients VAS, PPT, ankle dorsiflexion ROM with WBLT and FADI were done at baseline and 4<sup>th</sup> week (**figure 1**).

#### **Group FR**

These patients were treated with foam roller for pain beneath heel for 45 seconds with 15 seconds rest with 5 repetitions, 3 times in a week for 4 weeks (18).

#### **Guidelines for using foam roller**

Use foam roller with smooth surface and medium density, before the performance of exercise warm up your foot and calf muscles then sit comfortably and place the foam roller under your foot. The body weight should be gradually increased on the foam roller to target all affected areas roll foot back and forth and adjust foot accordingly after foam rolling stretch your calf muscles and plantar fascia (**figure 2**).

#### **Group JS**

These patients were treated with J-stroke myofascial release

beneath the heel for 15 seconds for 5 to 12 repetitions, 3 times in a week for 4 weeks.

#### **Technique of J-stroke myofascial release**

The patient should be comfortable with bare foot, apply a lubricant to plantar aspect of foot being treated. Place the thumb on medial aspect of plantar fascia, near heel than glide the thumb with gentle and sustained pressure on medial side of the plantar fascia while moving towards the ball of the foot. The stroke is applied in a J-shaped or inverted L-shaped pattern focusing on tenderness and tension in the area being treated and repeat strokes multiple times.

#### **Conventional treatment for plantar fasciitis**

##### *Towel curl up*

Participants sit with their foot flat on one end of the towel and the other end of the towel on a smooth surface, holding a little weight. For ten minutes, keep the heel on the ground while you curl and draw the towel towards your body.

##### *Active ankle exercises*

In supine lying, normal active ankle movements were performed 10 repetitions each.

##### *TA stretching*

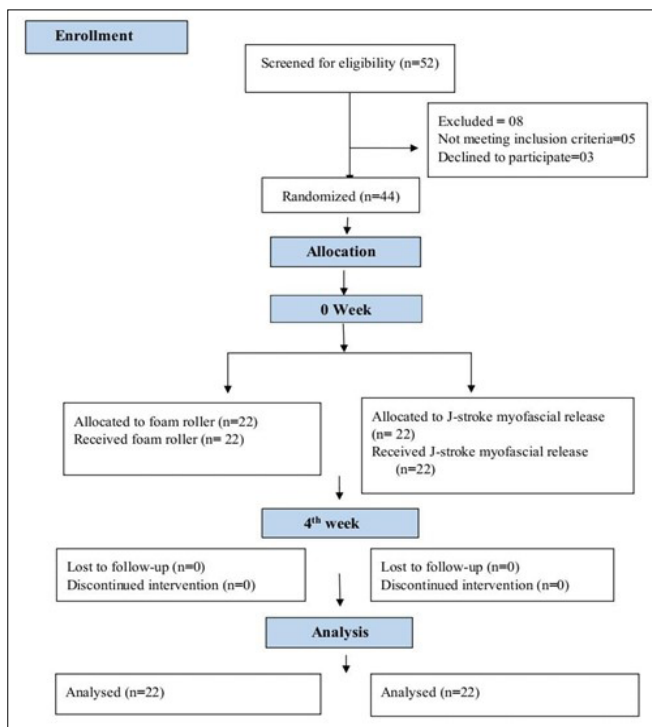
In standing the subject leans against wall to actively stretch Achilles tendon and holds stretch for 1 minute and 5 repetitions in every session (10).

#### **Sample size**

Sample size calculated was 40 ( $\alpha = 0.05$ , power = 0.8) through G\*power (3.1.9.4) software. Visual analogue scale was used for sample size calculation (18). The final sample size after considering 10% attrition was 44 patients.



**Figure 2.** A patient using a foam roller.



**Figure 3.** CONSORT flow diagram showing recruitment and assessment of patients.

## Data analysis

The window software, SPSS 26 version is used for analyzing data. The level of significance was set at  $p \leq 0.05$ . After assessing the normality by Shapiro-wilk to find normality of the data, P value was found to be more than 0.05, so for data analysis parametric test was used as the data was found normally distributed. Across group differences were evaluated through parametric test independent sample t-test. Within group differences were evaluated through parametric test paired sample t-test. Cohen's d was used to evaluate the effect size between the two groups. The effect size of 0.2, 0.5, and 0.8 were considered small, medium and large, respectively (26).

## RESULTS

The total sample size calculated was 44 with an attrition rate of 10%. These participants were randomized into two groups, so, for analysis data, 22 participants from Group FR and 22 participants from Group JS was used in the study. After the data collection, SPSS version 26 was used for the data analysis. All participants received a 4-week treatment protocol with 3 sessions per week on alternate days. Numeric variables were defined as mean  $\pm$  S.D. The significance

level was set at  $p < 0.05$ . The normality of data collected was checked by Shapiro-Wilk test, result value was more than 0.05 then the data was found under normal distribution curve and parametric tests were used. The details of patients are shown in CONSORT 2010 flow diagram for reporting randomized clinical trial (figure 3).

## Clinical and demographic characteristics of the patient

There were 7 males and 15 female patients in Foam roller group and 7 males and 15 female patients in J-stroke group. However, in group FR (Foam roller) participants have mean age  $39.82 \pm 4.80$  years, mean height  $1.67 \pm 0.11$  meters, mean weight  $73.63 \pm 7.41$  kgs, mean BMI  $26.64 \pm 4.12$  and 59.09% comes with complain of right side plantar fasciitis and 40.91% came with complain of left side. In group JS (J-stroke myofascial release) participants have mean age  $39.73 \pm 5.34$  years, mean height  $1.65 \pm 0.94$  meters, mean weight  $77.09 \pm 9.92$  kgs, mean BMI  $28.68 \pm 4.81$  and 68.18% reports right side affected, and 31.82% reports left affected side (table I).

## Intragroup analysis

Intragroup analysis shows the comparison between the Group FR and JS for the pre- and post-VAS, WBLT, PPT (Gastrocnemius, soleus and plantar fascia) and FADI treatment values by the independent sample t-test. The indepen-

**Table I.** Baseline characteristics of the study participants.

Variables	Group FR (n = 22) Mean $\pm$ SD	Group JS (n = 22) Mean $\pm$ SD
Age (Years)	$39.82 \pm 4.80$	$39.73 \pm 5.34$
Height (m)	$1.67 \pm 0.11$	$1.65 \pm 0.94$
Weight (kg)	$73.63 \pm 7.41$	$77.09 \pm 9.92$
BMI (kg/m <sup>2</sup> )	$26.64 \pm 4.12$	$28.67 \pm 4.81$
	Frequency (%)	Frequency (%)
Gender	Males = 7 (31.8%) Females = 15 (68.2%)	Males = 7 (31.8%) Females = 15 (68.2%)
Affected side	Left = 9 (40.91%)	Left = 7 (31.8%)
Affected side	Right = 13 (59.1%)	Right = 15 (68.2%)

BMI: Body mass index; SD: Standard Deviation; FR: Foam Roller; JS: J-Stroke; n: number of participants.

dent T-test for between the group analysis was not significant ( $p > 0.05$ ) for post VAS and post PPT (Plantar fasciitis) whereas post WBLT, PPT (Gastrocnemius and soleus) and post FADI were significant ( $p < 0.05$ ) (**table II**).

### Intergroup analysis

The results of paired t test for group *i.e.*, Foam roller group. The P-value was less than 0.05 for all the variables of within the group FR analysis, which shows that there was significant difference before and after the treatment application except the WBLT for which P-value is greater than 0.05 which shows that there was no significant difference before and after the treatment application (**table III**). The result of the paired t test for group *i.e.*, J-stroke myofascial release Group JS and shows that there was significant difference before and after the treatment protocol for within the Group JS analysis as P-value is less than 0.05. The mean difference showed that group (J-stroke myofascial release) was found more effective than group (Foam roller) intervention (**table IV**).

## DISCUSSION

The current study was done to check the comparative effects of Foam roller and J-stroke myofascial release in patients with plantar fasciitis on pain intensity, ROM, pain pressure threshold and disability. The parameters like VAS, WBLT (weight bearing lunge test), PPT (Pain pressure threshold) and FADI (foot and ankle disability index) were included to measure the effects of both treatment techniques in plantar fasciitis. To know the effects of both treatment techniques on the patients, a randomized clinical trial was carried out for 3 sessions per week on every alternate day for 4 weeks and around 44 patients were part of this study. The mean age in Group FR (Foam roller) was  $39.82 \pm 4.80$  years and in Group JS (J-stroke myofascial release) was  $39.73 \pm 5.34$  years. Data of both groups was analyzed for all the outcome measures after the data collection. All the participants in both groups were given a conventional treatment protocol exercises towel curl up, tennis ball stretch of plantar fascia, active ankle exercises, tendon Achilles stretching before applying the foam roller and J-stroke myofascial release

**Table II.** Intragroup comparisons (Independent t-test) in both groups.

Variables	Follow up	Group FR Mean $\pm$ SD	Group JS Mean $\pm$ SD	Mean difference (95% CI)	Effect size	P-value
VAS*	Pre	6.95 $\pm$ 1.17	2.87 $\pm$ 0.65	0.033 (0.836-0.902)	0.60	0.540
	Post	3.29 $\pm$ 0.70		0.41 (0.07-0.845)		
WBLT**	Pre	9.45 $\pm$ 0.81	9.22 $\pm$ 1.47	0.23 (0.51-0.98)	0.20	0.531
	Post	9.78 $\pm$ 1.46		2.1 (2.98-1.28)		
PPT*** (Gastrocnemius)	Pre	7.60 $\pm$ 1.40	7.01 $\pm$ 0.81	0.59 (0.13-1.31)	0.70	0.106
	Post	10.98 $\pm$ 1.11		0.98 (0.26-1.69)		
PPT (Soleus)	Pre	7.04 $\pm$ 0.66	6.99 $\pm$ 1.00	0.05 (0.47-0.58)	0.08	0.829
	Post	8.60 $\pm$ 1.27		2.06 (2.89-1.22)		
PPT (Plantar fascia)	Pre	7.09 $\pm$ 1.16	6.73 $\pm$ 1.29	0.359 (0.408-1.12)	0.30	0.350
	Post	9.47 $\pm$ 1.81		0.067 (1.18-1.04)		
FADI**** score	Pre	29.71 $\pm$ 1.89	29.25 $\pm$ 2.64	0.45 (0.97-1.89)	0.20	0.520
	Post	76.64 $\pm$ 15.06		15.38 (23.25-7.51)		

SD: Standard Deviation; FR: Foam Roller; JS: J-Stroke; CI: Confidence Interval; P-value less than 0.05 was considered significant; \*VAS: Visual Analog Scale; \*\*WBLT: Weight Bearing Lunge Test; \*\*\*PPT: Pressure Pain Threshold; \*\*\*\*FADI: Foot and Ankle Disability Index.

**Table III.** Intergroup comparison (paired T test) in Foam Roller group (n = 22).

Variables	Group Foam roller	Mean $\pm$ SD	Effect size	P-value
VAS*	Pre-treatment	6.95 $\pm$ 1.17	2.73	0.000
	Post-treatment	3.29 $\pm$ 0.70		
WBLT**	Pre-treatment	9.45 $\pm$ 0.81	0.18	0.398
	Post-treatment	9.78 $\pm$ 1.46		
PPT*** (Gastrocnemius)	Pre-treatment	7.60 $\pm$ 1.40	2.02	0.000
	Post-treatment	10.98 $\pm$ 1.11		
PPT (Soleus)	Pre-treatment	7.04 $\pm$ 0.66	1.18	0.000
	Post-treatment	8.62 $\pm$ 1.27		
PPT (Plantar Fascia)	Pre-treatment	70.09 $\pm$ 1.16	1.22	0.000
	Post-treatment	9.47 $\pm$ 1.81		
FADI****	Pre-treatment	29.71 $\pm$ 1.89	3.09	0.000
	Post-treatment	76.64 $\pm$ 15.06		

SD: Standard Deviation; FR: Foam Roller; JS: J-Stroke; CI: Confidence Interval; P-value less than 0.05 was considered significant; \*VAS: Visual Analog Scale; \*\*WBLT: Weight Bearing Lunge Test; \*\*\*PPT: Pressure Pain Threshold; \*\*\*\*FADI: Foot and Ankle Disability Index.

**Table IV.** Intergroup comparison (paired t test) in J- Stroke Myofascial release group (n = 22).

Variables	Group J-stroke MFR	Mean $\pm$ SD	Effect size	P-value
VAS*	Pre-treatment	6.92 $\pm$ 1.57	2.47	0.000
	Post-treatment	2.87 $\pm$ 0.65		
WBLT**	Pre-treatment	9.22 $\pm$ 1.47	1.32	0.000
	Post-treatment	11.92 $\pm$ 1.24		
PPT*** (Gastrocnemius)	Pre-treatment	7.01 $\pm$ 0.81	2.19	0.000
	Post-treatment	10.03 $\pm$ 1.17		
PPT (Soleus)	Pre-treatment	6.99 $\pm$ 1.00	1.94	0.000
	Post-treatment	10.68 $\pm$ 1.41		
PPT (Plantar Fascia)	Pre-treatment	6.73 $\pm$ 1.29	1.16	0.000
	Post-treatment	9.54 $\pm$ 1.75		
FADI****	Pre-treatment	29.25 $\pm$ 2.64	6.67	0.000
	Post-treatment	92.03 $\pm$ 9.55		

SD: Standard Deviation; FR: Foam Roller; JS: J-Stroke; CI: Confidence Interval; P-value less than 0.05 was considered significant; \*VAS: Visual Analog Scale; \*\*WBLT: Weight Bearing Lunge Test; \*\*\*PPT: Pressure Pain Threshold; \*\*\*\*FADI: Foot and Ankle Disability Index.

technique. After the application of the treatment protocol significant improvement was reported in both groups. Results show that within the groups, the foam roller Group FR and the J-stroke myofascial release Group JS have

almost equal and significant effects ( $p < 0.05$ ) in decreasing pain, pain pressure threshold, disability thus improving the ROM of the ankle dorsiflexion in patients of plantar fasciitis except in foam roller group where WBLT was



statistically insignificant but the mean difference between both groups suggested J-stroke myofascial release showed better results as compared to foam roller.

The outcomes of this study were consistent with Ranbhor *et al.*'s (2020) study, in which foam roller technique was found superior in relieving pain and increasing ROM in contrast to stretching in 50 participants that were randomly allocated into foam roller Group FR and the stretching group. Both groups were assessed at baseline and after the treatment immediately for VAS, PPT (Gastrocnemius, soleus, plantar fasciitis), WBLT. The between Group FR analysis of this study shows that there was no statistical significance in VAS, WBLT and plantar fascia PPT. The results of this study were in agreement to present study conducted because foam roller Group FR analysis showed similar result in case of WBLT which was found insignificant. The current study has conducted 3 sessions per week on alternate days for 4 weeks, so it showed long term effects of the treatment techniques rather than immediate effects (27).

Unlike the current study, a research conducted by Hameed and his coworkers in 2020, summarized that self-myofascial release with foam roller and tennis ball both were found to be beneficial choice of treatment in managing patients of plantar fasciitis. Outcomes at baseline were measured and after 2 weeks of treatment by VAS and FADI. Both groups showed improvement in VAS and FADI post treatment but between Group FR analysis was not found significant. The present study also showed significant results on VAS and FADI post treatment (13).

Another study conducted by Javed and colleagues (2021) in accordance with the current study found that myofascial release technique gave better results in alleviating pain and improving foot function when given along with conventional treatment rather than just conventional treatment. The intervention was given for 2-week time period on alternate days. Between Group FR analysis showed significant results on VAS and FFI (foot functional index) (28). Studies report that physical touch improves the patient satisfaction, as in a study by Barroni *et al.*, of 2021 it concluded that it improves collaboration with patient, and provide significant information about underlying adhesions or abnormalities helps in shared decision making of the clinical disorder. It acts as a leading tool of communication, and this supports better outcomes gained by J-stroke myofascial release technique in the current study (29).

In the current study no electrotherapeutic modality *i.e.*, ultrasound or hot pack was used as a conventional treat-

ment which contradicts the studies that reported use of ultrasound 1W/cm<sup>2</sup> using ratio of 1:4 pulsed mode, frequency of 10MHz for 5 minutes and use of contrast bath for 20 minutes as the conventional treatment another study Shah *et al.* (2018) is in accordance to report use of ultrasound as conventional treatment with exercises towel curl ups, active ankle exercise, tennis ball stretching and stretching of Achilles tendon (30).

A study conducted by Yoshimura *et al.* found effects of foam roller on ankle ROM that there was an immediate increase in ankle dorsiflexion ROM but no effect on muscle hardness and fascicle length were reported. Plantar flexion ROM at ankle was also not improved. In contrast, the current study reported no increase in dorsiflexion ROM at the ankle joint post-treatment with foam roller but pain pressure threshold at gastrocnemius muscle, soleus and plantar fascia produced significant results post-treatment (31).

This study's significant reduction in pain intensity is consistent with systematic review of Tandel and colleagues' effectiveness of myofascial release on pain intensity and function in individuals with plantar fasciitis, in which 7 RCT, 1 pre-post interventional, 1 prospective, 1 quasi-experimental study, were reviewed (10). Another study investigated that myofascial release is useful in treatment of plantar fasciitis results were measured by PPT, NPRS, FAAM and ROM outcome measures which reported significant difference after 10 day post treatment (32).

Clinicians may incorporate J-stroke myofascial release technique in their treatment protocol for patients with plantar fasciitis. Functional gait analysis may be done to evaluate improvements in gait and biomechanical alignment in patients with plantar fasciitis. Longitudinal outcome studies may be conducted to assess long term effectiveness and durability of J-stroke myofascial release. Future studies can be conducted to explore the synergistic effects of combining J-stroke with stretching exercises, orthotics and manual therapy.

## CONCLUSIONS

This study concluded that J-stroke myofascial release technique produced clinically relevant results and found significant for all the outcome measures as the effect size was large and more mean difference was reported in comparison to foam roller in reducing pain intensity, pain pressure threshold, disability and range of motion. So, J-stroke myofascial release is superior to foam roller technique when treating plantar fasciitis patients.



## Limitations of the study

In this study immediate effects of foam roller and J-stroke myofascial release were not assessed at 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> week in the study only two assessments were done at baseline and 4<sup>th</sup> week respectively. The results of the study cannot be generalized to both genders because more female patients were part of the study. Since there was no control group so it cannot be ruled out if pain subsided due to natural history of recovery. The absence of long-term follow-ups has not provided information on sustained effects over an extended period.

## FUNDINGS

None.

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## DATA AVAILABILITY

Data analyzed for this study is included in this article.

## CONTRIBUTIONS

MN: conceptualization, data curation, writing – original draft, writing – review & editing. FA: conceptualization. AM: data curation and formal analysis. AA, ZJ: formal analysis.

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## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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# Effects of Physical Exercise on Bone Mineral Density in Older Adults: A Systematic Review and Meta-Analysis of Randomized Controlled Trials

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## SUMMARY

**Objective.** Verify the effects of different physical exercises on bone mineral density in the older.

**Methods.** The PRISMA criteria were followed, and the study was registered with PROSPERO. The databases used were MEDLINE (via PubMed), Scopus, Cochrane, Web of Science, Embase, and Pedro.

**Results.** A total of 4,118 publications were found from the database search, and 13 RCTs were included in the present systematic review. The estimated average standardized mean difference was 0.26 (95%CI 0.00 to 0.52). The average result differed significantly from zero ( $p = 0.05$ ) and heterogeneity was estimated at  $I^2 = 43\%$ .

**Conclusions.** Until now, physical exercise has shown low efficacy and moderate evidence for gaining total bone mineral density in the elderly population.

## KEY WORDS

*Body mineral density; exercise; older; bone remodeling; Physical exercise*

## INTRODUCTION

The numbers of older adults and adults with age-related chronic diseases are expected to more than double between 2019 and 2050 (1). Although populations around the world are rapidly ageing, evidence that increasing longevity is accompanied by an extended period of good health is scarce (2, 3). Unfortunately, many people are subject to some type of frailty during the aging process (4, 5).

Fractures related to osteoporosis constitute a major health problem in our aging society, often causing the individual to lose independence. There is an increase in morbidity and mortality in elderly people with osteoporosis, especial-

ly in women, and prevention should occur from the age of 65 regardless of sex. Physical exercise and drug therapies are strategies used in the prevention and treatment of bone diseases (6, 7).

Aging, a natural physiological process, can cause some unfavorable morphofunctional changes, such as a reduction in total mineral density (total BMD) and physical fitness, thereby increasing the risk of developing disorders such as osteopenia, osteoporosis and decreased functional capacity (8).

Bones should be strong, to prevent fractures. Bone turnover markers predict fracture risk and treatment-induced changes in specific markers account for a substantial

proportion of fracture risk reduction (5). Bone modeling is sensitive to mechanical loading, emphasizing the importance of physical activity throughout growth. Physical exercise can improve bone health in middle-aged and postmenopausal women (9, 10).

This study is justified by the existence of approximately 25 published meta-analyses that have examined the effect of physical exercise on bone mineral density (11-35). Only 3 of these meta-analyses measured total bone mineral density, those by (19, 21, 34). However, the number of studies included in these meta-analyses was very small to measure total bone mineral density, contributing to the imprecision of the findings. The study (19) included two studies, (21) included four studies, and (34) included four studies, three of which involved participants using medications. Despite the recent nature of these meta-analyses, new RCTs measuring total bone mineral density have already been published, providing 8 new results (36-43) to be meta-analyzed.

With this, the objective of this study was to verify the effects of physical exercise on bone mineral density in the older.

