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Clinical and Morphological Changes Following 2 Rehabilitation Programs for Acute Hamstring Strain Injuries: A Randomized Clinical Trial

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Abstract

STUDY DESIGN—Randomized, double-blind, parallel-group clinical trial.

OBJECTIVES—To assess differences between a progressive agility and trunk stabilization rehabilitation program and a progressive running and eccentric strengthening rehabilitation program in recovery characteristics following an acute hamstring injury, as measured via physical examination and magnetic resonance imaging (MRI).

BACKGROUND—Determining the type of rehabilitation program that most effectively promotes muscle and functional recovery is essential to minimize reinjury risk and to optimize athlete performance.

METHODS—Individuals who sustained a recent hamstring strain injury were randomly assigned to 1 of 2 rehabilitation programs: (1) progressive agility and trunk stabilization or (2) progressive running and eccentric strengthening. MRI and physical examinations were conducted before and after completion of rehabilitation.

RESULTS—Thirty-one subjects were enrolled, 29 began rehabilitation, and 25 completed rehabilitation. There were few differences in clinical or morphological outcome measures between rehabilitation groups across time, and reinjury rates were low for both rehabilitation groups after return to sport (4 of 29 subjects had reinjuries). Greater craniocaudal length of injury, as measured on MRI before the start of rehabilitation, was positively correlated with longer return-to-sport

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time. At the time of return to sport, although all subjects showed a near-complete resolution of pain and return of muscle strength, no subject showed complete resolution of injury as assessed on MRI.

CONCLUSION—The 2 rehabilitation programs employed in this study yielded similar results with respect to hamstring muscle recovery and function at the time of return to sport. Evidence of continuing muscular healing is present after completion of rehabilitation, despite the appearance of normal physical strength and function on clinical examination.

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Keywords

MRI; muscle; return-to-sport criteria

Acute hamstring strain injuries are common in sports involving high-speed movements.[7,11,14,24,32] Many athletes return to sport at a suboptimal level of performance,[32] which may contribute to high reinjury rates reported to vary from approximately 15%[11,12,35,36] to more than 50%.[3,21] This has led to speculation that inadequate rehabilitation and/or a premature return to sport may be to blame.[21,24,31] Determining the type of rehabilitation program that most effectively promotes muscle tissue and functional recovery is essential to minimize the risk of reinjury and to optimize athlete performance.

Neuromuscular control exercises[9,23] and eccentric training[1,2,7,13,25,28] have been shown to reduce the likelihood of hamstring injury and are advocated by many to be included as part of rehabilitation following an acute strain injury. Eccentric strengthening, in particular, is believed to increase the series compliance of muscle and allow for longer operating lengths,[8,26] which may offset the effects of scar tissue.[27] Alternatively, Sherry and Best[30] found significantly lower reinjury rates in athletes who completed a progressive agility and trunk stabilization (PATS) program, compared to those whose rehabilitation programs focused on isolated hamstring strengthening and stretching. The authors speculated that the inclusion of exercises targeting muscles that control pelvic motion early in the rehabilitation process might have facilitated recovery from injury and thereby minimized reinjury risk. While both the PATS and the eccentric strengthening rehabilitation programs are promising and may be effective, they have not been directly compared with regard to restoring muscle integrity and function.

It is possible that, regardless of the rehabilitation employed, clinical determinants of recovery, as measured during physical exam (eg, no pain, full range of motion, and full strength), do not adequately represent complete muscle recovery and readiness to return to sport. Despite meeting clinical clearance, 37% of the athletes in a study by Connell et al,[10] as assessed with magnetic resonance imaging (MRI), showed continued evidence of muscle healing after returning to sport, suggesting that athletes may be in an injury-susceptible state.[4,10,29,31,34] The use of MRI near the time of injury has an established prognostic role in estimating convalescent period. A greater amount of T2 hyperintensity, reflective of edema, is associated with a longer rehabilitation time. This correlation has been made using measurements of cranio-caudal (CC) injury length,[10,29,34] percent cross-sectional area of injury,[10,31] distance of maximum signal intensity from the ischial tuberosity,[4] and maximum T2 hyperintensity.[10,31] Regardless of the rehabilitation employed, determining the extent of remaining injury on MRI using these same metrics following the completion of a rehabilitation program may yield further insights into the readiness of the athlete to return to sport.

The purpose of this study was to monitor clinical and morphological changes during the course of rehabilitation in individuals with acute hamstring strain injuries and to determine if differences in outcomes may exist between the 2 progressive rehabilitation programs. The rehabilitation programs utilized were a modified PATS program[30] and a progressive running and eccentric strengthening (PRES) program. We hypothesized that athletes participating in the PATS program would display a greater amount of muscle recovery at the time of return to sport compared to those in the PRES group. We further hypothesized that, regardless of the rehabilitation employed, the majority of athletes would display continued signs of healing on MRI after being clinically cleared to return to sport. Further analyses of time needed to return to sport and MRI measurements were performed to more fully characterize the timeline of hamstring muscle recovery following injury.

METHODS

Trial Design and Participants

This was an equal-randomized, double-blind, parallel-group study. Potential subjects were identified and recruited via physicians, athletic trainers, and physical therapists in Madison, WI and the surrounding communities over a 3-year period. To be eligible for enrollment, individuals had to present with a suspected hamstring injury occurring within the prior 10 days, to be 16 to 50 years of age, and to be involved in sports that require high-speed running (eg, football) a minimum of 3 days per week. All subjects or parents/guardians provided informed consent to participate in this study, according to a protocol approved by the University of Wisconsin Health Sciences Institutional Review Boards. All testing took place at the University of Wisconsin Hospital and Clinics.

All enrolled subjects received a physical examination and MRI within 10 days of the injury. Hamstring injury was confirmed by physical examination conducted by a physical therapist (B.C.H.) and was based on a sudden-onset mechanism and the presence of 2 or more of the following: palpable pain along any of the hamstring muscles, posterior thigh pain without radicular symptoms during a passive straight leg raise, weakness with resisted knee flexion, pain with resisted knee flexion, and/or posterior thigh pain with sports/running. Subjects were excluded from this study if they were identified as having a complete hamstring disruption or avulsion during the initial physical examination or MRI.

Randomization

Following the initial physical examination, the treating physical therapist (M.A.S.) used a 4-block, fixed-allocation randomization process to assign subjects to 1 of the 2 rehabilitation groups (the PATS or PRES group). This randomization process allowed stratification for age, initial injury or recurrent injury, and mechanism of injury. These variables have previously been shown to affect return-to-sport time and reinjury rates.[3,7,15-17] The random allocation sequence was generated by an independent biostatistician.

Interventions

Each subject completed rehabilitation with the same physical therapist (M.A.S.), who was blinded to any information obtained from the initial physical examination and MRI. Each rehabilitation program had 3 treatment phases. In the first phase, ice was applied to the posterior thigh for 20 minutes after completing each rehabilitation session. Subjects progressed into phase 2 when they could walk with the same stride length and stance time on the injured and non-injured limbs (visually assessed) and initiate a pain-free isometric hamstring contraction at 90° of knee flexion with a manual muscle testing grade judged to be at least 4/5. Subjects progressed into phase 3 when they could jog forward and backward with the same stride length and stance time on the injured and noninjured limbs (visually assessed) and demonstrate 5/5 strength on manual muscle testing of the hamstrings in 3 conditions: prone at 90° of knee flexion with the tibia in neutral position, the tibia rotated internally, and the tibia rotated externally.

