REVIEW

Nr 2023;13 (4):667-676

Quadriceps Tendon Tears Rehabilitation: A Narrative Review of the Literature

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DOI:
10.32098/mltj.04.2023.20

LEVEL OF EVIDENCE: 5

SUMMARY

Introduction. Knee extensor apparatus tears are uncommon conditions, affecting middle aged men more than women. Quadriceps tendon ruptures are usually described as an acute consequence of a trauma that could be characterized by a direct or indirect mechanism. Surgical intervention is often required, and several repair techniques have been described. However, the current literature does not focus on the rehabilitation after quadriceps tendon tears.

Conclusion. So, the aim of the current study is to find and describe the rehabilitation programs that could be used as a gold standard following surgical repair of the extensor apparatus.

KEY WORDS

Quadriceps tears; extensor apparatus tears; quadriceps tendon; surgery; rehabilitation.

INTRODUCTION

Quadriceps tendon ruptures (QTR) are uncommon condition, and mainly affect male patients (M:F = 4.3:1) during the fifth decades of life, with incidence of 1.35 cases per 100,000 persons per year (1). QTRs are usually an acute consequence of trauma direct or indirect. Acute QTRs are frequently the result of an unexpected eccentric contraction of the quadriceps muscle complex (2). Recently spontaneous ruptures, at times bilaterally, have been reported (3), usually in people with predisposing conditions such as chronic renal failure, rheumatoid arthritis, diabetes, gout and steroids abuse, or quinolone antibiotics use (4, 5). Tendon structural and mechanical abnormalities occur with ageing, such as lower collagen production, calcification, and fatty degeneration (6, 7), but rarely these conditions alone lead to spontaneous ruptures in the elderly (4). The injury mechanism is often described as a traumatic event while the knee is in hyperextension, followed by severe pain in the anterior side of the tight and absolute inability to extend actively the affected knee (8) (**figure 1**). The imaging procedures for diagnosis include plain radiography, ultrasound (US) and magnetic resonance imaging (MRI) (9, 10) (**figures 2,3**), but clinical examination is the most important (10). QTRs can occur following total knee arthroplasty (11). The current literature does not focus on the rehabilitation after quadriceps tendon tears. There is no consensus on when to initiate knee mobilization or weight bearing, with a high heterogeneity about full weight bearing timing and stairs climbing (12). Up to now, early rehabilitation is being tested also

in basic science studies, it seems that early passive motion after surgical treatment of ruptured tendons improves the healing process and enhances tendon tensile strength, and gives a greater joint mechanics when compared to immobilization (13-15). Immobilization can be potentially counterproductive and increase the risk of complications, such as deep vein trombosis, linked to the restricted weight bearing (16).
The aim of the current study is to describe and summarize the current knowledge on rehabilitation protocols following surgical repair of the quadriceps tendon. Written informed consent for publication of their clinical images was obtained from the patient.

Figure 1. Clinical signs and evaluation of a bilateral QTR.

Figure 2. Sonographic evidence of a 3.21 cm QTR.

Figure 3. MRI evaluation of a QTR.

TREATMENT OF QUADRICEPS TENDON RUPTURES

Non operative management is reserved for partial QTR with a residual partial or normal function of the extensor apparatus. Usually, the knee is immobilized in full extension for 6 weeks and treated with ice, compression, and aggressive management of the knee effusion (17). Operative management is indicated for incomplete tears with functional deficit and in complete tears (**figure 4**). The timing of intervention is crucial, because a delayed repair can result in tendon retraction and can make the repair very difficult (18).
Recent evidences studied the timing of intervention after chronic QTRs and set the cut off for early treatment at 2-3 weeks from the injury (19). Indeed, tears of extensor tendons rupture can undergo surgery at later stage than tears of other tendons, such as flexor digitorum profundus and superficialis tendons, as their retraction is not so pronounced (20, 21). There are several techniques for repairing a complete quadriceps tendon tear, depending on the location of the tear and the choice of augmentation. After a longitudinal midline skin incision and identification of the tear, necrotic tissue is removed from the edges and fresh margins are produced. If the tear has adequate proximal and distal tendon, it can be repaired by end-to-end repair with adsorbable sutures material (2). With knee fully extended, the suture ends are then tied together. The defect can be reinforced with