## METHODS

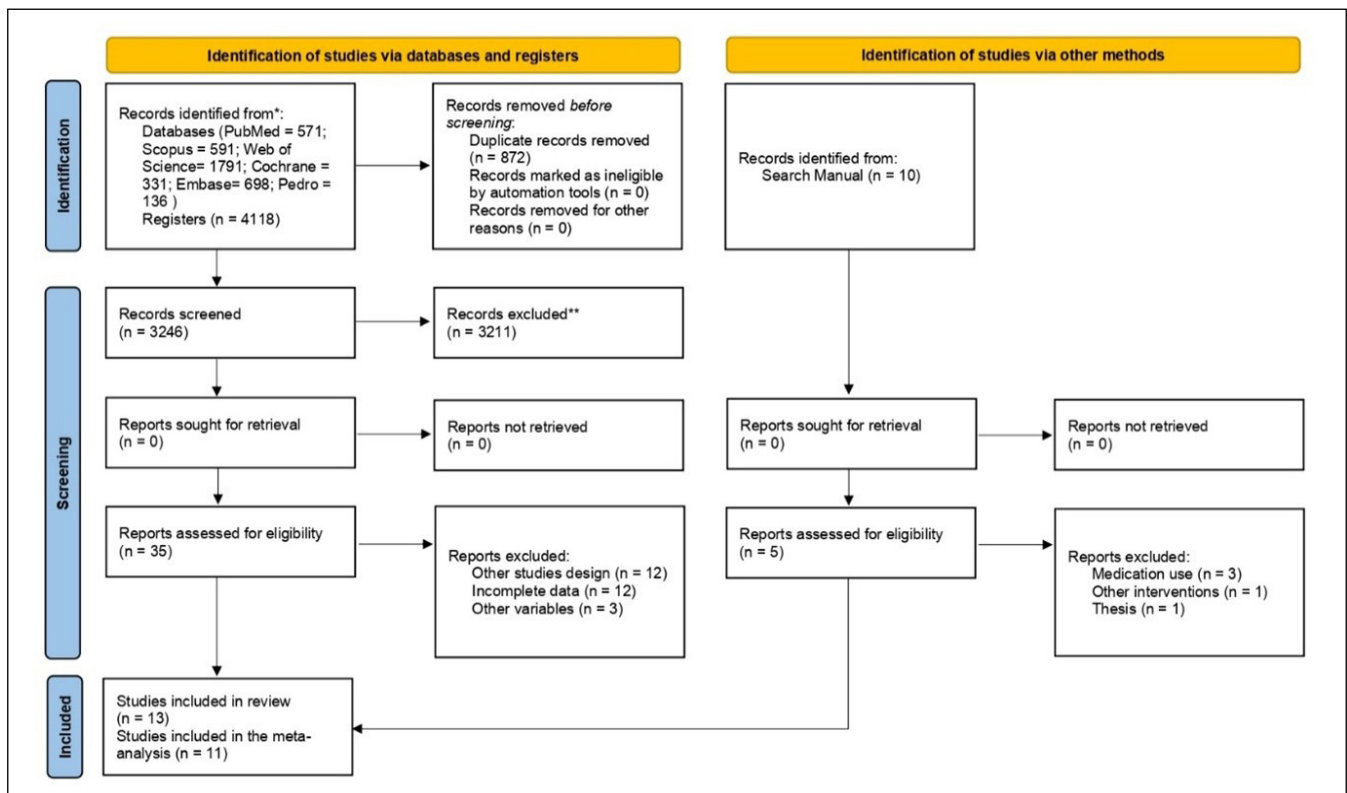
This systematic review and meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria (44) (**figure 1**), and was approved by the international prospective registry of systematic reviews (PROSPERO) under number CRD42023495223 - approval date: December 19, 2023.

### Inclusion criteria

The PICOS strategy was used, the population of older adults (aged  $\geq 60$  years) of both sexes, the intervention with physical exercise practitioners, the comparison with a control group, the outcome bone mineral density, the study design with randomized controlled trials (RCTs). Systematic review and meta-analysis studies, animal studies, participants under the age of 60 and studies that did not use physical exercise as the main intervention were excluded.

### Search strategy

The databases used were MEDLINE (via PubMed), Scopus, Cochrane, Web of Science, Science Direct, Embase, SciELO, and PEDro from November 01 to 15, 2024. The elec-



**Figure 1.** Flowchart of the 13 studies included in the meta-analysis according to PRISMA recommendations.



tronic search was conducted by two independent and experienced evaluators without language or time filters, and any conflict was resolved by a third reviewer. The search terms used were grouped with the operators (AND, OR) in a single Boolean phrase, the descriptors used were Older, Exercise, “Bone mineral density” and AND operator between descriptors and OR between their synonyms (**supplement 1**). Keywords related to the topic were selected based on a literature review and verified by Medical Subject Headings (MeSH) metadata systems. The selection of studies was carried out in three phases: 1) Identification and exclusion of duplicate studies using the Zotero 6.0.30 application; 2) Reading the titles and abstracts to see if the studies met the established inclusion criteria; and 3) Reading the entire text of the remaining studies with the same purpose.

### Bibliometric analysis by network visualization

The software used for this analysis was VOSviewer 1.6.20, the keywords are represented by the circle, the size of the circle indicates the weight of the item. The clusters are separated by color according to the group the item belongs to and the lines between the items represent the existing

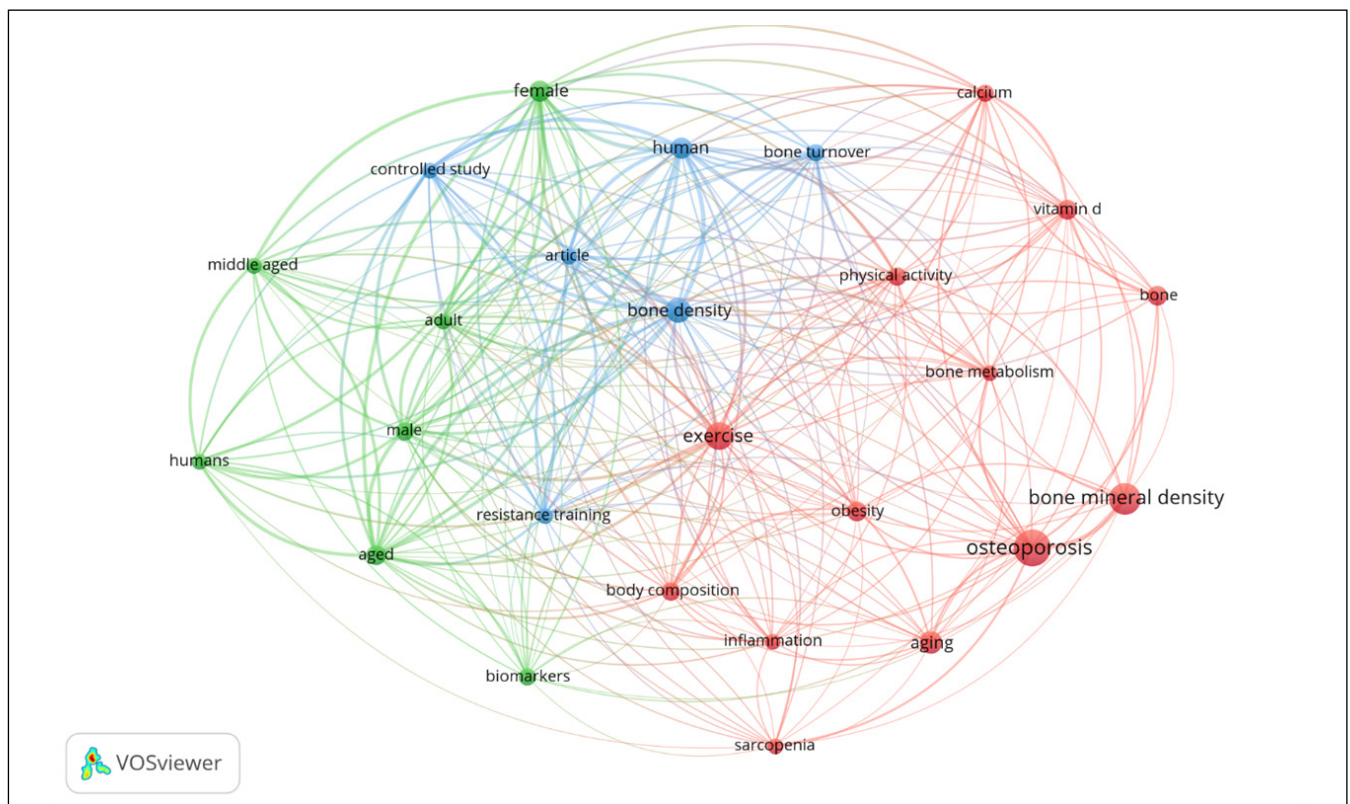
connections. The relationship between keywords is proportional to the distance, the closer they are, the greater the relationship between the terms (**figure 2**).

### Risk of bias assessment

Eligible RCTs in this study were assessed using the Cochrane Collaboration risk-of-bias tool, available at <https://training.cochrane.org/handbook/>. Two experienced authors independently assessed them, and any discrepancies were resolved by a third author. The bias of the following sources was evaluated: 1) random sequence generation; 2) allocation concealment; 3) blinding of participants and staff; 4) concealment of outcome assessments; 5) incomplete outcome data; 6) selective notification; 7) another bias. Each domain has the risk of bias set as low, uncertain, or high (**figure 3**).

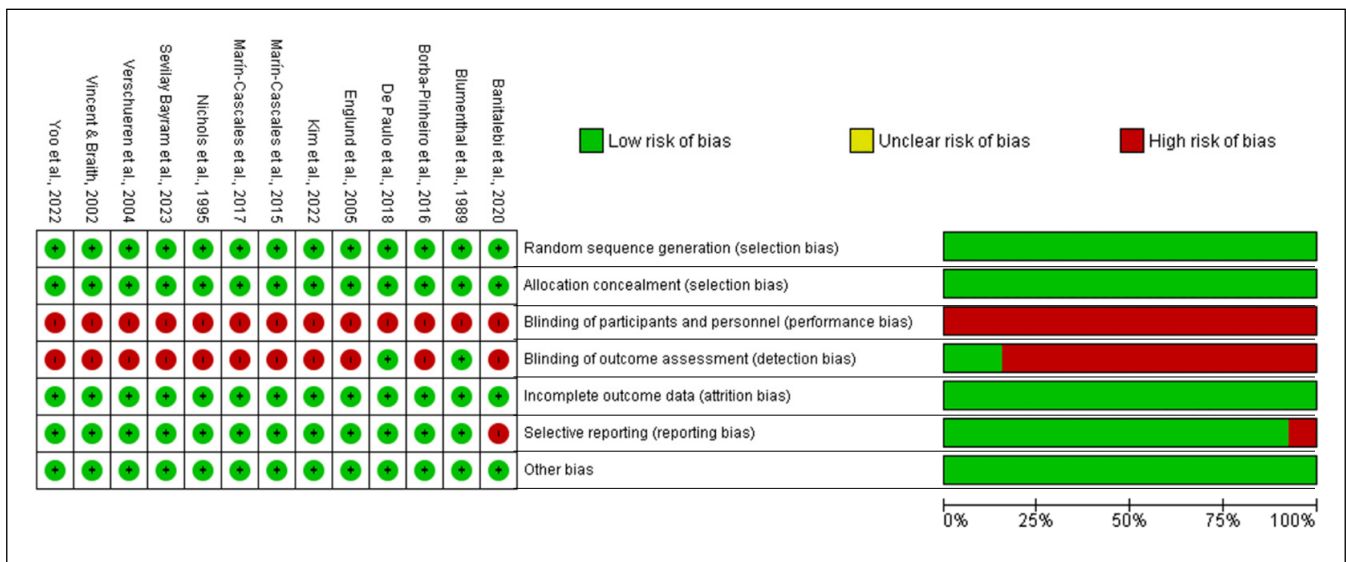
### Assessment of methodological quality

The quality assessment tool for studies and reports on physical exercise (TESTEX) is a 15-point scale used in experimental studies, including internal validity assessment criteria and presentation of the statistical analysis



**Figure 2.** Network visualization, among the bases used in this meta-analysis.





**Figure 3.** Risk of bias analysis for randomized studies.

used. In this tool, one point is assigned for each criterion defined on the scale and zero in the absence of these indicators (46) (**table III**).

### Data extraction

For better understanding, the extracted data was divided by authors, year of publication, country of origin, characteristics of the study population, intervention data including details of general and specific exercises, evaluation method and results.

### Meta-analysis

The Review Manager (RevMan), version 5.4, the Cochrane Collaboration, 2020 was used to analyze the effects of physical exercise bone mineral density in the older. Despite the total bone mineral density (BMD) having the same unit of measurement across all studies, the standardized mean difference (SMD) was chosen to classify the effect size according to Cohen (47). Each standardized mean difference (SMD) was weighted according to the inverse variance method. The SMD values in each study were pooled using a random model because the heterogeneity was significant. Heterogeneity between studies was analyzed using  $I^2$  statistics.  $I^2$  values are interpreted as low heterogeneity (0-50%), moderate heterogeneity (50-74%), and high heterogeneity ( $\geq 75\%$ ) (45, 48). SMD values were interpreted as:  $0.2 \leq TE < 0.5$  (weak);  $0.5 \leq TE \leq 0.8$  (moderate);  $TE \geq 0.8$  (strong) (47). A statistically significant effect was indicated by  $P$ -value  $< 0.05$ .

### Evidence-level assessment

Two authors independently assessed the certainty of evidence using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach with the GRADE PRO website, available at <https://grade.pro.org>. GRADE specifies four categories: “high”, “moderate”, “low”, and “very low”, applied to a body of evidence. RCTs begin with high-quality evidence. Five aspects can decrease the quality of evidence: methodological limitations, inconsistency, indirect evidence, inaccuracy, and publication bias (49).

## RESULTS

A total of 4,118 publications were found from the database search following the proposed research methodology (MEDLINE via PubMed = 571; Scopus = 591; Web of Science = 1,791; Cochrane = 331; Embase = 698; Pedro = 136). After using the selection criteria, a total of 13 RCTs were included in the present systematic review, and in the meta-analysis there were 11 studies and 13 results (**figure 1**).

**Figure 2** shows the network visualization, among the bases used in this meta-analysis. 1,999 keywords were found, of which 26 appear with at least 15 occurrences. Red circles indicate cluster 1 (13 circles). The terms “osteoporosis” and “bone mineral density” have the greatest weight. The green circles represent cluster 2 (7 circles) The term “female” has the highest weight and the other circles have balanced weight in both clusters. Blue circles indi-

cate cluster 3 (6 circles). The keywords “bone density” and “human” have the highest weight, not differing much from the other keywords in this cluster.

**Figure 3** presents the results of the risk of bias analysis of randomized studies using the Cochrane Collaboration tool. All studies were classified as “high risk”, not shielding participants and/or evaluators due to the difficulty of this procedure with interventions in humans.

**Table I** presents the methodological quality assessment using the TESTEX tool. All studies included in this systematic review obtained a score  $\geq 10$ . The domain “Exercise volume and energy expenditure were reported” did not

score 100% of the studies because they did not present data regarding caloric expenditure.

In **table II**, the study variables are arranged by author and year, country of origin, study design, age, sex, and number of participants per group. The average age of participants in the CG was 67 and EG was 66 years old. The studies appear in different countries, Iran (36), USA (42, 43, 50), Brazil (37, 38), Sweden (51), Spain (40, 41), Turkey (52), Korea (39), Belgium (53, 54).

**Table III** contains the data extracted from the studies included in this review. The details of the intervention, the type of exercise, the total duration of the intervention, the

**Table I.** TESTEX study quality assessment.

Study	Study Quality					Sub-Total (0 to 5)	Study Reporting										Sub-Total (0 to 10)	Total (0 a 15)
	1	2	3	4	5		6a	6b	6c	7	8a	8b	9	10	11	12		
(36)	1	1	1	1	0	4	1	1	1	1	1	1	1	1	1	0	9	13
(50)	1	1	1	1	0	4	1	1	1	1	1	1	1	1	1	0	9	13
(37)	1	1	1	1	0	4	1	1	1	1	1	1	1	1	1	0	9	13
(38)	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	0	9	14
(51)	1	1	1	1	0	4	1	0	1	1	1	1	1	1	1	0	8	12
(39)	1	1	1	1	0	4	1	1	1	1	1	1	1	1	1	0	9	13
(40)	1	1	1	1	0	4	1	1	1	1	1	1	1	1	1	0	9	13
(41)	1	1	1	1	0	4	1	1	1	1	1	1	1	1	1	0	9	13
(42)	1	1	1	1	0	4	1	1	1	1	1	1	1	1	1	0	9	13
(52)	1	1	1	1	0	4	1	1	1	1	1	1	1	1	1	0	9	13
(43)	1	1	1	1	0	4	1	1	1	1	1	1	1	1	1	0	9	13
(53)	1	1	1	1	0	4	1	0	1	1	1	1	1	1	1	0	8	12
(54)	1	1	1	1	0	4	1	0	1	1	1	1	1	1	1	0	8	12

Study quality: 1 = specific eligibility criteria; 2 = type of randomization specified; 3 = hidden allocation; 4 = similar groups at baseline; 5 = raters were blinded (at least one main outcome); 6 = outcomes assessed in 85% of participants (6a = 1 point if more than 85% completed; 6b = 1 point if adverse events were reported; 6c = if exercise attendance was reported); 7 = intention-to-treat statistical analysis; 8 = statistical comparison between groups was reported (8a = 1 point if between-group comparisons are reported for the primary outcome variable of interest; 8b = 1 point if statistical comparisons between groups are reported for at least one secondary measure); 9 = point measures and measures of variability for all outcome measures that were reported; 10 = activity monitoring in the control group; 11 = relative exercise intensity remained constant; 12 = exercise volume and energy expenditure were reported.

**Table II.** Population characteristics.

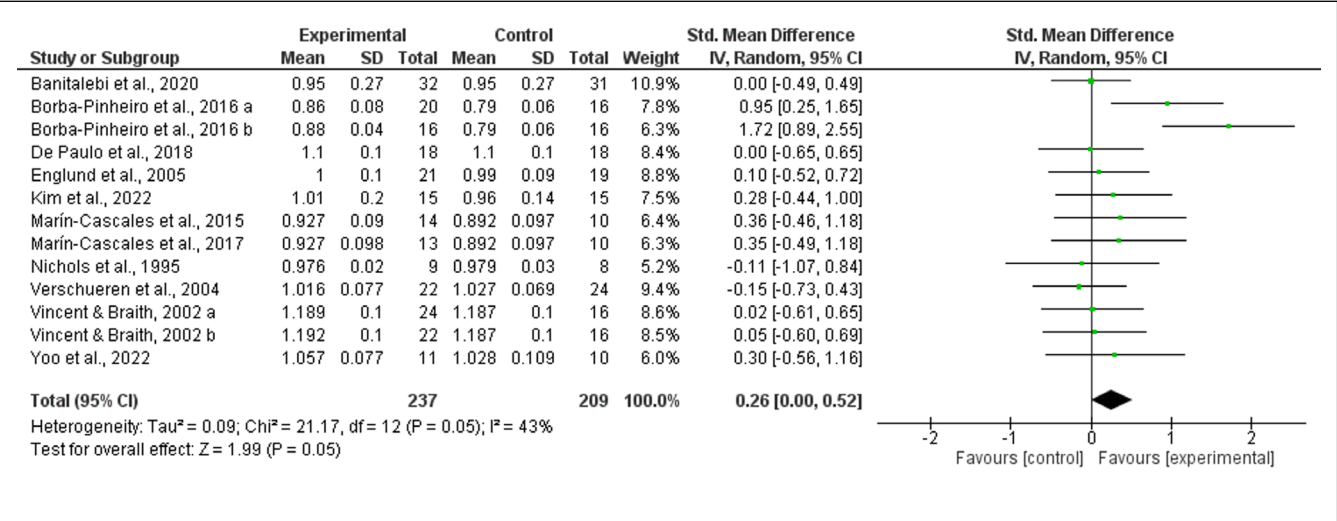
Author/ year	Country	Age (media/ SD)	Population	BMI (Kg/m <sup>2</sup> )	n
(36)	Iran	CG: 64.05 ± 3.35 EG: 64.11 ± 3.81	Osteosarcopenic obese women	CG: 33 EG: 34	CG: 31 EG:32
(50)	USA	CG: 66.8 ± 4.3 EG1: 66.5 ± 4.3 EG2: 67.8 ± 5.9	Healthy men	NI	CG: 34 EG1: 33 EG2: 34
(37)	Brazil	CG: 56.3 ± 5.2 EG1: 60.6 ± 7.5 EG2: 55.3 ± 6.8	Postmenopausal women	CG: 28 EG1: 26 EG2: 29	CG: 16 EG1: 20 EG2: 16
(38)	Brazil	CG: 66.6 ± 9.6 EG: 63.2 ± 7.1	Women with breast cancer	CG: 32 EG: 29	CG: 18 EG:18
(51)	Sweden	CG: 73.2 ± 4.9 EG: 72.8 ± 3.6	Postmenopausal Women	CG: 26 EG: 25	CG: 19 EG: 21
(39)	Korea	CG: 81.6 ± 4.78 EG: 79.6 ± 5.19	Obese women	CG: 34 EG: 35	CG: 15 EG:15
(40)	Spain	CG: 62.4 ± 5.1 EG: 57.7 ± 7.1	Postmenopausal Women	CG: 29 EG: 29	CG: 10 EG: 14
(41)	Spain	CG: 60.0 ± 6.3 EG: 60.0 ± 6.3	Postmenopausal Women	CG: 27 EG: 28	CG: 10 EG: 13
(42)	USA	CG: 67.8 ± 1.6 EG: 65.2 ± 1.2	Healthy women	CG: 27 EG: 26	CG: 17 EG:17
(52)	Turkiye	CG: 71.5±4.5 EG: 70.2±3.8	Healthy women	CG: 31 EG: 30	CG: 10 EG: 13
(43)	USA	CG: 71 ± 5 EG1: 67.6 ± 6 EG2: 66.6 ± 7	Healthy men and women	CG: 25 EG1: 27 EG2: 24	CG: 16 EG1: 24 EG2: 22
(53)	Belgium	CG: 64.2 ± 3.1 EG: 63.90 ± 3.8	Postmenopausal Women	CG: 27 EG: 27	CG: 24 EG: 22
(54)	Korea	CG: 71.1 ± 2.7 EG: 70.9 ± 2.7	Postmenopausal women	CG: 25 EG: 27	CG: 10 EG: 11

EG: experimental group; CG: control group.

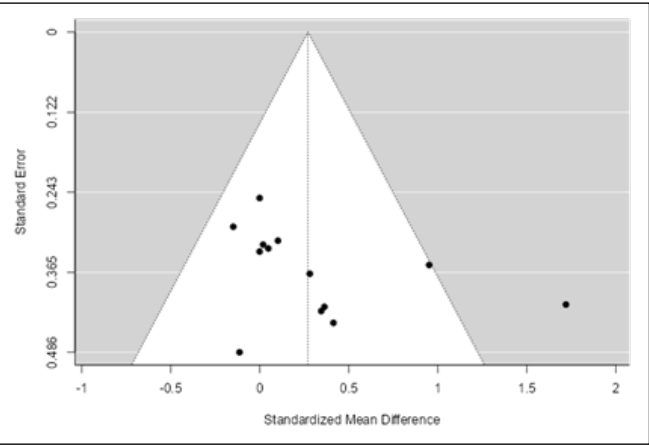
training volume indicating the session time and the number of sessions per week, and the results found in the experimental group of each study. The average time per session was 53 min, 3 sessions per week and the total intervention time was 27 weeks.

