Acute Quadriceps Muscle Strains

Magnetic Resonance Imaging Features and Prognosis

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Background: There has been no research examining the magnetic resonance imaging findings, and in turn the prognosis, for a series of acute quadriceps muscle strains.

Hypothesis: The magnetic resonance imaging findings of acute quadriceps muscle strain injuries are helpful in predicting their prognosis.

Study Design: Causal-comparative study.

Method: Forty professional players of Australian Rules football were followed over 3 years. Magnetic resonance imaging examinations were performed within 24 to 72 hours of muscle-strain injury. Imaging features of muscle strain injury included the anatomical location, size (cross-sectional area and length), and site (proximal, middle, or distal). The time from injury to return to full training was termed the rehabilitation interval.

Results: 25 clinical quadriceps muscle strain injuries occurred, with 15 cases involving the rectus femoris. The rectus femoris injuries could be further categorized into cases with straining about the central tendon (n = 7, mean rehabilitation interval = 26.9 days) or cases with straining in the periphery (n = 8, mean rehabilitation interval = 9.2 days). Six cases involved one of the vastus muscles (mean rehabilitation interval = 4.4 days). Three players had normal magnetic resonance imaging examinations (mean rehabilitation interval = 5.7 days).

Conclusions: The rectus femoris–central tendon injury is the red flag diagnosis associated with a significantly longer rehabilitation interval.

Clinical Relevance: Magnetic resonance imaging is helpful in predicting the prognosis for acute quadriceps strains.

Keywords: central tendon; rehabilitation interval

INTRODUCTION

Muscle strain injury is the most common injury in Australian Rules football.[27,29,34] The footballers are indeed "athletes at risk" of muscle strain injury,[2,13,24,27] with their game comprising repetitive efforts of sprinting, kicking, and jumping, often over a total period of play of more than 100 minutes. The hamstrings, quadriceps, and calf muscles, in that order, are the most commonly strained muscles.[27] These are the same muscle groups commonly injured in athletes of other sports.[13] There has been no research on the behavior of "acute" rectus femoris strains and no research on vastus muscle strains.

This study commenced when we recognized that our ability to clinically differentiate benign from serious (protracted rehabilitation) quadriceps strains, particularly in the first week after injury, was unreliable. MRI is considered the standard of imaging muscle strain injuries,[7,35,37] and by employing MRI as an adjunct to our clinical examination, we hoped to objectively define both the location and the size of clinical quadriceps muscle strain injuries.[35] The present study is a causal-comparative study designed to investigate the relationship between the MRI findings of

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a series of clinical quadriceps strain injuries and the recovery interval of those injuries.

METHOD

A causal-comparative study was undertaken to investigate the relationship between the MRI findings of a series of acute quadriceps strain injuries and the time taken for recovery, termed the rehabilitation interval (RI). Data were gathered over a 3-year period (1999-2001) from MRI examinations performed 24 to 72 hours after injury. Studies using a causal-comparative approach are ex post facto in nature. Data are collected after the events of interest have taken place, and the researcher seeks causes and relationships. The weaknesses of such designs are lack of control over independent variables and inability to control the selection of subjects. The null hypothesis tested was, in general, as follows: there is no relationship between the type of quadriceps injury and the time taken for rehabilitation.

Subjects

Over a 3-year period, both preseason and in season, 18 players from a team list of 40 male professional Australian Rules football players from 1 club in the national competition sustained a total of 25 clinical quadriceps injuries. These 18 players constituted the subjects for the study. The ages of the players ranged from 18 to 33 years, with the mean age of 23 years. Five players sustained more than 1 injury. It should be noted that the RIs for the injuries of these 5 players were consistent with the RIs of other players, and they were included in the study (a *t* test indicated that there was no significant difference in RI between players sustaining repeated injuries and players sustaining a single injury).

Players were included in the study if they experienced symptoms of pain, ache, or tightness in the anterior thigh, either during playing or training. A clinical examination was then performed by at least 1 of the authors qualified to do so. Tenderness over the anterior thigh was the only clinical sign necessary for inclusion. Players were excluded from the study if the onset of their symptoms (anterior thigh pain, ache, or tightness) was delayed until after finishing training or competing (to exclude "delayed onset muscle soreness"), and they were excluded if there was any suspicion of direct trauma to the anterior thigh (contusion). The dominant/preferred kicking leg was documented. Informed consent was gained from both the football club and each player in the series (N = 18).

