Original Research

Muscle Strains in the Lower Extremity of Japanese Professional Baseball Players

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Background: Predicting when athletes can return to play after muscle strains is not always simple because of difficulties in evaluating the severity of such injuries.

Purpose/Hypothesis: The purpose of this study was to evaluate the use of magnetic resonance imaging (MRI) to classify lower extremity muscle strains in Japanese professional baseball players. The hypothesis was that MRI grading can be used to diagnose the severity of muscle strains in the lower extremity and predict return to play in athletes.

Study Design: Case series; Level of evidence, 4.

Methods: A total of 55 muscle strains occurred in the lower extremity of players on a professional baseball team between the 2006 and 2015 seasons; all players had undergone MRI examination. Age, player position, location of injury, cause of injury, and duration until return to play (in days) were extracted from the medical records. MRI scans were classified using the following system: grade 0, no abnormal findings; grade 1a, T2-weighted high intensity only between muscles; grade 1b, T2-weighted high intensity between muscles and in muscle belly; grade 2, injury of musculotendinous junction; and grade 3, rupture of tendon insertion.

Results: The sites of injuries were distributed as follows: hamstrings (n = 33), quadriceps (n = 6), hip adductors (n = 6), and calves (n = 10). MRI findings revealed 9 muscle strains (16%), 19 grade 1a (34%), 19 grade 1b (34%), and 8 grade 2 muscle strains (16%). The length of time until return to training and competition, respectively, was 15 and 26 days for grade 1a injuries, 19 and 36 days for grade 1b injuries, and 55 and 69 days for grade 2 injuries.

Conclusion: Players with grade 1 injuries took 4 to 5 weeks to return to play, whereas players with grade 2 injuries took 10 weeks to return. MRI can be useful for diagnosing lower extremity muscle strains and predicting the time to return to play.

Keywords: muscle strain; lower extremity; return to play; baseball

Muscle injury is common among athletes. It has been reported that muscle strain commonly occurs with overuse of muscles in high school and collegiate sports in the United States.[4,12] According to the National Collegiate Athletic Association (NCAA) Injury Surveillance Program, hamstring strains are the most common type of muscle strain in athletes and occur frequently in American football, soccer, and sprinting.[5]

Most studies involving muscle strains in professional sports have been conducted in contact sports involving running and kicking[3,8,15-17]; studies involving professional baseball are relatively rare. Camp et al[2] analyzed 50,000 injuries occurring during 6 seasons in Major and Minor League Baseball players and found that injuries to the upper extremity occurred in 39% of cases, whereas injuries to the lower extremity occurred in 35% of cases. Of those injuries, the most common was hamstring strain.

When a muscle strain occurs, players cannot participate in practice or competition for a certain amount of time, to allow for healing from the injury.[3,7,8] Because players want to return to play as soon as possible, they may return before the complete healing of the muscle; consequently, they may

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be reinjured or experience chronic pain, potentially prolonging return to play.[3,7,8] To avoid this situation, medical staff are required to make an accurate diagnosis and prognosis.[8] The diagnosis of muscular injuries is based mainly on clinical findings, but magnetic resonance imaging (MRI) is helpful in confirming the diagnosis, identifying the extent of the injury, and providing prognosis and prediction for return to play.[7,8,17] In a study of Australian Football League players with calf injuries, Waterworth et al[17] found an association between missing at least 1 game and involvement of multiple muscles in the injury, musculotendinous junction strains, deep strains, and intramuscular tendon tears. In some professional sports, such as American football and soccer, MRI grading has been reported to be useful in predicting return to play.[3,8] Cohen et al[3] reported that MRI grading and scoring for hamstring strains are useful in determining the severity of the injury and predicting time missed from play in professional American football players. Ekstrand et al[8] found that MRI can be helpful in verifying the diagnosis of a hamstring injury and in predicting layoff time in professional soccer players. In Japan, Okuwaki[10] classified the muscle strains of athletes into 3 types according to MRI findings, and this classification is widely used as an index to return to play after muscle strains.

