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Posterior Thigh Muscle Injuries in Elite Track and Field Athletes

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Introduction: Posterior thigh muscle injuries in athletes are common, and prediction of recovery time would be of value.

Hypothesis: Knee active range of motion deficit 48 hours after a unilateral posterior thigh muscle injury correlates with time to full recovery.

Study Design: Cohort study (prognosis); Level of evidence, 2.

Methods: One hundred sixty-five track and field athletes with acute, first-time, unilateral posterior thigh muscle injuries were prospectively evaluated regarding knee active range of motion deficit. This was compared with the uninjured side 48 hours after injury. A control group was also examined. Ultrasound was used to image the muscle lesion. All athletes were managed nonoperatively with the same rehabilitation protocol. The ''full rehabilitation time'' (interval from the injury to full athletic activities) was recorded.

Results: Range of motion of the affected leg was decreased in the 165 injured athletes compared with the uninjured side and the control group. Sonography identified abnormalities in 55% (90 of 165) of the injured athletes. The biceps femoris was the most commonly affected muscle (68 of 90 [75%]). The musculotendinous junction (proximal or distal) was involved in 93% (85 of 90) of lesions. Eighty-one percent (133 of 165) of athletes had active range of motion deficit of less than 20°, and had returned to full performance at 2 weeks. In 6 of 165 athletes (3.6%), with active range of motion deficit of more than 30°, recovery time exceeded 6 weeks, with a significant correlation between full rehabilitation time and active range of motion deficit ($\chi^2 = 152.560$; $P = .0001$).

Conclusion: Knee active range of motion deficit is an objective and accurate measurement, predicting recovery time in elite athletes.

Keywords: hamstrings; athlete; knee range of motion; ultrasound; classification

Muscle strains of the posterior aspect of the thigh are common in athletes participating in high-speed running or activities requiring extremes of range of motion (ROM). Thigh strains were the most common diagnosis (16%) in a sports injuries surveillance study of the 2007 IAAF (International Association of Athletics Federations) World Athletics Championships.[1] Possibly, anatomical reasons (spanning of the hip and knee joints) make them prone to injury,[2,7,12,15-18,22,29,30] and prolonged absence from training and reinjury are not uncommon.[7,18,23] Characterizing the severity of muscle strain is important in prescribing appropriate rehabilitation and predicting recovery time. Approximately 30% of individuals with a previous hamstring strain experience a reinjury within 1 year of the initial injury.[21,30] It is therefore crucial to establish valid criteria to recognize severity and avoid premature return to full activity and the risk of reinjury. The size and location of the injury, as documented on MRI or ultrasound images, may constitute valid indicators of time back to preinjury level.[8,14,25,27] Clinical testing may be as useful as imaging in predicting recovery time.[3,5,26]

The current study investigated acute first-time posterior thigh muscle strains in elite track and field athletes, and correlated knee active range of motion (AROM) deficit and ultrasound imaging with time to return to full athletic activity.

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TABLE 1
Injured Athletes by Track and Field Discipline

Event	No. of Athletes
Sprint	75
Middle and long distance	13
Long and triple jump	39
Throws	15
Combined events	23
Total	165

METHODS

Participants and Eligibility Criteria

Elite track and field athletes (competing at both national and international levels) who sustained a first-time, acute, posterior thigh muscle injury while training or competing were enrolled in a longitudinal, control-based prospective study. The study protocol was approved by the Ethics Committee of the Greek Track and Field Federation, and all athletes gave their written informed consent to participate in the study. The recruitment period extended from January 1999 to December 2005.

All athletes entering the study were thoroughly examined by a single board-qualified senior sports and exercise medicine physician following detailed history taking regarding previous injuries or musculoskeletal problems and the recent injury situation (circumstances [competition or training]; timing; mechanism [running or stretching]). Exclusion criteria included unclear injury situation, bilateral concomitant or asynchronous hamstring strain, verified or even suspected earlier posterior thigh muscle injury, extrinsic trauma to the posterior thigh, pain on palpation in the area of origin or insertion of the posterior thigh muscles, avulsion of the tendon or total rupture of 1, 2, or 3 muscles of the hamstring muscle complex, chronic low back pain or sciatica, and pregnancy. All athletes had the following: (1) local tenderness on palpation at the injured site, (2) pain with resisted movements (hip extension, knee flexion), and (3) pain with passive stretching flexion of the hip with the knee extended.