MRI Examination

All MRI examinations were performed within 24 to 72 hours after injury. The MRI examination protocol was performed using coronal T1-weighted, T2-weighted with fat suppression and short Ti inversion recovery (STIR), and axial T2-weighted with fat suppression sequences. A marker was positioned over the clinical area of maximal tenderness. The slice spacing for the coronal T1-weighted sequence was 4 mm with a 1.5-mm gap, for the STIR it was 10 mm with no gap, and for the axial T2-weighted images with fat suppression it was 7 mm with a 3.5-mm gap. Both thighs were imaged for comparison. The machine used was a GE 1.5 Teslar Signa Horizon scanner (General Electric Medical Systems, Milwaukee, Wis). Usually, the protocol could be performed with a total examination time of 15 minutes and without requiring the use of gadolinium enhancement.

A muscle was considered injured if there was intramuscular high signal intensity on the T2-weighted with fat suppression images.[6,7,37] If more than one muscle was injured, the muscle with the greatest cross-sectional area and length of signal abnormality was considered the primary injury site.[7] Within each muscle, attention was focused on the location of the known proximal, distal, and intramuscular muscle-tendon junctions. We evaluated other signs of muscle injury including hematoma, recognized as a focal fluid collection with high signal intensity on T1- and T2-weighted images.[7] Hematoma may suggest a more severe muscular-strain injury with muscle-fiber disruption.[3] Actual muscular ruptures (grade 3 injuries[33]) were also evaluated. Based on the considerations of the precise location of the injury, 25 clinical quadriceps strains were categorized (eg, rectus femoris, vastus intermedius [VI]). The size of the injury was quantified by measuring its length and cross-sectional area. The length of the injury was assessed by counting the number of axial T2-weighted slices in which muscle edema and/or muscle fiber disruption was present and then multiplying this number by 10.5 mm (7-mm slice spacing, 3.5-mm gap). For consistency, cross-sectional area as a percentage (CSA%) was calculated by only 1 of the authors who undertook the clinical examinations. The axial T2-weighted with fat suppression sequences were analyzed to determine the slice with the greatest CSA% of injury, and the CSA% was then calculated using the methodology described by Walton et al.[42]

The region (proximal, middle, distal one third) of the involved quadriceps where the injury was maximal (CSA%) was assessed and was termed the *site of injury.* The distance of the skin marker (placed over the site of maximal tenderness) from the MRI axial image with the greatest CSA% was also assessed.

Rehabilitation Protocol

Prior to the start of the study, the rehabilitation protocol used was formulated and standardized as a collaborative effort by the sports medicine/sports science staff at the football club. It was noted that no universally accepted rehabilitation regimen exists for muscle strain injuries.[19,22] The rehabilitation protocol consisted of both the acute management (first 48 hours) and graded rehabilitation/remodeling phases. The first 48 hours involved strict adherence to the principles of rest, ice, compression, and elevation in an effort to minimize both bleeding and edema.

Remodeling phase. This phase involved a 4-stage running and kicking program combined with intensive physiotherapy involving soft tissue therapy and graduated stretching and strengthening exercises. The footballer was eligible to commence the staged running program when he had full pain-free passive range of motion (quadriceps length tested in prone knee flexion and compared with the contralateral side) and could complete 3 sets of 10 repetitions of single leg hops pain free. There was an emphasis on relatively pain-free exercise at all times, and the player could not graduate to the next stage until he had successfully completed the activities of the specific stage he was in. A gentle warm-up and cooldown involving 5 minutes of slow continuous jogging were done in each stage. Players did not run on consecutive days as this was considered potentially injurious.

- *Stage 1:* Jogging for 10 minutes × 2.
- *Stage 2:* Striding (40%-60% maximum) for 80-m intervals. Walk back to start. Three sets × 5 repetitions (rest and gentle stretch after each set of 5 repetitions).
- *Stage 3:* Sprinting (90%-100%) for middle 30 m of 80-m interval. Walk back to start. Three sets × 5 repetitions (rest and gentle stretch after each set of 5 repetitions). The player commenced a staged kicking program in this stage that initially involved kicking a smaller, lighter ball short distances and later progressed to a normal-size ball, kicking longer distances in stage 4 of the running program.
- *Stage 4:* Sport-specific running drills (90%-100% intensity) over 60 m to 80 m, which included shuttle runs, rapid change of direction activities/figure-8 drills, picking up the ball on the run, and kicking the ball on the run. Walk back to start. Three sets × 5 repetitions (rest and gentle stretch after each set of 5 repetitions).

Once the player had completed all 4 stages, he was integrated back into team training. The RI was defined as the number of days from the injury until the player returned to full team training. The decision to return a player to competition was a collaborative one made by the sports medicine/sports science members and was based on the player successfully completing full team training both pain free and with observed full function during that training session. No specific functional tests were used.