The purpose of this study was to evaluate the effectiveness of an MRI grading system for diagnosing the severity of lower extremity muscle strains in professional baseball players. We hypothesized that the MRI grades for muscle strains will be associated with layoff time from baseball and can be used to predict return to play in athletes.

METHODS

Patients and Data Collection

This work was approved by the ethical committee of our institute, and all data were retrospectively collected and analyzed in a deidentified and anonymous fashion in accordance with the Declaration of Helsinki.

Players on a Japanese professional baseball team during 10 seasons (between 2006 and 2015) were enrolled in this study. The mean number of players on the team was 71.5 per year (range, 69-77). In the Japanese professional baseball league (Nippon Professional Baseball Organization), 70 players can be registered per team. All data on injuries during the 10 seasons were retrieved from our medical records retrospectively and were analyzed. A total of 635 injuries required hospital visits as well as clinical examination using radiography, computed tomography scanning, or MRI; 239 of these injuries originated in a muscle, tendon, or ligament. Among these 239 muscle, tendon, and ligament injuries, 100 were diagnosed as muscle strains, and 69 of these muscle strains occurred in the lower extremities. We included players who had lower extremity muscle strains that were diagnosed by clinical findings: apparent cause, tenderness at injury site, and stretching and contraction pain. Players who had muscle strains but who had not undergone MRI were excluded. Players who had experienced subacute or chronic pain for >4 weeks (n = 3) and those with recurrences in the same muscle within 2 years (n = 11) were excluded.

Age at the time of injury, player position, location of injury, cause of injury, and length of time until return to play were retrospectively investigated. The injury rate for each position was calculated by dividing the number of injuries by the average number for each position for a season. Return to play was defined at 2 different points: return to practice (able to practice at the same level as the other players) and return to game (able to play a game without any symptoms). Follow-up for recurrence after the return to play was continued until the end of the season.

Magnetic Resonance Imaging

MRI was performed at multiple facilities. This was due to the need to have the examinations conducted promptly after the clinical diagnosis of muscle strain. Some of the MRI scans were also taken during the spring and autumn training camps or during the away games. The MRI scans taken at other facilities were shared as electronic media within the medical staff at our institute. Because MRI was conducted at >1 facility, the model and type of the MRI machine and the protocol for MRI were not unified. However, the field strength of the MRI machines was mostly 1.5 T (75%) or 3.0 T (18%). The minimum MRI sequences used to evaluate the muscle injuries were the axial and coronal planes T2-weighted with fat-suppression or short tau inversion recovery. When the sagittal plane and any other sequences were available, they were also used for evaluations.

On average, MRI was performed 3.2 days (range, 0-25 days) after the injury. All MRI scans were retrospectively evaluated by at least 2 team doctors (T.K., Y.M.), and injuries were classified according to Okuwaki[10] as follows: grade 0 (no abnormal finding); grade 1 (T2-weighted high-intensity area around muscles) (Figures 1 and 2); grade 2 (T2-weighted high-intensity area in the musculotendinous junction) (Figure 3); and grade 3 (complete discontinuity of tendon or muscle fibers). We further divided grade 1 injuries into 2 categories: grade 1a (T2-weighted high-intensity area only between muscles) (Figure 1) and grade 1b (T2-weighted high-intensity area between muscles and in the muscle belly) (Figure 2) as new subcategories based on the extent of T2-weighted high-intensity area in the muscles (Table 1).

Statistical Analysis

Three investigators (T.K., Y.M., A.I.) determined the MRI grading of the muscle strains in 20 randomly selected lower extremities in order to assess interrater reliability, and a single investigator (T.K.) repeated the MRI grading after 1 month to assess intrarater reliability. The intrarater and interrater reliabilities for the MRI grading system of the muscle strains were evaluated using intraclass correlation coefficients (ICCs) with 95% CIs.