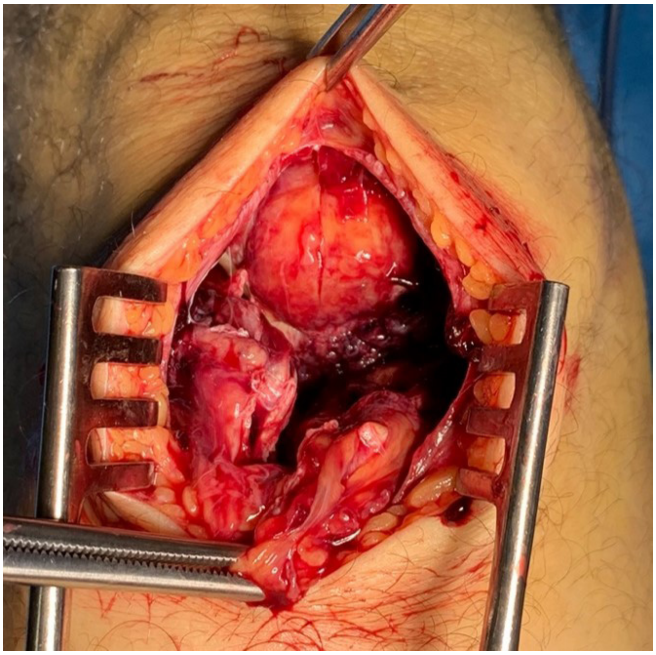

Figure 4. Intraoperative findings during QTR repair.

a quadriceps turndown flap. In this procedure a triangular flap is developed from the superficial part of the tendon tear and folded it over distally, to be sutured to the tendon (2). Once the tendon proper is repaired, associated retinacular tears are repaired with interrupted sutures. The position of the patella and the tensioning of the extensor apparatus are then evaluated before closure. Commonly, quadriceps tendon tears occur at the osteotendinous junction, so the technique described above cannot be used. Surgeons, usually prefer to produce a transpatellar bone tunnel to reinsert the quadriceps tendon. Two pairs of No. 5 non-adsorbable suture are locked end to end in the proximal tendon, to produce four free suture ends. Usually, the upper portion of the patella is then decorticated to facilitate healing. Three parallel longitudinal trans patellar bone tunnels are drilled with a 2.5 mm drill. Free suture strands from the proximal tendon are then passed thorough the tunnels using a Keith needle with the two central strands passing through the central tunnel. The sutures are then knotted distally along the inferior pole of the patella. Sometimes surgeons perform the repair using suture anchors. In this technique, two to three pilot holes are drilled in the upper pole of the patella after the "patellar trough" is prepared (22). The anchors are then placed, and the free suture ends are tied in a locking wave fashion to the proximal tendon. There is no significant difference in displacement following 1,000 loading cycles with a 150-N force between these two techniques aforementioned (23). Proponents of suture anchors point to reduced operative time, higher strength of the repair, and less stress along the suture line. Disadvantages include cost, detachment of the anchorage, and difficult device removal if infection occur (22). Surgeons sometimes opt for an augmentation, but it depends on the sizes of the tears and of the time of the surgery and usually it is not required for an acute primary repair (17, 24, 25). Quadriceps tendon augmentation can be performed both with autografts and allografts, depending on the size of the defect and the patient's clinical conditions, but also using synthetic augmentation (20). The autologous hamstring and peroneus longus (PL) tendon grafts are commonly used for chronically retracted and re-ruptured tendons. For example, McCormick and Rehman both described a bilateral hamstring autograft used to repair a large substance defect caused by a re-rupture of the quadriceps tendon after primary repair (26, 27). With the same aim, Rehman *et al*. performed a reinforcement with a prolene mesh and PRP injection (27). However, when comparing the results of the different surgical techniques, both the gracilis and semitendinosus showed better clinical results (ROM, active flexion and lag absence) and return to daily activities. Other autologous grafts are available: the contralateral ilio-tibial (IT) band, and a medial gastrocnemius-soleus rotational flap (28, 29). An alternative surgical technique is the use of suture anchors or double row suture anchors (30, 31). One of the most challenging problems of chronic quadriceps tendon ruptures is the difficult of having enough tendon length in order to perform a tendon free repair. First step is to detach the quadriceps muscle group from the femur, but if it is not sufficient for the tendon lengthening another procedure is indicated. The Codivilla technique for example is a well-accepted method used to achieve this result, using an inverted V flap from the proximal quadriceps tendon. The inferior edge of the inverted V should be 1 to 2 cm proximal to the rupture, with the apex folded distally and sutured. The open proximal portion of the inverted V is then repaired longitudinally from side-to-side fashion (17). Incidentally, as some authors have described there is no single superior repair method (32). Although there is an increasing trend toward early or immediate post-operative mobilization of the knee, we have found that early mobilization is associated with significantly higher rates of adverse events and total event than fixed immobilization for at least of 6 weeks (32-34).

