Systematic Review of Bracing After Proximal Hamstring Repair

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Background: Traditionally, postoperative rehabilitation protocols after proximal hamstring repair (PHR) for avulsion of the proximal hamstring tendon from its ischial insertion recommend bracing the hip and/or knee to protect the fixation. However, because of the cumbersome nature of these orthoses, recent studies have investigated outcomes in patients with postoperative protocols that do not include any form of postoperative bracing.

Purpose: To synthesize the current body of evidence concerning bracing versus nonbracing postoperative management of PHR.

Study Design: Systematic review; level of evidence, 4.

Methods: Using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, we conducted a thorough search of the PubMed/Medline, Cochrane, CINAHL (Cumulative Index to Nursing and Allied Health Literature), and Embase (OVID) databases on March 24, 2023. We analyzed complication rates, reoperation rates, patient satisfaction, return to sport, and patient-reported outcomes of studies that used postoperative bracing versus studies that used no postoperative bracing after PHR with at least 12 months of follow-up. A total of 308 articles were identified after initial search.

Results: In total, 25 studies were included in this review: 18 studies (905 patients) on bracing and 7 studies (291 patients) on nonbracing after PHR. The overall complication rate in the braced patients was found to be 10.9%, compared with 12.7% in nonbraced patients. The rate of reoperation due to retear of the proximal hamstring was found to be 0.05% in braced patients and 3.1% in nonbraced patients. Patient-reported outcome measures were found to be higher at the final follow-up in braced versus nonbraced patients, and patient satisfaction was found to be 94.7% in braced studies compared with 88.9% in nonbraced studies. The rate of 12-month return to sport in athletic patients was 88.4% with bracing and 82.7% without bracing.

Conclusion: The findings of this review demonstrated lower complication and reoperation rates, higher patient-reported outcome scores, higher patient satisfaction, and a higher rate of return to sport in braced patients compared with nonbraced patients.

Keywords: proximal hamstring repair; proximal hamstring avulsion; postoperative bracing; accelerated rehabilitation

Injury of the proximal hamstring may involve partial or complete rupture of any combination of the semimembranosus, semitendinosus, and biceps femoris tendons from their attachment site on the ischial tuberosity.[38] Proximal hamstring rupture and avulsion make up 10% of all hamstring injuries.[23,28] Although they make up a minority of hamstring injuries, which more often occur at the intramuscular or musculotendinous junction, they are associated with significant disability if misdiagnosed or missed on evaluation.[7,17] The mechanism of injury is most often a noncontact event in sports. However, proximal hamstring tendon rupture has been reported in a number of slip-and-fall accidents as well.[12,47] Avulsion or rupture of the proximal hamstring tendon is thought to occur in the rapid transition to the swing phase during running because of the brisk eccentric lengthening that imparts a supramaximal load on the proximal hamstring tendon or its attachment to the ischial tuberosity.[10,11,32,38] The severity of these injuries is often defined using imaging-based criteria.[15]

Although nonsurgical intervention (ie, physical therapy) is sometimes indicated for single-tendon tears with <2 cm of retraction, surgical repair has been shown to be superior in terms of return to sport or activity according to a large systematic review of 75 studies by Rudisill et al.[14,30,33,40] Endoscopic repair is being performed with increasing frequency and has been shown to have similar outcomes to open repair.[28,35] Postoperative management is highly variable, with the majority (71%) of protocols recommending some form of locked hip and/or knee bracing to

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protect the integrity of the repair.[27,28] Furthermore, bracing protocols reported in the literature are heterogeneous regarding day versus day and night bracing and length of time that bracing is used postoperatively, making comparison difficult. A prior biomechanical study demonstrated that cyclical loading at forces calculated for sprinting caused failure of sutures in cadaveric models.[16] However, these loads approximated forces associated with sprinting and are therefore not generalizable to the basic activities of daily living. Additionally, with complication rates reported as high as 29.38% in some studies, the argument for bracing may be born out of a concern for caution.[5]

However, patients often find these braces cumbersome and limiting to their early return to the activities of daily living.[25] For this reason, recent studies have investigated outcomes in patients who did not have any form of immobilization after surgery. In light of the shifting paradigm regarding postoperative management of proximal hamstring repairs (PHRs), the primary goals of this systematic review were (1) to describe and analyze the current body of literature on postoperative PHR management regarding bracing or nonbracing and (2) to compare the outcomes of patients who used postoperative bracing with those who did not. We hypothesized that the clinical outcomes would be similar between the bracing and nonbracing postoperative protocols.