Because analysis of all parameters showed a nonnormal distribution, 1-way analysis of variance with the Kruskal-

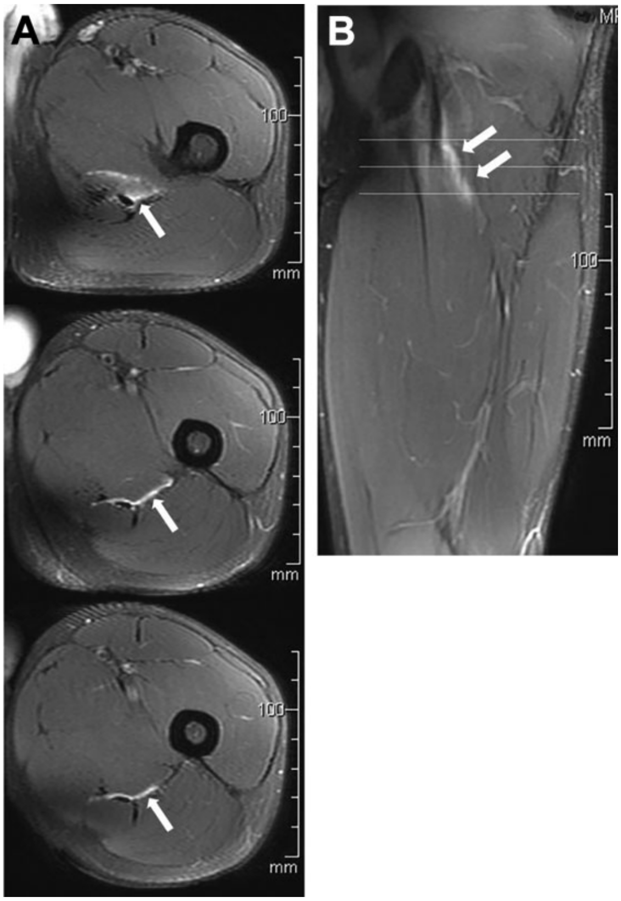

Figure 1. Grade 1a hamstring muscle strain involving the left biceps femoris muscle showing high intensity between the biceps femoris muscle and the gluteus maximus muscle only (arrows). (A) Axial views of T2-weighted magnetic resonance imaging scan with fat suppression (repetition time [TR], 3211 ms; echo time [TE], 80, ms). (B) Coronal view (TR, 3215 ms; TE, 80 ms). The lines indicate the locations of the slices in the axial view.