In the presence of all of the above, athletes were initially managed with the PRICE protocol (protect, rest, ice, compression, and elevation). Ice was applied for 15 minutes every hour for the first 6 hours after the trauma event and initial evaluation, and then every 3 hours. The thigh was protected and compressed using a compressive elastic bandage and was kept elevated. We allowed no motion for the first 6 hours and encouraged isometric exercises for all the periarticular muscles of the hip and knee thereafter, with AROM exercises and weightbearing within pain limits.

From a total of 260 athletes (150 male, 110 female; age range, 18-25 years) with a suspected injury who were initially examined, 165 athletes (97 male, 68 female; age range, 18-24 years) who participated in different track and field disciplines (Table 1) were included in the study. Ninety-five athletes were excluded according to our eligibility criteria. All the athletes enrolled in the study underwent clinical and ultrasonographic examination 48 hours after their injury. Athletes with a grade 3 (total rupture) muscle injury[24] were excluded. The contralateral uninjured leg of the 165 athletes served as the control. In addition, we studied a second control group of 86 elite track and field athletes (27 females, 59 males; age range, 19-25 years), matched for gender and age (±3 years), who had never experienced posterior thigh muscle injury. We did not perform formal power analysis testing.

Clinical Evaluation

Clinical evaluation 48 hours after the injury included the following: (1) inspection for bruising, (2) ability to walk on level ground without pain, (3) palpation of the posterior thigh with the athletes prone and knees extended (for presence or absence of tenderness), (4) provocation of pain on isometric contraction of the posterior thigh muscles, (5) provocation of pain on passive movements (hip flexion with the knee extended with the athlete supine), and (6) measurement of AROM of the knee on the injured and the uninjured side.

Measurements of knee AROM were performed[4,5] using the hamstring AROM supine 90/90 position assessment procedure.[10]

The athlete was supine on an examination couch, with the hip and knee flexed to 90°. The unaffected leg is placed flat on the couch with the knee fully extended, and maintained in this position throughout the test (Figure 1). The athlete is then instructed to actively extend the knee through the full available ROM until he or she experiences symptoms at the injured site and firm resistance is felt at the healthy side, while the hip is maintained at 90° of flexion (Figure 2). The stationary arm of an inclinometer (a double-arm 30-cm clear plastic inclinometer [Lafayette Instrument Company, Lafayette, Indiana]) is aligned along the femur with the reference point at the greater trochanter of the femur; the axis of movement at the lateral epicondyle at the knee, and the moving arm aligned with the lateral malleolus. We measured angles in degrees, in both affected and unaffected sides, representing the AROM.

The difference in ROM data between the injured and uninjured leg was expressed as "AROM deficit." The examiner could not be blinded regarding the presence of injury, as symptoms and signs (eg, pain, bruising) identified the injured leg. The same measurements were performed in both knees in the "control group."

Ultrasound Imaging

Ultrasonography was carried out 48 hours after the injury to identify and define the muscle injury. All scans were performed by the same musculoskeletal radiologist who was unaware of the participant's clinical data, using a 10-MHz linear array transducer. Both legs of the injured and "healthy" athletes were scanned in 2-dimensional real-time B mode. Participants lay prone, with knees fully

Figure 1. Knee extension goniometry: positioning of the inclinometer, starting position.

Figure 2. Knee extension goniometry: positioning of the inclinometer, measurement technique.

extended and feet hanging freely over the end of the examination table. Great care was taken to obtain strictly comparable views of the contralateral sides. Acousting coupling gel was applied to the posterior surface of the thigh. One or two focal zones were used. Imaging was performed in the longitudinal and axial planes. The biceps femoris, semimembranosus, and semitendinosus muscles were scanned along their entire length. The muscles were evaluated with respect to echogenicity and fiber disruption. Edema and hemorrhage was recorded as an area of increased echogenicity with or without muscle fiber disruption visible on orthogonal planes. At ultrasonography, the damaged area was identified. We assessed the following variables: injured muscle, location of injury within the muscle unit (proximal or distal tendon, musculotendinous junction, myofascial area), grade, and injured area (a percentage of the cross section). The injured area was scored according to both muscle strain grades 0 to 3 and the percentage of injured muscle in cross section, according to Peetrons classification of muscle injuries.[24] A grade 0 injury corresponds to a normal ultrasound appearance in spite of the presence of local clinical findings; in grade 1 injury, subtle ultrasound findings may be observed, including ill-defined hyperechoic or hypoechoic intramuscular areas or a swollen aponeurosis; grade 2 and grade 3 injuries correspond to partial and complete muscle tears, in which incomplete or full discontinuity of the muscle occurs.[24] Additionally, the ratio between the area of the maximal abnormality and the area of the entire muscle at the same level was used to obtain the cross-sectional area of muscle injury. The presence of an area of echotexture abnormality within the muscle or of a muscle hematoma was also recorded. The length of the lesions was not documented. This has been suggested to be of predictive value for recovery in other studies, but, at the time of inception of the study, there was no evidence in the literature that the length of the lesion was of any predictive value for recovery.[25] Also, we wanted to correlate our clinical data with a relative measurement of the injured muscle and not an absolute one.