RESULTS

Over the 3-year study period, 25 clinical quadriceps strains occurred (Table 1) in 18 subjects. There were 15 rectus femoris strains, 7 rectus femoris–central tendon (RF-CT) strains, and 8 not involving the central tendon but rather occurring in the rectus femoris–peripheral (RF-peri) area. Seven cases involved the vastus muscles, namely vastus intermediate (VI, n = 6) and vastus lateralis (VL, n = 1). There were no cases of vastus medialis injury. Three cases had MRI scans that were normal (MRI negative). There was only 1 case of a double injury, with player 7 having the primary injury about the central tendon and an adjacent secondary injury about the posterior lamina of the rectus femoris. Player 7 was categorized in the RF-CT group for statistical interpretation, as this was the location of his primary injury. There were no cases of muscular rupture (grade 3 injuries).

There were no recurrences of quadriceps muscle strain injury over the study period. Five players (players 1, 2, 4, 5, and 12) sustained more than one MRI positive quadriceps strain, but all these further injuries were either located in the contralateral thigh or at a different location in one of the ipsilateral quadriceps. As already described, the RIs for the injuries of these 5 players were consistent with the RIs of other players in the series.

Figures 1 and 2 (player 1) show the MRI appearance of an RF-CT injury. High T2-weighted signal surrounds the central tendon on the axial image, and a feather-like pattern of injury is seen in the coronal plane. Figure 3 (player 10) shows the axial MRI appearance of an RF-peri injury,

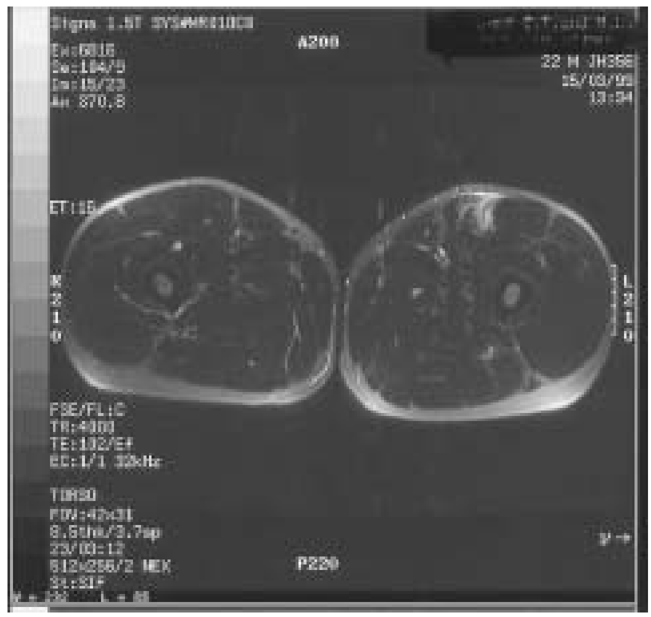

Figure 1. Acute RF-CT muscle strain injury (axial view), the acute bull's eye lesion.

Figure 2. Acute RF-CT muscle strain injury (coronal view).

Figure 3. Acute RF-peri muscle strain injury (axial view).

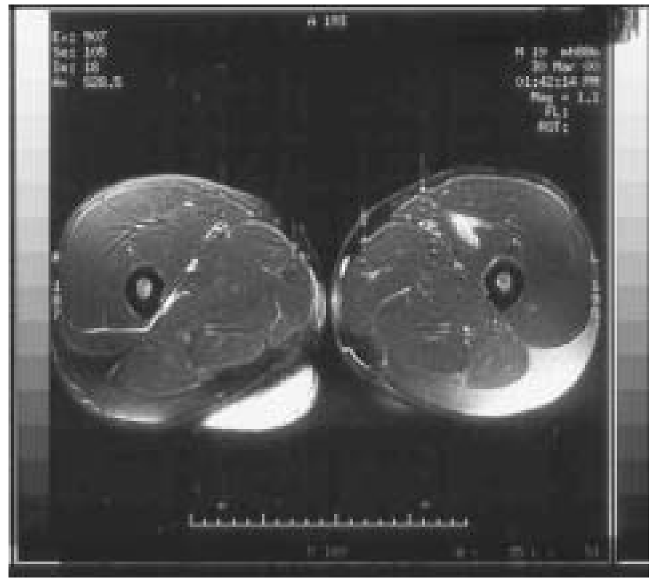

Figure 4. Acute VI muscle strain injury (axial view).