In **figure 4**, 13 results from 11 included studies were analyzed. The observed standardized mean differences ranged from -0.15 to 1.72, with the majority of estimates being positive (69%). The estimated average standardized mean difference

based on the random-effects model was 0.26 (95%CI 0.00 to 0.52). Therefore, the average outcome differed significantly from zero ( $z = 1.99$ ,  $p = 0.05$ ). According to the Q-test, the true outcomes appear to be heterogeneous ( $Q(15) = 21.17$ ,  $p = 0.05$ ,  $\tau^2 = 0.09$ ,  $I^2 = 43\%$ ). Hence, although the average outcome is estimated to be positive, in some studies the true outcome may in fact be negative. Neither the rank correlation nor the regression test indicated any funnel plot asymmetry ( $p = 0.06$  and  $p = 0.10$ , respectively) (**figure 5**).



**Figure 4.** Forest plot (BMD Total) of 11 studies with 13 results that evaluated bone mineral density by subgroups of type of physical exercise: RT (Resistance training), Aerobic, Combined (with more than one exercise modality) and Pilates.



**Figure 5.** Funnel plot (total BMD) of 11 studies with 13 results that were meta-analyzed. Each result was plotted by SE(SMD) on the Y axis and SMD on the X axis.

DISCUSSION

The objective of this meta-analysis was to analyze the possible effects of physical exercise on bone mineral density in the older.

The result of this meta-analysis, after considering the 11 studies with 13 results, showed a standardized mean difference = 0.26 [0.00 to 0.52]; p = 0.05, with a low and significant heterogeneity of 43 %; p = 0.05 (figure 4). Despite the statistical significance obtained, the clinical significance was low (55).

The result of this meta-analysis, involving 446 participants, provided a more precise confirmation of the results from previous meta-analyses by (21) with a mean difference = 0.00 [-0.03 to 0.03] g/cm<sup>2</sup>; p = 0.96 with I<sup>2</sup> = 0%; p = 1.00; (19) with a mean difference = 0.04 [-0.00 to 0.08] g/cm<sup>2</sup>; p = 0.06 with I<sup>2</sup> = 0%; p = 0.82; and (34) with a standardized mean difference = 0.257 [0.05 to 0.461]; p = 0.014 with I<sup>2</sup> = 0%; p = 0.83.

The studies (50, 52) were included in this systematic review but were not included in this meta-analysis because they presented a significant difference in initial total bone mineral density between the exercise group (GE) and the control group (GC) (table III). This initial heterogeneity in total bone mineral density between the groups may have affected the final outcomes of this outcome between the GE and GC, to be considered in the meta-analysis.

An important point for discussion is the fact that the total bone mineral density between the groups was primarily driven by the loss of total bone mineral density in the control groups. This occurred in six studies: (36,39,42,43,53,54), with the only significant decrease (p = 0.01) observed in one study (42) (table III).

This could lead to the following question: *were the results in the forest plot of standardized mean differences in favor of the exercise group due to the greater total bone mineral density loss in these control groups, making the relative difference appear to favor the exercise group?* So, this could lead to obtaining a significant total bone mineral density between the exercise and control groups. Yes, this can happen, espe-

**Table III.** Data extracted from the included studies.

Study/year	Intervention	Duration(weeks)	VT	BMD Total (g/cm <sup>2</sup> ± sd)	
(36)	EG: elastic band RT CG: no exercise	12	60 min x session; 3 x week	GC: Pre: 1.005 ± 0.450 Post: 0.947 ± 0.274	p = 0.54***
				GE: Pre: 0.929 ± 0.245 Post: 0.945 ± 0.271	p = 0.41**
(50)*	EG1: aerobic EG2: Yoga and Flexibility CG: no exercise	16	60 min x session; 3 x week	GC: Pre: 1.08 ± 0.04 Post: 1.05 ± 0.05	p = 0.008***
				EG1: Pre: 1.10 ± 0.06 Post: 1.11 ± 0.03	p = 0.11**
				EG2: Pre: 1.14 ± 0.05 Post: 1.13 ± 0.05	p = 0.00001**
(37)	EG1: RT 3 x semana EG2: RT 2 x semana CG: no exercise	52	60 min x session; 2 x week	GC: Pre: 1.00 ± 0.03 Post: 1.00 ± 0.03	p = 1.00***
				EG1: Pre: 0.99 ± 0.03 Post: 1.03 ± 0.04	p = 0.33**
				EG2: Pre: 1.00 ± 0.04 Post: 1.04 ± 1.02	p = 1.00**
(38)	EG: RT + aerobic CG: no exercise	36	100 min x session; 3 x week	CG: Pre: 1.1 ± 0.08 Post: 1.1 ± 0.1	p = 1.00***
				EG : Pre: 1.1 ± 0.1 Post: 1.1 ± 0.1	p = 1.00**
(51)	EG: strengthening, aerobic, balance and coordination exercise CG: no exercise	48	50 min x session; 2 x week	GC: Pre: 0.98 ± 0.10 Post: 1.00 ± 0.10	p = 0.54***
				EG: Pre: 0.97 ± 0.09 Post: 0.99 ± 0.09	p = 0.74**
(39)	EG: RT CG: no exercise	24	NI x session; 2 x week	CG: Pre: 0.97 ± 0.14 Post: 0.96 ± 0.14	p = 0.85***
				EG: Pre: 1.00 ± 0.21 Post: 1.01 ± 0.20	p = 0.65**
(40)	EG: Aerobic 50 – 60% HRR + RT CG: no exercise	12	30-45 min x session; 3 x week	GC: Pre: 0.886 ± 0.091 Post: 0.892 ± 0.097	p = 0.89***
				EG: Pre: 0.918 ± 0.103 Post: 0.927 ± 0.090	p = 0.44**



Study/year	Intervention	Duration(weeks)	VT	BMD Total (g/cm <sup>2</sup> ± sd)	
(41)	EG: Aerobic 50 – 60% HRR + Drop Jump CG: no exercise	24	30-60 min x session; 3 x week	GC: Pre: 0.886 ± 0.091 Post: 0.892 ± 0.097	p = 0.89***
				EG: Pre: 0.918 ± 0.103 Post: 0.927 ± 0.098	p = 0.45**
(42)	EG: RT CG: no exercise	48	30 min x session; 3 x week	CG: Pre: 0.997 ± 0.02 Post: 0.979 ± 0.02	p = 0.01***
				EG: Pre: 1.007 ± 0.02 Post : 0.976 ± 0.02	p = 0.16**
(52)*	EG: Pilates CG: no exercise	12	NI x session; 2 x week	GC: Pre: 0.86 ± 0.01 Post: 0.90 ± 0.14	p = 0.38***
				GE: Pre: 0.90 ± 0.01 Post: 0.91 ± 0.12	p = 0.00001**
(43)	EG1: RT a 30% 1RM EG2: RT a 50% 1RM CG: no exercise	24	30 min x session; 3 x week	GC: Pre: 1.196 ± 0.1 Post: 1.187 ± 0.1	p = 0.80***
				EG1: Pre: 1.195 ± 0.1 Post: 1.189 ± 0.1	p = 0.97**
				EG2: Pre: 1.192 ± 0.1 Post: 1.182 ± 0.1	p = 0.90**
(53)	EG: Aerobic 60 – 80% HRR + RT CG: no exercise	24	NI x session; 3 x week	GC: Pre: 1.030 ± 0.068 Post: 1.027 ± 0.069	p = 0.88***
				EG: Pre: 1.016 ± 0.078 Post: 1.016 ± 0.077	p = 0.52**
(54)	EG: Aerobic 60% HRR CG: no exercise	12	60 min x session; 3 x week	GC: Pre: 1.030 ± 0.111 Post: 1.028 ± 0.109	p = 0.97***
				EG: Pre: 1.053 ± 0.078 Post: 1.057 ± 0.077	p = 0.59**

VT: Training Volume; EG: Experimental Group; CG: Control Group; BMD: Body Mineral Density; RT: Resistance Training; sd: standard deviation; HRR: Heart Rate Reserve; \*study not included in the meta-analysis because it showed a significant difference in initial total BMD between CG vs EG; \*\*significance level of initial total BMD between CG vs EG using the mean difference test between groups; \*\*\*significance level of the final total BMD of the CG.

cially if the participants are unhealthy and the duration of the exercise program extends far beyond what is necessary. However, even so, physical exercises were beneficial for this population because they functioned as a protective factor, preventing the loss of bone mass in the groups of participants who engaged in physical exercises (**table III**).

Another important point to be discussed was the fact that the study (37) was the only one to report a statistically significant, albeit very small, increase in total bone mineral density (SMD = 0.95 [0.25 to 1.65]<sup>a</sup> and 1.72 [0.89 to 2.55]<sup>b</sup> – **figure 1**), after a large amount (52 weeks in duration, 3 times per week) of physical exercise (**table III**). However, this is a very important finding, especially because the participants in this RCT were postmenopausal women, a situation favorable to bone loss (56).

The strengths of this meta-analysis are the low and significant heterogeneity, providing more validity to the found result; the number of studies directly reflecting the quantity of 237 participants in the exercise group and 209 participants in the control group, making the found result more precise; the absence of suspicion of publication bias; and the certainty of the moderate evidence found (**figure 1** and **table I**).

On the other hand, the main limitation of this meta-analysis was the high risk of bias presented by all 11 included studies, despite being randomized controlled trials. The common cause for high risk of bias was the lack of blinding of participants, those who administered the physical exercises, and those who assessed total bone mineral density (**figure 2**). Future RCTs intending to study the effect of physical exercises on total bone mineral density should reduce the risk of performance and detection bias by including blinding.

Despite the low clinical significance, the results of this meta-analysis may contribute scientifically to future studies on such an important subject as the gain of total bone mineral density in the elderly population, since engaging

in physical exercises has low cost and no side effects. The elderly population, estimated to represent 16% of the population by 2050 (57, 58), suffers greatly from falls and bone fractures (58).

## CONCLUSIONS

Up to this point, the practice of physical exercise has shown low efficacy and moderate certainty of evidence for increasing total bone mineral density in the older population.

Future studies using physical exercises with longer intervention time (2 years or more) and with greater weekly frequency (> 4 × per week) could cause significant improvements in BMD.

## FUNDINGS

None.

## DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

## CONTRIBUTIONS

DGL, RGSV: formal analysis, writing – original draft, final assessments, data curation, writing – review & editing. GCPSMS, ABMCM: sample selection, evaluation, interim reviews. CJB, EBS, BGL: writing – original draft, formal analysis.

## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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# Combined Effect of Core and Scapular Stabilization Exercises on Position of Scapula and Bowling Speed among Cricket Bowlers with Scapular Dyskinesia: A Pilot Study

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## LEVEL OF EVIDENCE: 2B

## SUMMARY

**Background and objective.** Scapular dyskinesia refers to the deviation in the normal positioning of the scapula. Its prevalence among cricket fast bowlers is estimated to be around 10%. The relationship between scapular and core stability is crucial, as weakness of scapular muscles which is the main cause for scapular dyskinesia, subsequently reduces core strength. This not only impacts bowling performance but is often overlooked in the management of scapular dyskinesia. So, the objective of this study is to investigate how a combination of core and scapular stabilization exercises influences both scapular position and bowling speed in cricket fast bowlers with scapular dyskinesia.

**Methods.** Twenty asymptomatic professional cricket fast bowlers with scapular dyskinesia, aged 18-25 years, volunteered to take part in the study. Participants were randomly assigned to two groups: GROUP A (Experimental Group) received a combination of core stability exercises and scapular stabilizing exercises, while GROUP B (Control Group) underwent scapular stabilizing exercises only. Bowling speed was quantified using a Radar Gun, and the scapular position was evaluated using the Lateral Scapular Slide test pre-treatment, 6<sup>th</sup>-week post-treatment, and follow-up at 10<sup>th</sup> week.

**Results and conclusions.** Cricket fast Bowlers who received combined core and scapular stability Exercises demonstrated significant improvement in Bowling speed (P-value < 0.001) and Lateral scapular slide test (p < 0.001) compared to the cricket fast bowlers who received only scapular stability exercises.

## KEY WORDS

*Scapular dyskinesia; core stability; scapular stability; bowling performance.*

## INTRODUCTION

Scapular Dyskinesia is characterized by changes in the scapula's position and the patterns of scapular motion in relation to the thoracic cage (1). The scapula serves as a pivotal

structure for transmitting substantial forces and high energy from the lower body and trunk, which are the primary sources of power and energy, to the arms and hands, which function as the means of delivering this energy and force.



The proper functioning of the scapula is highly reliant on the performance of the scapular muscles. Strong scapular muscles are a fundamental requirement to ensure optimal stability and effective movement of the scapulothoracic joint (2). Evidence suggests that a lack of strength in the muscles responsible for stabilizing the scapula can result in changes in the scapula's alignment relative to the thoracic rib cage and in the way it moves in relation to the thoracic cage. These alterations in scapular positioning and motion patterns are called scapular dyskinesis. Bowling in cricket involves intricate movements that demand coordination between the upper and lower limbs to deliver a ball with proper technique. Research indicates that the prevalence of Scapular Dyskinesis in cricket bowlers is 10% (3). Core stability is defined as the ability to control the position and movement of the trunk over the pelvis, enabling the efficient generation, transmission, and management of force and motion to the extremities during integrated athletic activities (4). Sporting activities like bowling demand synchronization between the upper and lower limbs. The core serves as the central connection between these two segments, and maintaining stability in this region is essential for achieving peak athletic performance and reducing the risk of injuries. A strong core enables an athlete to efficiently transmit the forces produced by the lower extremities, through the torso, and into the upper extremities. Conversely, a weak core is thought to impede energy transfer, potentially leading to decreased athletic performance and an increased risk of injury (5).

The effective control of the scapula relies on the strength of the core muscles, enabling athletes to coordinate the movement of both the lower and upper extremities harmoniously. Consequently, a lack of control in the scapular region may be interconnected with diminished control in the core muscles, which are responsible for stabilizing the extremities. So, it is crucial to focus on core stability when addressing scapular dyskinesis (6). Studies have also demonstrated a significantly higher EMG activity in the Scapular Muscle during Core Exercise (7). Scapular and core muscles play an important role in the transfer of energy and are required for optimal athletic performance and injury prevention. Scapular stabilization exercises, which involve a combination of stretching and strengthening, enhance both the strength of scapular muscles and the awareness of joint positioning. The serratus anterior and trapezius muscles function as stabilizers for the scapula. Specifically, the serratus anterior is crucial for influencing scapular external rotation and posterior tilt, while the lower trapezius contributes to stabilizing the scapula, the weakness of these muscles contributes to altered

scapular position (8-10). Previous studies (6) have shown that diminished scapular control in the scapular region is interconnected with diminished control in the core muscles, which are responsible for stabilizing the upper extremity. Substandard core stability increases the risk of athletes' upper limb injury and performance. So, the present study aims to find the Combined effect of Core and scapular stabilization exercises on the bowling Speed and Position of the scapula among cricket fast bowlers with scapular dyskinesis.

## METHODS

### Study population, recruitment, and eligibility criteria

The current study included twenty Cricket Fast bowlers with Scapular dyskinesis. Approval was obtained from the Institutional Ethics Committee (IEC) of RV College of Physiotherapy (Ref: RVCP/RESEARCH/283A – date of approval: 29 August, 2022). Permission from the authorities to carry out the study was obtained. An informed written consent from the subjects was obtained after explaining the purpose of the study. 20 Professional Cricket Fast Bowlers with Asymptomatic scapular dyskinesis aged between 18-25 years willing to participate were recruited. Cricket Fast bowlers with low back pain, Lower Limb radiating pain, shoulder pathology, neck pain, neurological problems, history of the spinal, upper limb, or lower limb surgeries, and referred pain were excluded. Procedures were explained to all the subjects and informed consent was obtained. Demographic data of the subjects such as age, height, and body mass index were measured and recorded. The subjects were screened for Scapular Dyskinesis using the Scapular Dyskinesis test.

The Scapular Dyskinesis Test commenced with participants positioning their arms alongside their bodies, elbows extended, and shoulders in a neutral rotation. Participants were instructed to smoothly raise their arms overhead, adopting a “thumbs-up” position, maintaining the elevation for a 3-second count, followed by a controlled descent to a 3-second count (11). Subsequently, the test was repeated with participants holding dumbbells corresponding to their body weight: 1.4 kg (3 lb) for those weighing less than 68.1 kg (150 lb) and 2.3 kg (5 lb) for those weighing 68.1 kg or more. Any deviation from the normal scapular position was carefully observed and documented. The evaluation of Scapular Dyskinesis involved categorizing it as normal, subtle Dyskinesis, or obvious Dyskinesis based on the

observed outcomes of the Scapular Dyskinesis Test. Cricket bowlers with subtle and Obvious categories were included in the study. Cricket fast bowlers with scapular dyskinesis were randomly divided into two groups (Group A and Group B) each consisting 10 cricket fast bowlers using a Random number Generator application.

### Randomization and blinding

A computer-generated sequence of random numbers was employed for the randomization process which randomly assigned participants to either of the two therapies. Throughout the study, this sequence was meticulously recorded in a securely password-protected Excel table and maintained confidential from collaborators.

While group allocation to physical therapists or participants was not concealed, this was attributed to the inherent dissimilarities in the exercise programs. However, to ensure objectivity, outcome assessors and data analysts remained unaware of treatment allocations. They were not involved in participant recruitment, treatment assignment, or intervention administration. Participants were explicitly instructed not to disclose details of their intervention to outcome assessors, thus upholding the blinding protocol. Both the groups were assessed for Bowling speed by Radar Gun and Scapular dyskinesis (Position of the scapula) by lateral scapular glide test on Day 1 (Pre-Intervention), 6<sup>th</sup> Week (Post-intervention), and 10<sup>th</sup> Week (follow-up)

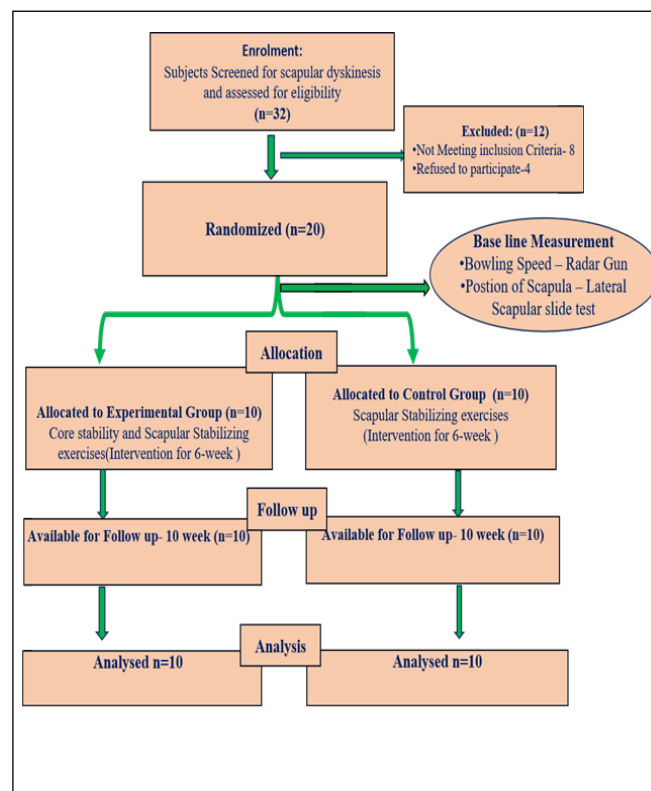
Bowling speed was assessed with a Radar Speed Gun positioned behind the nets at the batting end, aligned with the approximate height of the ball release and in line with the stumps placed at the batting end. Participants were instructed to bowl in their natural actions in the nets, aiming to deliver the ball as swiftly as possible towards the stumps. Each participant bowled three balls, and the resulting bowling speeds were measured. The averages of these three measurements were then recorded (12).

Lateral Scapular slide test included measurements from the inferior angle of the scapulae to the spinous process of the thoracic vertebrae, all on the same horizontal plane, in three distinct positions:

- In Position 1, the shoulder is maintained in a neutral position, with the arms resting comfortably at the sides.
- Transitioning to Position 2 involves medial rotation of the humerus and a 45-degree abduction, achieved by placing the patient's hands around the waist.
- In Position 3, the humerus is subjected to maximal medial rotation, combined with a 90-degree abduction (13). The differences between both sides in all 3 test positions were documented

GROUP A (Experimental Group) received core stability exercises and scapular stabilizing exercises and GROUP B (Control Group) received only scapular stabilizing exercises. Core Stability exercises included Abdominal 'tuck in' in the crook lying position, Abdominal 'tuck in' in sitting position with tactile cue on back, Abdominal 'tuck in' in a quadruped position, Bridging on the floor without leg extension, Bird dog exercise in a quadruped position, Planks, Abdominal crunches on the floor (hands behind head), Back bridging on the Swiss ball without leg rise, Wall squat with a Swiss ball, Abdominal crunches on Swiss ball (hands over chest) Back bridging on a Swiss ball with leg raise. Scapular Stability Exercises included Scapular clock exercises, Wall washes, corner stretch- sleeper stretch, lawn-mover and robbery maneuver, Black burn retraction, Alternating punches with TheraBand in diagonal, upward, and downward directions, scapular push-ups and Low row exercises, TheraBand Exercises- Scaption, standing boxer punch, standing dynamic hug, Bilateral external rotation with abduction 0 degrees, rowing exercises.

All the exercises were performed with a Frequency of 4 times/weeks for 6 weeks. Three sets for each exercise with



**Figure 1.** Flow chart showing the methodology.

10 repetitions in each set and intermittent rest in between. At the 10<sup>th</sup> week follow-up was done (**figure 1**).

