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REVIEW ARTICLE

Time to return to play and reinjury rate of hamstring injuries with and without intramuscular tendon involvement: A systematic review and meta-analysis

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ABSTRACT

Objective: Determine whether intramuscular hamstring tendon (IMT) injury prolongs return to play (RTP) and increases odds of reinjury compared to non-IMT injuries. Design: Systematic Review and Meta-Analysis. Data Sources: PubMed, CINAHL, SPORTDiscus, Cochrane Library and EMBASE. Eligibility Criteria: Studies investigating RTP and reinjury rates in athletes who had a hamstring injury and underwent MRI within 7 days. Study Quality & Certainty of Evidence: The PEDRO scale and GRADE approach were used. Results: Eight studies with 527 athletes, were included. Lack of blinding and high heterogeneity meant that the studies included were of fair quality and very low certainty of evidence. IMT injuries had an extended RTP compared to non-IMT injuries (mean difference:16.35 days, 95%CI: 8.51-24.19, p < .001). BAMIC 2c injuries prolonged RTP by 6.0 days compared to 2a & 2b combined (mean difference:6.03 days, 95% CI: 0.03-12.03, p = .05, Z = 1.97). The mean difference between BAMIC 3c and 3a/b injuries was 15 days (95% CI: -1.62-32.91, p = .08). Tendon involvement did not increase the odds of re-injury (OR = 2.98, 95%CI 0.93-9.59, Z = 1.83, p = .07). Conclusion: The overall very low quality of the included studies gravely impacts conclusions that may be drawn regarding comparisons of time to RTP and re-injury rate. IMT injuries may have an extended RTP duration of approximately two weeks compared to non-IMT injury. No between-group differences were found in re-injury rate. To provide accurate prognosis to inform clinical decisions for injuries with and without IMT involvement, high-quality prospective studies with blinding of treating clinicians for MRI findings are paramount.

Keywords: Hamstring, Intra-muscular tendon, tendon, Aponeurosis, Rehabilitation, Return to Play, Re-injury.

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INTRODUCTION

Hamstring injury remains a significant problem in sport, accounting for 10% of all injuries in field-based team sports and is the most frequently occurring injury during top-level international athletics championships (Edouard, Branco, & Alonso, 2016; Edouard et al., 2020). Medical staff are under increasing pressure to provide an accurate return to play (RTP) timeframe, manage player and coaching staff expectations, along with planning recovery and rehabilitation programs. Magnetic resonance imaging (MRI) is widely utilised in elite sports to assist with both diagnosis and the assessment of injury severity and can assist clinicians in treatment planning. Despite previous research suggesting that MRI findings are associated with RTP timeframes, a systematic review concluded that there was no strong evidence for any MRI findings as a prognostic factor for time for RTP (G. Reurink, Whiteley, & Tol, 2015). This was mainly due to the high risk of bias, notably the lack of blinding, in most of the studies included.

Increasing interest in the role of the intramuscular tendon (IMT) in hamstring injuries has led to considerable scientific and clinical debate. The IMT refers to the area of the tendon that has muscle fibres attached to it and extends both along and into the muscle belly (Brukner, Cook, & Purdam, 2018). Awareness of these injuries has increased since the development of the British Athletic Muscle Injury Classification (BAMIC) system (Pollock, James, Lee, & Chakraverty, 2014). Injuries that involve the IMT have been postulated to require a prolonged and potentially adapted rehabilitation and are also thought to increase re-injury risk (Brukner & Connell, 2016). High grade IMT injuries in athletics (i.e. type 3c) required a mean of 84 days (SD 49.4, range: 40-128) to return to full training, whereas higher grade myofascial or musculotendinous junction (MTJ) injuries required a mean of 41 (NA) days. Grade 3c injuries had a 57% re-injury rate whereas myofascial or MTJ injuries of a similar grade had an 8% re-injury rate (Pollock et al., 2016).

Currently, there is conflicting evidence regarding the effect of IMT injury presence on both RTP times and reinjury. Moreover, study cohorts vary in type of sports (athletics and field sports), level of play, and biases owing to lack of blinding for MRI findings, adding further uncertainty.