REHABILITATION

Following quadriceps tendon repair, the knee is immobilized in full extension (17). The rehabilitation program can last up to 6 months after surgery. There is no consensus on when to start knee mobilization, because of a significant hetero-

geneity in the current practice. Usually, the surgeon and physical therapist start rehabilitation the day after surgery. Up to now, few studies evaluated the quality of rehabilitation protocols after surgical repair of the extensor apparatus, most of which using a late weight-bearing and mobilization (35-39). Langenhan *et al*. compared an early functional post-operative mobilization protocol and a more restrictive one in patients surgically treated for QTRs. Of 66 patients, treated for unilateral QTR, 38 patients underwent to early functional rehabilitation while 28 patients followed a restrictive rehabilitation protocol. There were no statistically significant differences between the two protocols in terms of PROMs and return to work. However, early functional mobilization protocols are safe and effective in restoring the extensor mechanism function after surgical intervention (16).
In the current article, three protocols were evaluated and compared, and their main characteristics have been summarized in **table I**.

In a protocol proposed by Vitale *et al*. (40), brace was fixed at 30° of flexion during the first two post-operative weeks, at 45° at the third week and at 60° of flexion during the fourth week. From the fifth week the brace was not used anymore. Therapy sessions were daily (3 times a day for 30 minutes), and the physical therapist aimed to restore passive ROM (p-ROM) on flexion-extension with the use of a Kinetec without exceeding 3-4 Visual analogue scale (VAS) pain values, until he reached the maximum machine ROM capacity. With the increase of p-ROM, exercises for active ROM (a-ROM) were added: heel slides position supine, continuing with proprioceptive exercises and flexion-extension tasks for neuromuscular retraining, stationary bike modifying the height of the seat, and hydrokinetic exercises. Full a-ROM (> 140° of knee flexion) was reached within 18 weeks. Strength training was based on the gradual progression of contraction of the active musculature. Patient started with light isometric contractions with no flexion from

Table I. Comparison of three different rehabilitation protocols.

Protocol	Precautions	Weight bearing	ROM	Strengthening	Cardio	Balance/proprioception
			Timing: 0-14 days			
1*	HBKLE	Weight bearing as tolerated with HBKLE	Passive Rom (p-ROM)	Calf raises		
	No active knee extension			Quad sets		
	No passive knee flexion beyond 60°			Glute sets		
1-2	HBKLE	Partial for first 2 weeks				
	0° to 30° knee flexion					
3	HBKLE and 0° to 30° knee flexion			Submaximal quadriceps settings		
			Timing: 2-6 weeks			
1	Knee flexion PROM starts at 50°	Weight bearing as tolerated with HBKLE; full weight bearing by 6 weeks	Knee flexion p-ROM starts at 50°	Straight leg raises without lag	Upper body ergometer	Standing weight shifts
	HBKLE for standing/walking/sleeping		Progress 10 degrees/weeks until 90°	Side lying hip abduction and adduction, prone leg extension		Progress single limb balance including perturbation training
1-2	Knee flexion to 60° and 90° at 6 weeks	Full weight bearing at 6 weeks	60° maximum end of week 2	Standing hip abduction, adduction, and extension		
			70° maximum end of week 3	Glute bridge with legs straight elevated on a chair		

Protocol	Precautions	Weight bearing	ROM	Strengthening	Cardio	Balance/proprioception
			80° maximum end of week 4	Calf raises		
			90° maximum end of week 5			
			Patellofemoral joint mobilization			
			Heel slide			
			Sitting knee flexion to above ROM			
			Heel prop			
3			Aggressive patella mobility	Increased intensity with quadriceps settings		
Timing: 6-15 weeks						
1		Hinged brace unlocked for ambulation (0-60°) until the patient reaches a sufficient quadriceps control	Patellofemoral joint mobilization		Upper body ergometer	
			Flexion p-ROM with overpressure	Gym equipment: leg press machine, seated hamstring curl machine, hip abductor and adductor machine, hip extension machine, roman chair, seated calf machine	Stationary bicycle: begin with partial rotations, minimal resistance, and gradually progress time and resistance once full motion is achieved	
			Heel slide	Squat to chair	Elliptical: may begin once active knee flexion motion reaches at least 120° able to perform 10 straight leg raises without lag, and gait is normalized without assistive devices	
2		Start pool program and full weight bearing	Sitting knee flexion	Lateral lunges		
				Romanian deadlift (single and double legs)		
				Resisted triple extension in standing		
				Single leg progression		
				Proximal strengthening		