METHODS

This was a systematic review of studies published before March 24, 2023, that have investigated outcomes after PHR. This study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for self-reporting. This review was registered on PROSPERO (CRD42023422770). A single author (J.C.) searched the PubMed/Medline, Cochrane, CINAHL (Cumulative Index to Nursing and Allied Health Literature), and Embase (OVID) databases on March 24, 2023. The search strategy using MeSH terms was as follows: (((hamstring OR hamstrings OR "Hamstring Tendons" [Mesh] OR "Hamstring Muscles"[Mesh]) AND proximal) AND (rupture* OR tear* OR avulsion* OR lesion*)) AND (repair OR surgical OR surgery))). Duplicate papers were excluded automatically from the initial search results.

Screening and Inclusion and Exclusion Criteria

Three reviewers (P.W., T.D.H., and H.M.H.) independently screened all articles from the initial search using this review's inclusion and exclusion criteria. Each study was first reviewed by title and abstract. The full text of the studies that passed the initial screen was then assessed for final inclusion. Conflicts were resolved by a majority count from the 3 screening authors. Inclusion criteria were as follows: comparative or noncomparative studies, studies that assess any outcome after PHR, studies that explicitly state whether postoperative bracing was used or not used, at least 1 year of follow-up with participants, and at least 10 participants. Exclusion criteria were as follows: case reports, nonhuman (including cadaveric) studies, nonprimary PHR, <1 year of follow-up, no mention or ambiguity of whether bracing was or was not used, unclear number of participants who were braced versus unbraced, non-English papers, and studies with <10 patients.

The initial search returned 308 studies. Six duplicates were removed, leaving 302 papers for title and abstract screening. Then, 257 papers were excluded during title and abstract screening, leaving 45 papers for final full-text review. After full-text review, 26 studies[§] were determined to meet inclusion criteria and were included in the primary analysis of this systematic review. All the studies were classified as having used some form of bracing or no form of bracing. The study inclusion and exclusion process is illustrated in Figure 1.

Data Extraction

Data were extracted independently by 3 authors (P.W., T.D.H., and H.M.H.). The data extracted from each article included the study design, baseline patient characteristics, any reported outcomes (eg, patient-reported outcome scores, imaging, strength, range of motion, and patient satisfaction), and any reported complications. Of note, whether repairs were considered acute or chronic was left up to the definition of those respective terms as provided by the authors of each study.

Quality Assessment

During the data extraction process, each included study was assessed for risk of bias using the Newcastle-Ottawa Scale[42] for cohort studies and the Quality Assessment Tool for Case Series Studies (QATCSS), published by the National Institutes of Health.[43]

[§]References 1-4, 6, 8, 9, 12, 18-22, 24-26, 29, 31, 34, 36-39, 41, 45, 46.

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TABLE 1
Comparison of Braced and Nonbraced Studies[a]

Characteristic	Braced Studies (n = 19 studies; 905 patients)	Nonbraced Studies (n = 7 studies; 291 patients)
Age of patients, y	46.1 (29.2-64.2)	36.8 (15.1-51)
Length of follow-up, mo	47.4 (12-78)	47.9 (30-102)
Repairs, acute/chronic[b]	583/293	133/157
Overall complication rate	10.9%	12.7%
Complications	• Nerve injury in sciatic distribution (n = 90)[3,6,12,19,21,22,29,36,45,46] • Wound infection (n = 7)[1,6,19,20,45] • Rerupture (n = 5)[1,19,45] • DVT (n = 2)[19,36,45] • Hematoma (n = 2)[29,45] • Chronic draining sinus tract (n = 1)[19] • CRPS (n = 1)[20]	• Nerve injury in sciatic distribution (n = 12)[25,26,31,38,41] • Wound infection (n = 10)[4,18,26,38,41] • Rerupture (n = 9)[25,26,38] • DVT (n = 2)[25,38] • Osteomyelitis (n = 1)[25] • Partial wound dehiscence (n = 1)[38] • Seroma (n = 1)[38] • Hypertrophic scarring (n = 1)[26]
Overall reoperation rate[c]	0.05%	3.1%