Rehabilitation Protocol

All injured athletes received the same standardized rehabilitation program[19,20] and were supervised by experienced physiotherapists. The rehabilitation process was divided into 4 phases:

Acute Phase. Normalization of gait (this may involve the use of strapping and/or crutches); PRICE.

Range of Motion and Strength Phase. Regain pain-free ROM; starting with concentric training and progressing to eccentric training).

Functional Phase. Controlled lower limb loading and return to running activities; sport-specific training and agility drills; plyometric training.

Return-to-Play Phase. The duration of each phase varies depending on the severity of the injury and the athlete's response. Additionally, care was taken to avoid detraining during the rehabilitation period. Adjuncts that also need to be addressed include maintaining cardiovascular fitness, maintaining motor control skills where possible, and ensuring good hydration and nutritional status of the athlete.

Follow-up

The athletes were followed weekly in the clinic during the rehabilitation program and their return to high-performance activities was recorded. The clinical follow-up period lasted until the athlete returned to pain-free full sport activity. Telephone contacts with the athletes and their coaches were held at 3, 6, 12, 18, and 24 months after injury. The athletes were asked to record the first week they trained or competed unimpeded at their preinjury level with no symptoms and signs (pain, swelling, tenderness) of injury. In addition, we used objective criteria to determine full recovery time. These consisted of AROM deficit values similar to those of the control cohort, isokinetic strength difference at 60 deg/s and 180 deg/s less than 5%, and no difference in the single-legged triple hop

TABLE 2
Muscle Injury Characteristics in 90 of 165 Athletes With Abnormal Findings Documented by Ultrasound Imaging

Characteristics	No. of Athletes (%)
Biceps femoris	68 (75.6)
Semimembranosus	13 (14.4)
Semitendinosus	9 (10)
Musculotendinous junction (MTJ)	85 (93)
Proximal MTJ	19 (21.1)
Intramuscular tendon	34 (36.4)
Distal MTJ	32 (35.5)
Myofascial injury	5 (7)
Grades[a]	
Grade 1	58 (64.5)
Grade 2	32 (35.5)
Cross-sectional area[b]	
<25%	58 (64.4)
25%-50%	26 (28.8)
>50%	6 (6.7)
Hematoma	19 (21.1)

[a]According to Peetrons.[24]
[b]Ratio of the area (cross section) of muscle abnormality to the area of the entire muscle at the same level.

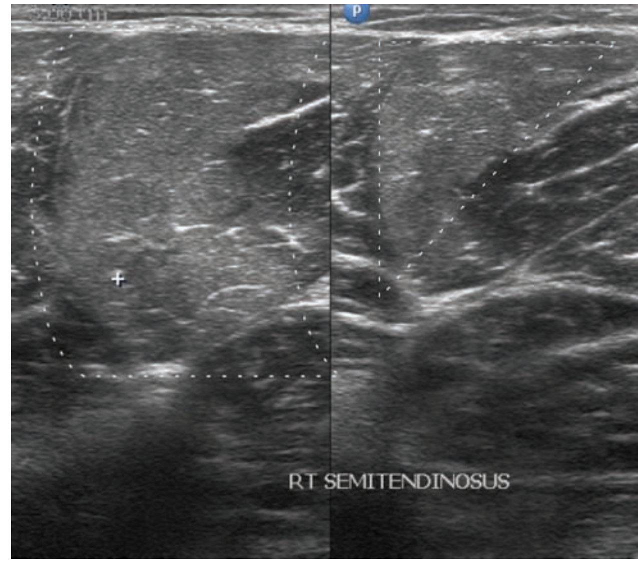

Figure 3. Ultrasound scan of a grade 1 injury according to Peetrons' classification system. Transverse ultrasound images of the semitendinosus muscle. An area of high reflectivity adjacent to the musculotendinous junction is seen (dotted shapes).