Assessing the importance of IMT involvement is crucial, as clinical examination alone may not detect these injuries without an MRI scan (Crema et al., 2017). Wangensteen et al., (2015) found that MRI may not add additional value beyond history and clinical examination. If robust evidence demonstrates that IMT involvement is not linked to injury outcomes, it could lower medical costs by reducing unnecessary MRI examinations, particularly in elite sport where the impact of reinjury or delayed return to play can be significant (Eliakim, Morgulev, Lidor, & Meckel, 2020).

The aim of this systematic review was therefore to compare time to RTP (in days) and odds of re-injury in elite and competitive athletes with an acute hamstring injury, with and without IMT involvement, confirmed with MRI.

Our hypothesis was that injuries to the IMT, when compared with myofascial and musculotendinous injuries, resulted in an extended RTP time and higher odds of re-injury.

METHODS

Eligibility criteria

Clinical human studies who evaluated time to RTP (in days) and odds of re-injury for elite and competitive athletes who suffered a hamstring injury confirmed by MRI within seven days of injury were included.

Literature search

A systematic literature search using PubMed, CINAHL, SPORTDiscus, Cochrane Library and EMBASE databases was undertaken (KM) to identify potentially eligible articles published in the last 10 years in May 2024. The search was prospectively registered with PROSPERO and included articles published in English and Dutch. The bibliography of individual papers was screened for any additional studies eligible for inclusion. The full search strategy can be found in Appendix 1.

Study selection

The study selection process consisted of title- and abstract screening followed by full-text screening by two authors independently (MOS & KM). A Third author (ADM) was available in case of disagreement regarding study selection.

Data collection

Two authors (MOS & KM) independently extracted data using a standardised data collection form. Authors were contacted in case of missing data and/or data needed in a different format than was available in the article. The primary outcomes were time to RTP (in days), and odds of re-injury which was calculated by REVMAN software using the reinjury rates taken directly from the papers.

Quality assessment

A methodological quality assessment was performed using the PEDro scale; a valid measure of methodological quality of clinical trials (de Morton, 2009). The PEDro scale is an 11-item checklist, of which 10 items contribute to the overall scoring. Studies with a score of 0-3 are considered "*poor*"; 4-5 "*fair*", 6-8 "*good*" and 9-10 "*excellent*". Two reviewers independently assessed PEDro scores (MOS & KM). A Third author (ADM) was available in case of disagreement.

Effect measures

For the analysis of time to RTP with and without IMT injury, measures of effect were calculated as mean differences and 95% confidence intervals (95% CI) in a random effects model using REVMAN software. Reinjury rates were taken directly from the papers and inputted to REVMAN which compared the number of IMT reinjuries and the number of non IMT injures from the total reinjury rate and were presented as odds ratios. Where data was originally presented by the authors as medians and interquartile ranges, raw data was retrieved to calculate means and standard deviations for pooling or these were converted to means and standard deviations (Luo, Wan, Liu, & Tong, 2018; Wan, Wang, Liu, & Tong, 2014). If the authors provided means and standard deviations for each BAMIC grade rather than the complete raw data, these were combined for analysis using the following formulas;

Combined mean

$$\bar{x}_{12} = \frac{(N_1 \cdot \bar{x}_1) + (N_2 \cdot \bar{x}_2)}{(N_1 + N_2)}$$

Combined standard deviation

$$\sigma_{12} = \sqrt{\frac{(N_1 - 1) \cdot \sigma_1^2 + (N_2 - 1) \cdot \sigma_2^2 + \frac{N_1 \cdot N_2}{N_1 + N_2} \cdot (\bar{x}_1^2 + \bar{x}_2^2 - 2\bar{x}_1\bar{x}_2)}{N_1 + N_2 - 1}}$$

Data synthesis

Data was pooled for meta-analysis using Review Manager (Version 5.4.1; The Cochrane Collaboration, 2020). Forest plots with tests of overall effect were created to visually represent estimates of treatment effect. Heterogeneity was calculated as the I^2-statistic on each of the plots. I^2 measures the proportion of variation in the combined estimates owing to study variance. An I^2-value of 0% represents the highest consistency between the results of individual studies, alternatively, an I^2-value of 100% indicates the highest inconsistency between studies. Firstly, RTP and reinjury rates with and without IMT injury, irrespective of severity/grade, were compared. Secondly, RTP and reinjury rates were then compared between BAMIC classifications with and without IMT (2a & 2b versus 2c, 3a & 3b versus 3c, etc.). Forest plots were used to visually represent comparisons. Thirdly, owing to recent discussion on whether type of sports impacted the effect of IMT involvement on prognosis, we repeated the analysis for field-based sports and athletics separately, and this analysis is included as an appendix.