[a]Data are reported as mean (range), n, or percent. CRPS, chronic regional pain syndrome; DVT, deep vein thrombosis.
[b]The cutoff for acute and chronic repairs differed among studies. It ranged from 3 to 6 weeks between injury and operation.
[c]Reoperation due to rerupture.

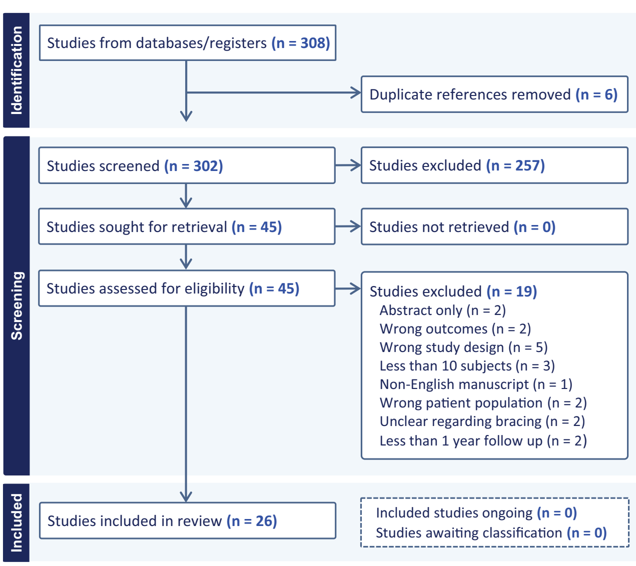

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart showing the study inclusion and exclusion process.

RESULTS

Study Characteristics

Of the 26 included articles, 7 studies[4,18,25,26,31,38,41] (n = 291 patients) reported on nonbracing postoperatively, and 19 studies[||] (n = 985 patients) reported on some form of postoperative bracing. Five of the studies on bracing used hip bracing to limit excessive hip flexion postoperatively,[3,12,36,39,45] 11 of the studies used a knee brace to limit excessive knee extension,[1,2,6,8,9,19-22,24,34] and 2 of the studies[29,37] used combined hip and knee bracing to limit both excessive knee extension and hip flexion. Table 1 further summarizes the characteristics of the braced and nonbraced studies, including complication rates.

Of the 26 included articles, 14 were retrospective case series, of which 12 studies[¶] were determined to have a low risk of bias according to the QATCSS and 2 studies[24,36] were considered to have a high risk of bias. The remaining 12 articles[#] were cohort studies, all of which were considered to have a low risk of bias according to the Newcastle-Ottawa Scale.

Patient-Reported Outcome Measures

Many patient-reported outcome measures were used among the 26 studies, but the Lower Extremity Functional Scale (LEFS) and the Perth Hamstring Assessment Tool (PHAT) were the only 2 that were used in both braced and nonbraced studies. In the two nonbraced studies that reported LEFS (n=73), average scores from the LEFS, reported as percentages, were found to be 87% and 89%, correlating to raw scores of 69.6 and 71.2 out of a maximum of 80 points, respectively.[25,41] There were 5 braced studies[1,6,8,12,39] that used the LEFS; the mean LEFS score among these studies was 74.9 (range, 73.3-77). The PHAT, which is measured on a scale of 0 to 100, was used in 1 nonbraced study,[4] in which the mean score was 76 at the final follow-up. In the 3 braced studies[2,9,19] that used PHAT, the mean score at the final follow-up was

[||]References 1-3, 6, 8, 9, 12, 19-22, 24, 29, 34, 36, 37, 39, 45, 46.

[¶]References 1, 2, 6, 8, 12, 20, 25, 29, 31, 38, 41, 46.