test for distance. The latter was the final criterion for return to full athletic activity. We refer to the time interval since the injury as the "full rehabilitation time" (FRT). At follow-up, 23 of the 165 athletes (13.9%) had experienced a second hamstring muscle injury. Of those, 11 were classified in group I, according to their AROM deficit, 10 in group II, and 2 in group III. Ultrasonography (after their first injury) revealed abnormalities in 14 of 23 athletes in this subgroup. These proportions are similar to those in the whole injured athletes' population, and no correlation can be established between AROM deficit or ultrasonographic appearance and risk of reinjury.

Statistical Analysis

Correlation between successful return to competition and clinical and imaging findings was performed using the Pearson correlation. The relationship between the clinical assessment, the criteria used to evaluate the injury on ultrasound, and the time required to return to competition was evaluated using 1-way analysis of variance, χ^2 test, and regression analysis. Ultrasonographic criteria entered included site of injury, cross-sectional area of injury (axial view), and presence of hematoma. Significance was set at $P < .05$. All analyses were performed with SPSS (version 16.0, SPSS Science Inc, Chicago, Illinois).

RESULTS

The AROM of the affected knee decreased in 165 injured athletes (mean, 58.14° ± 13.3°; range, 13°-97°) compared with the asymptomatic side (mean, 67.92° ± 9.3°; range, 44°-94°; $P < .001$). The mean AROM deficit between the injured and the uninjured leg of the study group was 10.75° ± 7.7°. In the control group, the mean ROM of the right knee was 67.0° ± 10.0°, and the mean ROM of the left knee was 68.0° ± 8.6° (range, 44°-97°). There were no significant differences in AROM values between the uninjured side of the 165 athletes of the study group and the control group ($P = .697$). There was a significant difference ($P = .001$) in AROM deficit between the injured leg of the athletes' study group and the control individuals.

Sonography identified abnormalities in 54.6% (90 of 165) of the injured athletes (Table 2, Figures 3 and 4). None of the athletes in this series had more than 1 injured muscle. Despite the clinical diagnosis of posterior thigh muscle injury, normal scans were documented in 45.4% (75 of 165) of the participants (grade 0 according to Peetrons[24]).

The number of days lost from training and competition ranged from 4 to 74 (mean, 14.7 ± 9.6). The posterior thigh muscle strain was categorized according to the AROM deficit. Four grades were used: grade I if the AROM deficit was less than 10°; grade II, AROM deficit between 10° and 19°; grade III, AROM deficit 20° to 29°; and grade IV, AROM deficit greater than 30°. According to this grading, 81% (133 of 165) of the athletes had a knee ROM deficit of less than 20° at 48 hours after their injury and had returned to full athletic activities in less than 2 weeks. Those athletes with a greater AROM deficit required longer recovery (Table 3).

Athletes with a normal scan (75 of 165 [45%]) on the injured side or an abnormal area of less than 25% of the entire muscle cross section (58 of 165 [35%]) had an AROM deficit of less than 20° (grades I and II according to our classification). None of the scans of these 133 athletes

TABLE 3
Classification of Posterior Thigh Muscle Strains in 165 Athletes[a]

Clinical Grade	AROM Deficit	FRT, days (SD)	No. of Athletes	Percent, %
I	<10°	6.9 (2.0)	75	45.4
II	10°-19°	11.7 (2.4)	58	35.2
III	20°-29°	25.4 (6.2)	26	15.8
IV	>30°	55.0 (13.5)	6	3.6

[a]AROM, active range of motion; FRT, full rehabilitation time. SD, standard deviation.