TABLE 1
Case Frequencies, MRI Findings, and Rehabilitation Interval (RI)[a]

Case	Player	Date of MRI	Injured Side	Age of Player	MRI Category	CSA%	Length (cm)	Site	Distance of Marker to Maximal CSA%	RI (days)
1	1	March 15, 1999	Left	22	RF-CT	42	22	Middle	3	32
2	2	March 24, 1999	Left	22	RF-CT	16	13	Proximal	3	25
3	7	April 1, 1999	Right	18	RF-peri	9	6	Proximal	3	10
4	3	May 11, 1999	Right	23	RF-CT	39	18	Middle	4	43
5	1	May 17, 1999	Right	22	RF-peri	24	13	Middle	2	5
6	4	June 28, 1999	Left	25	RF-CT	11	6	Proximal	3	14
7	15	June 16, 1999	Right	33	VL	4	5	Middle	1	6
8	16	June 2, 1999	Left	19	Negative					4
9	17	June 8, 1999	Left	20	Negative					10
10	18	June 8, 1999	Right	19	Negative					3
11	5	December 8, 1999	Right	23	RF-CT	20	26	Middle	1	30
12	13	March 30, 2000	Left	19	VI	13	6	Proximal	5	3
13	4	April 7, 2000	Left	25	VI	29	10	Proximal	0	2
14	2	May 8, 2000	Left	24	RF-CT	35	17	Middle	2	31
15	14	May 1, 2000	Left	29	VI	25	10	Proximal	0	7
16	12	May 2, 2000	Right	23	VI	14	12	Middle	1	5
17	8	June 23, 2000	Left	23	RF-peri	19	7	Middle	3	15
18	4	July 24, 2000	Right	25	VI	23	11	Proximal	1	6
19	5	July 27, 2000	Right	24	VI	16	11	Middle	2	2
20	6	January 24, 2001	Right	25	RF-CT	23	20	Middle	0	35
21	9	April 19, 2001	Right	28	RF-peri	17	8	Proximal	0	9
22	10	April 30, 2001	Left	25	RF-peri	46	13	Proximal	2	12
23	11	May 14, 2001	Right	29	RF-peri	27	8	Proximal	4	5
24	2	May 21, 2001	Left	25	RF-peri	13	6	Proximal	3	7
25	12	July 5, 2001	Left	24	RF-peri	10	7	Proximal	3	7

[a]CSA%, cross-sectional area as a percentage; RF-CT, rectus femoris–central tendon; RF-peri, rectus femoris–peripheral; VL, vastus lateralis; VI, vastus intermedius.

which by definition is distant from the central tendon. Figure 4 (player 13) reveals a VI injury about the anterior lamina of the muscle.

Four of the 7 RF-CT cases occurred within a 4-month period in year 1999. Six of the 7 vastus cases occurred within a 4-month period in year 2000. Five of the 8 RF-peri cases occurred within a 3-month period in year 2001. Three of the 3 MRI-negative cases occurred within a 1-week period in year 1999.

The mean distance of the skin marker (site of maximal tenderness) from the MRI axial image with the greatest CSA% was 2.09 cm. Overall, 18.2% of the markers were accurately placed, 36.4% were 1 cm to 2 cm away, whereas 45.4% were 3 cm or more distant from the maximal MRI muscle strain injury (see Table 1).

Statistical Analysis

Null hypotheses concerning the relationships of main effects (MRI categories, site of injury, length of injury, and cross-sectional area of injury) to the RI were tested. Testing was also completed to indicate possible interactional effects of MRI categories, site of injury, length of injury, and cross-sectional area of injury with the RI. These hypotheses, H1 to H7, are stated formally in the following section. In cases in which no statistically significant differences were identified (ie, preferred kicking leg, injured side, history of injury, and age), due to the small number of cases a power analysis was completed with calculated ds ranging from 0.485 to 3.80, power values of 0.6 to 0.9,[8] "phi estimated" ranging from 0.313 to 1.21, and power values ranging from 0.5 to 0.7, where v (degrees of freedom) = 2 in the case of CSA% and length of injury.[10]

Hypotheses

H1 to H3. There is no statistically significant difference: (H1) between the RI for an injury and the MRI category of the injury (main effect), (H2) between the RI for an injury and the site of the injury (main effect), and (H3) between the RI for an injury and the interactional effects of MRI categories and site of the injury. Tables 2 to 4 illustrate the results due to the testing of null hypotheses H1 to H3, respectively. The null hypotheses are rejected.

The MRI category RF-CT indicates a mean RI of 26.85, days, which is statistically significantly different from categories RF-peri and the vasti, with means of 9.17 days and 4.42 days, respectively (see Table 2). The middle site of injury indicates a mean RI of 16.18 days, which is statistically significantly different from the proximal site of injury, with a mean of 10.78 days (see Table 3). The MRI category RF-CT and the middle site of injury interact to produce a mean of 34.20, which indicates a statistically significantly different interaction from the interactions of MRI categories RF-peri and vasti with the proximal and middle sites of injury (see Table 4).

H4 and H5. There is no statistically significant difference: (H4) between the RI for an injury and the length of the injury (main effect) and (H5) between the RI for an injury and the interactional effects of MRI categories and length of injury. Tables 5 and 6 illustrate the results due to the testing of null hypotheses numbered H4 and H5, respectively. The null hypotheses are rejected.