Certainty of evidence

The certainty of evidence was assessed by 2 reviewers (MOS & KM) independently according to the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) criteria for meta-analysis (Hultcrantz et al., 2017). GRADE quantifies evidence certainty as "*High*", "*Moderate*" "*Low*" or "*Very Low*". In this protocol, randomised controlled trials are considered the highest certainty and non-randomised studies begin as "*moderate*" certainty. Evidence can be downgraded due to 1) risk of bias, 2) inconsistency (unexplained heterogeneity) 3) Imprecision (large CIs around the pooled estimate of the effects indicated by the upper and lower CIs having >0.50 difference) or 4) publication bias. "*High*" certainty evidence indicates that further investigation is unlikely to change confidence in the effect estimates, "*moderate*" indicates further research is likely to have an important influence on confidence in the effect estimates. "*Low*" and "*Very Low*" reflect that further research is very likely to change the effect estimates and high uncertainty about the current effect estimate respectively. The evidence was presented in summary of findings tables using GRADEpro GDT.

RESULTS

Study selection

Following the removal of duplicates (n = 81), the literature search yielded 402 articles. A total of 250 research studies were removed based on the title, and a further 114 articles were removed based on abstract screening. Thirty-eight articles were included in the full-text screening. Twenty-eight studies were excluded (Figure 1), leaving ten studies for inclusion. One study initially met the inclusion criteria but was subsequently removes as a number of hamstring injuries in the cohort required surgical intervention but it was possible to determine which injuries these were (Kerin et al., 2024). Nine studies were therefore included in the review (Eggleston, McMeniman, & Engstrom, 2020; McAuley, Dobbin, Morgan, & Goodwin, 2021; Pollock et al., 2021, 2016; Shamji et al., 2021; Van Der Made, Almusa, Reurink, et al., 2018; Van Der Made, Almusa, Whiteley, et al., 2018; Vermeulen et al., 2022).

Study characteristics

All studies were published between 2015 and 2023, the characteristics of which were taken directly as reported in the original manuscripts and presented in Table 1. Five were retrospective and four were prospective. In total, 557 athletes were included, 40 of whom were female (7.2%). Three studies included football players, two included track and field athletes, three included various sports, and one included Australian Rules Football players. There were 608 injuries, 199 of which with IMT injury (33%).

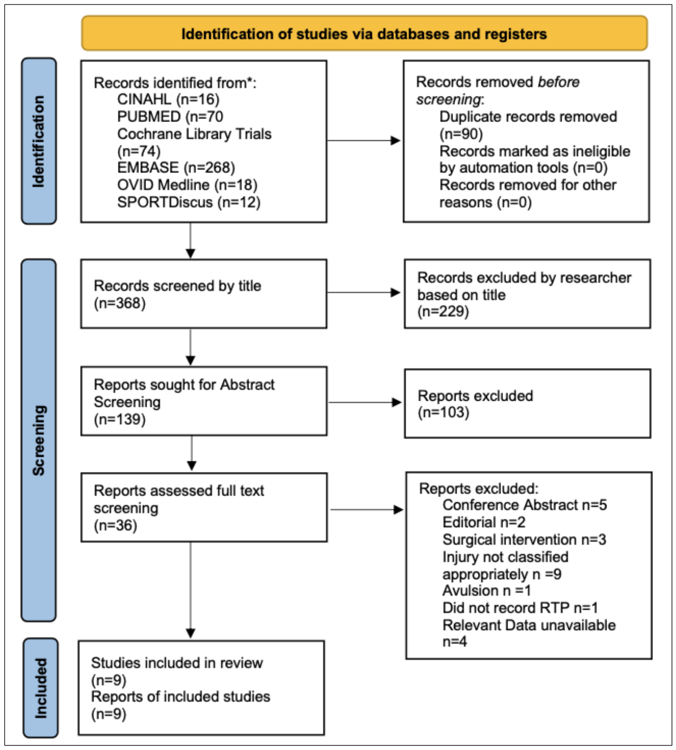

Figure 1 PRISMA Flow Diagram

Table 1 Characteristics of studies included in the review.