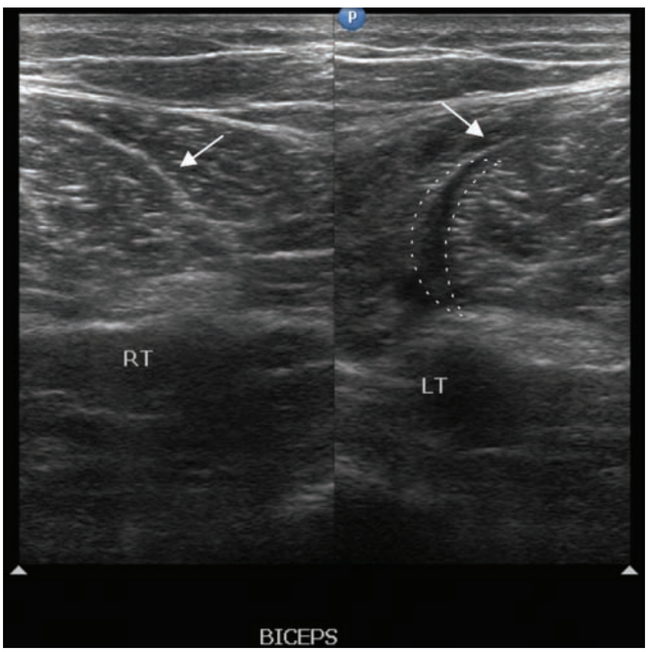

Figure 4. Ultrasound scan of a grade 2 (according to Peetrons) biceps femoris injury. Transverse gray-scale ultrasound images over the proximal part of the biceps femoris muscle: on the right, the scan demonstrates the musculotendinous junction partial tear as an area (dotted shape) of low echogenicity adjacent to the reflective aponeurosis (arrow); on the left, the contralateral normal musculotendinous junction is depicted.

(81%) revealed a hematoma, and the athletes returned to full activities at 2 weeks. On the other hand, an abnormality of more than 25% of the entire muscle cross-sectional area, found in 32 of our 165 athletes (19%), was always associated with an AROM deficit of 20° or more and increased recovery time. Hematoma was present in 19 of those 32 athletes (59%), classified as grades III and IV. At follow-up, 23 of the 165 athletes (13.9%) had experienced a hamstring muscle strain reinjury.

One-way analysis of variance showed a significant effect ($F_{3,162}$ = 68.579; $P < .001$) of the full recovery time factor (ie, there was significant difference between all 4 groups) regarding AROM deficit. Correlation was of AROM in degrees (48 hours after a unilateral posterior thigh muscle injury) with FRT. The post hoc Scheffe test showed that these differences were significant between all 4 groups ($P < .001$). Moreover, the χ^2 test indicates a significant relationship between FRT and AROM deficit (χ^2 = 152.560; $P < .001$). There was also a strong relationship between FRT and AROM deficit values, as the Pearson correlation value was r = .830. However, there was no association between the thigh region injured and days lost from competition.

In addition, the χ^2 test indicates a significant relationship between muscle strain Grade II and AROM deficit (χ^2 = 151.312; $P < .001$). Finally, regarding the prognostic value of AROM deficit measurements and ultrasound criteria, linear regression analysis revealed that only AROM deficit, cross-sectional area greater than 25%, and the presence of hematoma were significant predictors of recovery time (P = .003).

DISCUSSION

Evaluation of the severity of muscle strain is important to plan rehabilitation and predict recovery time, especially in elite athletes. Our study population included only elite track and field athletes and may therefore not reflect the injury characteristics in a different sporting population. Also, we do not know how recreational athletes would behave. This could be the subject of future research.

We believe that classifications based on criteria such as clinical tests, pain, and ability to bear weight are not sufficient. The classification scheme we propose is based on objective and reproducible clinical measurements that can be easily performed in the clinic. In addition, no specialized skills and no special equipment are required.

We performed our clinical and ultrasonographic evaluation 48 hours after the trauma event to allow partial recovery of the lower severity injuries. We thought that in the acute setting, immediately after the injury, significant pain and disability are present, and attempts to accurately determine the athlete's knee ROM on the injured side would be unreliable.

Of those athletes who had sudden onset of pain and tenderness, the ROM in the affected leg had decreased significantly (Table 3). This concurs with other studies.[3] We found that 4 of every 5 track and field athletes with a posterior thigh muscle injury will have a deficit in active knee motion of less than 10° or 20° 48 hours after their injury, and will have returned to full performance at 1 and 2 weeks, respectively. Very rarely (1 in 25), the recovery time exceeds 6 weeks, and these athletes can be identified early, as their knee motion deficit exceeds 30°.