[#]References 3, 4, 9, 18, 19, 21, 22, 26, 34, 37, 39, 45.

TABLE 2
Summary of Postoperative Patient-Reported Outcome Measures That Were Assessed in Both Braced and Nonbraced Studies[a]

Lead Author (Year)	Braced/Nonbraced	Length of Follow-up, mo	Postoperative LEFS Score[b]	Postoperative PHAT Score[b]
Leger-St-Jean (2019)[25]	Nonbraced (n = 34)	49.2	87 ± 21.3 (reported as percentage)	—
Skaara (2013)[41]	Nonbraced (n = 39)	30	89 ± 13 (reported as percentage)	—
Cohen (2012)[12]	Braced (n = 52)	33	• Acute repair: 76.2 (62-80) • Chronic repair: 71.5 (50-80)	—
Chahal (2012)[8]	Braced (n = 15)	36.9	74.9 (59-80)	—
Arner (2019)[1]	Braced (n = 64)	78	96 (68-100) (reported as percentage)	—
Bowman (2013)[6]	Braced (n = 17)	32	73.3 ± 9.9	—
Shambaugh (2018)[39]	Braced (n = 92)	43	• Acute repair: 73.3 • Chronic repair: 74.2	—
Blakeney (2017)[4]	Nonbraced (n = 88), braced (n = 8)	33	—	• Mean, 76. The mean increase from baseline was 34.7 for the total cohort ($P < .001$) • No significant difference in postoperative PHAT scores between braced and nonbraced patients
Best (2021)[2]	Braced (n = 226)	26.2	—	79.8 ± 19.1
Kanakamedala (2023)[19]	Braced (n = 46)	58.8	—	• Acute repair: 76.9 ± 18.8 • Chronic repair: 60.6 ±18.2
Chocholac (2023)[9]	Braced (n = 15)	46.2	—	78.8 (54.6-99.8)

[a]Data are reported as mean, mean ± SD, or mean (range). Dashes indicate that patient-reported outcome scores were not reported for that study. LEFS, Lower Extremity Functional Scale; PHAT, Perth Hamstring Assessment Tool.
[b]LEFS and PHAT are both scored on a scale of 0 to 100, with 100 being the highest level of function.

75.8. Table 2 further illustrates findings pertaining to the LEFS and PHAT patient-reported outcome measures.

Patient Satisfaction

One nonbraced study[25] used the Single Assessment Numeric Evaluation (SANE) as a way to assess patient satisfaction. The mean SANE score in this study was 86.9 (on a scale of 0-100, with 100 being the most satisfied). The mean SANE score (93.6%) in the single braced study[8] that used the SANE tool was higher. In terms of general patient satisfaction, 96 of the 108 (88.9%) nonbraced patients in 4 studies[18,26,31,41] reported they were satisfied with their surgical outcome at the final follow-up. In the 12 braced studies[**] that assessed patient satisfaction, 407 of 430 (94.7%) patients reported that they were satisfied with their surgical outcome.

Return to Sport

Of the 4 nonbraced studies[18,26,31,38] that assessed successful return to sport, 86 of the 104 (82.7%) patients returned to their prior sport of choice within 12 months of surgery. Ten braced studies[1,3,8,12,20-22,24,37,45] assessed return-to-sport rates within the first year postoperatively. Of the 336 athletic patients in these studies, 297 (88.4%) returned to sport within 12 months of their surgery.

DISCUSSION

Our systematic review demonstrated that with a mean follow-up length of 47.65 months, the results of this study showed higher complication rates in nonbraced postoperative patients (12.7%) than in their braced counterparts (10.9%) and a higher incidence of reoperation due to rerupture of the proximal hamstring insertion in braced (3.1%) versus nonbraced (0.05%) patients. Additionally, patient-reported outcome scores and return-to-sport rates tended to be higher in braced versus nonbraced patients.