The PATS group participated in a modified version of the original PATS rehabilitation program.[30] The original PATS program was modified from 2 phases to 3 phases, which allowed for more progressive resistance during the trunk stabilization exercises and added a lunge walk that required trunk rotation and pelvic control with the hamstrings in a lengthened position (APPENDIX A). The progressive agility exercises began with movements primarily in the frontal and transverse planes during phase 1 and progressed to agility and trunk stabilization movements in the transverse and sagittal planes during phase 2. Phase 3 increased the speed and/or resistance of the exercises.

The PRES group performed a rehabilitation program consisting of progressive running and eccentric strengthening that was modeled after the work of Baquie and Reid[6](APPENDIX B). Phase 1 consisted of a short-stride jog and hamstring isometric exercises. Phase 2 incorporated concentric and eccentric strengthening exercises, and phase 3 progressed to intense eccentric strengthening with a power component. Running during phases 2 and 3 consisted of performing a series of sprints with progressive acceleration/deceleration (APPENDIX C).

Treatment implementation and return-to-sport criteria were the same for both rehabilitation groups. Rehabilitation was to be completed 5 days per week at home. Subjects were asked to track their compliance on an exercise log that was submitted at each follow-up visit. Follow-up visits were scheduled according to patient progress and reported symptoms, and participants were monitored by phone calls or electronic mail every few days. A minimum of 1 weekly clinic visit was required of all subjects to monitor exercise technique and to re-evaluate their status. Subjects were allowed to return to sport when they had no palpable tenderness along the posterior thigh, demonstrated subjective readiness (no apprehension) after completing a series of progressive sprints working up to full speed, and scored 5/5 on manual muscle testing of the hamstrings performed on 4 consecutive repetitions in various knee positions. Knee flexion isometric strength testing was performed in prone with the hip in 0° of flexion and the knee flexed at 90° and 15°. Testing was performed with the tibia in neutral, external rotation, and internal rotation for both knee flexion angles. After being cleared to return to sport by the treating physical therapist, all subjects received a final physical exam and MRI. Any subject who incurred a re-injury at any time during rehabilitation or the 6 months following return to sport received a follow-up MRI as soon as possible after the reinjury and, at that point, discontinued study participation.

Outcomes

Primary Outcome Measures—The primary outcome measure was return-to-sport time (days), defined as the period from initial injury to completion of rehabilitation. The CC length of injury, as measured on MRI, was also of primary interest and was measured as the total injured area, accounting for the likelihood that more than 1 muscle would show signs of injury.[10,31,33] All MRI studies were conducted using a phased-array torso coil in a 1.5-T TwinSpeed scanner (GE Healthcare, Waukesha, WI). T2-weighted axial and coronal images were obtained using the following scan parameters: TR/TE_{eff}, 2200 to 3200 divided by 70 to 88 milliseconds; matrix, 512 × 512; 1 NEX; 5-mm axial with no gap; and 4.0/0.4-mm coronal. Images were interpreted by the same musculoskeletal radiologist (M.J.T.), who was unaware of rehabilitation group allocation or clinical details other than suspected hamstring injury. Each image set was examined separately to help ensure unbiased measurements.

Secondary Outcome Measures—Mediolateral width and anterior/posterior depth of the total injured area were also measured on MRI. The cross-sectional area (0.25 × **π** × mediolateral × anterior/posterior) of the injury, as a percentage of the total cross-sectional area, was calculated at the level where the injury had the largest absolute cross-sectional distribution in the muscle(s) (FIGURE 1).[5,10,29,31,34] In addition, the axial slice on the initial examination with the brightest signal intensity was used to measure maximum T2 hyperintensity. On the final MRI, T2 hyperintensity was measured at the corresponding anatomical location. To account for variations in signal quality between examinations, these values were normalized to the average signal intensity in normal, uninjured muscle tissue at their respective time points. Finally, the site of injury was categorized as having occurred to the biceps femoris, semimembranosus, or semitendinosus, as well as having occurred in either the tendon or the proximal, middle, or distal musculotendon junction. Note that no subject in this study experienced an injury to the distal aspect of any of the hamstring muscles.

Both physical examinations were conducted by the same physical therapist (B.C.H.), who was unaware of the type of rehabilitation employed or any information obtained from MRI. The subjects' use of ice and nonsteroidal anti-inflammatory drugs (NSAIDs) prior to enrollment was noted, and all subjects were asked to refrain from NSAIDs once enrolled. The physical examination included bilateral measures of range of motion, strength, and both location and distribution (length) of pain. Surface palpation was used to determine the location of maximal tenderness, which was measured (cm) relative to the ischial tuberosity. The total CC length (cm) of pain in the muscle/tendon unit was also measured with palpation. The passive straight leg raise was performed with the knee in full extension, whereas active and passive knee extension was performed with the hip in 90° of flexion, and joint angles were recorded at the instant of initial hamstring discomfort/pain on the injured side. Isometric knee flexion strength was measured with the subject prone and the knee flexed to 90° and 15°. When the knee was flexed to 90°, knee flexion strength was also measured with the lower leg in neutral, internal rotation, and external rotation. Isometric hip extension strength was measured with the knee at 0° and 90° of flexion. Pain provocation was noted for all strength tests, with strength recorded using a standard manual muscle testing grading scale. As part of the physical examination performed at the time of return to sport, subjects were asked (yes/no) if they (1) were back to their preinjury level of performance, and, if not, whether the hamstring injury was a limiting factor, (2) had any remaining symptoms, and (3) felt hamstring symptoms during running.

After returning to sport, reinjury occurrence was monitored by phone calls or electronic mail at 2 weeks and at 3, 6, 9, and 12 months. A subject was considered to have a reinjury if there was a specific mechanism that caused a return of posterior thigh pain, pain with resisted knee flexion, tenderness to palpation along the muscle/tendon unit, and decreased ability to do sporting activities (perceived strength and power).

Statistical Analysis

A priori sample-size calculation, based on time to return to sport, was performed under the assumption that the standard deviation of time to return to sport would be equal to the difference in time to return to sport between the 2 rehabilitation programs. To achieve 80% power for a *t* test under these assumptions, it was necessary to include 17 subjects per group.

All data were analyzed based on intention to treat. Missing data were treated as missing at random. Subjects who sustained a reinjury were documented, and reinjury rates were compared between groups. The data of subjects who sustained a reinjury were included in the analysis up to the time of reinjury and considered as missing after the reinjury, so as not to skew their rehabilitation results. This method should not have greatly affected the results, because reinjury rates were uncommon and similar between the groups.

Analysis of subject baseline characteristics between the 2 randomly assigned rehabilitation groups was conducted using *t* tests or Wilcoxon rank-sum tests for nonnormally distributed data and the Fisher exact test for categorical characteristics. Analysis of time to return to sport was performed with a 2-sample *t* test. Analyses of change in variables over time were examined with repeated-measures analyses of variance, with time, intervention group, and their interaction as fixed effects and subject as a random effect. The repeated-measures analyses of variance were used to estimate the mean and 95% confidence interval (CI) at each of the time points. Analyses of the association of categorical outcomes and program assignment were conducted with Fisher exact tests. The correlation between time to return to sport and CC length of injury per MRI measure was calculated with a Pearson correlation coefficient. All tests were 2 sided, and significance was set at $\alpha = .05$.

RESULTS

Of the 31 subjects enrolled, 1 subject was excluded because of a biceps femoris avulsion identified on initial MRI, and 1 subject was excluded due to sacroiliac pathology with referred posterior thigh pain (FIGURE 2). Twenty-nine subjects began rehabilitation. Two of those subjects dropped out of the study without reinjury prior to completion of rehabilitation. In addition, 2 subjects sustained a reinjury during the course of rehabilitation. One reinjury occurred during the sprinting portion of return-to-sport testing (subject 26, PRES group). The other reinjury occurred during phase 3 of the PATS program, while performing a single-leg chair bridge (subject 27). A total of 25 subjects completed rehabilitation; however, only 24 subjects (19 male, 5 female; mean ± SD age, 24 ± 9 years; height, 1.80 ± 0.09 m; weight, 79 ± 15 kg) completed return-to-sport testing, because subject 3 sustained a re-injury on the same day he was cleared to return to sport but prior to his scheduled return-to-sport testing.