The length of injury 13 cm plus indicates a mean RI of 20.58 days, which is statistically significantly different from length-of-injury categories 1 to 7 cm and 8 to 12 cm, with means of 9.42 days and 5.70 days, respectively (see

TABLE 2
MRI Categories

	Rehabilitation Interval (days)		Main Effect	
MRI Category	Mean	SE	*F*	*P*
Rectus femoris–central tendon	26.85	1.75	48.55	.001
Rectus femoris–peripheral	9.17	1.70		
Vasti	4.42	1.59		

TABLE 3
Site of Injury

	Rehabilitation Interval (days)		Main Effect	
Site of Injury	Mean	SE	*F*	*P*
Proximal	10.78	1.33	7.74	.013
Middle	16.18	1.41		

TABLE 4
MRI Category × Site

	Rehabilitation Interval (days): MRI Categories × Site			Interaction Effect	
Site	N	Mean	SE	*F*	*P*
Rectus femoris–central tendon					
Proximal	2	19.50	7.78	5.66	.014
Middle	5	34.20	5.26		
Rectus femoris–peripheral					
Proximal	6	8.33	2.50		
Middle	2	10.00	7.07		
Vasti					
Proximal	4	4.50	2.38		
Middle	3	4.33	2.08		

TABLE 5
Length of Injury

	Rehabilitation Interval (days)		Main Effect	
Length of Injury (cm)	Mean	SE	*F*	*P*
1-7	9.42	1.91	4.11	.038
8-12	5.70	1.82		
13 plus	20.58	1.77		

TABLE 6
MRI Category × Length of Injury

Site	Rehabilitation Interval (days): MRI Categories × Length			Interaction Effect	
	N	Mean	SE	*F*	*P*
Rectus femoris–central tendon (cm)					
1-7	1	14.00	0.00	5.49	.016
13 plus	6	32.66	6.02		
Rectus femoris–peripheral (cm)					
1-7	4	9.75	3.77		
8-12	2	7.00	2.83		
13 plus	2	8.50	4.95		
Vasti (cm)					
1-7	2	4.50	2.12		
8-12	5	4.40	2.30		

Table 5). The MRI category RF-CT and a length of injury 13 cm plus interact to produce a mean of 32.66, which indicates a statistically significantly different interaction from the interactions of MRI categories RF-peri and vasti with 1 to 7 cm and 8 to 12 cm lengths of injury (see Table 6).

H6 and H7. There is no statistically significant difference (H6) between the RI for an injury and the cross-sectional area (main effect) and (H7) between the RI for an injury and the interactional effects of MRI categories and cross-sectional area. Tables 7 and 8 illustrate the results due to the testing of null hypotheses numbered H6 and H7, respectively. The null hypotheses are rejected.

Cross-sectional area 15% to 24% and cross-sectional area 25% plus (in effect 15% plus) indicate a mean RI of 14.56 days and 16.11 days, respectively, which is statistically significantly different from cross-sectional area 1% to 14% with a mean of 8.89 days (see Table 7). The MRI category RF-CT and cross-sectional area 15% to 24% and cross-sectional area 25% plus (in effect 15% plus) interact to produce means of 30.00 days and 35.33 days, respectively, which indicate a statistically significantly different interaction from the interactions of MRI categories RF-peri and vasti with cross-sectional areas 1% to 14%, 15% to 24%, and 25% plus (see Table 8).

DISCUSSION

There are several significant findings from our study. Results indicate that for acute quadriceps muscle strains, the prognosis is significantly dependent on both the site and the size (CSA% and the length independently predictive) of the muscle strain injury. However, the precise anatomical location of muscle strain injury, termed the *MRI category*, is the most significant predictor of the RI. In particular, the RF-CT diagnosis carries the least favorable prognosis and may be considered the "red flag" injury that heralds a protracted rehabilitation. Pomeranz and Heidt[31] demonstrated a significant correlation between CSA% and the prognosis for a series of acute hamstring strains. There was, however, no distinction made between injuries associated with the intramuscular tendons or more peripherally sited strain injuries.[15,31] That is, these injuries were not anatomically categorized.