The purpose of this systematic review was to compare outcomes and complications between differing philosophies of postoperative management of PHR. Historically, bracing of the hip and/or knee in the immediate postoperative period has been recommended to prevent supramaximal load transmission to the repaired tendon that may cause fixation failure. However, more recent studies have suggested that accelerated postoperative rehabilitation programs that do not include bracing may have good outcomes as well. No prior study has compared these 2 approaches to postoperative management. This systematic

**References 1, 3, 6, 8, 9, 12, 18, 21, 22, 34, 36.

review illustrates the heterogeneous body of literature on this topic and attempted to compare the 2 approaches to postoperative management.

The bracing used after PHR is often thought to be cumbersome. Some authors believe that the immobilization these braces provide may limit a timely return to prior levels of activity and decrease patient satsifaction.[25] However, in the present study, patient satisfaction was higher on average in patients who were braced postoperatively than in patients who were not braced (94.7% vs 88.9%). This may reflect the fact that satisfaction was reported at the final follow-up and not during the immediate postoperative period. Therefore, it is still not clear whether bracing is as limiting as we think in the immediate postoperative period. It does appear, however, that patient satisfaction is not significantly affected by these cumbersome braces at a follow-up of >1 year. A prior systematic review found that patient satisfaction in 198 participants after PHR ranged from 88% to 100%.[44] This coincides with the satisfaction rates reported in the studies of this review.

The mean 12-month return-to-sport rate in the nonbraced studies was 82.7%. However, the higher mean rate found in the braced studies (88.4%) closely reflects the rate reported by Coughlin et al[13] (87%), in a large meta-analysis of 846 patients after PHR. The mean length of time to return to sport in their meta-analysis was 5.8 months (range, 1-36 months). It is worth noting that the authors of the meta-analysis found a stronger association between rate of return to sport and patients with a lower level of preinjury sport participation. In the present systematic review, the mean age of the braced patients was 9.3 years older than the mean age of the nonbraced patients (46.1 vs 36.8 years). For this reason, it is reasonable to suspect that the older participants had lower levels of prior sport activity. This may be the reason that the return-to-sport rate was higher in the older nonbraced group when compared with the younger nonbraced group.

A similar argument can be made regarding the reason for higher complication and reoperation rates in the nonbraced group. The reoperation rate (due to retears) was 3.1% in the nonbraced group versus 0.05% in the braced group. This discrepancy may be because younger, and presumably more active, patients in the nonbraced group may be more likely to reinjure their surgical repair. Nevertheless, the rate of 3.1% in the nonbraced population found in the present study is close to the reoperation rate of 2.57% found by Bodendorfer et al,[5] in a meta-analysis of 796 hamstring avulsion injuries. The rate of reoperation in nonbraced patients, although higher than that in braced patients, is in line with the expected overall reoperation rates after PHR.

Limitations

This study is not without limitations. The findings of this review show consistently higher outcome measures (LEFS, PHAT, SANE, and patient satisfaction) and lower complication and rerupture rates in braced patients compared with nonbraced patients. However, there is a large discrepancy in the number of studies investigating nonbraced patients (n = 7) versus braced patients (n = 19). This discrepancy reflects the historical dominance of the bracing paradigm over the relatively new paradigm of nonbracing. Additionally, with advances in biomechanical research over the years, the evolution of surgical techniques has likely increased surgeons' confidence in the pull-out strength of the anchors used in these repairs. This may introduce another source of bias, making older studies more likely to utilize bracing than newer studies. Furthermore, arthroscopic PHRs have become increasingly common over the past decade, introducing further bias because of the heterogeneity of the surgical technique in the included studies.

Additionally, we speculate that bias may exist in surgeon selection of those who receive postoperative bracing. For instance, a surgeon may be more likely to be more conservative postoperatively (ie, recommend bracing) in patients with morbid obesity, with revision surgeries, or deemed to be at higher risk of retear. A meta-analysis was not performed because of the limited overlap in outcomes reported between the braced and nonbraced studies and the high level of heterogeneity in the study and bracing protocols. Therefore, our study lacked statistical analyses that included confidence intervals and I^2 heterogeneity analyses. Despite these limitations, this systematic review demonstrates a consistent pattern that favors bracing postoperatively to decrease the rate of complications (including reoperation), increase the chances of successful return to sport, and improve overall patient satisfaction.