### Statistical analysis

The data was analyzed using descriptive statistics and inferential statistics:

- Descriptive statistics - The quantitative variables are described by the means of descriptive statistics like mean, median, and standard deviation with standard error of the mean and 95% confidence interval for the mean. Wherever necessary the results are presented graphically.
- Inferential statistics – Repeated measures of ANOVA are applied within the Group. Students Unpaired t-test is applied to test the difference in means between groups.

## RESULTS

Results are reported in **tables I-III** and **figures 2-5**.

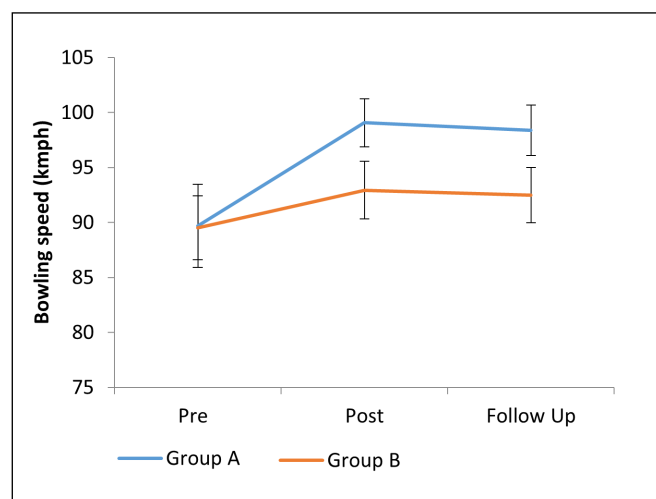
## DISCUSSION

This study compared the combined effectiveness of core stability exercises and scapular stabilization exercises *versus* scapular stability exercises alone on Bowling speed and position of the scapula in cricket fast bowlers with scapular dyskinesis. The findings revealed that the combined program resulted in more substantial improvements in both bowling speed and scapular position compared to the group that only received scapular stabilization exercises.

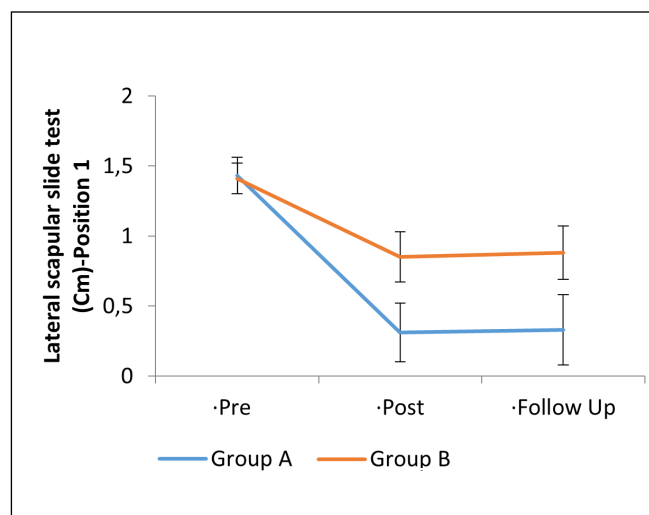
The scapula plays a critical role in ensuring optimal shoulder function, where its anatomy and biomechanics work together to produce efficient movement. Normally, the scapula serves as a stable foundation, allowing for proper glenohumeral mobility. The stability of the scapulothoracic joint is largely dependent on the surrounding muscles, which must dynamically position the glenoid for efficient glenohumeral movement. However, when there is weakness or dysfunction in the scapular muscles, normal scapular positioning and mechanics can become compro-

**Table I.** Comparison of baseline clinical variables (Age, height, weight, and BMI among the experimental and control group).

Variables	Experimental Group	Control Group	Total	P-value
Age in years	20.2 ± 2.1	20 ± 1.89	20.1 ± 1.94	0.825
Height(m)	1.77 ± 0.04	1.77 ± 0.04	1.77 ± 0.04	0.795
Weight (kg)	70.78 ± 2.88	71.38 ± 2.53	71.08 ± 2.66	0.627
BMI	22.53 ± 1.56	22.82 ± 0.78	22.67 ± 1.21	0.617



**Figure 2.** Bowling speed (kmph): comparison within and between experimental and control



**Figure 3.** Lateral scapular slide test (cm): comparison within and between experimental and control group in position 1.

**Table II.** Bowling speed (kmph): comparison within and between experimental and control group.

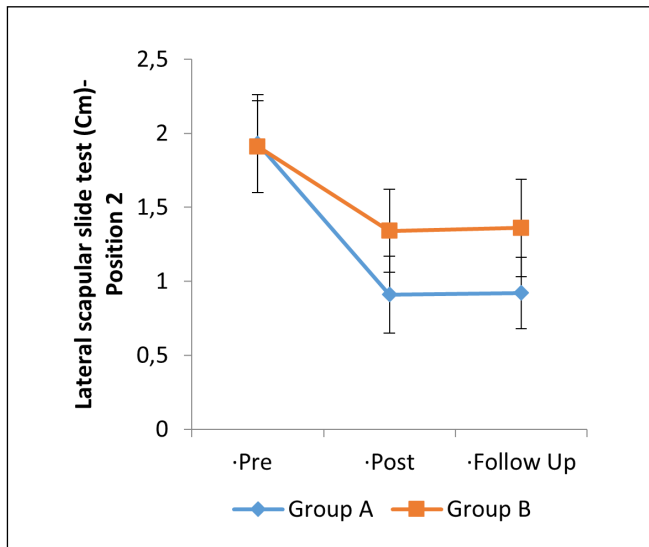
Variables	Experimental Group	Control Group	Total	P-value
Pre	89.68 ± 3.77	89.51 ± 2.92	89.59 ± 3.28	0.915
Post	99.07 ± 2.18	92.93 ± 2.62	96 ± 3.93	< 0.001**
Follow Up	98.38 ± 2.31	92.48 ± 2.52	95.43 ± 3.83	< 0.001**
Repeated Measures F	183.69	39.078	59.435	-
P-value	< 0.001**	< 0.001**	< 0.001**	-

\*\*Statistically significant.

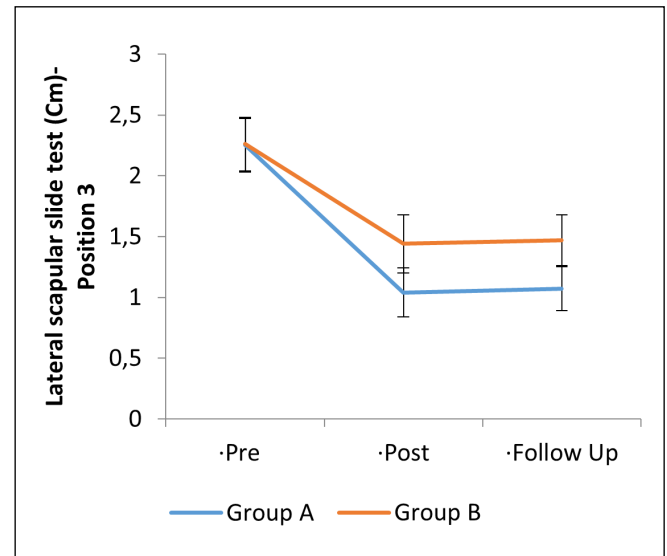
**Table III.** Lateral scapular slide test (cm): comparison within and between experimental and control group.

Lateral scapular slide test (Cm)	Group A	Group B	Total	P-value
Position 1				
Pre	1.43 ± 0.13	1.41 ± 0.11	1.42 ± 0.12	0.719
Post	0.31 ± 0.21	0.85 ± 0.18	0.58 ± 0.33	< 0.001**
Follow Up	0.33 ± 0.25	0.88 ± 0.19	0.61 ± 0.35	< 0.001**
Repeated Measures F	254.394	59.148	104.762	-
P-value	< 0.001**	< 0.001**	< 0.001**	-
Position 2				
Pre	1.93 ± 0.33	1.91 ± 0.31	1.92 ± 0.31	0.890
Post	0.91 ± 0.26	1.34 ± 0.28	1.13 ± 0.34	0.002**
Follow Up	0.92 ± 0.24	1.36 ± 0.33	1.14 ± 0.36	0.003**
Repeated Measures F	92.082	147.911	105.540	-
P-value	< 0.001**	< 0.001**	< 0.001**	-
Position 3				
Pre	2.25 ± 0.22	2.26 ± 0.22	2.26 ± 0.21	0.920
Post	1.04 ± 0.2	1.44 ± 0.24	1.24 ± 0.29	< 0.001**
Follow Up	1.07 ± 0.18	1.47 ± 0.21	1.27 ± 0.28	< 0.001**
Repeated Measures F	236.801	152.436	225.471	-
P-value	< 0.001**	< 0.001**	< 0.001**	-

\*\*Statistically significant.



**Figure 4.** Lateral scapular slide test (cm): comparison within and between experimental and control group in position 2.



**Figure 5.** Lateral scapular slide test (cm): comparison within and between experimental and control group in position 3.

mised. This failure in scapular stabilization can lead to inefficient shoulder function, decreased neuromuscular performance, and an increased risk of shoulder injury. Scapular dyskinesia is thought to be more prevalent among overhead athletes due to their heavy reliance on unilateral upper extremity function (14).

In a systematic review by Matthew *et al.*, twelve studies involving 1,401 athletes (1,257 overhead and 144 non-overhead; average age  $24.4 \pm 7.1$  years; 78% male) were analyzed. The review found that scapular dyskinesia was more common in overhead athletes, with a prevalence of 61%, compared to 33% in non-overhead athletes (15).

In the study by Sathya *et al.*, the scapular position in cricket bowlers without shoulder issues was evaluated using the Modified Lateral Scapular Slide Test. The findings indicated that abnormal lateral displacement of the scapula was more commonly observed in the unloaded Scaption position among pace bowlers (16).

Similarly, in Surbhi Abhange *et al.*'s study on the "Prevalence of Scapular Dyskinesia Among Cricket Bowlers," 30 male cricket bowlers aged 18 to 35 years, each with at least two years of bowling experience, were assessed for scapular dyskinesia using the Scapular Dyskinesia Test. The study found that 10% of the fast bowlers exhibited scapular dyskinesia (17).

Scapular dyskinesia has the potential to disrupt shoulder mechanics, impacting the efficiency of force generation and

transmission throughout the bowling motion. This alteration in mechanics can impair the coordination and timing of shoulder movements, which are crucial elements for achieving Bowling speed.

Several studies, conducted by multiple researchers (18), have explored the effectiveness of rehabilitation programs centered around scapular stabilization to mitigate and manage such concerns. For instance, De Mey *et al.* (19) research unveiled that a six-week training regimen resulted in significant improvements in the activation of scapular muscles among overhead athletes, consequently enhancing their performance.

Moreover, Neeraj Singh and Pragma's (20) studies demonstrated that scapular stabilizing exercises contributed to enhanced throwing performance among baseball players exhibiting signs of scapular dyskinesia

A study by Elif Turgut (21) demonstrated improvement in scapular kinematics following scapular stabilization exercise. Pradeep Shankar's (22) study highlighted the effectiveness of a scapula stabilization exercise protocol in addressing Scapular type-2 Dyskinesia, as assessed through the lateral scapular slide test.

All these studies demonstrated the effect of scapular stabilizing exercises among different overhead athletes in improving their athletic performance which supports the current study stating the control group who received scapular stability exercises improved bowling speed and position of the scapula.



However, the current study not only showcased the efficacy of scapular stability exercises in ameliorating scapular dyskinesis and enhancing bowling speed, thereby contributing to improved overall performance but highlighted that incorporating core stability exercises alongside scapular stability exercises resulted in superior improvements in scapular dyskinesis and bowling speed compared to focusing solely on scapular stabilization.

Core stability refers to the ability to control the position and motion of the trunk in coordination with the pelvis and lower extremities. This enables the core to generate, transfer, and regulate force and motion to the distal segments (23). Dynamic stability of the spine involves the functional utilization of muscular strength and endurance to effectively control the spine during activities that are both functional and athletic (24). Enhanced core stability has been scientifically demonstrated to support optimal body mechanics, enabling athletes to maximize the generation of force while minimizing the stress placed on proximal joints (4). Considering the significance of kinetic chain principles in everyday activities and especially during intricate sports movements like bowling adaptations in the scapulothoracic joint may influence core muscle strength and movement quality within the kinetic chain, consequently impacting the outcome. The stability of both scapular and core muscles is linked to both injury risk and performance. Additionally, there is a mutual influence between scapular and core muscle endurance. In a prior study conducted by Gamze Cobanoglu *et al.* (25), it was discovered that core muscle endurance exhibited a positive correlation with scapular muscle endurance indicating weak scapular muscle can influence core muscle strength. Shuang Qin Etal (26) study demonstrated combined core stability training and scapular muscle training over five weeks helped improve the scapular muscle activation, scapular muscle balance ratios during shoulder movement, and the function overhead athletes with scapular dyskinesis.

Combined core and scapular stability had a significant effect and the mechanism could be due to the thoracolumbar fascia which covers the trunk like a band. The thoracolumbar fascia serves as a vital connection between the lower and upper extremities, bridging the superior/inferior and right/left components of the kinetic chain (27). Comprising anterior, middle, and posterior layers, the superficial lamina of the posterior layer originates from the latissimus dorsi muscle, while the transversus abdominis extensively attaches to the middle and posterior layers (28). Progressing posterior-

ly, the superficial lamina forms a fascial cover containing key muscle groups such as pectoralis major and minor, rhomboideus major and minor, trapezius, and serratus anterior. Continuing towards the caudal end, it extends to the latissimus dorsi and gluteus maximus (17, 29). These layers play crucial biomechanical roles as mediators in load and energy transfer between the upper and lower extremities and the abdominal wall and lumbopelvic region (30).

Studies emphasizing muscle activation patterns during sporting activities have underscored the significance of core stability. It has been observed that, in response to swift arm movements, muscle activation patterns initiate in the lower extremity, progress through the trunk, and extend to the arm (31). This sequential force development, starting from the ground through the core to the extremities, has been demonstrated in sports like tennis (32).

Enhanced core stability not only contributes to increased scapular muscle stability but also reduces the risk of shoulder injuries. This, in turn, ensures normal functioning of the upper extremity and enhances the performance of bowlers. To mitigate injury risks and optimize performance, integrating both core and scapular stabilizing exercises is imperative for cricket bowlers dealing with scapular dyskinesis.

## CONCLUSIONS

The optimal function of the scapula, scapulothoracic muscles, and core muscles collectively play a pivotal role in the overall functionality of the upper extremity. Effective scapular control relies on the strength of the core muscles, enabling athletes to synchronize the movement of the lower and upper extremities. Consequently, a lack of control in the scapular region may be linked to a deficiency in core stability, responsible for stabilizing the extremities. In the kinematics of bowling, the force generated from the legs and trunk is transferred to the upper extremity through the scapula. Weakening of the scapular muscles alters the core strength, thereby influencing the biomechanics of the upper extremity. This alteration results in excessive stress and forces being applied to both proximal and distal components within the kinetic chain. The current study illustrated that incorporating combined core and scapular stability exercises led to a significant improvement in bowling speed and a reduction in scapular dyskinesis compared to relying solely on scapular stability exercises.

## FUNDINGS

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## DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

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## CONTRIBUTIONS

PD: conceptualization, methodology, writing – original draft. SP: writing – review & editing, supervision.

## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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# Acute Capsaicin Supplementation may not Be Effective in Improving the Physical and Cognitive Performance of Taekwondo Athletes and Para Athletes

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## SUMMARY

**Purpose.** The present study aimed to investigate the acute effect of capsaicin supplementation on Taekwondo performance.

**Methods.** This was a crossover, double-blind, placebo-controlled study that evaluated 13 Taekwondo athletes ( $24.8 \pm 10.6$  years;  $64.5 \pm 10.9$  kg;  $171 \pm 9.16$  cm), male ( $n = 10$ ) and female ( $n = 3$ ), athletes ( $n = 8$ ) and para athletes ( $n = 5$ ). The volunteers performed two experimental supplementation conditions: capsaicin (CAP) (12 mg) or Placebo (PLA). Performance evaluation included the frequency of kick test multiple series (FSKTMult), countermovement jump (CMJ), and Stroop test. The relative perception effort during the tests (RPEtest) and after the sessions (RPEsession), as well as capillary lactate concentration and blood glucose, were also recorded.

**Results.** No significant differences were found between the experimental conditions in the FSKTMult test (CAP:  $265.46 \pm 21.85$ ; PLA:  $262.31 \pm 22.96$ ;  $p = 0.413$ ); CMJ (CAP:  $37.25 \pm 10.31$  cm; PLA:  $36.97 \pm 10.86$  cm;  $p = 0.761$ ), and Stroop Test (Stroop test 1: CAP:  $978.73 \pm 185.43$  ms; PLA:  $950.02 \pm 174.82$  ms; Stroop test 2: CAP:  $881.16 \pm 212.74$  ms; PLA:  $813.75 \pm 155.04$  ms;  $p = 0.490$ ). No significant differences were also found between the experimental conditions in the results of the RPEtest, RPEsession, lactate concentration, and blood glucose ( $p > 0.05$ ).

**Conclusions.** Acute capsaicin supplementation may not be effective in improving the physical and cognitive performance of Taekwondo athletes and para athletes.

## KEY WORDS

*Ergogenic aids; nutrition; martial arts; TRPV cation channels; sports.*

## INTRODUCTION

Capsaicin, a substance found in peppers, may be effective in enhancing physical performance, particularly related to strength resistance and reducing perceived exer-

tion (1, 2). In humans, there is evidence that capsaicin can improve performance in running (3, 4), resistance training (5, 6), concurrent training protocols (7), and CrossFit (8). Da Silva *et al.* (9) reported that capsaicin increased power

performance of JiuJitsu athletes in the bench press exercise. Thornton *et al.* (10) suggest that capsaicin supplementation may enhance cognitive function.

The primary mechanism of action of capsaicin is through the activation of the transient receptor potential vanilloid 1 (TRPV1), present in the sarcoplasmic reticulum of skeletal muscles (11), in the central nervous system, in myelinated nerve fibers, and non-myelinated nociceptors (1, 12). The potential ergogenic effect of capsaicin is thought to occur via increased and sustained release of calcium ions ( $\text{Ca}^{2+}$ ) by the sarcoplasmic reticulum, thereby sustaining muscle contraction for a longer period and enhancing strength resistance (5, 6). Furthermore, capsaicin may increase pain and discomfort thresholds, leading to a reduction in perceived exertion (2, 5), mainly through the saturation of capsaicin-sensitive afferent neurons, which can induce a desensitization response of nociceptors (1). Additionally, by activating TRPV1 receptors in the central nervous system (CNS), capsaicin may trigger the release of neurotransmitters in the prefrontal cortex, which can directly influence cognitive performance and improve decision-making (13). Taekwondo is a sport characterized by intermittent demands that must be sustained for several minutes during training sessions and competitions (14). Therefore, optimal development of various physical aptitudes is required for competitive success, particularly related to overall endurance, strength, and the ability to react to stimuli and make decisions (15, 16). Given the potential positive effects of capsaicin supplementation to increase strength resistance, reduce perceived exertion (1), and potentially influence cognitive aspects (13), Taekwondo athletes may benefit from this ergogenic aid in training and competition. Therefore, the present study aimed to investigate the acute effect of capsaicin supplementation on Taekwondo performance. We hypothesized that capsaicin would enhance physical and cognitive performance in Taekwondo.

## METHODS

### Study design

This was a crossover, double-blind, placebo-controlled study. Data were collected over four experimental sessions, which took place during a period of three weeks. Familiarization was conducted in two sessions during the first week. In the subsequent two weeks, the experimental sessions were carried out with a one-week interval between them. Volunteers were instructed not to engage in physical activity or strenuous exercise twenty-four hours before the experi-

mental sessions to ensure recovery and minimize the interference of weekly training loads on test results.

In the first experimental session, sample characterization and familiarization with the Stroop test (17) were conducted. Additionally, 48 hours after the initial familiarization session, the Stroop Test protocol was repeated to assess the reliability of this measure. Sample characterization included recording body mass, body fat percentage, height, and a 24-hour dietary recall. In the subsequent experimental sessions, supplementation protocols and performance tests were conducted, with volunteers consuming either capsaicin (CAP) or placebo (PLA). The distribution of participants was counterbalanced, with the order of treatments randomly assigned.

The tests performed were Frequency Speed of Kick Test Multiple series (FSKTMult), countermovement jump (CMJ) (18), and the Stroop test (19). At the beginning of the supplementation and performance test sessions, data from the perceived recovery scale (PRS) were collected to assess the volunteers' recovery status (20). Additionally, capillary serum lactate and glucose concentration were recorded before (pre-test) and after (post-test) the sessions.

To minimize potential influences of variations in participants' diet, dietary recalls were conducted before each experimental session. Volunteers were instructed to maintain their usual dietary patterns throughout the study and replicate the meal before each experimental session. If the intake of macronutrients (carbohydrates, lipids, proteins) and energy showed a variation of 5% or more, positive or negative, between sessions, the volunteer would be excluded. No volunteer was excluded. Nutritional analysis was performed using the Diet-Box® application (version 6.8.3, Brazil) (21).

### Participants

Thirteen Taekwondo athletes ( $n = 8$ ) and para athletes ( $n = 5$ ) ( $24.8 \pm 10.6$  years old,  $64.5 \pm 10.9$  kg;  $171 \pm 9.16$  cm) of both sexes (males  $n = 10$ ; females  $n = 3$ ) participated in the study. The para athletes were classified into the K44 competitive category (athletes with unilateral amputation from the knee to the hand joint, unilateral dysmelia, monoplegia, hemiplegia light and size difference in the lower limbs) (22). All participants were black belts and experienced in international competitions.

The sample size was defined a priori based on the study by Freitas *et al.*, (5), the effect size of 0.84 was adopted, referring to the effect of capsaicin supplementation on the strength resistance (total volume). A power of 0.8 and alpha of 0.05 were considered. Using the Gpower software (version 3.1), a sample size of 13 volunteers was obtained. Participants were recruited through the promotion of the



research in Taekwondo training centers, research institutions, and social media platforms.

The inclusion criteria were as follows: not being a smoker or allergic to pepper, being a Taekwondo athlete of at least 14 years old, not having experienced any type of joint and/or muscle injury in the lower limbs in the six months prior to the start of the study, not being users of nutritional and pharmacological ergogenic aids, and not presenting a potential health risk after responding the Physical Activity Readiness Questionnaire (PAR-Q). Volunteers would be excluded if they incurred injuries during the study or had any conditions that could interfere with the testing protocol. No participants were excluded from the present study.