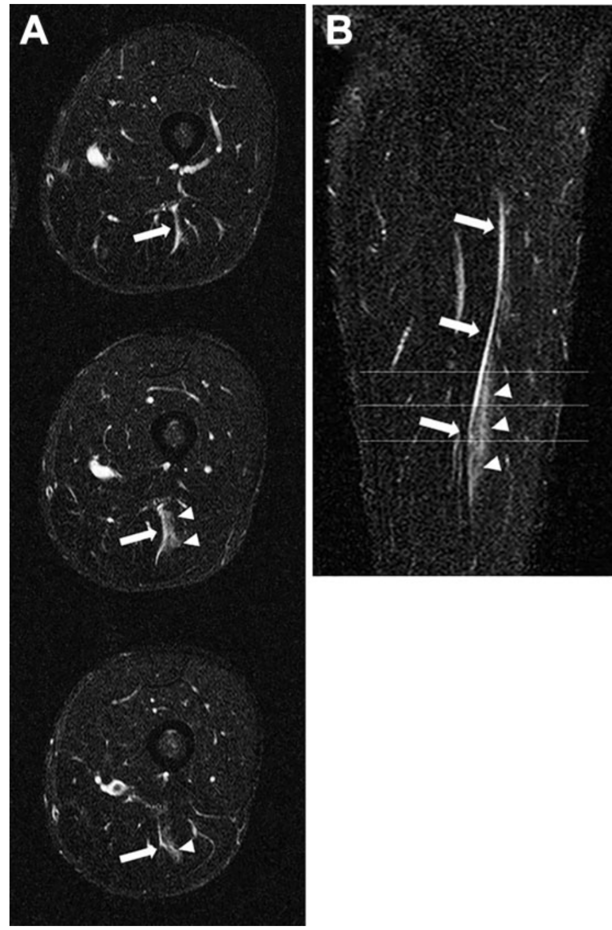

Figure 2. Grade 1b hamstring muscle strain involving the left semimembranosus muscle showing high intensity between the semimembranosus muscle and the biceps femoris muscle (arrows). However, high intensity is also slightly spread in the muscle belly (arrowheads). (A) Axial views of T2-weighted magnetic resonance imaging scan with fat suppression (repetition time [TR], 3417 ms; echo time [TE], 60 ms). (B) Coronal view (TR, 2899 ms; TE, 60 ms). The lines indicate the locations of the slices in the axial view.

Wallis test was conducted to determine significant differences in age, return to practice, and return to game play between MRI grades (grade 1a, grade 1b, and grade 2). Chi-square analysis was used to evaluate relationships between MRI grades and each factor (positions, muscles involved, and causes of injury). The significance level was set as $P < .05$. All statistical analyses were performed using SPSS software (Version 23; SPSS Inc).

RESULTS

Clinical Data

A total of 55 lower extremity muscle strains in 43 players occurred during the study period: 9 grade 0 muscle strains (16%), 38 grade 1 muscle strains (69%), and 8 grade 2 muscle strains (16%) (Table 2). The mean age of the players at the time of injury was 29.0 years (range, 18-39 years). Pitchers had the largest number of muscle strains, followed by infielders, outfielders, and catchers. However, the injury rates according to the positions were 48% in pitchers, 29% in catchers, 152% in in infielders, and 101% in outfielders. No significant relationship was found between the MRI grade and player position ($P = .27$). The largest number of muscle strains was seen in the hamstrings (n = 33; 60%), followed by calves (n = 10; 18%), quadriceps (n = 6; 11%), and hip adductors (n = 6; 11%). No significant relationship was seen between the MRI grade and the location of the strain ($P = .57$). More than half of the muscle strains (58%) occurred during the game (base-running, fielding, and pitching), whereas approximately one-third (33%) occurred during practice (batting, running, and dashing). The cause of the remaining cases (9%) was unknown. Base-running was the top activity at the time of injury during games, followed by pitching and fielding. No significant