All 22 of the MRI-positive cases in our study showed straining about known muscle tendon junctions concurring with basic science studies.[1,14] There were no cases of grade 3 injury, in particular not a single case of the classically described distal rupture of the rectus femoris,[5,18,37] suggesting that this injury may be less common than was previously thought. The rectus femoris was the most commonly injured muscle in the series (15 out of 22 MRI-positive cases), which is consistent with clinical reports[5,13,16,33] that it is an "at-risk" muscle. All 25 clinical quadriceps strains had maximal tenderness over the midline of the anterior thigh, despite 7 occurring in a vastus muscle and 3 being MRI negative (tenderness over the rectus femoris does not necessarily equal an injury of the rectus). Moreover, the site of maximal tenderness was often 3 cm or more from the site of maximal MRI muscle strain injury. The ability of MRI to "probe beneath the skin" and objectively define

TABLE 7
Cross-sectional Area

Cross-sectional Area (%)	Rehabilitation Interval (days)		Main Effect	
	Mean	SE	*F*	*P*
1-14	8.89	1.87	4.49	.033
15-24	14.56	1.56		
25 plus	16.11	1.67		

TABLE 8
MRI Category × Cross-sectional Area[a]

Site	Rehabilitation Interval (days): MRI Categories × CSA%			Interaction Effect	
	N	Mean	SE	*F*	*P*
Rectus femoris–central tendon (%)					
1-14	1	14.00	4.34	3.47	.039
15-24	3	30.00	3.51		
25 plus	3	35.33	2.51		
Rectus femoris–peripheral (%)					
1-14	3	0.00	2.51		
15-24	3	9.67	2.51		
25 plus	2	8.50	3.07		
Vasti (%)					
1-14	3	4.67	2.51		
15-24	2	4.00	3.07		
25 plus	2	4.50	3.07		

[a]CSA%, cross-sectional areas as a percentage.

not only the precise anatomical location but also the size of muscle strain injury is appreciated.[7,31,35]

Clustering of MRI Injury Categories

Over the 3-year study period, we observed clustering or rather "epidemics" of all 4 MRI injury categories. The most significant clustering was found in the vastus and MRI-negative categories. It is recognized that the causes of muscle strain injury are multifactorial and that sound scientific evidence identifying individual proposed risk factors is confounded by this.[13,27] Past muscle strain injury is perhaps the most recognized risk factor.[13,27] Other proposed risk factors include low muscle strength, muscle fatigue, age, lack of warm-up, muscle temperature, and poor flexibility.[13,24,27] For quadriceps muscle strains in Australian Rules footballers, Orchard found that both recent (less than 8 weeks) and remote quadriceps strain injury, recent hamstring strain, dominant kicking leg, short stature, and ground hardness were all associated with increased risk.[27] Orchard was describing the incidence of clinical quadriceps muscle strains over a 7-year period in the national competition; that is, these injuries were not routinely defined by MRI, and therefore it is not known what type (MRI category) of quadriceps strain had occurred. However, to study risk factors for quadriceps strain injury was not the primary objective of our study, and we can only speculate on the clustering that did occur. The training schedule was periodized into intensive and less intensive weeks. Cross-training activities (pool sessions, light weights circuits, running on the beach) were interspersed into the program. Coaching staff may plan or react to an area of perceived skill deficiency by increasing practice in that area (eg, kicking). The timing of weight sessions around team field training often changed week to week based on the timing of the upcoming match. Training with wet footballs and ground hardness also changed over time.

The explanation for the clustering of injury categories is thought to be multifactorial. This finding warrants further investigation.

Rectus Femoris Strains

The most commonly described strain injury to the rectus femoris is the complete rupture of the distal musculotendinous junction with a resultant anterior thigh mass retracting proximally.[5,16,33] More recently aided by the advent of advanced imaging (CT and MRI), a second type of rectus femoris strain injury was recognized occurring "proximally" within the belly of the muscle.[7,10,12,17,18,20,37] Hughes et al[20] and Hasselman et al[18] (published in series) realized this proximal strain injury contradicted the basic science studies that had found strain injury occurs at or near the muscle-tendon junction.[1,14] They performed cadaveric dissection on the rectus femoris muscle and for the first time described the unique anatomy of the "intramuscular tendon of the indirect head" forming an intramuscular muscle-tendon junction.[18] For brevity, we have termed this intramuscular tendon the *central tendon.*

The importance of defining the anatomy of the musculotendinous junction to understand the imaging of muscle strain injury was first noted by Garrett et al.[15] They performed cadaveric dissection and found the musculo-tendinous junctions of the hamstrings to be complex and to extend into the muscle belly for each of the hamstring muscles.[15]

Only 3 studies (all retrospective) have been published describing a series of remote muscle strains of the rectus femoris.[20,32,39] Moreover, all 3 describe proximal rectus femoris injuries, as described above. Rask and Lattig[32] described a series of 5 such injuries with a mean time to presentation of 6 months. Hughes et al[20] described a series of 10 cases with a mean time to presentation of 39 weeks, and Temple et al[39] described a series of 7 cases with a mean time to presentation of 5 months. In all these cases (19 men, 3 women), the patients complained of a tender anterior thigh mass and/or weakness and pain with athletic activity (eg, running, kicking).