### Ethical care

All procedures and the purpose of the study were explained to the volunteers, as well as the possible risks and benefits. This research complied with the legislation of the National Health Council - Brazil (Res 466/2012). The present study was approved by the Ethics and Research Committee of the Federal University of Minas Gerais (protocol number: 5.765.153 – date of approval: November 19, 2022). All participants signed the informed consent form.

### Procedures

The protocols of the familiarization with the countermovement jump (CMJ) and FSKTmult tests were the same as those adopted by Silva *et al.* (18). In the Stroop Test familiarization sessions, volunteers performed the test six times, to minimize the learning effect. After the familiarization sessions, the results obtained in the first and second sessions of each test were compared. If there was a significant difference, a third session would be held 48 hours later. It was not necessary to perform an additional familiarization session. Performance in the tests of the two sessions was used to determine the intraclass correlation coefficient (ICC) and the Standard Error of Measurement (SEM) (23).

Capsaicin (Manipulatta Compounding Pharmacy, Brazil) supplementation dose was 12 mg, as it was the same dose adopted in studies that identified the effectiveness of this substance in improving performance (3-5, 7), without occurrences of side effects (21). The Placebo capsule contained 50 mg of starch, being identical to the Capsaicin capsules. The distribution of volunteers was random by draw, but it was ensured that the number of participants in both situations was the same. The capsules were ingested 45 minutes before the experimental session, as capsaicin has its peak concentration after this time, when ingested (1,7).

The FSKTmult test was adopted in the present study as

a specific physical test for Taekwondo (18, 24, 25). To maximize the similarity of the study protocol with actual combats, three rounds of FSKTmult were conducted, with a one-minute interval between each round. The protocol was the same as that adopted by Silva *et al.* (18). The variables analyzed included the number of kicks applied in each series, the total number of kicks, and the fatigue index. The fatigue index was calculated using the following equation (26):  $Fatigue\ index\ (\%) = 1 - [(FSKTmult\ total\ kicks) / (best\ FSKT \times number\ of\ sets)] \times 100$ .

The FSKTmult tests were filmed, and the Kinovea video analysis software (Kinovea® version 0.8.15) was used to count the number of kicks. The counting started when the athlete initiated the attacking foot movement and ended when they contacted the Boomboxe® (26). Only kicks that reached the target within 10 seconds were considered valid (kicks that started within 10 seconds but contacted the Boomboxe® after 10 seconds were not counted) (26).

The CMJ was adopted as a test of general physical performance (18). The data analyzed from the CMJ test included the variables of jump height, maximum relative power, and mean relative power (W/kg) (27). The CMJ technique in the present study was the same as that adopted by Silva *et al.* (18). The Stroop Test was adopted in the present study as a general cognitive test to observe the effect of executive function and its usefulness was to measure the response time to a visual stimulus (reaction time) (17). The test presents a non-sequential series of color names printed in different colors (yellow, white, red and orange, on a black background). It evaluates the level of color interference, since the volunteer must name the color of the font instead of reading the written color name, which will always be incongruous. This test comprises 25 stimuli. This test was presented to the athletes on a notebook, programmed in HTML format (28), and was carried out between the FSKTmult series, with the test carried out between the first and second series of the FSKTmult being classified as Stroop test 1. FSKTmult, and Stroop test 2 between the second and third series of FSKTmult. Each Stroop Test battery lasted 50 seconds. In this test, only the time taken to react to the visual stimulus was calculated (18, 29).

The relative perception of effort (RPE) was recorded using the Borg Scale (30), modified by Foster *et al.* (31). RPE was recorded immediately after the end of each round of the FSKTmult (RPEtest) (32). The RPE in relation to the entire session (RPEsession) was recorded 30 minutes after the completion of the three rounds of the FSKTmult. Each athlete reported a value on the scale, related to the effort perceived in the training session (18). This measure allowed recording the general perception of effort relative to the test

session in its entirety, being determined at rest, as a form of recall. This can minimize biases in identifying the level of effort immediately after completing the task, which can be influenced by discomfort and momentary fatigue. The RPEsession was calculated based on the equation by Foster *et al.* (31) ( $RPE_{session} = RPE (CR-10) \times training\ duration\ (minutes)$ ).

Due to the possible metabolic changes caused by ingesting capsaicin (2, 5), a comparison was made between the blood lactate and blood glucose concentrations, pre- and post-test (24, 33). Before the experimental supplementation and testing sessions, volunteers remained at rest for 10 minutes so that capillary blood glucose levels and pre-test serum lactate concentrations could be collected. At the end of the FSKTmult (after the 3<sup>rd</sup> round), after an interval of approximately one minute the blood glucose and post-test serum lactate concentration were measured. Such procedures were the same as those adopted by Silva *et al.* (18). To performance these procedures, were used a FreeStyle Optium Neo glucometer (Abbott Laboratórios do Brasil Ltda) and an Accutrend Plus lactimeter (Roche Diagnostics Ltda, Brazil).

The Perceived Recovery Scale (PRS) was proposed to monitor the recovery status of athletes (20). In this tool, the athlete indicates what their recovery status is in relation to the previous training session. The evaluator instructed the participant to choose a descriptor and then a number from 0 to 10. The maximum value (10) must be compared to fully recovered and the minimum value (0) is the not recovered condition (18).

### Statistical analysis

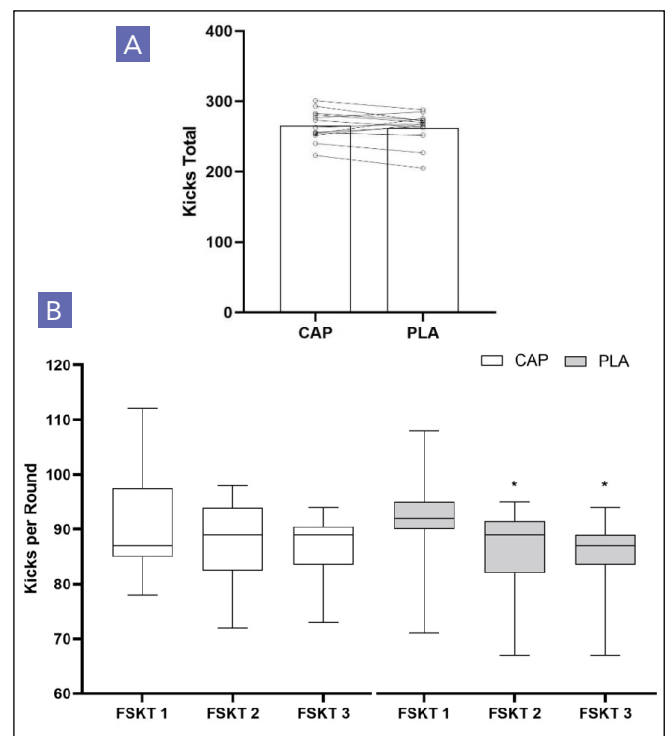
Data normality was checked using the Shapiro-Wilk test. To verify the stabilization of Stroop test performance, in the familiarization sessions, a paired student test was used. To verify the relative reliability of the Stroop test, the two-way mixed intraclass surface coefficient was used. A paired student t-test or Wilcoxon test (when data is not normally distributed) were used to compare the number of total kicks, jump height, mean relative power, maximum power, PRS between treatments. Two-way ANOVA for repeated measures analyzing fixed factors (Treatment and Time) was used to analyze the results on the number of kicks per round, fatigue index, Stroop test, RPE, blood glucose and lactate, under the proposed experimental conditions. Bonferroni post-hoc was used to identify where differences exist, when necessary. To compare the means of the dietary profile at the beginning and end of the experimental intervention, the paired student t-test was used. For all statistical analyses was adopted  $p < 0.05$ . For all variables, the effect size was evaluated using Cohen's  $d$ , which presents the classifications small (0.2-0.3), medium (0.5-0.8) and large (greater than 0.

8) (34). The JAMOVI software (version 2.3.26) was used for statistical analyses and the GraphPad Prism software (version 9.5.1) was used to produce the graphs. A descriptive analysis of the data was also carried out.

## RESULTS

Lactate concentration, jump height, maximum power, mean power, fatigue index of the adapted FSKTmult, Stroop Test and RPEsession showed normal data distribution. PRS, RPEtest; blood glucose, and the mean total number of kicks in the FSKT showed a non-normal distribution.

No significant differences between treatments were shown for the total number of kicks (CAP:  $265.46 \pm 21.85$ ; PLA:  $262.31 \pm 22.96$ ; 95%CI -11.27, 4.964; SEM: 3.725;  $p = 0.1833$ ;  $d = 0.14$ ; **figure 1A**). Also, no significant difference was identified in the number of kicks applied in each round, when comparing CAP (FSKT1:  $91.08 \pm 9.85$ ; FSKT2:  $87.54 \pm 7.38$ ; FSKT3:  $86.85 \pm 5.67$ ) and PLA (FSKT1:  $91.00 \pm 8.78$ ; FSKT2:  $86.46 \pm 7.90$ ; FSKT3:  $84.85 \pm 7.54$ ) (95%CI -4.996, 7.099; SEM: 2.930;  $p = 0.99$ ;  $d = 0.129$ ). However, in the PLA



**Figure 1.** Frequency speed of kick test multiple series for CAP and PLA.

CAP: capsaicin; PLA: Placebo; FSKTmult: Frequency speed of kick test multiple series; \*significant difference compare with FSKT1.

condition the number of kicks performed in the FSKT1 was significantly greater than that performed in the FSKT2 ( $p = 0.017$ ) and FSKT3 ( $p = 0.0032$ ) (**figure 1B**). There was no significant difference between the Fatigue Index values for the CAP ( $7.623 \pm 4.015\%$ ) and PLA ( $7.704 \pm 3.969\%$ ) conditions ( $95\%CI -2.457, 2.295$ ;  $SEM = 1.151$ ;  $p = 0.99$ ;  $d = 0.02$ ). When analyzing jump height, maximum relative power, mean relative power, and Stroop test, no significant differences were found between the experimental conditions. However, in comparison between Stroop Test 1 and Stroop Test 2, there was a significant difference in both experimental conditions ( $95\%CI 72.90, 160.90$ ;  $p = 0.0001$ ;  $d = 0.25$ ). Additionally, there was no significant difference in PRS, RPE, RPE session, and lactate concentrations. Regarding blood glucose, the pre-test and post-test moments also did not show a significant difference between CAP and PLA. However, when analyzing the time factor, there was a significant difference, with higher blood glucose values reported for the PLA condition when comparing the pre-test and post-test moments ( $p = 0.013$ ;  $d = -0.21$ ). **Table I** shows these results.

## DISCUSSION

The present study aimed to investigate the possible acute effects of capsaicin supplementation on the performance of Taekwondo athletes and para athletes. The results showed there was no significant difference between the experimental conditions, when comparing the physical and cognitive performance variables. Therefore, the results of this study refute the hypothesis that capsaicin could acutely increase performance in Taekwondo.

The variables analyzed in the specific FSKTmult test (number of total kicks, number of kicks per block and fatigue index) showed no difference, with a trivial effect size in all of them. These findings are similar to other studies, which also did not find an increase in physical performance with acute capsaicin supplementation (8, 9, 21, 35-37). However, other studies concluded that acute capsaicin supplementation was effective in improving performance in 400 m, 1,500 m and 3,000 m running (3, 4), and strength performance (5, 38). The positive effects of capsaicin supplementation are attributed to the possible increase in  $Ca^{2+}$  concentration

**Table I.** Mechanical and psychobiological variables.

	CAP	PLA	95%CI	P-value	Cohen d
Jump Height(cm)	37.25 $\pm$ 10.31	36.97 $\pm$ 10.86	-0.436, 0.655	0.347	0.11
Max Power(W/kg)	23.83 $\pm$ 6.35	23.68 $\pm$ 6.70	-0.396, 0.698	0.295	0.15
Med Power(W/kg)	10.55 $\pm$ 3.45	10.55 $\pm$ 3.59	-0.497, 0.590	0.433	0.04
Stroop 1(m/s)	978.73 $\pm$ 185.43	950.02 $\pm$ 174.82	-93.56, 189.7	0.490	0.30
Stroop 2(m/s)	881.16 $\pm$ 212.74	813.75 $\pm$ 155.04			
RPEsession	155 $\pm$ 52.4	154 $\pm$ 62.6	-21.4, 24.8	0.876	0.04
RPEtest	6.54 $\pm$ 2.48	6.54 $\pm$ 2.52	-1.94, 1.94	0.999	0.00
LAC			-1.308, 2.054	0.979	0.07
LAC pre(mmol/L)	2.25 $\pm$ 0.93	1.90 $\pm$ 0.55			
LAC post(mmol/L)	10.32 $\pm$ 3.73	9.92 $\pm$ 4.09			
BG			10.15, 7.92	0.995	0.11
BG pre	98.62 $\pm$ 11.77	96.77 $\pm$ 7.38			
BG post	109.62 $\pm$ 21.29	113.69 $\pm$ 16.70			
PRS	7.38 $\pm$ 2.26	8.00 $\pm$ 1.78	-3.00, 5.80	0.152	-0.56

CAP: capsaicin; PLA: placebo; Max Power: maximum relative power; Med Power: mean relative power; RPE: Rate of Perceived Exertion; LAC: lactate concentration; BG: blood glucose; PRS: perceived recovery scale.

in the sarcoplasm and the possible analgesic effect of this substance (1, 2, 5).

However, the possible positive effects expected from acute capsaicin supplementation were not effective in improving Taekwondo performance, suggesting a specificity of the response in relation to the demand characteristic. No other studies were found that investigated capsaicin supplementation in Tekwondo or that compared the effectiveness in different modalities, which indicates the need for studies with these objectives. Also, Simões *et al.* (21) suggest that the response to supplementation is individual (39, 40) and for trained individuals, a higher dosage of the supplement is necessary. Other studies with animals indicated that the effect of capsaicin may be dose dependent (41-43). Therefore, studies with humans are needed to investigate and compare different doses of acute capsaicin supplementation, especially with doses related to the individuals' body mass.

The results of the present study showed no differences in the variables analyzed in CMJ, indicating that capsaicin supplementation was not effective in improving general physical performance. However, the literature presents evidence contrary to the present study. Da Silva *et al.* (9) investigated acute capsaicin supplementation in JiuJitsu fighters, when performing the bench press exercise, using the same dosage as in the present study (12 mg). The results show an increase in power production, one of the variables analyzed in the present study, through the CMJ. The authors hypothesized that the effectiveness of capsaicin to increase power was due to a possible sympathetic modulation that causes the release of acetylcholine in the presynaptic cleft (1). In the present study, volunteers performed CMJ, an exercise that also assesses power and uses the ATP and phosphocreatine (PCr) systems primarily, and no evidence was found that corroborates the study by Silva *et al.* (9). Once again, a possible explanation for the difference in study results would be individual variation in response to supplementation (21, 39, 40).

Regarding the Stroop test, acute Capsaicin supplementation did not influence the results, contrary to Thornton *et al.* (10), who state that capsaicin can improve functions associated with cerebrovascular function and cognition. In the results of the present study, differences were identified between the Stroop test 1 and the Stroop test 2, in both experimental conditions. This result can be justified by the inverted U theory (44). Once the ability of exercise to stimulate cognition and increase the focus of attention is understood (44), this attention may have been raised to an optimal state of activation, allowing an increase in

performance when comparing the two tests. Some studies obtained positive responses in executive function through acute Caffeine (29) and nitrate (NO<sub>3</sub><sup>-</sup>) (19) supplementation in the Stroop Test. However, no other studies were found that investigated capsaicin supplementation and cognitive performance in sport, which limits the discussion of the results and indicates the need for new studies on this topic. The present study presents a limitation when evaluating cognitive function, since reaction time alone may be insufficient to define cognition in the modality.

In relation to biopsychological parameters, when analyzing the PRS proposed by Laurent *et al.* (20), it was identified that the volunteers were recovered before the experimental sessions, indicating that possible accumulated fatigue did not affect performance in both experimental conditions. Regarding RPEsession and RPEtest, no significant differences were found between capsaicin supplementation and placebo. This result was similar to those found by several other studies (7, 8, 21, 36, 37, 45). However, some studies reported a positive effect on reducing RPE with capsaicin supplementation (3, 5, 38). The justification presented by these studies is related to the desensitization of afferent nerve terminals, reducing the sensation of discomfort and perception of effort. In the specific protocol of the present study, this possible effect was not enough to influence RPEsession and RPEtest in the demand imposed on Taekwondo athletes and para athletes, also indicating a possible specificity in relation to the demand and to the individual.

The results of the lactate blood concentration demonstrated that the responses were similar in both experimental conditions. The same result was reported by Freitas *et al.* (3), Freitas *et al.* (5), Freitas *et al.* (7) and Ah Morano *et al.* (37), who investigated the effect of acute capsaicin supplementation on different exercise protocols, as capsaicin can increase the oxidation of substrates, sparing muscle glycogen (43). However, the results of this and other studies indicate that capsaicin may not be effective in significantly increasing anaerobic lactic mobilization. Therefore, measuring blood lactate may be unnecessary in future studies. The results of the present study indicate that blood glucose levels increased significantly only in the PLA condition, but not sufficiently to be significantly different from the CAP condition. Some authors (42, 43, 46) suggest that capsaicin can reduce the mobilization of circulating glucose. However, this potential effect was not sufficient to alter the contribution of the lactic energy system, as evidenced by the behavior of lactate concentration. Finally, this response did not affect physical and cognitive performance.

In addition to the limitations presented throughout the text

so far, it is important to highlight that the present study has other limitations. The sample size may be limited, despite being representative in relation to the selection and inclusion criteria. Also, other cognitive aspects were not measured through other tests, mainly specific to the modality. Furthermore, the results should be considered with caution by nutritionists, athletes and coaches in Taekwondo training, as this is possibly the first study on capsaicin supplementation in Taekwondo. Given this, the present work has advanced in science, but new studies are important to improve protocols for capsaicin supplementation in Taekwondo, in different dosages, administrations of the substance, characteristics of athletes and in combat itself, with the aim to robustly evaluate the effectiveness of this nutritional strategy.

## CONCLUSIONS

Acute capsaicin supplementation may not be effective in improving the physical and cognitive performance of Taekwondo athletes and para athletes. Furthermore, supplementation may not reduce the Rate of Perceived Exertion (RPE) of Taekwondo athletes and para athletes during general and specific physical tasks. Additionally, capsaicin supplementation does not alter responses to blood lactate and glucose concentration.

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## DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

## CONTRIBUTIONS

RS, RN, MD: data curation, formal analysis, writing – original draft. MD, RN, MM, GA, AS, MM, RS: writing – review & editing.

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## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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# Possible Relationship between the Spine Curvatures and the Presence of Scapular Dyskinesia: A Possible Association

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## SUMMARY

**Background.** Scapular dyskinesia is defined as an abnormality in the static or dynamic position of the scapula during movements of the shoulder complex, being classified as dysrhythmia, winging or mixed. It is speculated that this abnormality may be associated with the positioning of the spine, pain in the shoulders or cervical spine, as several muscles cross these same joints.

**Objective.** The study aims to verify the relationship between spinal curvatures and the presence of scapular dyskinesia.

**Methods.** Participants were 28 young adults (15 males and 13 females) who were evaluated using the scapular dyskinesia test, resisted by dumbbells during shoulder abduction, scaption and flexion movements and by evaluating cervical and thoracic curvatures using the flexicurve method. The angulations were calculated using the “Biomec Flex” software and statistical analysis was performed using the SPSS v26.0 software using the t test for independent samples and chi-square test.

**Results.** Participants with scapular dyskinesia have greater angulations in the curvatures of the cervical spine and there was an association between the variables, indicating that participants classified as having normal curvatures or with cervical hyperlordosis had a higher prevalence of scapular dyskinesia, while those with rectification curvatures had a lower prevalence.

**Conclusions.** There is relationship between spine curvatures and presence of scapular dyskinesia, therefore, a broader perspective on the evaluation of individuals with scapular dyskinesia is important.

## KEY WORDS

*Cervical spine; kyphosis; scapular dyskinesia; spine; thoracic spine.*

## INTRODUCTION

Scapular dyskinesia is a term given to alterations in scapular position, movement, and biomechanics (1). It can be classified as winged types (I and II), dysrhythmic (type III), or both. In type I, the inferior angle of the scapula becomes prominent; in type II, the entire medial border is displaced; and in type III, there is excessive elevation or insufficient upward rotation of the scapula (2). These

changes impact the scapulohumeral rhythm and the biomechanical function of the scapular and glenohumeral joints (1).

Studies suggest some factors related to the causes of scapular dyskinesia, including muscle imbalances in the scapular girdle. This imbalance can manifest as hyperactivity of muscles like the upper trapezius, middle trapezius, and pectoralis minor (3, 4), or as hypoactivity of the lower

trapezius and serratus anterior (4-6). Additionally, the most common kinematic alterations are increased scapular internal rotation and decreased upward rotation (4). Scapular dyskinesis can also be a consequence of neurological injuries, as the accessory spinal and long thoracic nerves are affected, resulting in a loss of function in parts of the trapezius and serratus. It may be symptomatic or asymptomatic or generate a series of crepitations, as articular friction occurs during scapular movement, which is strongly related to shoulder injuries such as impingement syndrome, rotator cuff tears, and joint instabilities (7).

Considering that scapular muscles have proximal insertion points on the cervical and thoracic spine (8), it is important for the spine to be in a proper position and mobility to maintain functionality and the absence of pain, directly influencing scapular movements (9-11). However, in some cases, there may be angular changes in the spinal curvatures, referred to as straightening, hyperkyphosis, and hyperlordosis. In many cases, these alterations can be asymptomatic, depending on the degree of alteration and the individual's lifestyle habits, affecting the distribution of biomechanical loads across the shoulder and spinal complex (11). Nevertheless, few studies have investigated the alterations in spinal curvatures and their relationship with the presence of scapular dyskinesis.