Studies using MRI[25,27] or ultrasound scanning[5,8,25] showed that increased cross-sectional muscle injury area provided a useful prediction for time to return to competition. In addition, those athletes with normal imaging had a significantly faster return to competition, but there was no correlation between the presence of hematoma and recovery.[8] Other authors, however, found that fluid or hemorrhagic collections, cross-sectional involvement greater than 50%, and distal musculotendinous injury were associated with longer recovery times.[25]

We chose ultrasonography to obtain imaging of the injured muscles, as it is less expensive and more accessible than MRI in our setting. Imaging of the injured muscles was used to confirm the diagnosis and to identify complete muscle or tendon ruptures that would indicate operative management. We found that larger (>25%) cross-sectional lesions were associated with longer recovery, whereas the site of injury was not. The site of muscle injury did not correlate with length of recovery, which is contradictory to the findings of other authors.[4] The chosen 48-hour time interval since the injury also allows better delineation of the muscle lesion; muscle strain injuries appear on ultrasound as avulsion and retraction of muscle fibers from the tendon or aponeurosis to which they attach. Sonographic signs of muscle tears include avulsion and proximal retraction of the fibrofatty septa. In low-grade injuries, the space between the retracted septa and the aponeurosis is filled with a hyperechoic area reflecting extravasation of blood and clots. On the other hand, larger muscle tears are characterized by a more substantial blood collection that makes them easily detectable. This does not occur immediately after the trauma, but rather 1 to 2 days later, when the collection tends to become more hypoechoic.[6]

The predominance of biceps femoris injuries in our cohort is consistent with other reports.[8,9,12,16,17,28] The incidence of injury to semitendinosus and semimembranosus muscles in our study was 10% (9 of 90) and 15% (13 of 90), respectively. It varies among different studies,[8,9,11,16,25,28] and this may reflect the difference in the injury patterns among different sports.[9] Several studies have shown, similarly to ours, that injuries occur mostly at the proximal or distal musculotendinous junctions.[8,9,13,17,27]

We observed a correlation between knee motion deficit and sonographic findings. Normal scans and those revealing small cross-sectional abnormal areas in the muscle and no hematoma were associated with an AROM deficit of less than 20°. Consequently, FRT was shorter than 2 weeks. The presence of hematoma was an indicator of injury severity, but was not a consistent finding in athletes with AROM deficit greater than 20° or even 30°. Nevertheless, an abnormal cross-sectional area of more than 25% indicated higher severity and recovery longer than 2 weeks.

Whether imaging is necessary in the assessment of posterior thigh injuries in athletes can be debated. Clinical evaluation can be more accurate than MRI in predicting the time required to return to competition.[26] Our findings support that clinical evaluation alone was adequate in predicting recovery time. Possibly, imaging is indicated only in athletes with excessive reduction in knee ROM (more than 30°), when a hematoma or complete rupture of the muscle is suspected. Routine imaging in clinical practice is probably not justified. Currently, we do not obtain ultrasound scans for grade I and II injuries, making our protocol more practical and cost-effective.

In conclusion, the proposed classification system of posterior thigh muscle injuries is based on an objective, reproducible clinical criterion (active knee ROM deficit), is easily applicable, and was indicative of length of recovery of the athletes.