In the series by Hughes et al,[20] imaging studies (CT and/or MRI) demonstrated chronic lesions about, or adjacent to, the central tendon. Hughes et al coined the term the "bull's eye" lesion, which refers to an injury associated with enhancement of signal about the central tendon on T1-weighted scans after intravenous gadolinium.[20] The location of acute RF-CT injuries we defined is identical to the bull's eye lesions described by Hughes et al. Moreover, the MRI appearance is strikingly similar. The high signal seen on T1-weighted image after intravenous gadolinium enhancement in the bull's eye is consistent with the increased vascularity (chronic inflammation) of the lesion.[20] The high signal, best seen on axial T2-weighted images, centered about the central tendon in the acute RF-CT lesions in our study, is thought to represent varying degrees of edema, hemorrhage, and muscle detritus.[6] We have, in turn, termed these lesions *acute bull's eye lesions.*

A theory of Hughes et al[20] explaining the chronic pain and dysfunction experienced by the subjects in their series, was that the indirect (central tendon) and direct heads of the proximal tendon begin to act independently, creating a shearing phenomenon in contrast to what occurs in the normal rectus femoris. We borrow this hypothesis of Hughes et al to explain the longer RI associated with acute RF-CT injuries.

Fortunately, in our series, we did not have a single case of chronic pain or dysfunction, with the longest RI being 43 days for the 7 acute RF-CT cases. Our conjecture for this is that our series involved professional athletes with intensive initial physical therapy and a graded supervised rehabilitation program. The majority of the patients, in the 3 studies mentioned above, were high school or collegiate athletes or soldiers and perhaps had less rigorous one-on-one initial management. Strict attention to initial therapy may limit the initial injury (bleeding in particular), and a graded rehabilitation may remodel the muscle-tendon junctions optimally.

It is interesting to note that the 7 cases with straining in the RF-peri do not behave in the same way as RF-CT injuries (significantly less RI). Indeed, when size is assessed, larger RF-peri lesions have a significantly shorter RI than smaller RF-CT injuries (see Table 1, player 10 vs player 2). There is only 1 case illustrated in the literature of an RF-peri lesion[30] and no reports of their clinical behavior. We cite the hypothesis of Hughes et al[20] that in the context of muscle strain injury about the central tendon, the direct and indirect heads of the proximal tendon begin to act independently, creating a shearing effect, and that this effect does not occur in RF-peri injuries.

Vastus Strains

Seven cases had straining in the vastus muscles (6 VI, 1 VL). One case of VI muscle strain injury[23] and 1 case of VL injury[43] are illustrated in the literature, with no reporting of their clinical behavior. The 3 vastus muscles cross only the knee joint, are composed predominantly of type 1 fibers, and act synergistically to decelerate knee flexion at heel strike.[25,36] The VI arises from the greater trochanter and from the anterior and lateral surfaces of the upper two thirds of the femur. The anterior surface of the muscle is covered by an aponeurosis, which is continued down to the quadriceps tendon.[25] Two cases in our series showed straining about the anterior femoral shaft, and 4 had straining about the anterior aponeurosis (distal muscle-tendon junction, see Figure 4). Both these types of VI strains behaved similarly. The VL case involved straining about the lateral intermuscular septum (proximal muscle-tendon junction).[25] The vastus cases have a significantly shorter RI (mean 4.4 days) than RF-CT cases (mean 26.9 days) but a similar RI to RF-peri and MRI negative cases (mean 9.2 and 5.7 days, respectively).

We suggest that the shorter RI associated with the vastus cases may relate, first, to the fact that a large bulk of muscle is acting synergistically around the involved muscle and, second, that these muscles only cross 1 joint and are composed predominantly of type 1 fiber.

MRI-Negative Cases

Three out of 25 clinical quadriceps muscle strains were MRI negative. The high signal on T2-weighted images is reported to peak 24 hours to 5 days after the time of muscle strain injury.[11,40] How can we explain these 3 footballers' symptoms? Our explanation is twofold. Their anterior thigh pain may have been referred by neuromeningeal structures associated with the femoral nerve.[4] The phenomenon of "back-related" hamstring strains is well recognized, and negative CT[15] and MRI[41] scans for clinical acute hamstring strains have been described. Alternatively, the muscle strain injury was missed on the initial MRI, perhaps because the lesion was too small to be resolved or the edema/inflammatory response was delayed until after the acute MRI (ie, the MRI was done too early).[9]

El-Noueam et al[9] describe 4 cases of muscle strain injury (hip flexor, hip adductor, and periscapular muscles) in which the initial T2- and STIR-weighted MRI images were negative, but after intravenous gadolinium enhancement, lesions were identified. The 4 professional athletes in this series had protracted rehabilitation, with the shortest RI being 2 months. El-Noueam et al stated it was unlikely the nonenhanced images missed the injuries because they were too small but rather because the MRI was done too early (all images done within 48 hours). El-Noueam et al did not advocate the routine use of intravenous gadolinium but rather suggested the consideration of its use in the setting of clinically suspected muscle strain injuries, not visualized on T2- and STIR-weighted images.[9]

The mean RI for the MRI-negative category, in our study, was 5.7 days. Most importantly, this suggests we did not miss any acute bull's eye lesions, as an RI of 5.7 days suggests that if a muscle strain was missed it was from a more benign MRI category (eg, RF-peri or vastus muscles). The disadvantages of the risk and increased scanning time associated with intravenous contrast, we believe, outweigh the benefit, and we do not advocate its use for quadriceps muscle strains.