Initial MRI

The time of initial MRI relative to the time of injury occurred later in the PRES group, with a median (interquartile range [IQR]) of 7 (6-7) days after injury, compared to 5 (3-6) days in the PATS group ($P = .041$). With respect to which muscles were determined as being injured, the MRI and physical examinations agreed in all but 9 of the 29 initial cases; 3 subjects showed no abnormal T2 intensity on initial MRI, and 6 showed disagreement between the clinical and MRI diagnoses as to the primary muscle injured (TABLE 1).

The following results consider only the 26 subjects with MRI indication of injury (T2 hyperintensity). Injury was isolated to only 1 muscle in 12 subjects, visible in 2 muscles for 10 subjects, visible in 3 muscles for 3 subjects, and visible as T2 hyperintensity in 4 muscles for 1 subject (group difference, $P = .180$) (TABLE 1). The median (IQR) initial percent cross-sectional area injured, when considering all muscles involved, was 63% (36%-79%) in the PATS group and 61% (48%-91%) in the PRES group ($P = .233$), and the mean ± SD maximum T2 signal intensity was 3.1 ± 1.0 times that of the uninjured muscle in the PATS group and 2.8 ± 0.7 times that of the uninjured muscle in the PRES group ($P = .518$) (TABLE 2). No significant differences between rehabilitation groups were found for any of the initial MRI measurements.

Initial Physical Examination

The initial physical examination occurred a median (IQR) of 4 (3-6) days after injury in the PATS group and 6 (4-7) days after injury in the PRES group ($P = .161$). Subject questioning revealed that 17 of the 29 subjects (9 of 16 in the PATS group and 8 of 13 in the PRES group) took NSAIDs within 1 to 3 days after the injury and that 7 subjects (3 in the PATS group) continued NSAID use until enrollment in this study. All of the subjects reported using ice within 1 to 3 days after injury, and 18 (8 in the PATS group) continued icing through enrollment in this study. The median (IQR) distance of maximum pain during palpation was 7.4 cm (0.0-16.1) distal to the ischial tuberosity in the PATS group and 7.1 cm (5.5-9.3) in the PRES group ($P = .961$). The mean ± SD length of pain with palpation was 9.9 ± 5.2 cm and 8.3 ± 3.0 cm in the PATS and PRES groups, respectively ($P = .507$). Manual strength testing revealed that not all of the subjects exhibited strength deficits on their injured limb during all tests; however, every subject showed a strength deficit during at least 1 strength test (TABLE 3). Range-of-motion tests revealed that some of the subjects exhibited greater range of motion in their injured limb compared to the uninjured limb. No significant differences between rehabilitation groups were found for any of the initial physical examination measurements.

Primary Outcome Measures

The mean ± SD time to return to sport was 28.8 ± 11.4 days in the PRES rehabilitation group and 25.2 ± 6.3 days in the PATS rehabilitation group ($P = .346$). The mean CC length of injury from the initial MRI examination was 12.8 cm (95% CI: 7.7, 18.0) in the PATS group and 17.3 cm (95% CI: 9.8, 24.7) in the PRES group ($P = .229$). Initial CC length of injury was significantly associated with a longer return-to-sport time ($r = 0.41$, $P = .040$). At return to sport, CC length in the PRES group was 15.9 cm (95% CI: 8.4, 23.4) compared to 7.9 cm (95% CI: 2.7, 13.1) in the PRES group ($P = .037$). The subjects in the PRES group also displayed less improvement in injury length, with an average improvement from baseline of 1.4 cm (95% CI: –1.9, 4.7) compared to 5.0 cm (95% CI: 2.7, 7.2) for those in the PATS group ($P = .035$). Ede-ma and hemorrhage can extend into the fascial plane, which can lengthen the CC extent of injury over time (FIGURE 3). As a result, the change in CC injury length over the course of rehabilitation was variable among all subjects, ranging from a 137% increase in length (subject 22) to a 100% decrease in length. The mean ± SD improvement of only those subjects with MRI indication of injury who completed all rehabilitation and testing (24 subjects) was 39% ± 35% (TABLE 2).

Secondary Outcome Measures

Rehabilitation—The median (IQR) number of days until return to sport was 23 (21-28) and 28 (20-33) in the PATS and PRES groups, respectively ($P = .512$). The median (IQR) number of clinic visits was 4 (3-5) in both groups, and subjects completed a median (IQR) of 20 (13-21) days of rehabilitation at home in the PATS group and 21 (13-28) days in the PRES group ($P = .577$). Based on self-reported exercise logs, rehabilitation compliance was slightly but not significantly higher in the PRES group (mean ± SD, 88% ± 9%) than in the PATS group (80% ± 12%, $P = .070$). No significant differences in return-to-sport time, clinic visits, or rehabilitation compliance were noted between rehabilitation groups.

Final MRI—No subject showed complete injury resolution (no T2 hyperintensity) after being cleared to return to sport (TABLE 2). The mean percent cross-sectional area injured, when considering all muscles involved, was 45.0% (95% CI: 28.9%, 61.1%) at baseline in the PATS group and 61.9% (95% CI: 38.8%, 85.1%) at baseline in the PRES group ($P = .145$). The PATS group improved to a remaining mean percent cross-sectional injured area of 19.2% (95% CI: 2.6%, 35.8%) at follow-up, compared to 33.3% (95% CI: 9.0%, 57.7%) in the PRES group ($P = .244$). The mean improvement from baseline in percent cross-sectional area injured was 25.8% (95% CI: 8.3%, 43.3%) in the PATS group, compared to 28.6% (95% CI: 9.8%, 47.4%) in the PRES group ($P = .822$). The mean normalized T2 signal intensity decreased from baseline slightly more in the PATS group (–0.75; 95% CI: –1.2, –

0.31) compared to the PRES group (–0.50; 95% CI: –0.98, –0.03), but this difference was not significant (P = .438). Finally, the presence of early scar tissue formation was apparent in many of the subjects (FIGURES 3 and 4).

Final Physical Examination—Eleven subjects (7 of 13 remaining subjects in the PATS group and 4 of 12 remaining subjects in the PRES group) indicated that they felt remaining hamstring symptoms (eg, pain, tightness) after being cleared to return to sport (P = .444). Twelve subjects (7 in the PATS group and 5 in the PRES group) indicated that they did not feel that they had returned to their preinjury level of performance (P = 1.0). However, only 3 subjects (2 in the PATS group and 1 in the PRES group) reported that their hamstring injury was a limiting factor in their performance, and general deconditioning was the most cited limiting factor. Pain with palpation and during manual strength tests was nearly absent for all subjects at the time of return to sport (TABLE 3). The subjects in the PRES group showed greater range of motion during the straight leg raise in the noninjured limb at the final physical exam, as opposed to those in the PATS group, who exhibited greater range of motion in the injured limb. Additionally, the subjects in the PRES group tended to show greater mean side-to-side difference in the straight leg raise (noninjured limb – injured limb) at the final physical examination (3.4°; 95% CI: –4.0°, 10.7°) compared to those in the PATS group (–1.8°; 95% CI: –9.7°, 6.2°), but that difference was not significant (P = .337). This trend in the magnitude of the side-to-side difference between groups was consistent with the findings at baseline, where the side-to-side difference was 18.6° (95% CI: 11.6°, 25.7°) for the PATS group and 9.4° (95% CI: 2.0°, 16.7°) for the PRES group (P = .074). No significant differences between rehabilitation groups were observed during the final physical examination or in the amount of improvement between the initial and final physical examinations.