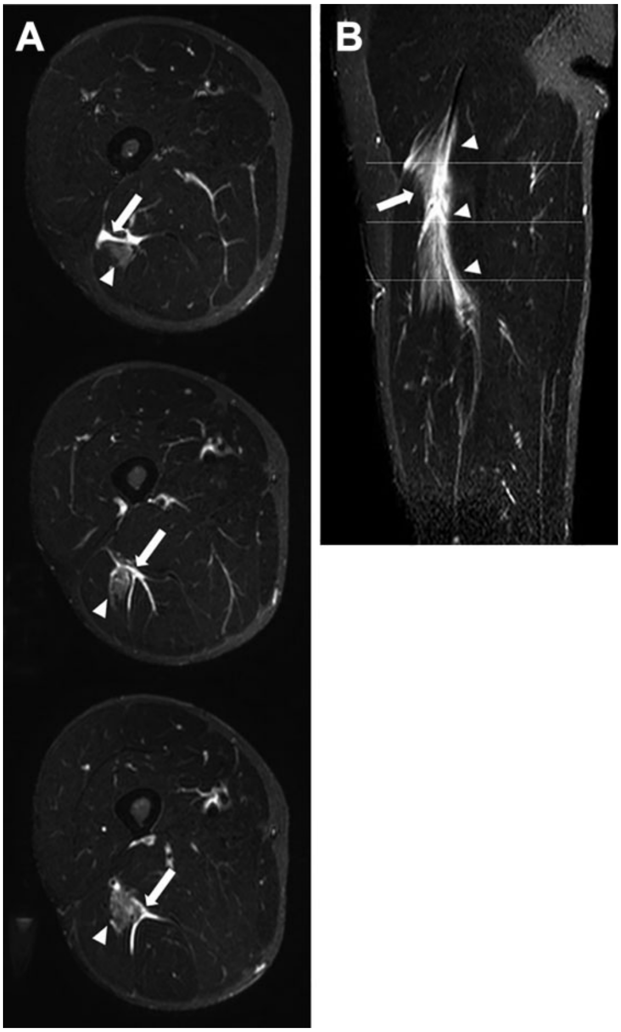

Figure 3. Grade 2 hamstring muscle strain involving the right biceps femoris muscle indicates injury of the musculotendinous junction (arrows). The high-intensity area is widespread throughout the muscle (arrowheads). (A) Axial views of T2-weighted magnetic resonance imaging scan with fat suppression (repetition time [TR], 6533 ms; echo time [TE], 60 ms). (B) Coronal view (TR, 2738 ms; TE, 60 ms). The lines indicate the locations of the slices in the axial view.

relationship was found between the MRI grade and cause of injury (*P* = .57).

MRI Grading

The ICC values for intrarater and interrater reliabilities for MRI grading were 0.92 (95% CI, 0.72-0.98) and 0.87 (95% CI, 0.63-0.96), respectively, and were both considered to reflect excellent reliability.

Of the 38 grade 1 muscle strains, 19 were subclassified as grade 1a and 19 as grade 1b, as shown in Table 2. The muscle strains with less severe findings on MRI were mostly grade 1. The frequency of the more severe grade 2 strains was relatively low (n = 8); in our cohort, no pitchers were diagnosed with a grade 2 strain. Grade 3 strains were not observed in any of the players. The causes of grade 2 muscle strains were base-running during the game (n = 6) and running during practice (n = 2). The lengths of time until return to practice and games were, respectively, 15 and 26 days in grade 1a strains, 19 and 36 days in grade 1b strains, and 55 and 69 days in grade 2 strains (Table 2). No significant difference between grade 1a and grade 1b strains was seen in time to return to practice and return to games (*P* = .25 and .06, respectively); however, a significant difference was noted between grade 1b and grade 2 strains in times to return to practice and return to games (*P* = .01 and .04, respectively). The players with grade 0 muscle strains were not restricted from practice if their symptoms were mild, therefore no effective data were available for these players regarding return to play. Recurrence occurred in 3 cases of grade 1a and 3 cases of grade 1b strains (11% of all muscle strains).

TABLE 1
Grading of Muscle Strains Based on Magnetic Resonance Imaging Findings[a]

Grade	Definition
1	T2-weighted high-intensity area around the muscle
1a	T2-weighted high-intensity area only between muscles without high intensity in the muscle
1b	T2-weighted high-intensity area between muscles and in the muscle belly
2	T2-weighted high-intensity area within muscle and tendon in the musculotendinous junction
3	Distinct T2-weighted high-intensity area at the tendon insertion

[a]Grading modified from Okuwaki.[10]

DISCUSSION

To our knowledge, this is the first study reporting prediction of return to play after lower extremity muscle strains by MRI grading in professional baseball players. We found that 85% of the muscle strains diagnosed by MRI were not severe in Japanese professional baseball players; however, even the mild injuries took about 1 month before the player could return to play. MRI was useful in predicting time missed from play in this study.

Muscle strains in the lower extremity are the most common injuries in athletes.[1,5,7,8,9,13] The high incidence of hamstring strains has been reported in previous studies.[5,13] Hamstring strains are also recognized as a cause of disability in many sports.[1] Dick et al[6] reported that according to 16 years of data from the US NCAA Injury Surveillance Program, upper leg injuries accounted for 12% of all reported game time-loss injuries in collegiate baseball.