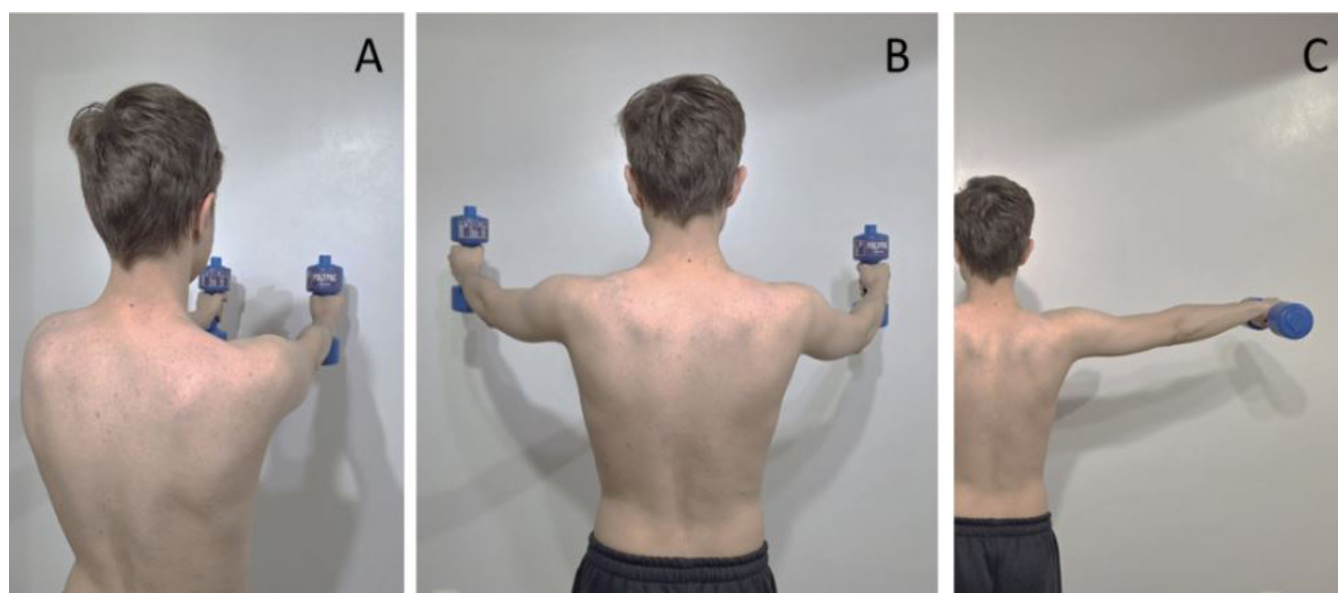
Given the above, it is speculated that changes in scapular and glenohumeral joint movements, as well as in cervical and/or thoracic spinal angulations, could result in mechan-

ical overloads on structures and contribute to symptoms in the cervical region (8, 12). Understanding this interrelationship is essential for developing effective assessment and intervention strategies. Therefore, the objective of the study was to investigate the relationship between spinal curvatures and the presence of scapular dyskinesis. Secondly, it aimed to compare cervical and thoracic curvature angles between individuals with and without scapular dyskinesis.

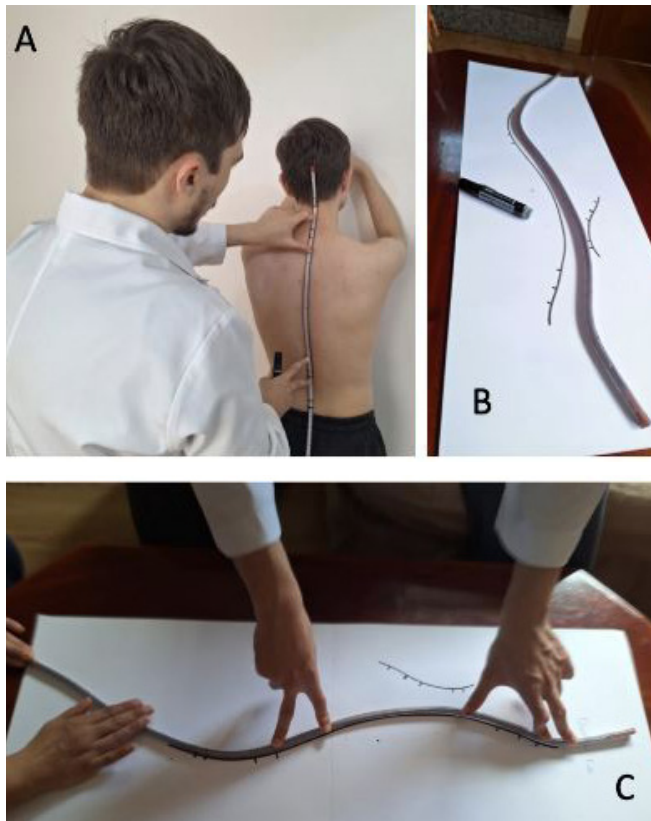
## MATERIALS AND METHODS

### Participants

The study included 28 young adults (15 men, 13 women, aged  $22.1 \pm 4.1$  years, weight  $64.8 \pm 10.7$  kg, and height  $1.71 \pm 0.10$ m), students at the Centro Universitário da Serra Gaúcha (FSG) who were invited to participate via social media. Healthy participants aged 18 to 35 years were included. Participants who presented shoulder or spinal pain, paresthesia, or diagnosed injury, a history of fractures or surgeries in the spinal or scapular region, or diagnosed scoliosis with a curvature  $> 20$  degrees (moderate or severe) were excluded. All participants signed an informed consent form, approved by the Ethics and Research Committee of the Centro Universitário da Serra Gaúcha under opinion no. 6.582.706 – date of approval: December 13, 2023.



**Figure 1.** Scapular Dyskinesis Test for flexion (A); elevation in the scapular plane (B); and shoulder abduction (C).



**Figure 2.** Molding (A); marking (B); positioning of the flexicurve (C).

## Procedures

The data collection was conducted at the Integrated Health Center of the Centro Universitário da Serra Gaúcha, according to the availability of researchers and study participants. It consisted of evaluating the presence of scapular dyskinesia using a validated clinical test (13, 14) and assessing cervical, thoracic, and lumbar spinal curvatures in the sagittal plane with the flexicurve method (15, 16).

## Scapular Dyskinesia Test

The scapular dyskinesia test (13, 14) was performed with participants undressed, shoulders in a neutral rotation, elbows straight, and arms at their sides. Participants were asked to perform 5 bilateral repetitions of flexion, scaption, and active, resisted, and weighted shoulder abduction, with the evaluator observing from the posterior view and recording a video.

During execution, participants held dumbbells according to their body weight: for participants under 68.1 kg, a 1.4 kg dumbbell; for participants 68.1 kg or above, a 2.3 kg dumb-

bell. These weights were provided by plastic dumbbells calibrated with sand and water to achieve the specified load (figure 1).

As the participants performed these movements, researchers observed scapular movements, especially noting the presence of dysrhythmia (altered scapulohumeral rhythm) and winging (prominent inferior angle and/or medial border) or normality. Researchers recorded their assessments, and if there was disagreement, the video was reviewed later.

## Flexicurve

The flexicurve is a flexible ruler that can be molded and marked along the spinous processes, allowing for the measurement of spinal curvatures (cervical, thoracic, and lumbar) in the sagittal plane (15, 16).

After palpating and marking (using a demographic pencil) specific anatomical points and correctly positioning the participant, the flexicurve should be molded over the spinous processes in the area of the spine being evaluated, with the marks transferred directly onto the flexicurve. The flexicurve is then carefully repositioned onto an A3 sheet, where the contours of the participant's spinal curvature are transcribed (figure 2).

In the cervical spine evaluation (15), the occipital protuberance (C0), posterior tubercle of atlas (C1), and the spinous processes of C2, C7, T1, and T2 should be marked. Immediately afterward, the individuals should sit down, close their eyes, flex and extend the head twice, and then stop in a neutral position with open eyes and no movement.

In the thoracic and lumbar curvature evaluation (16), the spinous processes of vertebrae C7, T1, T12, L1, L5, and S1 should be marked. The participants should stand with feet parallel and bare, in their usual posture, with shoulders and elbows flexed at 90° and the back uncovered, supported against a wall to avoid possible movements during the flexicurve molding (figure 2).

## Data and Statistical Analysis

Flexicurve data were analyzed using Biomec Flex software. The contours of the cervical, thoracic, and lumbar curvatures were captured via digital photographs and imported. All points were identified by region (cervical or thoracolumbar) and, through trigonometric equations, the software generated a plot with the equations, curvatures, flexicurve angles, and Cobb angles.

Statistical analysis was performed in SPSS v26.0. Initially, data normality was verified using the Shapiro-Wilk test. Associations between nominal variables were analyzed with



**Table I.** Results of the Scapular Dyskinesis Test.

Shoulder Flexion			
Yes - 50% (16 mild e 12 obvious)		No - 50% (28 normal)	
<b>Normal</b> 50% (n = 28)	<b>Dysrhythmia</b> 28.6% (n = 16)	<b>Winging</b> 14.3% (n = 8)	<b>Both</b> 7.1% (n = 4)
Elevation in the Scapular Plane			
Yes – 46.4% (20- mild e 6 obvious)		No – 53.6% (30 normal)	
<b>Normal</b> 53.6% (n = 30)	<b>Dysrhythmia</b> 28.6% (n = 16)	<b>Winging</b> 10.7% (n = 6)	<b>Both</b> 7.1% (n = 4)
Shoulder Abduction			
Yes – 39.3% (18 mild e 4 obvious)		No – 60.7% (34 normal)	
<b>Normal</b> 60.7% (n = 34)	<b>Dysrhythmia</b> 25.0% (n = 14)	<b>Winging</b> 7.1% (n = 4)	<b>Both</b> 7.1% (n = 4)

**Table II.** Classification of spinal curvatures in the sagittal plane (n = 56).

Variables	Normality	Hyperlordosis or Hyperkyphosis	Rectification
Flexicurve Angle CC	42.9% (n = 24)	32.1% (n = 18)	25.0% (n = 14)
Cobb Angle CC	21.4% (n = 12)	3.6% (n = 2)	75% (n = 42)
Flexicurve Angle CT	14.3% (n = 8)	46.4% (n = 26)	39.3% (n = 22)
Cobb Angle CT	21.4% (n = 12)	50% (n = 28)	28.6% (n = 16)

CC: Cervical Spine; CT: Thoracic Spine.

**Table III.** Comparison of spinal curvature values between individuals with and without scapular dyskinesis in flexion, elevation, and abduction movements.

Variables		Abduction	Elevation	Flexion
Flexicurve Angle CC	Yes	45.7 ± 6.5°	42.3° ± 6.8°	42.2° ± 6.8°
	No	36.3° ± 9.8°	38.0° ± 11.5°	29.2° ± 8.6°
	p	< 0.0001*	0.05*	0.049*
Cobb Angle CC	Yes	34.1° ± 5.4°	32.8° ± 4.3°	32.8° ± 4.4°
	No	29.0 ± 7.3°	29.4° ± 8.4°	29.2° ± 8.6°
	p	0.002*	0.018*	0.016*
Flexicurve Angle CT	Yes	38.8° ± 6.9°	37.5° ± 8.9°	37.2° ± 9.8°
	No	36.6° ± 9.4°	37.5° ± 8.2°	37.7° ± 7.1°
	p	0.460	0.768	0.693
Cobb Angle CT	Yes	40.2 ± 5.8	39.1° ± 7.0°	38.9° ± 8.4°
	No	38.2 ± 8.1	38.9° ± 7.7°	39.1° ± 6.1°
	p	0.420	0.818	0.742

\*Significant difference (p < 0.05); CC: Cervical Spine; CT: Thoracic Spine.

Pearson's Chi-Square test ( $X^2$ ). Comparisons were made using the t-test for independent samples (parametric), with a 95% significance level.

## RESULTS

The study included 28 young adults (15 men and 13 women) with an average age of  $22.2 \pm 4.1$  years, height of  $171.4 \pm 10.7$  cm, and weight of  $64.8 \pm 11.3$  kg, with 56 shoulders analyzed. **Table I** shows the results of the scapular dyskinesis test for flexion, scaption, and shoulder abduction movements. **Table II** presents the classification of spinal curvatures, while **table III** shows a comparison of the curvature values measured with the flexicurve between participants with and without scapular dyskinesis. It can be observed that participants with scapular dyskinesis had higher flexicurve and Cobb angles in the cervical region compared to those without dyskinesis for abduction ( $p < 0.001$ ; 0.002), scaption ( $p = 0.05$ ; 0.018), and flexion ( $p = 0.049$ ; 0.016).

It can be observed that participants with scapular dyskinesis had higher flexicurve and Cobb angles in the cervical region compared to those without abduction dyskinesis ( $p < 0.001$ ; 0.002), scaption ( $p = 0.05$ ; 0.018), and flexion ( $p = 0.049$ ; 0.016). Additionally, there was an association between the presence of scapular dyskinesis and cervical curvature classification (hyperlordosis, normality, and rectification) for abduction ( $X^2 = 6.297$ ;  $p = 0.047$ ), scaption ( $X^2 = 9.796$ ;  $p = 0.007$ ), and flexion ( $X^2 = 10.032$ ;  $p = 0.07$ ), indicating that individuals with rectification values typically did not exhibit dyskinesis, while those classified as normal or with cervical hyperlordosis had a higher prevalence of scapular dyskinesis.

## DISCUSSION

The objective of this study was to investigate the relationship between spinal curvatures and the presence of scapular dyskinesis. It was found that individuals with scapular dyskinesis exhibited significantly greater cervical curvature angles and a higher prevalence of cervical hyperlordosis and angles in normality compared to individuals without dyskinesis, who tended to have straighter cervical curves. These results highlight the relationship between the evaluated structures during different movements, showing possible postural adaptations that increase cervical curvature or lead to scapular dyskinesis as an attempt to stabilize or adapt movement and positioning. On the other hand, thoracic spine analysis showed no significant differences between the groups, which may reflect the lower functional impact of the thoracic region on scapular mechanics.

The literature includes various studies investigating the cervical spine in patients with cervical pain and scapular dyskinesis (8, 9, 17). Kaaragaç *et al.* (17) found that individuals with nonspecific chronic cervical pain show a higher prevalence of scapular dyskinesis and reduced muscle strength in the cervical and scapulothoracic regions than asymptomatic individuals. Another study by Ludewig and Braman suggests that scapular compensations may serve as adaptive mechanisms to protect adjacent structures, such as cervical and thoracic muscles, especially during high-demand physical movements. These findings emphasize the importance of scapular biomechanics as a fundamental component of postural rehabilitation, suggesting that interventions focused on reducing cervical curvature and restoring scapular control could provide significant benefits in preventing dysfunctions and associated pain.

These aspects are supported by Castelein *et al.* (8), who demonstrated that individuals with cervical pain and scapular dyskinesis showed reduced EMG activity in the middle trapezius during elevation in the scapular plane and increased activity in the pectoralis minor during the towel wall slide. This muscle activity imbalance suggests that the scapula increasingly relies on muscles that contribute to internal rotation and anterior tilt, such as the pectoralis minor, resulting in compensations that can influence cervical posture. These findings reinforce the importance of the relationship between the structures due to their similar muscular attachments, which may vary depending on the type of scapular dyskinesis described by Wannaprom *et al.* (18), demonstrated that the group with cervical pain and scapular dyskinesis of the scapular winging type showed decreased clavicular retraction and increased internal rotation and anterior tilt. Additionally, it was found that individuals with scapular dyskinesis and dysrhythmia showed reduced scapular upward rotation (9). Thus, by examining the biomechanical relationship of these aspects, we can speculate that individuals with scapular dyskinesis who show greater EMG activity in the pectoralis minor and lower activity in the middle trapezius may experience kinematic changes in the scapula, leading to internal rotation and clavicular protraction (8). If we consider that the upper trapezius has a proximal attachment to the external occipital protuberance, the nuchal ligament, and a distal attachment to the lateral clavicle and acromial end, while the middle trapezius has a proximal attachment to the nuchal ligament and the first thoracic vertebrae with a distal attachment on the acromion, it can be speculated that changes in scapular kinematics may be related to increased cervical lordosis angles due to these attachments.

However, it is important to acknowledge that the associations observed in this study do not allow for establishing a causal relationship between scapular dyskinesis and cervical curvature alterations. Factors such as chronic pain, mechanical overload, and compensatory patterns may contribute to these postural adaptations without one phenomenon being the direct cause of the other. Longitudinal studies are needed to clarify the causes and effects of this relationship, which could aid in more targeted and effective therapeutic interventions.

Corroborating our findings, Akodu *et al.* (19) found that undergraduate students with excessive smartphone use exhibited a similar posture. Like our study, the sample comprised asymptomatic young adults, raising the possibility that scapular dyskinesis may be a relatively common finding in asymptomatic populations. For athletes, especially those involved in overhead activities such as tennis and swimming, the prevalence of scapular dyskinesis is even higher and often associated with symptoms of pain and functional limitations (20, 21). Thus, individuals with increased cervical angles show a higher prevalence of dyskinesis, reinforcing the relationship between the shoulder girdle muscles, which attach to both the scapula and the cervical and occipital regions.

Regarding the thoracic region, Welbeck *et al.* (12) show no relationship between the presence of scapular dyskinesis and thoracic spinal curvature in swimmers with and without shoulder pain. Another study reports that patients with cervical region pain, shoulder issues, and scapular protrusion should investigate thoracic spinal curvature, as they may have reduced shoulder range of motion (22). Although muscles such as the rhomboids, middle, and lower trapezius have proximal attachments on the thoracic vertebrae and distal attachments on the scapular spine, our results did not reveal differences in thoracic curvature angle between individuals with and without scapular dyskinesis. This suggests that the lower mobility of the thoracic spine, compared to the cervical spine, may limit the biomechanical adaptations resulting from scapular alterations. The literature indicates a possible relationship between the presence of stiffness in the latissimus dorsi and scapular dyskinesis in swimmers (23). Despite the muscle attaching to both the thoracic and lumbar regions, there is still limited investigation in the literature, with no apparent relationship between the regions; however, an increased anterior pelvic tilt is observed in individuals with dyskinesis (24).

The practical application of this study suggests that movement professionals should consider the relationship

between spinal curvatures, with special attention to the cervical region, in individuals with scapular dyskinesis. Integrating this evaluation into the protocol for patients with scapular dyskinesis can facilitate the development of more specific prevention and rehabilitation programs, including scapular stabilization exercises and strengthening of cervical muscles, which can reduce postural compensations and improve shoulder complex functionality (25). It is also important to mention that there is a difference between the functional stability of the upper limb and perception of strength and sense of joint position between subjects with and without scapular dyskinesis. Physical therapist involved in the treatment needed to evaluate impaired posture, glenohumeral joint mobility and neuromuscular control or performance of the shoulder (26). Assessment of posture and biomechanics of the cervical spine and scapular kinematics should be an integral part of treatment to reduce compensations and enhance the overall function of the shoulder complex.

The study presents some limitations that should be mentioned. The first limitation is the lack of a larger sample size across all classifications of scapular dyskinesis, which may influence the extrapolation results to the population. The second limitation is potential human error in palpating anatomical structures, testing dyskinesis, and transferring curvature to paper; however, to minimize these errors, each researcher was assigned a specific stage of the evaluation. The third limitation is the sample profile, as it only included young adults without musculoskeletal complaints or pathologies, so future studies should include these assessments across different age groups and populations. Nonetheless, the results in young adults showed that even without symptoms or pathologies, there are biomechanical relationships between scapular dyskinesis and the cervical region.

## CONCLUSIONS

It can be concluded that individuals with scapular dyskinesis exhibit greater cervical spinal curvature angles than those without scapular dyskinesis. There was an association between scapular dyskinesis and cervical spine classifications, demonstrating that individuals with straightened cervical spines did not exhibit scapular dyskinesis, while those classified with normal or cervical hyperlordotic curvatures had a higher prevalence of scapular dyskinesis. Thus, the biomechanical relationship between the scapular and cervical regions is important for a broader approach to the rehabilitation of individuals with scapular dyskinesis.

## FUNDINGS

None.

## DATA AVAILABILITY

Data are available within the article.

## CONTRIBUTIONS

GFP: conceptualization, methodology, writing – original draft, formal analysis. EB: data collection, writing – original

draft. WRO: writing – original draft, supervision. WD: investigation, resources, writing – review & editing, supervision.

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## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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# ChatGPT Provided Excellent or Satisfactory Answers to Questions about de Quervain's Tenosynovitis, but still Requires Verification by Health Care Professionals

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## SUMMARY

**Objective.** ChatGPT, an AI chatbot by OpenAI, is increasingly utilized in patient and resident education due to its ability to provide information across various medical topics. However, the accuracy and reliability of its responses, particularly for specialty-specific conditions, are still being evaluated. This study aims to assess ChatGPT's accuracy in answering standardized questions on de Quervain's tenosynovitis to determine its effectiveness in supporting medical education.

**Materials and methods.** Frequently asked questions regarding de Quervain's tenosynovitis were identified from medical websites, and ten questions were selected by consensus among the authors. On July 4, 2024, these questions were posed to ChatGPT (version 4), and the responses were evaluated for accuracy and quality using the ChatGPT Response Rating System, with consensus reached among authors in cases of differing opinions.

**Results.** Based on the ChatGPT Response Rating System, 30% (n = 3) of the responses scored a 1 (excellent, requiring no clarification), 50% (n = 5) scored a 2 (satisfactory, needing minimal clarification), and 20% (n = 2) scored a 3 (satisfactory, requiring moderate clarification). Extraneous details were omitted to condense the responses into summary sentences focused on the main answer.

**Conclusions.** ChatGPT provided excellent or satisfactory answers to questions about de Quervain's tenosynovitis, indicating its potential as a supplementary tool in medical education for this condition. However, the accuracy of its information can vary, necessitating verification by medical experts, and while not fully ready for integration into medical education, ChatGPT is expected to improve with further refinement of its data inputs.

## KEY WORDS

ChatGPT; de Quervain's tenosynovitis; artificial intelligence; hand surgery; education.

## INTRODUCTION

Chat Generative Pre-Trained Transformer (ChatGPT), an artificial intelligence (AI) chatbot launched by OpenAI in November 2022, is estimated to have over 100 million active users (1). ChatGPT is a powerful communication tool capa-

ble of answering questions and engaging in natural language conversations on a wide range of topics, including health-care (2). High-quality surgical training materials are essential for good medical education. Creating these materials can be quite time-consuming, even for experienced medi-

cal educators. AI-generated content can reduce the workload of professional educators and be particularly valuable in facilitating access to information for resident doctors (3). ChatGPT contains a wide range of information, including triage, diagnosis, treatment, research, and preoperative planning (4). Therefore, it has increasingly been used in educational activities, literature reviews, or the writing of scientific articles (5). As a result, the accuracy and reliability of ChatGPT, particularly in answering specialty-specific questions, have come under scrutiny. Studies have shown that ChatGPT can serve as a virtual teaching assistant and provide reasonably accurate answers to standardized medical questions (6). Additionally, ChatGPT has passed Step 1 of the United States Medical Licensing Examination (USMLE) and achieved a ranking at the level of a third-year orthopedic resident in the orthopaedic surgery in-training examination (OITE) supervised by the American Academy of Orthopaedic Surgeons (AAOS) (7, 8). However, ChatGPT could not pass the first part of the European Board of Hand Surgery (EBHS) diploma examination (9). Studies indicate that different results are obtained in exams depending on the specialty. This highlights the need to evaluate ChatGPT's accuracy specific to the specialty and subject matter. There are limited evidence evaluating ChatGPT's responses in hand surgery topics (10).