Symptoms and Reinjury Through 12 Months

Two of the 4 subjects who reinjured themselves did so between completion of rehabilitation and the following 12-month period. Subject 3 (PRES group) sustained a reinjury on the same day as being cleared to return to sport, and subject 17 (PRES group) sustained a reinjury 4 days after completion of rehabilitation. At 2 weeks following return to sport, only 5 subjects (1 in the PATS group and 4 in the PRES group) reported continued symptoms that limited their normal participation in sport. At approximately 6 weeks after return to sport, subject 10 (PRES group) ruptured the anterior cruciate ligament in the contralateral knee while landing from a jump while playing basketball, thereby limiting participation in sport. At 3, 6, 9, and 12 months following return to sport, anywhere between 2 and 5 subjects reported continuing symptoms.

MRI of Reinjury

Of the 4 subjects who sustained a reinjury, only 3 received additional MRI. Re-injuries for those 3 subjects occurred in generally the same location as the initial injury, and injury severity did not appear worse than the initial injury (FIGURE 4). To help establish whether any MRI measurement could be a predictor of reinjury, post hoc analysis was conducted to compare the extent of muscle damage measured on initial MRI between the 4 subjects who were reinjured and the other 25 subjects. The reinjured subjects had a significantly greater percent area injured on initial MRI (4 reinjured subjects, 87% [95% CI: 68%, 100%]; the remaining 25 subjects, 54% [95% CI: 43%, 65%]; P = .015). CC length and normalized T2 hyperintensity were not significantly different between the 4 subjects who reinjured themselves and the remainder of subjects.

DISCUSSION

The purpose of this study was to compare clinical and morphological recovery characteristics between 2 progressive rehabilitation programs for an acute hamstring strain injury. Despite all subjects achieving a nearly complete resolution of pain and return of isometric muscle strength on physical examination following completion of rehabilitation (TABLE 3), no subjects exhibited complete resolution of injury on MRI (TABLE 2), and early signs of scar tissue formation were apparent for most subjects (FIGURES 3 and 4). Contrary to our first hypothesis, there were few differences between rehabilitation groups with respect to muscle recovery and function. Most notably, return-to-sport times were similar between groups, and overall reinjury rates were low (1 of 16 subjects in the PATS group and 3 of 13 subjects in the PRES group).

In support of our hypothesis, the presence of injury on MRI was not resolved when subjects returned to sport. Throughout the course of rehabilitation, the size of injury increased for some subjects in terms of both CC length and cross-sectional area (TABLE 2). Cross-sectional area increased as a result of a more diffuse but larger distribution of T2 hyperintensity. At the time of return to sport, the CC length of injury was longer for the PRES group compared to the PATS group. Nevertheless, few clinical conclusions can be drawn from this result, because edema drainage into the fascial plane may occur during the course of rehabilitation and increase the apparent CC length of injury and extend the MRI measurements beyond the actual muscle/tendon damage (FIGURE 3). Although cross-sectional area and volume of injury are relevant indicators of damaged tissue,[10,31] our findings suggest that changes in these measures over time may not be good indicators of injury recovery.

Through 1 year after return to sport, only 4 of the 29 subjects had sustained a reinjury, which is a substantially lower rate than that reported by most of the previous studies.[3,11,12,21,35,36] Of these 4 re-injuries, 2 occurred during rehabilitation and 2 within the first 2 weeks after return to sport. The median return-to-sport time was 23 days, approximately 1 week longer than other reported times.[7,18] Seriousness of participation in sport may affect the commitment of an athlete to complete rehabilitation without undue desire to return to sport too quickly. Specifically, unlike other investigations,[3,11,12,35,36] none of the subjects in this study were professional athletes. Further, we utilized 2 of the most supported rehabilitation programs, which is likely a key factor as to why so few subjects sustained reinjuries. Although we observed very few differences in recovery features between rehabilitation groups, one potential limitation of the PRES rehabilitation program is that the majority of the rehabilitation exercises were only performed on the injured limb. This was done to ensure the stimulus was applied to the injured leg and not compensated for by the uninjured leg. We did not observe any clinical strength deficits at return to sport (TABLE 3) or apprehension with sports-specific explosive movements, but it is possible that neuro-muscular imbalances exist upon return to sport.

The CC length of injury as measured by MRI at the time of injury has been advocated as a strong predictor of time needed to return to sport.[4,10,29,31] Our results support these findings. However, when considering the size of initial injury, past studies have considered only the primary muscle involved when making MRI measurements.[4,10,29,31] Because edema and hemorrhage are often present in more than 1 muscle,[10,31,33] we chose to estimate percent cross-sectional area relative to all of the muscles involved in the initial injury. We believe that this serves as a more comprehensive assessment of initial injury severity.

It is interesting to note that the 2 subjects (subjects 2 and 11) who exhibited some of the greatest remaining muscle injury on final MRI were also the 2 subjects with the greatest reported pain and strength deficits during the final physical examination. Specifically, the CC lengths of injury for subject 2 (28.6 cm) and subject 11 (22.8 cm) were both substantially longer than the group average (15.3 cm) of those that did not reinjure from both groups. (TABLE 2). This finding supports the idea that edema and hemorrhage are related to discomfort and loss of strength.[19,20] Regardless, 3 subjects presented with clinical indication of hamstring strain injury but showed no signs of T2 hyperintensity on their initial or final MRI examinations (TABLE 2). This is not uncommon, as it has been found that 18 of 58 athletes enrolled in a previous study[29] showed clinical indication of hamstring injury but no sign of injury on MRI; 17 of these 18 athletes were classified as having a grade 1 injury. It is therefore possible that MRI evidence of injury may not be present for mild, yet painful, hamstring injuries.

Compared to the initial injury, reinjuries within the same playing season have been shown to occur at the same location and to be more severe on MRI.[22] Based on the follow-up MRI measures in subjects who had sustained a reinjury in this study, the reinjuries occurred in the same location as the initial injury but were not substantially worse (FIGURE 4). It is unclear what might have caused the contrast between these findings across the 2 studies. Post hoc analysis indicated that the percent area injured on initial MRI in the 4 subjects who sustained reinjuries was significantly greater than that in the subjects who were not reinjured. Percent injured area, when including all muscles injured, may be a clinically relevant measure to aid in determining which subjects are most at risk for reinjury; however, further study is needed to investigate the relationship between reinjury rates and percent injured cross-sectional area.

There are several limitations in the present study that prevented direct comparisons with the literature and statistical conclusions and correlations between the imaging and clinical measurements performed in this study. As some studies have done,[30] we used the period from injury to completion of rehabilitation as our definition of return-to-sport time, whereas others have used return to competition[10,29] or return to preinjury level of performance.[4,5] Thus, our return-to-sport time interval (median, 23 days) was considerably less than that of others (median, 112 days).[4] A consistent limitation between our study and others[10,29,34] is the use of MRI at the time of injury. Although MRI measurements may aid the diagnosis and treatment of hamstring strain injuries, it is not feasible for most recreational athletes to obtain MRI following injury. Consistent with common clinical practice, we measured strength using isometric manual muscle testing procedures. Though this measure may be less sensitive than computerized assessments involving a dynamometer, we opted to assess isometric strength at multiple joint positions, including short and long lengths of the hamstring muscles. Finally, we were unable to enroll 17 subjects in each rehabilitation group, as we initially estimated. However, our relatively small subject numbers and diverse athletic population allowed us to present valuable data for clinicians on individual athletes, which highlights how diversity among athletes and injury characteristics may affect recovery during the course of rehabilitation.