MRI allows for identification of the site and severity of the injury to be assessed and helps determine the appropriate treatment.[3,8,14] Peetrons[11] classified muscle injuries into 3 grades according to severity using ultrasound examination: grade 1, lesion and minimal elongation;

TABLE 2
MRI Grades Stratified by Injury Characteristics[a]

	Grade 0	Grade 1a	Grade 1b	Grade 2	Grade 3	Total
Muscle strains, n	9	19	19	8	0	55
Age, y (range)	28.8 (18-32)	28.4 (18-37)	29.6 (21-36)	29.0 (22-39)	—	29.0 (18-39)
Position, n[b]						
Pitcher	4	4	8	0	—	16
Catcher	0	1	0	1	—	2
Infielder	4	7	7	5	—	23
Outfielder	1	7	4	2	—	14
Muscles involved, n[b]						
Hamstring	5	12	11	5	—	33
Quadriceps	3	1	1	1	—	6
Hip adductor	1	2	3	0	—	6
Calf	0	4	4	2	—	10
Cause, n[b]						
Base-running	2	4	7	6	—	19
Fielding	2	2	2	0	—	6
Pitching	2	1	4	0	—	7
Batting	0	1	0	0	—	1
Running	1	5	1	2	—	9
Dash	2	3	3	0	—	8
Unknown	0	3	2	0	—	5
Return to practice, d (range)[c]	—	15 (8-25)	19 (10-25)	55 (21-106)	—	25 (8-106)
Return to game, d (range)[c]	—	26 (13-49)	36 (21-53)	69 (52-116)	—	39 (13-116)
Recurrence, n	—	3	3	0	—	6

[a]Dashes indicate no valid data corresponding to the related factors. MRI, magnetic resonance imaging.
[b]No significant tendency between MRI grades and the related factors by chi-square test.
[c]No significant difference was found between grade 1a and 1b, but a significant difference was found between grade 1b and 2 ($P = .01$ for return to practice and $P = .04$ for return to games; Kruskal-Wallis test).

grade 2, lesion and partial muscle rupture; and grade 3, lesion and complete muscle tear. Ekstrand et al[8] modified this grading system for MRI evaluation: grade 0, negative MRI without any visible pathology; grade 1, edema but no architectural distortion; grade 2, architectural disruption indicating partial tear; and grade 3, total muscle or tendon rupture. Cohen et al[3] used a similar MRI grading system according to the T2-weighted hyperintense signal of muscles or tendons. In Japan, the Okuwaki classification[10] of MRI findings is commonly used for diagnosis of muscle injuries. In this classification, type 1 indicates bleeding around the muscle; type 2 is classified by a musculotendinous junction lesion, especially aponeurosis injury; and type 3 indicates tendon rupture or avulsion of tendon insertion. These classifications are based on the same concept of severity (mild = minor damage to the muscle and tendon fiber; moderate = partial tear; and severe = complete tear), although each system uses different descriptions to define the grades. We adopted the Okuwaki classification to evaluate muscle strains in the current study.

In a grade 2 musculotendinous junction injury, hematoma can spread outside the muscle boundaries longitudinally.[11] In this situation, even if the injury is not severe, the bleeding area appears to be widely spread in the sagittal and coronal views of the MRI. Thus, we mainly used the axial view for grading to ensure that we did not overestimate mild lesions as more severe lesions. Most of the lower extremity muscle strains in baseball players (85%) were mild according to the MRI findings. In a prospective cohort study of 23 European professional soccer teams, 13% of injured players had grade 0 injuries, 57% had grade 1 injuries, 27% had grade 2 injuries, and 3% had grade 3 injuries.[8] Similarly, in a retrospective study focusing on hamstring strains in 2 professional American football teams during 10 seasons, 40% of injured players had grade 1 injuries, 36% had grade 2 injuries, and 24% had grade 3 injuries.[3] The muscle strains in football players were more severe in comparison with those of baseball players investigated in this study. Because grade 2 and 3 muscle strains affected <15% of our series and grade 1 affected approximately two-thirds, we divided the grade 1 strains into 2 groups.