REFERENCES

1. Alonso JM, Junge A, Renström P, Engebretsen L, Mountjoy M, Dvorak J. Sports injuries surveillance during the 2007 IAAF World Athletics Championships. *Clin J Sport Med*. 2009;19(1):26-32.
2. Árnason Á, Sigurdsson SB, Gudmundsson Á, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. *Am J Sports Med*. 2004;32(1):S5-S16.
3. Askling C, Saartok T, Thorstensson A. Type of acute hamstring strain affects flexibility, strength, and time back to pre-injury level. *Br J Sports Med*. 2006;40:40-44.
4. Askling CM, Tengvar M, Saartok T, Thorstensson A. Acute first-time hamstring strains during high speed running: a longitudinal study including clinical and MRI findings. *Am J Sports Med*. 2007;35:197-206.
5. Askling CM, Tengvar M, Saartok T, Thorstensson A. Acute first-time hamstring strains during slow speed stretching: clinical, magnetic resonance imaging, and recovery characteristics. *Am J Sports Med*. 2007;35:1716-1724.
6. Bianchi S, Martinoli C, eds. *Ultrasound of the Musculoskeletal System*. Berlin: Springer-Verlag; 2007.
7. Brooks JHM, Fuller CW, Kemp SPT, Reddin DB. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. *Am J Sports Med*. 2006;34:1297-1306.
8. Connell DA, Schneider-Kolsky ME, Hoving JL, et al. Longitudinal study comparing sonographic and MRI assessment of acute and healing hamstring injuries. *AJR Am J Roentgenol*. 2004;183:975-984.
9. De Smet AA, Best TM. MR imaging of the distribution and location of acute hamstring injuries in athletes. *AJR Am J Roentgenol*. 2000;174(2):393-399.
10. Gajdosik R, Lusin G. Hamstring muscle tightness: reliability of an active-knee-extension test. *Phys Ther*. 1983;63:1085-1088.
11. Garrett WE. Muscle strain injuries. *Am J Sports Med*. 1996;24(6):S2-S8.
12. Garrett WE Jr, Rich FR, Nikolaou PK, Vogler JB III. Computed tomography of hamstring muscle strains. *Med Sci Sports Exerc*. 1989;21:506-514.
13. Garrett WE Jr, Safran MR, Seaber AV, Glisson RR, Ribbeck BM. Biomechanical comparison of stimulated and nonstimulated skeletal muscle pulled to failure. *Am J Sports Med*. 1987;15:448-454.
14. Gibbs NJ, Cross TM, Cameron M, Houang MT. The accuracy of MRI in predicting recovery and recurrence of acute grade one hamstring muscle strains within the same season in Australian Rules football players. *J Sci Med Sport*. 2004;7:248-258.
15. Jonhagen S, Nemeth G, Eriksson E. Hamstring injuries in sprinters: the role of concentric and eccentric hamstring muscle strength and flexibility. *Am J Sports Med*. 1994;22:262-266.
16. Koulouris G, Connell D. Evaluation of the hamstring muscle complex following acute injury. *Skeletal Radiol*. 2003;32:582-589.

17. Kujala UM, Orava S, Karpakka J, Leppävuori J, Mattila K. Ischial tuberosity apophysitis and avulsion among athletes. *Int J Sports Med*. 1997;18:149-155.
18. Lempainen L, Sarimo J, Heikkilä J, Mattila K, Orava S. Surgical treatment of partial tears of the proximal origin of the hamstring muscles. *Br J Sports Med*. 2006;40:688-691.
19. Malliaropoulos N. *Hamstring Injuries* [dissertation]. London: Queen Mary University of London, Centre for Sports and Exercise Medicine; 1999.
20. Malliaropoulos N, Papalexandris S, Papalada A, Papacostas E. The role of stretching in rehabilitation of hamstring injuries: 80 athletes follow-up. *Med Sci Sports Exerc*. 2004;36(5):756-759.
21. Orchard J, Best TM. The management of muscle strain injuries: an early return versus the risk of recurrence. *Clin J Sport Med*. 2002;12:3-5.
22. Orchard J, Best TM, Verrall GM. Return to play following muscle strains. *Clin J Sport Med*. 2005;15(6):436-441.
23. Orchard JW. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med*. 2001;29:300-303.
24. Peetrons P. Ultrasound of muscles. *Eur Radiol*. 2002;12(1):35-43.
25. Pomeranz SJ, Heidt RS. MR imaging in the prognostication of hamstring injury: work in progress. *Radiology*. 1993;189:897-900.
26. Schneider-Kolsky ME, Hoving JL, Warren P, Connell DA. A comparison between clinical assessment and magnetic resonance imaging of acute hamstring injuries. *Am J Sports Med*. 2006;34:1008-1015.
27. Slavotinek JP, Verrall GM, Fon GT. Hamstring injury in athletes: using MR imaging measurements to compare extent of muscle injury with amount of time lost from competition. *AJR Am J Roentgenol*. 2002;179:1621-1628.
28. Speer KP, Lohnes J, Garrett WE. Radiographic imaging of muscle strain injury. *Am J Sports Med*. 1993;21:89-96.
29. Verrall GM, Slavotinek JP, Barnes PG, Fon GT. Diagnostic and prognostic value of clinical findings in 83 athletes with posterior thigh injury: comparison of clinical findings with magnetic resonance imaging documentation of hamstring muscle strain. *Am J Sports Med*. 2003;31:969-973.
30. Woods C, Hawkins RD, Maltby S, et al. The Football Association Medical Research Programme: an audit of injuries in professional football—analysis of hamstring injuries. *Br J Sports Med*. 2004;38:36-41.