CONCLUSION

In general, subjects with an acute hamstring strain injury treated with either the PATS or PRES rehabilitation program demonstrated a similar degree of muscle recovery at the time of return to sport. Despite this, there were no subjects who exhibited complete resolution of injury on MRI, and 2 of the 4 subjects who reinjured themselves did so within the first 2 weeks after return to sport. It remains to be known how the gradually decreasing presence of injury on MRI affects risk of reinjury once athletic activity is resumed. Given the results of this study, it is important that clinicians recognize the presence of ongoing hamstring muscle healing upon completion of a supervised rehabilitation program, despite the appearance of normal strength and function on clinical examination. Based on these findings, athletes may benefit from a gradual return to the demands of full sporting activity and from continued independent rehabilitation after return to sport to aid in minimizing reinjury risk.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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APPENDIX A

The progressive agility and trunk stabilization program consisted of 3 phases. The program was designed to last approximately 2 to 6 weeks but progressed on a subject-specific basis, using criteria as indicated. Intensity was used to guide the stationary biking and agility exercises. Descriptions of the intensity levels were given to athletes and assessed qualitatively during the activity. Low intensity was described as little to no exertion; this intensity can be thought of as primarily used to create motion. Moderate intensity was described as that above daily activity, with some perceived exertion. High intensity was described as a perceived exertion near that of competitive sports.

	Exercises	Sets
Phase 1	Stationary bike • Low intensity	1 × 10 min
	10-m back-and-forth sidestep shuffle • Low to moderate intensity • Pain-free speed and stride	5 × 30 s
	10-m back-and-forth grapevine • Low to moderate intensity • Pain-free speed and stride	5 × 30 s
	Fast foot stepping in place	3 × 30 s
	Prone body bridge (forearm plank)	5 × 10 s
	Side body bridge (plank)	5 × 10 s on each side
	Supine bent-knee bridge	10 × 5 s
	Standing single-leg balance • Progressing from eyes open to eyes closed • Lean forward slightly	4 × 20 s for each limb
Phase 2	Stationary bike • Moderate intensity	1 × 10 min
	10-m back-and-forth sidestep shuffle	6 × 30 s

	Exercises	Sets
	• Moderate to high intensity • Pain-free speed and stride	
	10-m back-and-forth grapevine • Moderate to high intensity • Pain-free speed and stride	6 × 30 s
	10-m back-and-forth boxer shuffle • Low to moderate intensity • Pain-free speed and stride	4 × 30 s
	Rotating body bridge (hand plank) • 5-s hold on each side	2 × 10 repetitions on each side
	Supine bent-knee bridge with walk-outs **1** Begin with knees very bent **2** Holding hips up entire time, alternate small steps out with feet, decreasing knee flexion	3 × 10 repetitions
	Single-leg windmill touches without weight	4 × 8 repetitions per arm per lower limb
	Lunge walk with trunk rotation, opposite-hand toe touch, and T lift • Hip flexed such that the chest and back leg are parallel to the ground as the toe reaches to the opposite foot	2 × 10 steps per limb
	Single-leg balance with forward trunk lean and opposite-leg hip extension	5 × 10 s per limb
Phase 3	Stationary bike • Moderate to high intensity	1 × 10 min
	30-m back-and-forth sideshuffle • Moderate to high intensity • Pain-free speed and stride	6 × 30 s
	30-m back-and-forth grapevine • Moderate to high intensity • Pain-free speed and stride	6 × 30 s
	10-m back-and-forth boxer shuffle • Moderate to high intensity • Pain-free speed and stride	4 × 30 s
	Forward/backward accelerations • Pain-free progression from 5 m to 10 m to 20 m	6 × 30 s
	Rotating body bridge with dumbbell • 5-s hold on each side • 1.4 to 3.6 kg (3-8 lb) based on individual body weight and ability	2 × 10 repetitions
	Supine single-leg chair bridge	3 × 15 repetitions

Exercises	Sets
1 1 leg on a high chair with hip flexed **2** Raise hips, lower, and repeat • Progress from slow to fast speed	
Single-leg windmill touches with dumbbells • 2.3 to 6.8 kg (5-15 lb) based on individual body weight and ability	4 × 8 repetitions per arm per lower limb
Lunge walk with trunk rotation, opposite-hand toe touch, and T lift • Hip flexed such that the chest and back lower limb are parallel to the ground as the toe reaches to the opposite foot • 2.3 to 6.8 kg (5-15 lb) based on individual body weight and ability	2 × 10 steps per limb
Symptom-free individual practice of sport, avoiding sprinting and high-speed maneuvers	

APPENDIX B

The progressive running and eccentric strengthening program consisted of 3 phases. The program was designed to last approximately 2 to 6 weeks but progressed on a subject-specific basis, using criteria as indicated. Intensity was used to guide the stationary biking and agility exercises. Descriptions of the intensity levels were given to athletes and assessed qualitatively during the activity. Low intensity was described as little to no exertion; this intensity can be thought of as primarily used to create motion. Moderate intensity was described as that above daily activity, with some perceived exertion. High intensity was described as a perceived exertion near that of competitive sports.

	Exercises	Sets
Phase 1	Stationary bike • Low intensity	1 × 10 min
	Increasing-effort hamstring isometrics • Submaximal to maximal	10 × 10 s at 3 knee flexion angles (30°, 60°, 90°)
	Bilateral supine heel slides **1** Lie supine on slippery surface **2** Slide heels to buttock and back out	15 repetitions
	Progressive running program (APPENDIX C)	
Phase 2	Stationary bike • Moderate intensity	1 × 10 min
	Prone hamstring curls • Prone with hip flexed at edge of a table (chest and stomach on the table) • Use ankle weights or resistance band	3 × 12 repetitions, injured limb only
	Prone hip extension off edge of bed or table through full range of motion (chest and stomach on the table)	3 × 12 repetitions, injured limb only

	Exercises	Sets
	• Use ankle weights or resistance band	
	Prone leg lift and knee curl **1** Lift straight leg slightly off floor (extend hip) **2** Flex knee without dropping leg	2 × 12 repetitions, injured limb only
	Progressive running program (APPENDIX C)	
Phase 3	Stationary bike • Moderate to high intensity	1 × 10 min
	Nordic hamstring drop-curl progression • Complete 2 pain-free sessions before progressing to next level • Complete all 3 sessions, drop only, then progress through sessions again with drop and curl	3 times per week; (1) 2 × 5 to 8 repetitions, drop only; (2) 3 × 5 to 8 repetitions, drop only; (3) 3 × 9 to 12 repetitions, drop only
	Prone foot catches with ankle weight **1** Lie prone with hip flexed at edge of table **2** Lift leg until parallel with table **3** Drop leg quickly **4** Try to slow the fall and pause just before foot hits the floor	2 × 10 to 20 repetitions, injured limb only
	Prone hip extension off the edge of bed or table for full range of motion • Use ankle weight **1** Lift leg parallel to the floor **2** Drop and catch before leg touches floor	2 × 10 to 20 repetitions, injured limb only
	Standing 1-leg foot catches **1** Stand against the wall **2** Repeat the swing phase of sprinting, pausing just prior to full hip flexion, with the knee extended	2 × 20 repetitions, injured limb only
	Symptom-free individual practice of sport, avoiding sprinting and high-speed maneuvers	

APPENDIX C

PROGRESSIVE RUNNING SCHEDULE

Exercises
• 5 min of gentle stretching before and after each session 3 × 20 s each - Standing calf stretch - Standing quadriceps stretch - Half kneeling hip flexor stretch - Groin or adductor stretch - Standing hamstring stretch

Exercises
• Repeat each level 3 times, progressing to the next level when pain free • Maximum of 3 levels per session • On the following session, start at the second-highest level completed • Ice after each session, 20 min

	Acceleration Distance, m	Constant Speed (Maximum, 75% Speed) Distance, m	Deceleration Distance, m
Level 1	40	20	40
Level 2	35	20	35
Level 3	25	20	25
Level 4	20	20	20
Level 5	15	20	15
Level 6	10	20	10

	Acceleration Distance, m	Constant Speed (Maximum, 95% Speed) Distance, m	Deceleration Distance, m
Level 7	40	20	40
Level 8	35	20	35
Level 9	25	20	25
Level 10	20	20	20
Level 11	15	20	15
Level 12	10	20	10

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KEY POINTS

FINDINGS: A modified PATS rehabilitation program and a PRES program produced similar results with respect to muscle recovery and function following a hamstring strain injury. Athletes participating in both rehabilitation groups continued to show indication of injury on MRI following completion of rehabilitation, despite meeting clinical clearance to return to sport.