Prediction of the return time to play after injuries is more difficult when it is based only on clinical findings, such as swelling, pain, and tenderness. Therefore, imaging modalities such as MRI are useful methods for diagnosis and prognosis. After sustaining an injury, it is critical to ensure that players can return to play or games as soon as possible, without experiencing a recurring injury or chronic pain. This is also important for managers and coaches of the team, who want to know how long players must rest after an injury, when they can start training, and when they can return to competition. Usually, injured players gradually return to play, starting with muscle strength training, followed by walking, running, and agility training.

After rehabilitation by trainers and therapists, the players can return to play. The process of returning to play has 2 critical points: return to practice (able to practice at the same level as the other players) and return to competition (able to play the game without any symptoms); therefore, these 2 time points were evaluated in this study.

Younger athletes have the ability and potential to heal and return to play sooner than older athletes.[3] The incidence of muscle injury increases with age.[7,8] However, mean age of players at the time of injury were not significantly different when stratified by grade, suggesting that muscle strain severity did not correlate with age in the current study. Infielders and outfielders experienced more lower extremity muscle strains than pitchers and catchers, possibly because such injuries usually occurred during running. We found that the most injured site was the hamstrings, as observed in other reports as well.[1-3,5,7-9,12,15,16] The cause of muscle strain was most often base-running during games. In this motion, the runners step on a base while they stretch their feet forward and, consequently, overstretch the hamstrings. We presumed that most of the hamstring strains occurred because of eccentric contraction of the muscle.

The times to return to practice and games were 15 and 26 days in grade 1a injuries, 19 and 36 days in grade 1b injuries, and 55 and 69 days in grade 2 injuries. Cohen et al[3] reported that grade 1 injuries (no visible disruption of muscle fibers) by traditional MRI grading yielded an average of 1.2 games; grade 2 (fiber disruption of less than half the tendon or muscle width), 1.7 games; and grade 3 (disruption of more than half the tendon or muscle width), 6.4 games in professional American football players. Because football games are held once a week, it took about 2 weeks for players with grade 1 and 2 injuries to return to the game, with no statistically significant difference between the grades. Ekstrand et al,[8] investigating hamstring injuries in European professional football teams that were classified using a similar MRI grading system (grade 1, edema but no disruption; grade 2, partial tear of muscle or tendon; grade 3, complete tear) reported layoff times after injury of 17, 22, and 73 days in grade 1, 2, and 3 injuries, respectively. In our study, return to play required 4 to 5 weeks in grade 1 injuries and 10 weeks in grade 2 injuries. This difference in times to return may be due to competition characteristics; baseball players tend to not want to play even with slight discomfort because movements during baseball require changing from a static state to a dynamic state. Although we found no significant difference in return to practice and return to games between grades 1a and 1b, there was a 1-week difference between the 2 groups. In reality, grade 1b muscle strains require 1 more week until return to practice and return to games compared with grade 1a muscle strains.

Several potential limitations in this study should be acknowledged. First, length of time until return to play and MRI findings were retrospectively reviewed in only 1 professional baseball team. In addition, time to return to play depends on all of the medical approaches used to manage injuries, including physiotherapy, acupuncture, massage, and medication, and these approaches changed over the 10 seasons of the study. However, differences in treatment were not considered a factor in this study. Our hypothesis was that MRI grading for muscle strains was associated with layoff time from baseball. More severe MRI findings can be expected to result in players taking longer to return to play. There may be some bias as it applies to the hypothesis. However, we were interested in the relationship between the grading system and the time it took to return to play. Another limitation was that MRI was performed for diagnosis and follow-up after the injury but was not performed before return to play to confirm whether the injured site was healed. Finally, the MRI scans were performed at multiple facilities with different machines and protocols, although most MRI scans were conducted at a main hospital facility. The findings might change depending on the imaging conditions. In terms of future directions, a prospective multicenter study in a single season with a consistent MRI protocol should be considered in the near future.