MRI Look-alikes

The possibility that the MRI lesions seen in the quadriceps muscles were secondary to delayed onset muscle soreness, or direct trauma (contusion), was analyzed. The concept of "MRI look-alikes" has been emphasized by Shellock and Fleckenstein, who advised that muscle strain injury can have the same MRI appearance as both delayed onset muscle soreness and muscle contusion.[35] A thorough clinical history was taken from each of our patients, and inclusion and exclusion criteria were strictly adhered to.

Risk of Recurrence

The finding of persistently abnormal MRI scans when an athlete is considered to be functionally rehabilitated is a phenomenon that has been the subject of recent editorial comment.[28] The high signal would most likely represent persisting edema associated with the inflammatory healing response.[28] Basic science animal studies concur that healing of muscle strain injury may take several weeks/months.[2,21,26,38] Are such athletes with persistent high signal (or scarring) on MRI at any increased risk of recurrent muscle strain injury? We did not perform routine follow-up MRI scans and in turn cannot comment on this aspect of the behavior of acute quadriceps strains. We did find, however, that over the 3-year study period, there were no recurrent injuries in any of the 22 MRI-positive cases. We propose that if the rehabilitation is optimal, the risk of recurrent quadriceps muscle strain injury is minimized.

Indications for MRI

In the acute setting, we believe, and others agree,[6,7,31] that MRI is indicated for a professional and/or elite amateur athlete in cases when both the athlete and others (coach, trainer, manager) would appreciate both an accurate diagnosis and prognosis. Our results suggest that the diagnosis of an acute bull's eye lesion is important information for the athlete and all concerned. For the recreational athlete, the present cost of MRI is, in most circumstances, prohibitive and is not recommended. Our findings suggest that if such a patient is in his or her second or third week of rehabilitation and is still troubled by anterior thigh pain and/or dysfunction, then a bull's eye lesion should be suspected and the patient be carefully rehabilitated.

For remote quadriceps strains (> 8 weeks) troubled by chronic pain and/or dysfunction, we believe MRI is indicated for both the high-level and recreational athlete, to document one of several potential complications (bull's eye lesion,[20] myositis ossificans). Information from MRI is helpful in managing these patients conservatively and will aid surgical planning if they fail to improve in 12 to 18 months.[6,18,20,32,39]

The importance of clinical examination (range of motion, quadriceps strength, functional testing) in assessing both the elite and the recreational athlete should not be overlooked. The MRI should be viewed as an adjunct to the clinical examination.

Limitations and Future Directions

There are some limitations in our methodology to take into account. First, the sports medicine/sports science staff were not blinded to the MRI diagnosis. This may be a potential confounder; however, it should be reiterated that the criteria for progression through the staged rehabilitation program were unambiguous and strictly adhered to. Second, only one of the authors measured the CSA% to facilitate consistency of measurement; however, this situation may have introduced a degree of bias. The T1-weighted axial views were not routinely performed, and this may have affected our ability to differentiate soft tissue planes.[6] We suggest the T1-weighted axial sequence is perhaps more important for imaging hamstring injuries because the anatomy of the intramuscular tendons, and the differentiation of individual muscles, is more complex than the quadriceps.

We have not calculated volumes in this study. The finding that both CSA% and length are predictive of a greater RI suggests that the volume of muscle strain injury may be a significant predictor of prognosis. There have been no volumetric studies of muscle strain injury, and we believe there may be a significant association within a group of similar synergistic muscles (ie, muscles that cross the same number of joints and are of similar fiber composition) between the volume of muscle strained and the RI. New software affords such volumetric measurements and presents new research possibilities for muscle strain injuries.

CONCLUSIONS

This study of the behavior and MRI findings of a series of 25 clinical quadriceps strains has demonstrated several interesting findings:

- MRI objectively defines which quadriceps muscle is injured and where the injury occurs in that muscle with respect to known muscle-tendon junctions, and it enables estimation of the size of the injury.
- The size of the muscle strain injury, assessed by estimating the CSA%, and its length are both independently predictive of the RI.
- A strain about the central tendon of the rectus femoris, the acute bull's eye lesion, is the red flag diagnosis that heralds a significantly longer RI.

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