Protocol	Precautions	Weight bearing	ROM	Strengthening	Cardio	Balance/proprioception
			Full ROM recovery			
3	Open brace to 45°-60° at week 6; 90° at week 7			Begin multiplane straight leg raising and closed kinetic chain strengthening program - Initiate open kinetic chain to closed kinetic chain multiplane hip strengthening progressing	Begin elliptical training and treadmill walking program forward and backward	Normalize gait pattern
			Timing: 4-6 months after surgery			
2	Begin sub-max sport specific training in the sagittal plane		Symmetry on handheld dynamometer			
	Progress to plyometric ad agility program		Full ROM, resolved swelling, no pain with walking, at least 80% limb			
1			Step up-down progression			
			Lateral lunges max 45°			
			Light monopodalic leg press in full ROM uphill treadmill walk with or without weight vest			
3			Begin leg extension	Advance gym strengthening	Begin bilateral progressing to unilateral plyometric drills	
				Being pool running program advancing to land as tolerated	Begin multidirectional field/court drills	
			Timing: 6-8 months after surgery			
1-2	Progress running/ sprinting program			Add sport specific exercised based on patient's desired sport goals		
	Improve multidirectional dynamic movements and control of acceleration/ deceleration					
	Improve power in plyometrics and landing mechanics			Complete aerobic and strength training		
	Restore full quadriceps strength					
	Return to sport/ competitions with minimal risk of re-injury					

*Intervention: ice, compression. Protocol 1: Vitale *et al.* (40); Protocol 2: Massachusetts General Brigham Hospital; Protocol 3: Rosenberg Cooley Metcalf; HBKLE: Hinged brace knee locked in extension; ROM: Range of movement; p-ROM: Passive range of movement.

the second week to prevent the effect of arthrogenic muscular inhibition (aMi). From the fourth week, neuro Muscular Electric stimulation (nMEs) was included to support voluntary contraction and to increase the motor units recruited and their intensity of contraction in a second phase, along with the gradual load gain. The patients started isometric exercises at greater degrees of flexion, light isotonic exercises, and hydrokinetic exercises, to re-establish gradual load on both legs. In this phase the physiotherapist can introduce exercises with elastic bands, light isometric two legs squats and stationary bike-cycling. From the thirteenth week, athletes started a heavy-slow resistance training and continued with isotonic training progression. An important variable of the progression of the rehabilitation concerned the transition from bipodalic to single leg exercises. From week 24, the beginning of the last phase of rehabilitation, athletes increased training workloads, especially eccentric training, resistance training, and completed aerobic retraining. Once the subject was able to walk safely with one crutch, hydrokinetic exercises were included, reducing the height of the water to increase the load. Walking without crutches started at week 11. Once walking was stabilized, running re-training started at week 17 and, at this point, treadmill speed was used for training progression. Whenever the subject was able to run 10 minutes at a certain speed, treadmill speed was raised by 0.5-1 km/h. A rehabilitation protocol developed by the Massachusetts General Brigham Hospital consist of four phases (41). The first one was the immediate post operatory phase (33, 41). It lasted fourteen days and was characterized using a knee brace locked in full extension, with weight bearing as tolerated by the patient (33, 42, 43). The first mobilization phase started from passive range of motion exercise with no passive knee flexion beyond 60 degrees (42). The second phase lasted 6 weeks (44). It was characterized from the progress of 10 degrees for each week until 90 degrees were achieved (44). At this stage, active ROM exercises were introduced (41). Weight bearing was permitted as tolerated during the first period, then walking should have been full weight by six weeks with the hinged knee brace locked in full extension (45). Mobilization of patellofemoral joint was performed (45, 46). Some exercises for strengthening were started (38, 47). The third phase lasted until 15 weeks after surgery (16, 41). Restoring active ROM exercises with a progression not faster than 10 degrees per week before the 12 weeks post-op, continuing with the proximal and distal strengthening (35, 48). The hinged brace was unlocked for walking (0-60 degrees) only when the patient demonstrated sufficient quadriceps control (46, 49). Phase four was the longest and could last between 4 and 6 months after surgery (50). It aimed at full recovery, restoring the full ROM and muscle length of quadriceps, quadriceps strength, single leg balance with a progressive return to sport at the end of this phase (48, 51). Another phase was foreseen for athletes and aimed to improve multidirectional dynamic movement and to restore full quadriceps strength (50). There is a paucity of evidence regarding quadriceps tendon injuries rehabilitation protocols and therefore, further studies are needed to clarify and identify a gold standard rehabilitation protocol.