CONCLUSION

While the findings of this review suggest that postoperative bracing may be associated with superior outcomes compared with nonbracing, the complication rate (including reoperation) and patient satisfaction appear to reflect the reported statistics from the greater body of literature on PHR outcomes. However, because of the limited number of studies that did not use a postoperative bracing protocol, definitive conclusions regarding the superiority of bracing versus nonbracing cannot be made at this time. More studies investigating patient satisfaction and complication rates after a nonbracing postoperative protocol are needed.

REFERENCES

1. Arner JW, Freiman H, Mauro CS, Bradley JP. Functional results and outcomes after repair of partial proximal hamstring avulsions at midterm follow-up. *Am J Sports Med*. 2019;47(14):3436-3443. doi:10.1177/0363546519879117
2. Best R, Meister A, Meier M, Huth J, Becker U. Predictive factors influencing functional results after proximal hamstring tendon avulsion surgery: a patient-reported outcome study after 227 operations from a single center. *Orthop J Sports Med*. 2021;9(10):23259671211043097. doi:10.1177/23259671211043097
3. Birmingham P, Muller M, Wickiewicz T, Cavanaugh J, Rodeo S, Warren R. Functional outcome after repair of proximal hamstring avulsions. *J Bone Jt Surg*. 2011;93(19):1819-1826. doi:10.2106/JBJS.J.01372