De Quervain's tenosynovitis is tenosynovitis of the abductor pollicis longus (APL) and extensor pollicis brevis (EPB) tendons located in the first extensor compartment (11). It is one of the common diseases in hand surgery practice, with an incidence of approximately 1.3% among women and 0.5% among men (12). Patients present with pain and inflammation around radial styloid. Conservative treatment includes non-steroidal anti-inflammatory drugs, splint application, activity modification, and local steroid injections. If symptoms do not improve with conservative treatment, surgical intervention may be necessary (13). This study aimed to evaluate the responses given by ChatGPT to standardized questions related to de Quervain's tenosynovitis. To our knowledge, this is the first study in the literature conducted specifically on de Quervain's tenosynovitis.

## MATERIALS AND METHODS

Since this study did not involve any *in vivo* procedures, institutional ethics committee approval was not required. The formulation of the 10 questions was based on a structured approach aimed at capturing the most relevant aspects of de Quervain's tenosynovitis. Initially, we performed a comprehensive search of frequently asked questions on medical

websites related to the condition. These included questions covering its diagnosis, natural course, non-surgical treatment options, and surgical interventions. To ensure that the selected questions were representative of real-world clinical scenarios, we held discussions among the authors to reach a consensus. Each author contributed insights based on their clinical experience, and the final set of questions was chosen through an iterative process that emphasized the importance of clinical relevance, educational value, and clarity for both patients and healthcare professionals. This methodical approach allowed us to cover the key aspects of de Quervain's tenosynovitis while ensuring that the questions could be used to reliably assess the accuracy of ChatGPT's responses (14). On July 4, 2024, these questions were asked to the AI chatbot ChatGPT (version 4) without any additional guidance, and no limits were set on the length of the responses. ChatGPT's responses were recorded after the initial query and were not re-queried. The responses were evaluated for accuracy and quality using an evidence-based scientific approach by the authors and rated using the ChatGPT Response Rating System (**table I**) introduced by Mika *et al.* (15). This rating system assessed the responses in four categories: 1: "Excellent response with no explanation needed": The response was deemed accurate, comprehensive, and required no further explanation. 2: "Satisfactory with minimal explanation required": The response was correct but required minimal additional explanation to clarify finer points in the literature. 3: "Satisfactory with moderate explanation required": The response was still correct but needed moderate explanation due to outdated or unrelated information. 4: "Unsatisfactory, requires significant explanation": The response contained incorrect information or was overly generalized, leading to potential misinterpretation. In cases of differing opinions, the responses were re-evaluated until a consensus was reached among all authors.

**Table I.** ChatGPT Response Rating System.

Response Accuracy Score	Response Accuracy Description
1	Excellent response not requiring clarification
2	Satisfactory requiring minimal clarification
3	Satisfactory requiring moderate clarification
4	Unsatisfactory requiring substantial clarification

## RESULTS

Below are 10 questions related to de Quervain's tenosynovitis, the responses provided by ChatGPT, and their respective rating scores (**table II**). According to the ChatGPT Response Rating System, 30% ( $n = 3$ ) of the questions received a score of 1, 50% ( $n = 5$ ) received a score of 2, and 20% ( $n = 2$ ) received a score of 3. Extraneous details that did not pertain to the main answer were omitted to condense the responses into summary sentences.

### Question 1: What is de Quervain tenosynovitis?

*ChatGPT response: De Quervain tenosynovitis is a painful condition affecting the tendons on the thumb side of your wrist. It occurs when the two tendons around the base of your thumb become swollen. The swelling causes the sheaths (casings) covering the tendons to become inflamed. This puts pressure on nearby nerves, causing pain and numbness along the back of your thumb and up the side of your wrist.*

*Symptoms: Pain near the base of your thumb, swelling near the base of your thumb, difficulty moving your thumb and wrist when doing activities that involve grasping or pinching, a "sticking" or "stop-and-go" sensation in your thumb when moving it.*

#### Analysis: Satisfactory requiring moderate clarification

It is correctly stated that de Quervain's tenosynovitis is an inflammatory condition affecting the two tendons and their sheath on the thumb side. However, it does not mention that these tendons are the APL and EPB located in the first dorsal compartment (16). The symptoms are accurately described as pain near the base of the thumb, swelling, and difficulty moving the thumb and wrist during activities involving grasping or pinching. However, it does not specifically emphasize the pain in the radial side of the wrist and around the radial styloid (16-18). It is also not mentioned that the nerve that may become compressed due to inflammation and swelling is the superficial branch of the radial nerve, and this condition can develop after prolonged symptoms (19).

### Question 2: What is the anatomy relevant to de Quervain tenosynovitis?

*ChatGPT response: De Quervain tenosynovitis involves the anatomy of the wrist and thumb, specifically focusing on the tendons and their sheaths. Here is an overview of the relevant anatomy:*

1. *Tendons; APL and EPB.*
2. *Tendon Sheaths; These tendons run through a fibrous tunnel (the first dorsal compartment) on the thumb side of the wrist.*
3. *Extensor Retinaculum; A fibrous band on the back of the wrist that holds the extensor tendons in place. The APL and EPB tendons pass underneath this structure.*

#### 4. *Bones; Radius and Metacarp.*

*In de Quervain tenosynovitis, the tendons of the APL and EPB and their sheaths become inflamed.*

#### Analysis: Satisfactory requiring minimal clarification

It is clearly and explicitly stated that the anatomical structures affected in de Quervain's tenosynovitis are the APL and EPB tendons located in the first dorsal compartment and the fibrous tunnel (tendon sheaths) through which these tendons pass (20, 21). However, it does not mention that in approximately 40% of the population, the EPB and APL tendons may be separated by a septum and that multiple tendon slips can be present for the APL (16).

### Question 3: What causes de Quervain tenosynovitis?

*ChatGPT response:*

1. *Repetitive Motion: Overuse; Examples include typing, playing musical instruments, knitting, or using hand tools. Repeatedly grasping, pinching, or lifting objects.*
2. *Direct injury, trauma, strain.*
3. *Inflammatory Conditions; Rheumatoid Arthritis and other inflammatory conditions.*
4. *Hormonal Changes; Pregnancy.*
5. *Age and Gender.*  
*Age: The condition is most common in people between the ages of 30 and 50.*  
*Gender: It is more frequently seen in women than in men.*
6. *Occupational Factors.*
7. *Anatomical Variations.*  
*Tendon Sheath Narrowing: Some individuals may have a naturally narrower tendon sheath, which can predispose them to developing the condition with less provocation.*
8. *Infections.*

#### Analysis: Excellent response not requiring clarification

It is clearly and explicitly stated that activities involving repetitive and strenuous movements of the wrist and thumb, such as typing, playing musical instruments, knitting, and childcare, can cause de Quervain's tenosynovitis (16, 22). ChatGPT provides a complete and excellent response by also identifying pregnancy, trauma, age, female gender, inflammatory diseases like rheumatoid arthritis, and anatomical variations such as narrowing of the tendon sheath as risk factors for the development of de Quervain's tenosynovitis (19, 23-24).

### Question 4: How common is de Quervain tenosynovitis?

*ChatGPT response: Estimates suggest that it affects about 0.5% of men and 1.3% of women in the general population. Women are significantly more likely to develop de Quervain tenosynovitis than men. Some studies suggest it is up to 10 times more common in women. Most commonly affects individuals between the ages of 30 and 50.*

**Analysis: Excellent response not requiring clarification**

ChatGPT provides an excellent and literature-consistent response by stating that de Quervain's tenosynovitis is most commonly seen between the ages of 30 and 50, with an incidence rate of approximately 0.5% in men and 1.3% in women in the general population, and noting that some studies report it to be about 10 times more common in women (22-26).

**Question 5: Which physical findings are characteristic of de Quervain tenosynovitis?**

*ChatGPT response: Characteristic physical findings of de Quervain tenosynovitis include localized tenderness at the radial styloid and first dorsal compartment, swelling near the base of the thumb, decreased thumb mobility with a "sticking" sensation, a positive Finkelstein's test, crepitus on movement, decreased grip strength, pain on resisted thumb extension and abduction, and soft tissue thickening.*

*Finkelstein's Test: To perform this test, the patient makes a fist with the thumb tucked inside the fingers. The wrist is then ulnarly deviated (moved toward the little finger). A positive test is indicated by sharp pain along the distal radius at the site of the tendons.*

**Analysis: Satisfactory requiring minimal clarification**

The physical examination findings are correctly and comprehensively described, noting that de Quervain's tenosynovitis can cause pain, swelling, and tenderness over the radial styloid region and the first dorsal compartment, as well as crepitus during tendon movements. It also mentions difficulty in moving the thumb, especially during gripping or pinching motions. Additionally, it correctly explains the use of Finkelstein's test for diagnosis and its application (16, 21). However, it does not mention the Eichhoff test, which, despite having lower specificity than Finkelstein's test, is also used for diagnosis, nor does it mention the wrist hyperflexion and abduction of the thumb (WHAT) test (23, 27-29).

**Question 6: What is the role of radiographs in the evaluation of de Quervain tenosynovitis?**

*ChatGPT response: De Quervain tenosynovitis is primarily a clinical diagnosis based on history and physical examination. Radiographs are not typically needed for diagnosing de Quervain tenosynovitis but can be useful to rule out fractures, osteoarthritis, and calcifications, assess concurrent wrist pathologies, aid in pre-surgical planning, and provide baseline imaging for future comparisons.*

**Analysis: Excellent response not requiring clarification**

ChatGPT provides a complete and accurate response consistent with the literature by stating that the diagnosis of de Quervain's tenosynovitis is a clinical diagnosis based on history and physical examination, and that routine radio-

graphs (X-rays) are not necessary for diagnosis. However, X-rays can be used to rule out other pathologies such as associated fractures, first carpometacarpal joint arthritis, carpal bone pathologies, and calcifications around the tendons (16, 23, 28). Since the question specifically asked about the role of radiography in diagnosis, ChatGPT did not provide information about ultrasound (USG) and MRI. However, when the question was phrased as 'What is the role of radiology in the evaluation of de Quervain tenosynovitis?', ChatGPT also provided information on radiological methods used for diagnosis, such as ultrasound and MRI (23, 30).

**Question 7: What is included in medical therapy for de Quervain tenosynovitis?**

*ChatGPT response: Medical therapy for de Quervain tenosynovitis typically includes a combination of conservative treatments aimed at reducing inflammation, relieving pain, and preventing further irritation of the tendons. Medical therapy includes rest, activity modification, ergonomic adjustments, splinting with a thumb spica splint, NSAIDs (oral and topical), physical therapy (therapeutic exercises and ultrasound therapy), local steroid injections, ice therapy, patient education, ergonomic modifications, and alternative therapies like acupuncture and occupational therapy. Follow-up care is essential to monitor progress and adjust treatment.*

**Analysis: Satisfactory requiring minimal clarification**

The response accurately describes medical treatment as a combination of conservative therapies aimed at reducing pain and inflammation. The main components of medical treatment are activity modification to reduce repetitive wrist and thumb movements, the use of a thumb-spica wrist splint, NSAID use, ice application, physical therapy modalities, and local steroid injections, providing a clear answer (16-17, 21-22). However, it does not mention platelet-rich plasma (PRP) injections, which have been shown to be effective in treatment and have comparable mid-term outcomes with local steroid injections according to some studies (22-23). Additionally, the response does not highlight the high success rates of local steroid injections, which are known to be one of the most successful non-surgical treatment methods with success rates between 62% and 100%. The potential complications of local steroid injections, such as skin and subcutaneous tissue atrophy, skin depigmentation, and tendon rupture, are also not mentioned (16, 28).

**Question 8: What is the role of surgery in the treatment of de Quervain tenosynovitis?**

*ChatGPT response: Surgery for de Quervain tenosynovitis is considered when conservative treatments fail, severe pain persists, or there is significant functional impairment. The*



*procedure involves making an incision, releasing the inflamed tendons (abductor pollicis longus and extensor pollicis brevis) sheath and removing any adhesions or thickened tissues. Post-operative care includes pain management, wound care, physical therapy, and activity modification. Surgery generally has a high success rate, low recurrence rate, and potential risks include infection, nerve injury, and scarring.*

**Analysis: Satisfactory requiring minimal clarification**

ChatGPT correctly states that surgical treatment for de Quervain's tenosynovitis is indicated for patients with persistent symptoms who do not benefit from conservative treatments such as rest, splinting, NSAID use, physical therapy, and local steroid injections. It also accurately describes that the goal of surgical treatment is to release the first dorsal compartment to alleviate pain and restore function, aligning with the literature (20-22, 31). However, it mentions a very broad time range, stating that conservative treatment should be applied for several weeks to several months before considering surgery. According to the literature, surgery is recommended for patients with symptoms persisting for more than 3-6 months despite conservative treatment (11, 24, 28, 32).

**Question 9: What are the operative details for surgical treatment of de Quervain tenosynovitis?**

*ChatGPT response: The surgical treatment for de Quervain tenosynovitis typically involves a procedure called the first dorsal compartment release. Preoperative preparation includes patient evaluation, informed consent, and anesthesia. Local anesthesia is commonly used, but regional or general anesthesia may be considered in some cases. A small, longitudinal or transverse incision is made over the first dorsal compartment at the radial styloid. The subcutaneous tissue is carefully dissected and care is taken to avoid injuring the superficial branches of the radial nerve. The extensor retinaculum is incised longitudinally to release the tendon sheath. The tendons of the APL and EPB are inspected for any signs of damage or thickening, and any adhesions are carefully removed. If there are multiple slips of the APL tendon, they are all released. Postoperative care involves pain management, wound care, physical therapy, and activity modification.*

**Analysis: Satisfactory requiring moderate clarification**

ChatGPT provides a near-excellent response in line with the literature by stating that patients with de Quervain's tenosynovitis need to be informed and give consent prior to surgery. It highlights the importance of using a tourniquet to maintain a bloodless field and mentions that the surgery can be performed under local, regional, or general anesthesia. The response also describes the procedure for surgical intervention: a longitudinal or transverse incision over the radial styloid area and the first dorsal compartment, ensuring that the

superficial sensory branch of the radial nerve is not damaged, and the longitudinal release of the first dorsal compartment tendon sheath, followed by inspection of the APL and EPB tendons. It notes the possibility of multiple APL tendon slips and the need to release these slips and any adhesions present (16,24,31). However, it does not mention that an oblique incision might also be used or discuss the advantages and disadvantages of transverse *versus* longitudinal incisions (25, 31). Additionally, it omits information about the need to open the tendon sheath from the dorsal side to prevent postoperative subluxation, the potential for pulley reconstruction to avoid this complication, the excision of aberrant APL tendon slips, the presence of an additional septum between the EPB and APL tendons that may also need to be released, and the use of endoscopic release methods in de Quervain's tenosynovitis surgery (16, 19, 21, 24, 33-35).

**Question 10: What are possible complications of the surgical treatment of de Quervain tenosynovitis?**

*ChatGPT response: The surgical treatment of de Quervain tenosynovitis, while generally effective and safe, can have potential complications. These complications are infection, nerve injury (superficial radial nerve), excessive scar formation, tendon adhesions, incomplete release, recurrence of symptoms, complex regional pain syndrome (CRPS), joint stiffness, bleeding and hematoma formation, and delayed wound healing. While these complications are possible, they are uncommon. Proper surgical technique, thorough preoperative evaluation, and comprehensive postoperative care are crucial in minimizing the risk of complications.*

**Analysis: Satisfactory requiring minimal clarification**

ChatGPT provides a thorough explanation of potential complications during de Quervain's tenosynovitis surgery, noting the risk of injury to the superficial sensory branch of the radial nerve, inadequate release, and postoperative recurrence. It also highlights possible postoperative issues such as bleeding, hematoma, infection, delayed wound healing, and the development of hypertrophic scarring or keloids. Additionally, it describes the potential for tendon adhesions, restricted movement, and complex regional pain syndrome, including the symptoms and treatment options for these complications (11, 16, 24, 25, 31, 36). However, it does not address the possibility of volar subluxation of the tendons in the first dorsal compartment post-surgery and the associated symptoms (16, 24, 25, 35).

## DISCUSSION

The use of artificial intelligence technology in medicine is enhancing medical education by providing new teaching



**Table II.** Questions and response accuracy score.

Questions	Response Accuracy Score
What is de Quervain tenosynovitis?	3
What is the anatomy relevant to de Quervain tenosynovitis?	2
What causes de Quervain tenosynovitis?	1
How common is de Quervain tenosynovitis?	1
Which physical findings are characteristic of de Quervain tenosynovitis?	2
What is the role of radiographs in the evaluation of de Quervain tenosynovitis?	1
What is included in medical therapy for de Quervain tenosynovitis?	2
What is the role of surgery in the treatment of de Quervain tenosynovitis?	2
What are the operative details for surgical treatment of de Quervain tenosynovitis?	3
What are possible complications of the surgical treatment of de Quervain tenosynovitis?	2

methods and facilitating the training of healthcare professionals (2, 6, 37). ChatGPT can be utilized for clinical evaluations related to diagnosis and treatment by posing different real patient scenarios and questions, offering practical insights. ChatGPT is an AI system that autonomously learns from data and generates outputs after training on datasets (2, 37). However, unreliable data sources can mislead ChatGPT, causing it to provide incorrect answers. Therefore, the use of AI technologies like ChatGPT in medical education raises concerns and necessitates the verification of the accuracy of the information provided (37). As medicine and surgery increasingly adopt technology-assisted data management, including potential AI applications and telemedicine, it is evident that this will contribute more universally to the standardization of data provision and storage (38).

Studies show that while ChatGPT provides reasonably accurate answers to medical questions, the quality and accuracy of the responses can vary depending on the specialty and topic (6-9). In our study, we analyzed the responses provided by ChatGPT to standardized questions about de Quervain's tendinitis. We found that 70% of the answers required at least minimal to moderate explanation, and no unsatisfactory responses were identified (**table II**). This finding is consistent with other studies in the literature (15, 39). We believe that with the increasing availability of AI-generated data in the future, coupled with advancements in the ability to verify the accuracy of this data, AI will likely be used more frequently in daily practice within medicine and orthopedics. In the near future, we anticipate that AI will

be more reliably utilized in various medical domains such as diagnosis, preoperative planning, education, patient communication, and data archiving. As these technologies continue to evolve, their integration into clinical workflows will enhance both the efficiency and quality of care provided, while still requiring ongoing validation and oversight by medical professionals.

## CONCLUSIONS

ChatGPT has provided excellent or satisfactory answers to questions about de Quervain's tendinitis. Although our evaluation is subjective, these responses suggest that ChatGPT can be a useful and supplementary tool in medical education regarding de Quervain's tendinitis. However, it is important to remember that the accuracy of the provided information can vary due to numerous factors, and it is the responsibility of the relevant medical experts to verify it. Additionally, the study's findings are based on questions from a specific time period. As language models are continuously updated, it is likely that future iterations could yield higher accuracy if the same questions were revisited. While ChatGPT may not be fully ready to be integrated into medical education at its current state, it is expected to reach this level soon with further expansion and improvement of academic data inputs.

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None.

## DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

## CONTRIBUTIONS

KU, MB, MKY: conceptualization. ÖSH, MAC: methodology. KU, ÖSH: formal analysis, investigation. KU, MB, MKY: writing – original draft preparation. AK: writing – review & editing. AK, MAC: supervision.

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## DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES

During the preparation of this work the authors used ChatGPT in order to edit language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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# The Prevent Injury and Enhance Performance Training Program Enhances Postural Control in Soccer Players with and without Anterior Cruciate Ligament Reconstruction

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## SUMMARY

**Objective.** The purpose of the present study was to investigate and compare the effect of prevent injury and enhance performance (PEP) training program on the center of pressure (CoP) displacement in soccer players with and without anterior cruciate ligament reconstruction (ACLR).

**Materials and methods.** Twenty-one soccer players (male; median age 25.43 years) 15.12 months post- ACLR, and twenty-one healthy soccer players (male; median age 22.79 years) underwent postural control assessment during a single-leg landing task. The mean and maximal CoP displacement in anteroposterior (A-P) and mediolateral (M-L) directions was evaluated in both groups before and after eight-week of PEP training program. Differences in all variables were analyzed using a 2 (group) × 2 (time) repeated measures ANOVA, with statistical significance set at ( $p \leq 0.05$ ).

**Results.** A significant difference was observed in the mean of (M-L) displacement ( $p = 0.002$ ) in the healthy group between pre-training and post-training. Additionally, significant differences were observed in both the maximal ( $p = 0.027$ ) and mean of (M-L) displacement ( $p = 0.003$ ) in the ACLR group between pre-training and post-training. The comparison between groups in the pre-training showed a significant difference in the maximal (M-L) displacement ( $p = 0.011$ ) between the two groups. No significant differences were observed in the (M-L) and (A-P) components between the two groups in the post-training assessment.

**Conclusions.** Our findings support the premise that a PEP training program during the pre-season alters lower extremity biomechanics in soccer players. Participation in PEP training program improves postural control in both healthy and ACLR soccer players, which may explain the protective effect of this type of training program in reducing the risk of anterior cruciate ligament (ACL) injury or re-injury.

## KEY WORDS

Anterior cruciate ligament (ACL); ACL injury; knee injury prevention; PEP program; soccer.

## INTRODUCTION

One of the highest intensity sports that is being played every day throughout the world is soccer. With the growing popularity of the sport and the rapid growth of the number of

subjects, particularly in youth divisions, the prevalence of sports-related injuries on the field is also rising (1). Nearly 70% of soccer-related injuries occur in the lower extremities, with the knee being the most commonly affected site

(2). One of the most severe and complex knee injuries is an anterior cruciate ligament (ACL) tear. This injury often results in long-term consequences such as osteoarthritis, financial burden, proprioception deficits, and knee joint instability (3).