CONCLUSION

Professional Japanese baseball players with grade 1 MRI strains returned to play in 4 to 5 weeks, whereas those with grade 2 strains required almost 10 weeks before returning to play. MRI can be useful for diagnosing muscle strains and predicting when players can return to practice or games.

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REFERENCES

1. Ahmad CS, Dick RW, Snell E, et al. Major and Minor League Baseball hamstring injuries: epidemiologic findings from the Major League Baseball Injury Surveillance System. *Am J Sports Med*. 2014;42(6): 1464-1470.
2. Camp CL, Dines JS, van der List JP, et al. Summative report on time out of play for Major and Minor League Baseball: an analysis of 49,955 injuries from 2011 through 2016. *Am J Sports Med*. 2018;46(7): 1727-1732.
3. Cohen SB, Towers JD, Zoga A, et al. Hamstring injuries in professional football players: magnetic resonance imaging correlation with return to play. *Sports Health*. 2011;3(5):423-430.
4. Collins CL, Comstock RD. Epidemiological features of high school baseball injuries in the United States, 2005-2007. *Pediatrics*. 2008; 121(6):1181-1187.
5. Dalton SL, Kerr ZY, Dompier TP. Epidemiology of hamstring strains in 25 NCAA sports in the 2009-2010 to 2013-2014 academic years. *Am J Sports Med*. 2015;43(11):2671-2679.
6. Dick R, Sauers EL, Agel J, et al. Descriptive epidemiology of collegiate men's baseball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train*. 2007;42(2):183-193.
7. Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med*. 2011;39(6):1226-1232.
8. Ekstrand J, Healy JC, Waldén M, Lee JC, English B, Hägglund M. Hamstring muscle injuries in professional football: the correlation of

MRI findings with return to play. *Br J Sports Med*. 2012;46(2):112-127.
9. McGuine TA, Post EG, Hetzel SJ, Brooks MA, Trigsted S, Bell DR. A prospective study on the effect of sport specialization on lower extremity injury rates in high school athletes. *Am J Sports Med*. 2017;45(12):2706-2712.
10. Okuwaki T. Muscle strains by sports and its treatment [in Japanese]. *Pain and Clinical Treatment*. 2007;7(4):390-396.
11. Peetrons P. Ultrasound of muscles. *Eur Radiol*. 2002;12(1):35-43.
12. Roos KG, Marshall SW, Kerr ZY, et al. Epidemiology of overuse injuries in collegiate and high school athletics in the United States. *Am J Sports Med*. 2015;43(7):1790-1797.
13. Saw R, Finch CF, Samra D, et al. Injuries in Australian rules football: an overview of injury rates, patterns, and mechanisms across all levels of play. *Sports Health*. 2018;10(3):208-216.
14. Shelly MJ, Hodnett PA, MacMahon PJ, Moynagh MR, Kavanagh EC, Eustace SJ. MR imaging of muscle injury. *Magn Reson Imaging Clin N Am*. 2009;17(4):757-773.
15. Verrall GM, Slavotinek JP, Barnes PG, Fon GT, Spriggins AJ. Clinical risk factors for hamstring muscle strain injury: a prospective study with correlation of injury by magnetic resonance imaging. *Br J Sports Med*. 2001;35(6):435-440.
16. 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(6):969-973.
17. Waterworth G, Wein S, Gorelik A, Rotstein AH. MRI assessment of calf injuries in Australian Football League players: findings that influence return to play. *Skeletal Radiol*. 2017;46(3):343-350.