4. Blakeney WG, Zilko SR, Edmonston SJ, Schupp NE, Annear PT. Proximal hamstring tendon avulsion surgery: evaluation of the Perth Hamstring Assessment Tool. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(6):1936-1942. doi:10.1007/s00167-016-4214-y
5. Bodendorfer BM, Curley AJ, Kotler JA, et al. Outcomes after operative and nonoperative treatment of proximal hamstring avulsions: a systematic review and meta-analysis. *Am J Sports Med*. 2018;46(11):2798-2808. doi:10.1177/0363546517732526
6. Bowman KF, Cohen SB, Bradley JP. Operative management of partial-thickness tears of the proximal hamstring muscles in athletes. *Am J Sports Med*. 2013;41(6):1363-1371. doi:10.1177/0363546513482717
7. Buckwalter J, Westermann R, Amendola A. Complete proximal hamstring avulsions: is there a role for conservative management? A systematic review of acute repairs and non-operative management. *J ISAKOS*. 2017;2(1):31-35. doi:10.1136/jisakos-2016-000105
8. Chahal J, Bush-Joseph CA, Chow A, et al. Clinical and magnetic resonance imaging outcomes after surgical repair of complete proximal hamstring ruptures: does the tendon heal? *Am J Sports Med*. 2012;40(10):2325-2330.
9. Chocholac T, Buhl L, Nuesch C, Bleichner N, Mundermann A, Stoffel K. Modified surgical anchor refixation in older patients with acute proximal hamstring rupture: clinical outcome, patient satisfaction and muscle strength. *Arch Orthop Trauma Surg*. 2023;143(8):4679-4688. doi:10.1007/s00402-022-04752-3
10. Clanton TO, Coupe KJ. Hamstring strains in athletes: diagnosis and treatment. *J Am Acad Orthop Surg*. 1998;6(4):237-248. doi:10.5435/00124635-199807000-00005
11. Cohen S, Bradley J. Acute proximal hamstring rupture. *J Am Acad Orthop Surg*. 2007;15(6):350-355. doi:10.5435/00124635-200706000-00004
12. Cohen SB, Rangavajjula A, Vyas D, Bradley JP. Functional results and outcomes after repair of proximal hamstring avulsions. *Am J Sports Med*. 2012;40(9):2092-2098. doi:10.1177/0363546512456012
13. Coughlin RP, Kay J, Shanmugaraj A, Memon M, Naji L, Ayeni OR. Return to sport after surgical management of proximal hamstring avulsions: a systematic review and meta-analysis. *Clin J Sport Med*. 2020;30(6):598-611. doi:10.1097/JSM.0000000000000688
14. Degen RM. Proximal hamstring injuries: management of tendinopathy and avulsion injuries. *Curr Rev Musculoskelet Med*. 2019;12(2):138-146. doi:10.1007/s12178-019-09541-x
15. Forlizzi JM, Nacca CR, Shah SS, et al. Acute proximal hamstring tears can be defined using an imaged-based classification. *Arthrosc Sports Med Rehabil*. 2022;4(2):e653-e659. doi:10.1016/j.asmr.2021.12.007
16. Harvey MA, Singh H, Obopilwe E, Charette R, Miller S. Proximal hamstring repair strength: a biomechanical analysis at 3 hip flexion angles. *Orthop J Sports Med*. 2015;3(4):2325967115576910. doi:10.1177/2325967115576910
17. Hofmann KJ, Paggi A, Connors D, Miller SL. Complete avulsion of the proximal hamstring insertion: functional outcomes after nonsurgical treatment. *J Bone Joint Surg Am*. 2014;96(12):1022-1025. doi:10.2106/JBJS.M.01074
18. Kaila R, French SR, Wood DG. Outcomes of adolescent athlete proximal hamstring bone avulsions. *J Pediatr Orthop Part B*. 2023;32(3):278-286. doi:10.1097/BPB.0000000000000978
19. Kanakamedala AC, Mojica ES, Hurley ET, Gonzalez-Lomas G, Jazrawi LM, Youm T. Increased time from injury to surgical repair in patients with proximal hamstring ruptures is associated with worse clinical outcomes at mid-term follow-up. *Arch Orthop Trauma Surg*. 2023;143(2):951-957. doi:10.1007/s00402-022-04421-5
20. Kayani B, Ayuob A, Begum F, Khan N, Haddad FS. Surgical management of chronic incomplete proximal hamstring avulsion injuries. *Am J Sports Med*. 2020;48(5):1160-1167. doi:10.1177/0363546520908819
21. Klingele KE, Sallay PI. Surgical repair of complete proximal hamstring tendon rupture. *Am J Sports Med*. 2002;30(5):742-747. doi:10.1177/03635465020300051901
22. Konan S, Haddad F. Successful return to high level sports following early surgical repair of complete tears of the proximal hamstring tendons. *Int Orthop*. 2010;34(1):119-123. doi:10.1007/s00264-009-0739-8
23. Koulouris G, Connell D. Evaluation of the hamstring muscle complex following acute injury. *Skeletal Radiol*. 2003;32(10):582-589. doi:10.1007/s00256-003-0674-5
24. Lefevre N, Bohu Y, Klouche S, Herman S. Surgical technique for repair of acute proximal hamstring tears. *Orthop Traumatol Surg Res*. 2013;99(2):235-240. doi:10.1016/j.otsr.2012.05.006
25. Leger-St-Jean B, Gorica Z, Magnussen RA, Vasileff WK, Kaeding CC. Accelerated rehabilitation results in good outcomes following acute repair of proximal hamstring ruptures. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(10):3121-3124. doi:10.1007/s00167-018-4964-9
26. Lempainen L, Sarimo J, Heikkila J, Mattila K, Orava S. Surgical treatment of partial tears of the proximal origin of the hamstring muscles. *Br J Sports Med*. 2006;40(8):688-691. doi:10.1136/bjsm.2006.028191
27. Lightsey HM, Kantrowitz DE, Swindell HW, Trofa DP, Ahmad CS, Lynch TS. Variability of United States online rehabilitation protocols for proximal hamstring tendon repair. *Orthop J Sports Med*. 2018;6(2):2325967118755116. doi:10.1177/2325967118755116
28. Looney AM, Day HK, Comfort SM, Donaldson ST, Cohen SB. Proximal hamstring ruptures: treatment, rehabilitation, and return to play. *Curr Rev Musculoskelet Med*. 2023;16(3):103-113. doi:10.1007/s12178-023-09821-7
29. Maldonado DR, Annin S, Lall AC, et al. Outcomes of open and endoscopic repairs of chronic partial- and full-thickness proximal hamstring tendon tears: a multicenter study with minimum 2-year follow-up. *Am J Sports Med*. 2021;49(3):721-728. doi:10.1177/0363546520981767
30. Moatshe G, Chahla J, Vap AR, et al. Repair of proximal hamstring tears: a surgical technique. *Arthrosc Tech*. 2017;6(2):e311-e317. doi:10.1016/j.eats.2016.10.004
31. Orava S, Hetsroni I, Marom N, et al. Surgical excision of posttraumatic ossifications at the proximal hamstrings in young athletes: technique and outcomes. *Am J Sports Med*. 2015;43(6):1331-1336. doi:10.1177/0363546515574065
32. Petersen J, Hölmich P. Evidence based prevention of hamstring injuries in sport. *Br J Sports Med*. 2005;39(6):319-323. doi:10.1136/bjsm.2005.018549
33. Rudisill SS, Kucharik MP, Varady NH, Martin SD. Evidence-based management and factors associated with return to play after acute hamstring injury in athletes: a systematic review. *Orthop J Sports Med*. 2021;9(11):23259671211053830. doi:10.1177/23259671211053833
34. Rust DA, Giveans MR, Stone RM, Samuelson KM, Larson CM. Functional outcomes and return to sports after acute repair, chronic repair, and allograft reconstruction for proximal hamstring ruptures. *Am J Sports Med*. 2014;42(6):1377-1383. doi:10.1177/0363546514528788
35. Ryan MK, Crozier MW, Beason DP, Emblom BA. Biomechanical comparison of open and endoscopic proximal hamstring repair techniques. *Orthop J Sports Med*. 2018;6(7 suppl 4):2325967118S00148. doi:10.1177/2325967118S00148
36. Sallay PI, Ballard G, Hamersly S, Schrader M. Subjective and functional outcomes following surgical repair of complete ruptures of the proximal hamstring complex. *Orthopedics*. 2008;31(11):1092.
37. Sandmann GH, Hahn D, Amereller M, et al. Mid-term functional outcome and return to sports after proximal hamstring tendon repair. *Int J Sports Med*. 2016;37(7):570-576. doi:10.1055/s-0035-1564170
38. Sarimo J, Lempainen L, Mattila K, Orava S. Complete proximal hamstring avulsions: a series of 41 patients with operative treatment. *Am J Sports Med*. 2008;36(6):1110-1115. doi:10.1177/0363546508314427
39. Shambaugh BC, Miller SL, Wuerz TH. Does time from injury to surgery affect outcomes following surgical repair of partial and complete