IMPLICATIONS: The physical therapist should consider that hamstring muscle recovery continues after an athlete meets clinical clearance to return to sport.

CAUTION: The relatively small sample size in this study limits any conclusions regarding the effectiveness of either rehabilitation program at minimizing reinjury risk.

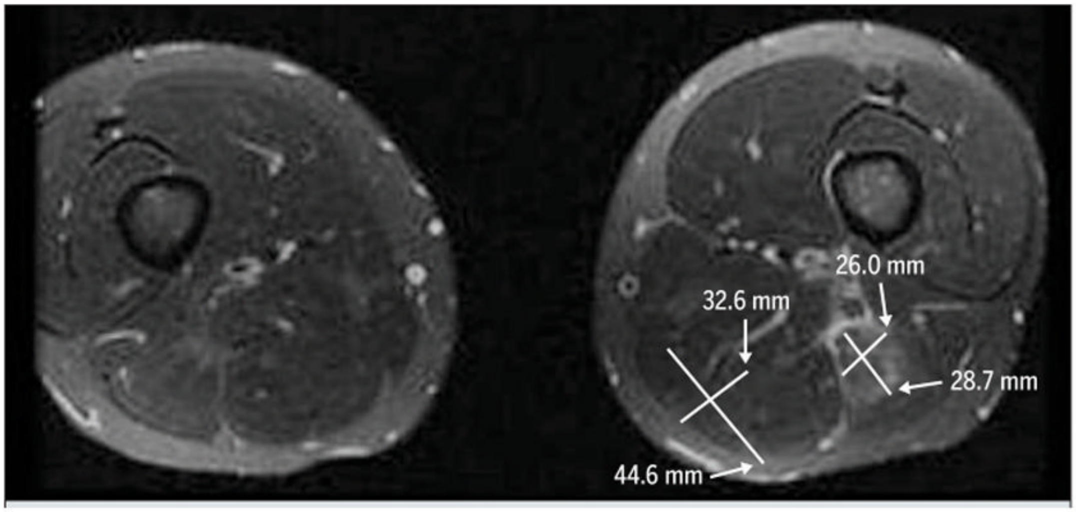

FIGURE 1.
The percent cross-sectional area of injured muscle was estimated by considering all muscles that exhibited T2 hyperintensity.

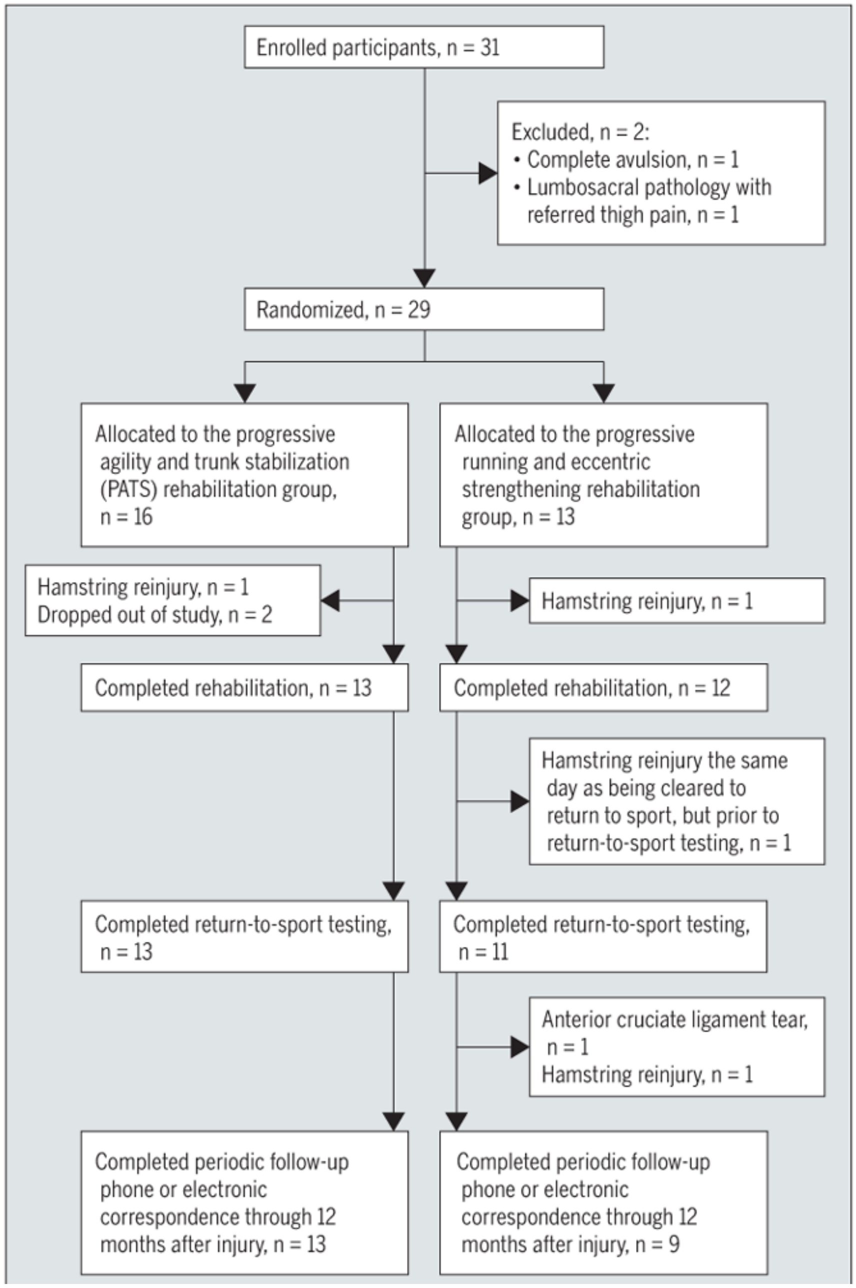

FIGURE 2.
Flow diagram outlining enrollment and testing procedures.