Finally, the Rosenberg Cooley Metcalf protocol is divided in five different phases. The first phase is the phase of maximum protection for the patient and it lasts 6 weeks.

In the first 2 weeks, patients have to use the brace locked in full extension, ice and drugs to reduce pain and inflammation, ROM maximum 0-30 degrees. Begin submaximal quadriceps contraction. Patella mobility is performed aggressively, and partial weight bearing is practiced. During the end of first month the weight bearing became as tolerated, with progressive removal of crutches, the ROM is until 60 degrees and patella mobilization is also performed. The last 2 weeks of the first phase are characterized by the restoration of full weight bearing, and a ROM until 90 degrees. Submaximal quadriceps contractions are increased.

The second phase is characterized by progressive restoration of range of motion with early strengthening. It lasts another 6 weeks. By the eighty week, patient reach full weight bearing, with the brace to 45-60 degrees of flexion at week 6, until 90 degrees at week 7.

Continuing with swelling control and patella mobilization and progressing to full range of motion. At this moment, the protocol initiates multi plane straight leg raising and closed kinetic chain strengthening, with open kinetic chain exercises progressing to closed kinetic chain hip strengthening. It could be useful to begin stationary bike, the pool program and normalize the gait pattern. This second phase ends with a restored full range of motion, beginning treadmill walking program forward and backward. The third phase lasts from week 12 to week 16 with increasing intensity exercises on bike treadmill and elliptical trainer, to execute advanced open and closed kinetic chain strengthening. Compared to other phases, this is characterized by the start of gym strengthening like leg press, hamstring curl, ab and adduction. Finally, the last two phases start, it lasts other eight week and the goal is to improve strengthening and mobility doing advanced gym exercise or performing running and sprinting program. All these protocols are finalized to return to sport, and may presents some limitation. In literature, actually, is often described that, despite a well performed surgery and a well done physiotherapic path, patients can present loss of hyperextension, quadriceps atrophy, knee stiffness and re-rupture (11). As Lee *et al*. (11) described in their paper, the complication rate is relatively low with decreased quadriceps strength and loss of full knee flexion that represent the most commonly reported (17, 52). Up to 75% of patients can show a persistent quadriceps atrophy, although the functional results is often equivocal (18).

FUTURE PERSPECTIVES

The quadriceps tendon tear, like other tendon injuries could be treated in the near future with cell-based therapy and with gene therapy (53). Despite the confusion in terminology and functionality of cell-based therapies, there has been a rapid rise in the use of stem cells attempting, for example, to "grow new cartilage" or regenerate tendon tissues. Two studies on patellar tendinopathy were identified. In both, cells were injected directly into the patellar tendon under ultrasound guidance, showing an improvement (53).

Moreover, some high intensity training protocols can prevent the rupture of quadriceps tendon, but further studies are needed to clarify it.

In conclusion future perspectives in the rehabilitation of quadriceps tendon look promising with many opportunities for new techniques and methods of treatment based on biology.

CONCLUSIONS

The present study showed that in the current practice full weight bearing does not start until the second post-operative week. Surgical repair of QTRs is just the first step of quadriceps tendon healing. Immediate rehabilitation and mobilization are a gold standard in our practice after tendon repair procedures, such as after Achilles tendon repair for insertional Achilles tendon rupture, with good clinical outcomes. Indeed, we stress that immediate postoperative weight-bearing and early mobilization should be achieved to restore the homeostasis of the whole enthesis and extensor apparatus. For these reasons, further studies are needed to establish a protocol followed by surgeons and physical therapist, to guarantee a full recovery and return to sport and daily living activities.

FUNDINGS

None.

DATA AVAILABILITY

Data are provided along with the review.

CONTRIBUTIONS

FO: conceptualization. EM, FC: writing – original draft. NM, FO: writing – review & editing, supervision. All authors: final approval.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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