proximal hamstring ruptures? *Orthop J Sports Med*. 2018;6(7 suppl 4):2325967118S00110. doi:10.1177/2325967118S00110
40. Sheean AJ, Arner JW, Bradley JP. Proximal hamstring tendon injuries: diagnosis and management. *Arthroscopy*. 2021;37(2):435-437. doi:10.1016/j.arthro.2020.12.201
41. Skaara HE, Moksnes H, Frihagen F, Stuge B. Self-reported and performance-based functional outcomes after surgical repair of proximal hamstring avulsions. *Am J Sports Med*. 2013;41(11):2577-2584. doi:10.1177/0363546513499518
42. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol*. 2010;25(9):603-605. doi:10.1007/s10654-010-9491-z
43. Study Quality Assessment Tools. National Institutes of Health–National Heart, Lung, and Blood Institute. Accessed August 23, 2022. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools
44. van der Made AD, Reurink G, Gouttebarge V, Tol JL, Kerkhoffs GM. Outcome after surgical repair of proximal hamstring avulsions: a systematic review. *Am J Sports Med*. 2015;43(11):2841-2851. doi:10.1177/0363546514555327
45. Willinger L, Siebenlist S, Lacheta L, et al. Excellent clinical outcome and low complication rate after proximal hamstring tendon repair at mid-term follow up. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(4):1230-1235. doi:10.1007/s00167-019-05748-0
46. Wilson TJ, Spinner RJ, Mohan R, Gibbs CM, Krych AJ. Sciatic nerve injury after proximal hamstring avulsion and repair. *Orthop J Sports Med*. 2017;5(7):2325967117713685. doi:10.1177/2325967117713685
47. 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(1):36-41. doi:10.1136/bjsm.2002.002352