Most soccer players opt for surgical treatment to safely return to their pre-injury level of performance. Anterior cruciate ligament reconstruction (ACLR) is considered the gold standard treatment for active patients with an ACL injury (4). Recent research continues to demonstrate a relatively low rate of return to pre-injury levels of play among athletes following ACLR (5, 6). Recently, it was reported that 86% of elite male soccer players still played soccer 3 years after ACLR, but only 65% competed at their pre-injury level (7). Additionally, recent studies indicate that the rate of re-injury and subsequent ACL injury among young athletes ranges from 24% to 29% (8, 9).

Furthermore, aberrant movement strategies, muscle weakness, and biomechanical deficits persist in these athletes even beyond the typical return-to-sport timeframe of 12 to 60 months (10, 11). Similar to primary ACL injuries, the majority of second ACL injuries occur as noncontact episodes, suggesting that neuromuscular and postural control deficits in the lower extremities are significant risk factors. Additionally, previous studies have identified postural control deficits as one of the primary factors contributing to re-injury in the reconstructed limbs (10, 12). A common method for the characterization of postural control is to quantify the displacement of the center of pressure (CoP) (13). Previous studies have identified CoP displacement as a reliable measure for assessing postural control (14-16). In this regard, the study conducted by Culvenor *et al.* (17) demonstrated that CoP deficits persisted 12 months after ACLR. Therefore, correction neuromuscular and postural control deficits in athletes with ACLR may enable them to safely return to sport.

Neuromuscular training (NMT) programs effectively modify biomechanics deficits, improves postural control and reduce the incidence of ACL injuries in athletes (18). Unlike traditional strength or balance training, NMT programs are designed to enhance sensory-motor and achieve optimal postural control by focusing on movement quality across all three planes of motion (19). Yarsiasat *et al.* (20) concluded that the most successful programs are multi-modal and include a focus on enhancing strength, plyometric, balance, flexibility, and jump-landing stabilization. Furthermore, Chappell and Limpisvasti reported that the implementation of a NMT can alter motor control strategies in select jump-landing tasks and improve athletic performance measures (21).

In this context, the Santa Monica Orthopedic and Sports Medicine Research Foundation designed the Prevent Injury and Enhance Performance (PEP) Program in 1999 (22). This program includes warm-up, strengthening, stretching, plyometric, and agility exercises designed to address neuromuscular deficits and enhance the stability of the muscles surrounding the knee joint. Additionally, PEP program does emphasize instruction in movement mechanics (*i.e.*, “soft landing” and “preventing knee valgus”) (23). Previous studies have reported enhanced performance following participation in the PEP training program (24, 25). For instance, Lim *et al.* (26) demonstrated improvements in muscle strength and flexibility. Furthermore, other studies have reported improvements in landing technique and muscle imbalances after participation in the PEP training program (25, 27).

In addition to enhancing performance, this program has been shown to reduce the risk of ACL injuries in athletes, particularly those with a history of ACL injury (22). However, it remains unclear whether the reduction in ACL injury incidence is solely attributable to improvements in strength, balance, or other performance-related characteristics, or whether biomechanical factors such as enhanced postural control following PEP training also contribute to this reduction. Furthermore, Mandelbaum *et al.* (23) suggested that future studies should investigate the biomechanical mechanisms underlying the effects of the PEP training program on reducing the incidence of ACL injuries in athletes. However, current evidence indicates that biomechanical variables associated with ACL injury, such as postural control deficits, have received limited attention in research following the implementation of the PEP program. For this reason the purpose of this study was to compare of the effect of PEP Training program on postural control in soccer players with and without ACLR.

## METHODS

This study followed a longitudinal semi-experimental trial with convenience sampling. The statistical population of the present study consisted of professional soccer players from 15 teams in the first and second division leagues of the country. Sample size calculation was performed with G\*Power which determined that 21 subjects would be necessary to detect a statistical difference in each group given an estimated effect size of a power set at 0.80 and  $\alpha = 0.05$ . A P-value significance level was set at 0.05 (28). 42 soccer players were selected as the statistical sample using purposive and convenience sampling methods. The participants in this study



were divided into two groups: an ACLR group ( $n = 21$ ) and a healthy control group ( $n = 21$ ). Participants in the ACLR group consisted of 21 male soccer players who had undergone surgery: 17 with ACLR in the dominant limb and four with ACLR in the non-dominant limb).

The time since the participants' surgery was 6 to 18 months (mean  $15.12 \pm 3.86$ ) and their age ranged from 20 to 30 years. Additionally, all participants had a minimum of three years of soccer experience. Exclusion criteria included: 1) previous knee injury or surgery (except for ACL injury), 2) re-injury or re-surgery in the ACLR knee, 3) injury or surgery in the contralateral knee, 4) Other conditions that affect daily functioning (*e.g.*, visual or vestibular disorders that may impact balance), 5) knee pain within the last three months, and (6) non-participation in more than three sessions or two consecutive sessions of the PEP training program.

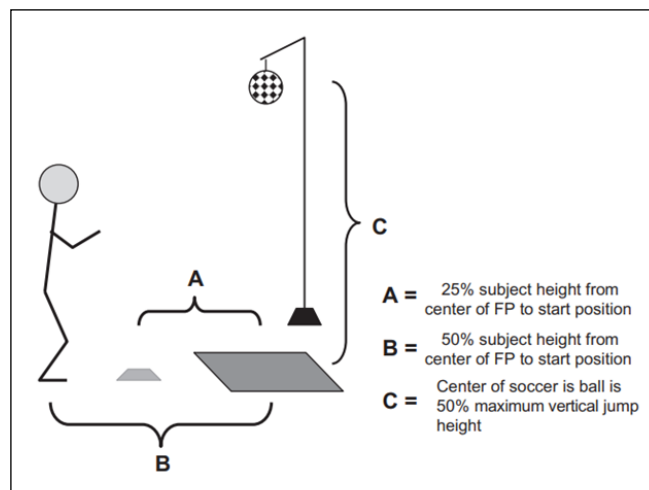
The present study was approved by the Ethics Committee of the Iranian Research Institute of Physical Education and Sport Sciences (approval code: SSRI.REC-2312-2560 – date of approval: February 29, 2024).

## Procedures

All tests were conducted under the supervision of a sports and biomechanics laboratory expert. Demographic data, including age, height, weight, body mass index (BMI), and Tegner activity scale (TAS), were collected from all 42 participants. After demographic data collection, participants performed a jump and, following a soccer-specific jump heading task, landed on the force plate using a single leg. Kinetic data were recorded using a Kistler force plate device at a sampling frequency of 1 kHz. The mean and maximal displacement (mm) of the CoP were collected in the ML and AP directions. These variables demonstrated good to excellent reliability, with intraclass correlation coefficients ( $ICC = 0.73-0.87$ ) (29).

## Jumping and landing task

Subjects were asked to start at a position that was half of their body height away from the center of the force plate. They were then asked to jump over a 7.5-cm cone, which was placed halfway between the start position and the force plate. The subjects were then instructed to perform a jump header (the center of the ball was kept stationary and positioned above the head of the subject at 50% of the subject's maximum jump height) and then perform single leg landing (**figure 1**) (30). Also, the subjects were asked to remain on one leg for  $\geq 5$  seconds after landing (31). If the opposite leg came in contact with either the floor or the leg being tested, the trial was terminated. No further landing instructions



**Figure 1.** Diagram of subject testing set-up.

FP: force plate.

were provided since this study aimed to quantify the inherent postural strategy of individuals. The gaze point was not specified during landing for safety reasons (32).

## Tegner activity scale (TAS)

Tegner activity scale (TAS) was used to check the activity level of ACLR patients. The TAS was designed as a score for activity level to complement the functional knee score for patients with ACL injuries. The instrument scores a person's activity level between 0 and 10 where 0 is 'on sick leave/disability' and 10 is 'participation in competitive sports such as soccer at a national or international elite level'. Pertinently, activity levels 6-10 can only be achieved if a person takes part in recreational or competitive sports (33).

## Data Processing

Kinetic data were analyzed using Nexus 1.8.5 and Visual3D software. Kinetic data were smoothed using a fourth-order Butterworth filter with a cutoff frequency of 20 Hz and normalized to the subject's body weight (34). AP displacement is the range of CoP movement in the AP direction, and ML displacement is the range of CoP movement in the ML direction. CoP measurement on force plate during jumping and landing were conducted three times for each person, and the average value of three trials was analyzed. In this study, the maximum and mean displacement of the CoP in two M-L and A-P directions were analyzed.

## PEP training program

The PEP training program consists of five components:

**Table I.** PEP\* training program.

Phase	Activity (Duration of Time to Complete Activity)	Time at Which Activity	Purpose
1. Warm-up (purpose: preparation)	Jog line-to-line (30 sec)	0 to 0.5 min	Prepare for training session
	Shuttle run (side-to side) (30 sec)	0.5 to 1 min	Engage hip abductors and adductors; promote speed; avoid inward caving of knee joint
	Backward run (30 sec)	1 to 1.5 min	Engage hip extensors and hamstrings
2. Strengthening (purpose: leg strength)	Walking lunges (1 min)	1.5 to 2.5 min	Strengthen quadriceps
	Russian hamstring (1 min)	2.5 to 3.5 min	Strengthen hamstrings
	Single toe raises (1 min)	3.5 to 4.5 min	Strengthen calf; improve balance
3. Plyometrics (purpose: power, strength, speed)	Lateral hops over cone (30 sec)	4.5 to 5 min	Increase power and strength; emphasize neuromuscular control
	Forward and backward hops over cone (30 sec)	5 to 5.5 min	Increase power and strength; emphasize neuromuscular control
	Single leg hops over cone (30 sec)	5.5 to 6 min	Increase power and strength; emphasize neuromuscular control
	Vertical jumps with headers (30 sec)	6 to 6.5 min	Increase vertical jump
	Scissor jump (30 sec)	6.5 to 7 min	Increase vertical jump
4. Agilities	Forward run with 3-step deceleration	7 to 8 min	Increase dynamic stability of ankle-knee-hip complex
	Lateral diagonal runs	8 to 9 min	Encourage technique and stabilization of hip and knee; avoids “knock-knee” position
	Bounding run (44 yd)	9 to 10 min	Increase hip-flexion strength, power, and speed
5. Stretching (can be performed after warm-up)	Calf stretch (30 sec × 2 repetitions)	10 to 11 min	Stretch calf; focus on lengthening muscle
	Quadriceps stretch (30 sec × 2 repetitions)	11 to 12 min	Stretch quadriceps; focus on lengthening muscle
	Figure four hamstring stretch (30 sec × 2 repetitions)	12 to 13 min	Stretch hamstrings; focus on lengthening muscle
	Inner thigh stretch (20 sec × 3 repetitions)	13 to 14 min	Stretch adductors; focus on lengthening muscle
	Hip flexor stretch (30 sec × 2 repetitions)	14 to 15 min	Stretch hip flexors; focus on lengthening muscle

PEP\*: Prevent injury and Enhance Performance.

warm-up, strength training, plyometric, agility exercises, and stretching (35) (**table I**). Both healthy and ACLR groups performed PEP training for eight-week and three sessions a week. The duration of each session in the protocol ranged from 15 to 20 minutes. Additionally, the PEP training program include verbal feedback to correct movement patterns. Coaches and trainers should emphasize correct posture, vertical jumps without excessive lateral movement, and reinforce soft landings. For this reason,

the correct training techniques were explained to the players during a one-hour instructional session. The necessary equipment for performing the exercises included cones and agility obstacles. It is important to note that these exercises were conducted during the pre-season period, prior to the start of competitions.

### Statistical analysis

The Shapiro-Wilk test was used to assess normality for all

**Table II.** Demographic characteristics.

Variable	Healthy (n=21) Mean $\pm$ SD	ACLR (n=21) Mean $\pm$ SD
Age (y)	22.79 $\pm$ 2.09	25.43 $\pm$ 2.20
Height (cm)	182.29 $\pm$ 24.14	180.54 $\pm$ 20.31
Weight (kg) BMI*(kg/m <sup>2</sup> )	74.66 $\pm$ 7.29	74.32 $\pm$ 6.93
Time since surgery (mo)	N/A	15.12 $\pm$ 3.86
Tegner activity scale	8.43 $\pm$ 2.81	7.59 $\pm$ 3.33
Injured limb (Dominant Limb)	N/A	17

BMI\*: Body Mass Index.

**Table III.** Changes in postural control variables (mean  $\pm$  SD).

Variable		Healthy (n = 21) Mean $\pm$ SD		ACLR (n = 21) Mean $\pm$ SD
Maximal displacement (A-P) (mm)	Pre. test	283.44 $\pm$ 23.44	G=0.22	316.44 $\pm$ 16.44
	Post. test	256.71 $\pm$ 20.18	T=0.001	281.71 $\pm$ 22.18
	Effect size	0.53 (-0.42, 0.98)	G $\times$ T=0.001	0.81 (-0.13, 1.22)
Maximal displacement (M-L) (mm)	Pre. test	343.73 $\pm$ 36.09	G=0.41	387.73 $\pm$ 44.28
	Post. test	303.68 $\pm$ 9.41	T=0.001	318.68 $\pm$ 29.90*,**
	Effect size	0.64 (-1.08, 0.18)	G $\times$ T=0.001	1.26 (0.41, 1.92)
Mean displacement (A-P) (mm)	Pre. test	209.76 $\pm$ 25.63	G=0.11	246.76 $\pm$ 23.84
	Post. test	187.76 $\pm$ 18.78	T=0.001	202.76 $\pm$ 35.00
	Effect size	0.71 (-0.12, 1.25)	G $\times$ T=0.001	1.26 (-0.36, 1.60)
Mean displacement (M-L) (mm)	Pre. test	233.65 $\pm$ 49.79	G=0.32	297.65 $\pm$ 61.79
	Post. test	194.46 $\pm$ 53.01*	T=0.001	229.46 $\pm$ 52.01*
	Effect size	0.89 (-1.08, 0.23)	G $\times$ T=0.001	1.56 (-0.91, 2.16)

\*Significant difference between pre-test and post-test; \*\*significant difference between Healthy and ACLR groups; G: Group effect; T: Time effect; G $\times$ T: Group  $\times$  Time interaction effect; A-P: Anteroposterior; M-L: Mediolateral; ACLR: Anterior Cruciate Ligament Reconstruction.

measured values. Differences in all variables were analyzed using a 2 (group)  $\times$  2 (time) repeated measures ANOVA. When a significant F-value was achieved across time or groups, Bonferroni *post-hoc* procedures were performed to identify the specific pairwise differences. Additionally, the effects of training (effect size (36) were calculated using Cohen's d (37) Statistical analysis was performed using IBM SPSS version 26.0 software with a significance level of  $p \leq 0.05$ .

## RESULTS

The demographic characteristics of the subjects are reported in **table II**.

The results indicated a significant difference in the maximal ML displacement ( $p = 0.001$ ) between the healthy and

ACLR groups in the pre-test. Also, the results showed no significant differences in any of the components in the post-test between the two groups ( $p \geq 0.05$ ) (**table III**).

Furthermore, the results indicate a significant difference in the mean ML displacement ( $p = 0.001$ ) in the healthy group between the pre-test and post-test. Additionally, the results demonstrate that after eight weeks of PEP training, there were significant differences in both the mean ( $p = 0.001$ ) and maximal ( $p = 0.001$ ) ML displacement in the ACLR group between the pre-test and post-test (**table III**).

## DISCUSSION

The purpose of this study was to examine the effect of preventing injury and enhance performance training

program on postural control in soccer players with and without anterior cruciate ligament reconstruction. The results of the present study demonstrated that eight-week PEP training program can reduce the CoP displacement in the A-P and M-L components in soccer players, with and without ACLR. Although there was a significant difference in maximal ML displacement between the two groups during the pre-test, no significant difference was observed in the post-test following the eight-week PEP training program. This indicates that the PEP training program had a positive effect on the ACLR group.

Most current prevention programs last between 6 to 8 weeks and have been proven to be effective (38). In the present study, PEP training program was performed for eight-week. It appears that six weeks correlates with the time frame needed to increase motor recruitment, but it does not correlate with what is needed for muscle hypertrophy or improved endurance. In this regard, in a study similar to the present study, Lemos *et al.* investigated the effects of 6 weeks of NMT on the postural control of soccer players. The results showed that 6 weeks of multi component training significantly reduced ML CoP displacement (41). Unlike our study, in this study, the AP CoP displacement was also significantly reduced. Webster *et al.* reported comparable findings in a study involving soccer players. In this investigation, the training group underwent two months of resistance, balance, and strength exercises. Following this intervention, a significant reduction in the components of CoP was observed, indicating the effectiveness of the exercise regimen in improving postural control (42). However, certain studies in the literature do not corroborate the efficacy of NMT in enhancing postural control. For instance, the study conducted by McKeon *et al.* indicated that six weeks of balance exercises failed to produce any significant changes in the postural stability of 31 adult men across all components of CoP. This suggests that the effectiveness of NMT may vary depending on specific conditions or populations (38). Similarly, the study by Verhagen *et al.* showed that a 5.5-week balance exercise program had no effect on any of the CoP fluctuation components (39).

Given the dynamic nature of soccer, which includes frequent jumping, landing, and rapid directional changes on a single leg, maintaining postural control and stability is crucial for minimizing the risk of ACL injuries. In our study, soccer players who had undergone ACLR exhibited greater single-leg swing in the pre-test compared to the healthy group. The study by Sugimoto *et al.*, which investigated single-leg postural stability following ACLR, reported findings consistent with those of the present study (40). Specifically, they

demonstrated that postural control deficits in the ACLR limb were significantly greater compared to those in the healthy group. Additionally, studies also demonstrated that postural control deficits in the injured limb were significantly greater compared to the contralateral limb (17, 40). Single-leg stability deficits after ACLR may be explained by sensory nerve deficits. When the ACL is injured, the sensory nerves within the ACL bundle are also torn. Although ACLR can provide mechanical stability in the knee joint, the nervous system is disturbed and may not be restored for years (17). On the other hand a recent study found that injured limbs not only generated lower torque but also exhibited higher force complexity (sample entropy, SE), indicating less efficient motor patterns. This altered SE correlated with poorer hop test performance (41). These findings suggest that postural control deficits in ACLR patients may stem from combined strength loss and impaired neural coordination. Maintaining balance during jump landing requires simultaneous postural control in both the AP and ML dimensions. On the other hand, larger deviations in both the AP and ML directions would likely indicate greater postural instability. In our study, the postural control deficits in the ML direction during the pre-test were greater than those in the A-P direction. The study by Culvenor *et al.* (17) showed the larger ML direction deficits observed following ACLR likely reflect the greater demands placed on the control of M-L knee movement during a single-leg landing. While we did not investigate knee valgus in the present study, knee valgus was more observed in ACLR group compared to healthy subjects during landing (42). On the other hand, a review of the existing literature confirms changes in the EMG activity of the knee and proximal hip stabilizer muscles following ACLR, which may contribute to altered postural control during unipodal tasks (43). This alteration in postural control may lead to increased body oscillation and imbalance in the medio-lateral plane of movement (frontal plane) in ACLR patients.

The participants in the present study were soccer players. Soccer involves multi-plane movements and requires multi-component training across various planes of motion. Indeed, intervention programs that target multiple planes of movement are necessary to effectively reduce the risk of ACL injury. While, regular muscle strength programs usually work on the sagittal or coronal plane, PEP program also works on the transverse plane, where ACL injuries usually occur. For this reason, recent studies have tried to establish an association between NMT and an improvement in postural control in a variety of populations, of which populations with chronic ankle instability and ACL injuries are

the most common (44, 45). The improvement in postural control following ACLR and after PEP program can also be attributed to brain neuroplasticity. In their research, Chaput *et al.* (46) found that in the ACLR group, NMT can improve visual cognition. On the other hand, visual memory was associated with neural activity in the cerebral cortex, but no neural correlates were observed in the control group. These findings indicate that PEP training program in ACLR patient may induce unique neuroplasticity that results in visual cognition contributing to proprioception and postural stability to a degree that healthy controls do not require. While our PEP program improved dynamic postural control, recent work suggests conventional proprioception tests like passive knee joint position sense (JPS) may lack sensitivity to detect these functional gains. Jebreen *et al.* (47) found no significant JPS differences between ACL-reconstructed and healthy knees, despite known postural deficits in ACLR patients. This discrepancy highlights that PEP's benefits - observed in our CoP measures - likely reflect integrated neuromuscular control rather than isolated joint position awareness, further supporting the need for task-specific assessments like ours.

Regardless of the cause of the observed post-training change in postural control, our results point to the modification of biomechanical/neuromuscular risk factors as being a potential mechanism by which injury prevention programs are successful in decreasing ACL tears. Our findings are particularly compelling because the ACL injury prevention training program implemented in this study has been shown to reduce the incidence of ACL injuries in soccer athletes. We found that participation in an eight-week PEP training program resulted in biomechanical changes that may be considered to be "ACL protective". Our findings suggest that the protective effect afforded by ACL injury prevention training may be achieved through improved postural control. According to the mentioned materials, sports coaches can use the PEP training program to prevent ACL injury or re-injury. Additionally, as highlighted in the study by Pollard *et al.*, the PEP training program can optimize biomechanical deficits during landing after injury, subsequently reducing the risk of injury (27).

### Limitations and research suggestions

The present study has several limitations that should be

considered. We did not control the lifestyle of any of the participants, for instance sleep and exhaustion from study, which may affect the results. Additionally, we did not account for different ACL graft types (*e.g.*, hamstring autograft, patellar tendon, allograft), which could influence rehabilitation outcomes. An additional limitation of the current study was that it was limited to soccer players: future studies should consider including athletes from different cutting and landing sports such as volleyball and basketball (20, 48). Finally, athlete satisfaction and functional improvements were not addressed during the present study.

## CONCLUSIONS

Our findings support the implementation of the PEP training Program, or a similar program, for clinicians aiming to improve lower extremity mechanics and improve postural control. Participation in an 8-week PEP training program in the preseason improves the postural control in both ACLR and healthy athletes while perform a landing task, which may explain the protective effect of this type of training program on injury or re-injury of ACL.

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None.

## DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

## CONTRIBUTIONS

ASM: conceptualization. MM: data curation. M G: writing – original draft, writing – review & editing, formal analysis. HD: formal analysis.

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## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.



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