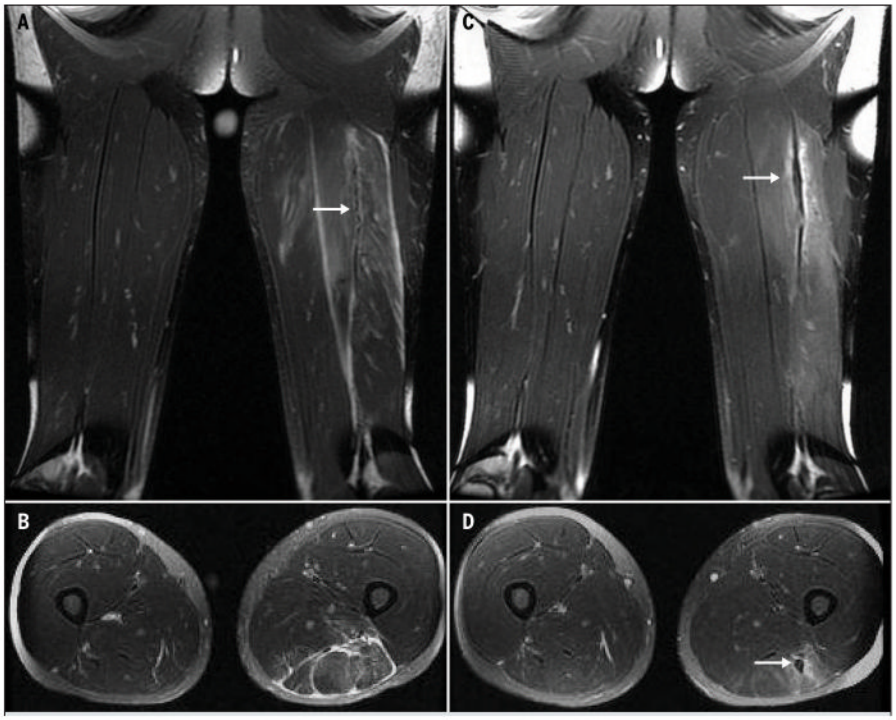

FIGURE 3.
Coronal and axial T2-weighted MRI scans taken after injury (A and B) and after completion of rehabilitation (C and D). The tendon of the injured limb can initially appear wavy (A; arrow). Scar tissue begins to form during the course of rehabilitation and is clearly visible on MRI scans obtained after completion of rehabilitation (C and D; arrows). Edema and hemorrhage (T2 hyperintensity) can extend into the fascial plane (A and B). Over the course of time, fascial drainage can lengthen the craniocaudal extent of injury and result in MRI measurements longer than the actual muscle/tendon damage. T2 hyperintensity was often more concentrated during the initial MRI examination (A and B), compared to a more diffuse signal present in the follow-up MRI examination (C and D). Abbreviation: MRI, magnetic resonance imaging.

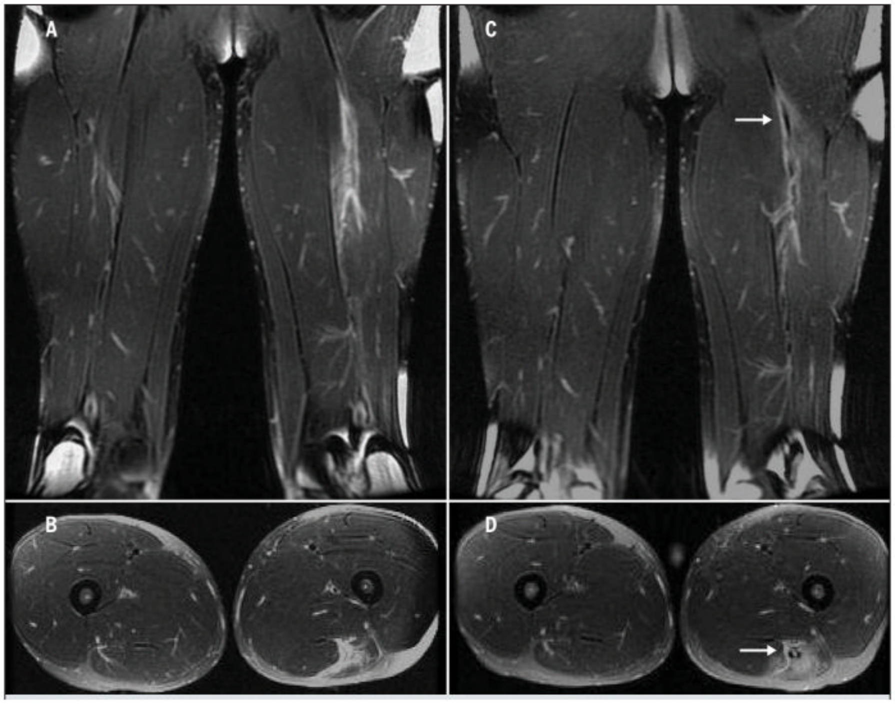

FIGURE 4.
Coronal and axial T2-weighted magnetic resonance images of subject 3, taken after initial injury (A and B) and 7 days after reinjury (C and D). The location of reinjury was similar to the initial injury. Early signs of scar tissue formation can be seen on the second set of images (C and D; arrows).

TABLE 1

Subject Characteristics*

Program/Subject	Gender, Age	Method of Injury	Muscles Involved, n	Primary Muscle	Primary Location	Distance From Origin, cm	Return to Sport, d	Clinic Visits, n	Rehabilitation Compliance (Completed/Assigned), d
PATS									
4	Female, 16 y	Sprinting	2	SM†	Tendon	0.0	37	6	29/34
5	Male, 21 y	Sprinting	1	BF	Tendon	19.0	34	6	19/30
6	Male, 43 y	Sprinting	1	BF†	Mid-MTJ	12.4	33	4	20/27
11	Male, 18 y	Sprinting	2	ST†	Prox MTJ	0.0	28	5	12/13
12	Male, 25 y	Sprinting	2	BF	Prox MTJ	6.3	27	4	12/21
13	Female, 20 y	Extreme stretch	0	NA†	NA	NA	23	4	13/17
14	Female, 18 y	Cutting maneuver	1	SM	Prox MTJ	21.2	23	5	16/20
15	Male, 46 y	Sprinting	1	BF	Tendon	17.3	23	2	14/20
16	Male, 40 y	Sprinting	3	BF	Mid-MTJ	12.6	23	4	18/20
18	Male, 20 y	Sprinting	0	NA†	NA	NA	21	3	16/19
20	Male, 16 y	Sprinting	2	ST	Prox MTJ	8.5	20	3	12/12
23	Male, 21 y	Extreme stretch	1	BF	Distal MTJ	21.1	18	3	10/13
24	Female, 19 y	Extreme stretch	0	NA†	NA	NA	17	3	12/13
27	Male, 36 y	Sprinting	3	BF	Mid-MTJ	5.2	Reinjury	Reinjury	NA
28	Male, 18 y	Extreme stretch	2	BF	Tendon	18.1	Dropout	Dropout	NA
29	Female, 30 y	Sprinting	3	BF	Tendon	0.0	Dropout	Dropout	NA
PRES									
1	Male, 44 y	Sprinting	2	BF†	Prox MTJ	3.7	49	6	36/42
2	Male, 27 y	Sprinting	4	BF	Everywhere	4.4	47	7	35/40
3	Male, 17 y	Sprinting	1	BF†	Mid-MTJ	7.2	40	7	32/40
7	Male, 16 y	Sprinting	2	BF	Tendon	6.9	30	3	28/28
8	Male, 18 y	Sprinting	2	BF	Mid-MTJ	7.0	29	5	22/27
9	Male, 28 y	Sprinting	1	BF	Prox MTJ	8.4	28	4	19/24
10	Male, 28 y	Sprinting	2	BF	Mid-MTJ	13.8	28	3	18/21

Program/Subject	Gender, Age	Method of Injury	Muscles Involved, n	Primary Muscle	Primary Location	Distance From Origin, cm	Return to Sport, d	Clinic Visits, n	Rehabilitation Compliance (Completed/ Assigned), d
17	Male, 17 y	Sprinting	1	BF†	Prox MTJ	0.0	23	4	12/13
19	Male, 16 y	Sprinting	1	BF	Mid-MTJ	17.5	20	3	17/17
21	Male, 17 y	Sprinting	1	BF	Prox MTJ	9.3	19	4	12/13
22	Male, 21 y	Extreme stretch	1	SM	Prox MTJ	5.5	19	2	11/13
25	Female, 22 y	Cutting maneuver	1	SM	Mid-MTJ	15.7	13	2	13/13
26	Male, 19 y	Sprinting	2	BF	Mid-MTJ	7.1	Reinjury	Reinjury	NA

Abbreviations: BF, biceps femoris; MRI, magnetic resonance imaging; MTJ, musculotendon junction; NA, not applicable; PATS, progressive agility and trunk stabilization; PRES, progressive running and eccentric strengthening; Prox, proximal; SM, semimembranosus; ST, semitendinosus.

*Subjects are numbered and sorted based on return-to-sport time (number of days from injury until being cleared to return to sport). Sixteen subjects participated in the PATS program and 13 subjects participated in the PRES program. MRI was used to determine the number of muscles involved in the injury, the primary muscle injured, the primary location of injury, and the distance of injury from the ischial tuberosity (distance of maximum T2 hyperintensity). Compliance of home rehabilitation was calculated as the ratio of completed home rehabilitation days (per self-report exercise log) divided by the number of days assigned. NA represents no MRI indication of injury (ie, no T2 hyperintensity). No subject in this study experienced an injury to the distal aspect of the muscle; therefore, all injury locations are relative to the proximal aspect of the muscle.

†With respect to the muscle injured, the physical examination diagnosis and MRI disagreed in 9 subjects. No T2 hyperintensity was present in the initial MRI examination of 3 subjects. The muscles injured, as determined from the initial physical examination, in these subjects were as follows: subject 13, ST and SM; subject 18, common insertion; subject 24, ST and SM. The muscles injured, as determined on the initial physical examination, for the remaining 6 subjects were as follows: subject 1, ST and SM; subject 3, ST; subject 4, BF; subject 6, SM; subject 11, BF; subject 17, ST.

TABLE 2

Summary of MRI Measures Conducted Before and After Completion of Rehabilitation*

	Craniocaudal Length, cm		Cross-sectional Area, %		Normalized Maximum T2 Hyperintensity	
Program/Subject	Initial	Final	Initial	Final	Initial	Final
PATS						
4	3.2	0.0	100	0	1.5	1.2
5	9.3	7.3	25	37	1.9	1.6
6	18.8	5.5	79	1	2.5	1.7
11	23.7	22.8	71	55	4.6	3.4
12	17.1	6.9	20	2	3.3	2.0
13	NA	NA	NA	NA	NA	NA
14	7.7	2.5	47	6	3.4	2.0
15	16.6	6.8	36	14	3.5	2.2
16	25.2	23.5	79	55	3.5	2.9
18	NA	NA	NA	NA	NA	NA
20	12.8	3.6	33	12	4.2	1.4
23	12.2	4.8	40	43	2.6	2.5
24	NA	NA	NA	NA	NA	NA
27	33.1	Reinjury	100	Reinjury	1.5	Reinjury
28	19.3	Dropout	86	Dropout	3.3	Dropout
29	13.6	Dropout	100	Dropout	4.1	Dropout
PRES						
1	15.6	11.4	64	22	2.4	2.1
2	35.5	28.6	48	28	2.9	3.3
3	18.7	Reinjury	98	Reinjury	3.3	Reinjury
7	30.4	27.8	55	16	2.1	2.1
8	23.5	23.1	61	33	1.8	1.5
9	15.5	12.5	100	40	3	2.6
10	8.7	8.6	35	13	3.4	2.5
17	24.1	22.8	91	100	2.8	2.4
19	7.9	10.4	16	30	3	2.8

Program/Subject	Craniocaudal Length, cm		Cross-sectional Area, %		Normalized Maximum T2 Hyperintensity	
	Initial	Final	Initial	Final	Initial	Final
21	13.1	14.6	100	25	2.4	1.6
22	5.2	12.3	70	43	4.6	2.2
25	8.7	2.3	9	2	2.1	1.9
26	6.8	Reinjury	58	Reinjury	2.9	Reinjury

Abbreviations: MRI, magnetic resonance imaging; NA, not applicable; PATS, progressive agility and trunk stabilization; PRES, progressive running and eccentric strengthening.

*MRI was used to determine the craniocaudal length of injury, percent cross-sectional area, and normalized maximum T2 hyperintensity after injury and after completion of rehabilitation. Because more than 1 muscle is often injured,[10,31,33] craniocaudal length and percent cross-sectional area were measured with respect to the total injured area. NA represents no magnetic resonance imaging indication of injury (no T2 hyperintensity).

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TABLE 3

Summary of Physical Examination Results Conducted Before and After Completion of Rehabilitation*

	PATS†			PRES‡		
	Noninjured	Injured	Reported Pain, n	Noninjured	Injured	Reported Pain, n
Initial evaluation						
Hip extension strength§						
Knee flexed	5 (4+ to 5)	4 (2 to 5)	7	5 (4+ to 5)	4+ (3 to 5)	5
Knee extended	5 (4+ to 5)	4 (2 to 5)	9	5 (4+ to 5)	4 (3 to 5)	8
Knee flexion strength§						
Knee flexed to 15°	5 (5)	4+ (3 to 4+)	10	5 (5)	4+ (3+ to 5)	11
Knee flexed to 90°	5 (5)	4 (3+ to 4+)	10	5 (5)	4 (4+ to 5)	10
Knee flexed to 90° with IR	5 (5)	4 (3 to 5)	8	5 (5)	4 (3 to 5)	7
Knee flexed to 90° with ER	5 (5)	4 (4+ to 5)	5	5 (5)	4 (3+ to 5)	7
Straight leg raise, deg ‖	81 ± 14	63 ± 18	…	80 ± 15	70 ± 16	…
Active knee extension, deg	23 ± 10	21 ± 21	…	29 ± 12	26 ± 9	…
Passive knee extension, deg ‖	34 ± 17	34 ± 20	…	39 ± 22	35 ± 21	…
Length of pain with palpation, cm ‖	0.0	9.9 ± 5.2	…	0.0	8.3 ± 3.0	…
Final evaluation						
Hip extension strength§						
Knee flexed	5 (4+ to 5)	5 (4+ to 5)	0	5 (5)	5 (4+ to 5)	1
Knee extended	5 (4+ to 5)	5 (4+ to 5)	0	5 (5)	5 (4+ to 5)	0
Knee flexion strength§						
Knee flexed to 15°	5 (5)	5 (4 to 5)	1	5 (5)	5 (5)	0
Knee flexed to 90°	5 (5)	5 (4+ to 5)	0	5 (5)	5 (4+ to 5)	1
Knee flexed to 90° with IR	5 (5)	5 (4 to 5)	1	5 (5)	5 (4+ to 5)	1
Knee flexed to 90° with ER	5 (5)	5 (5)	0	5 (5)	5 (5)	0
Straight leg raise, deg ‖	86 ± 14	83 ± 13	…	78 ± 13	80 ± 13	…
Active knee extension, deg ‖	18 ± 8	18 ± 10	…	26 ± 12	23 ± 11	…
Passive knee extension, deg ‖	13 ± 9	13 ± 9	…	21 ± 11	18 ± 9	…

	PATS[†]			PRES[‡]		
	Noninjured	**Injured**	**Reported Pain, n**	**Noninjured**	**Injured**	**Reported Pain, n**
Length of pain with palpation, cm[//]	0.0	0.0	…	0.0	0.0	…

Abbreviations: ER, external rotation; IR, internal rotation; PATS, progressive agility and trunk stabilization; PRES, progressive running and eccentric strengthening.

[*] Two of the original 29 subjects dropped out of the study and 2 subjects sustained a reinjury prior to completion of rehabilitation.

[†] At initial evaluation, n = 16; at final evaluation, n = 13.

[‡] At initial evaluation, n = 13; at final evaluation, n = 11.

[§] Values are median (range of scores reported), with a 5-point maximum. Isometric strength tests were done using a standard manual muscle testing grading scale. For each strength test, the number of subjects who reported pain in their injured limb is indicated.

[//] Values are mean ± SD.