Author	Year	LOE	Study Design	Sports	Study Period	Number of Athletes	Age(years)	Blinding of treating physician to MRI
Eggleston et al.	2020	IV	Retrospective	Professional AFL	6 seasons	24	Mean 23.5 ± 4	No
McAuley et al.	2022	IV	Retrospective	Professional Football	4 seasons	52	Mean 26 ± 4	No
Pollock et al.	2015	IV	Retrospective	Elite Athletics	4 years	44	Mean 24 ± 4	No
Pollock et al.	2022	IV	Prospective	Elite Athletics	4 years	46	Mean 24.6 ± 3.7	No
Shamji et al.	2021	IV	Retrospective	Professional Football	8 seasons	36	Median 26 (IRQ; 18-36)	No
Tears et al.	2022	IV	Retrospective	Professional Football	9 seasons	30	Mean 26.3 ± 4.6	No
van der Made et al.	2018	II	Prospective	Multiple Competitive Sports	6 months follow up	70	Median 26 (IRQ; 22-31)	Yes
van der Made et al.	2018	II	Prospective	Multiple Competitive Sports	6 months follow up	165	Median 24 (IRQ; 21-30)	Yes
Vermeulen et al.	2022	II	Prospective	Multiple Competitive Sports	4 years	90	Early Lengthening group; 26 ± 4 Delayed Lengthening group; 25 ± 5	Yes

Note. LOE: Level of Evidence; AFL: Australian Rules Football; IRQ: Interquartile range; R: Retrospective; P: Prospective.

Table 2. PEDRO Score of included studies.

Author	Eligibility Criteria	Random Allocation	Concealed Allocation	Baseline Similarity	Blinding of Subjects	Blinding of Therapists	Blinding of Assessors	Measures of Key Outcomes for more than 85% of Subjects	Intention to Treat Analysis	Between Group Statistical Comparisons	Point Measures and Measures of Variability	Total Score	Rating
Eggleston et al. (Eggleston et al., 2020)	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	4	Fair
McAuley et al. (McAuley et al., 2021)	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	4	Fair
Pollock et al.(Pollock et al., 2016)	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	4	Fair
Pollock et al.(Pollock et al., 2021)	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	4	Fair
Shamji et al.(Shamji et al., 2021)	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	4	Fair
Tears et al.	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	4	Fair
van der Made et al. (Van Der Made, Almusa, Whiteley, et al., 2018)	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	6	Good
van der Made et al. (Van Der Made, Almusa, Reurink, et al., 2018)	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7	Good
Vermeulen et al. (Vermeulen et al., 2021a)	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	5	Fair

Quality assessment

Each of the studies was assessed for quality using the PEDro scale. Seven of the nine studies (78%) were rated as "*fair*" and two (22%) were rated as "*good*". The full quality assessment for each study is outlined in Table 2.

Results of synthesis

Time to RTP

Nine studies were pooled to compare time to RTP for hamstring injury with and without IMT injury (Figure 2). This analysis did not differentiate between injury grades. Hamstring injuries with IMT injury had a longer time to RTP than injuries without IMT injury (mean difference: 14.92 days, 95% CI: 8.15-21.69, $p < .001$, Z = 4.32).

For BAMIC 2 injuries, analysis of eight pooled studies demonstrated an extended RTP for IMT injuries (mean difference: 6.30 days, 95% CI: 1.10-11.49, $p = .02$, Z = 2.38).

For BAMIC 3 injuries four pooled studies demonstrated no significant difference in RTP between those with IMT or no-IMT involvement (mean difference: 12.82 days, 95% CI: -2.22 – 27.84, $p = .09$, Z = 1.67).

BAMIC grade 4 injuries could not be pooled due to insufficient numbers of grade 4 injuries across studies. In total 24 BAMIC grade 4 injuries with IMT involvement were reported with a mean RTP of 34.4 days.

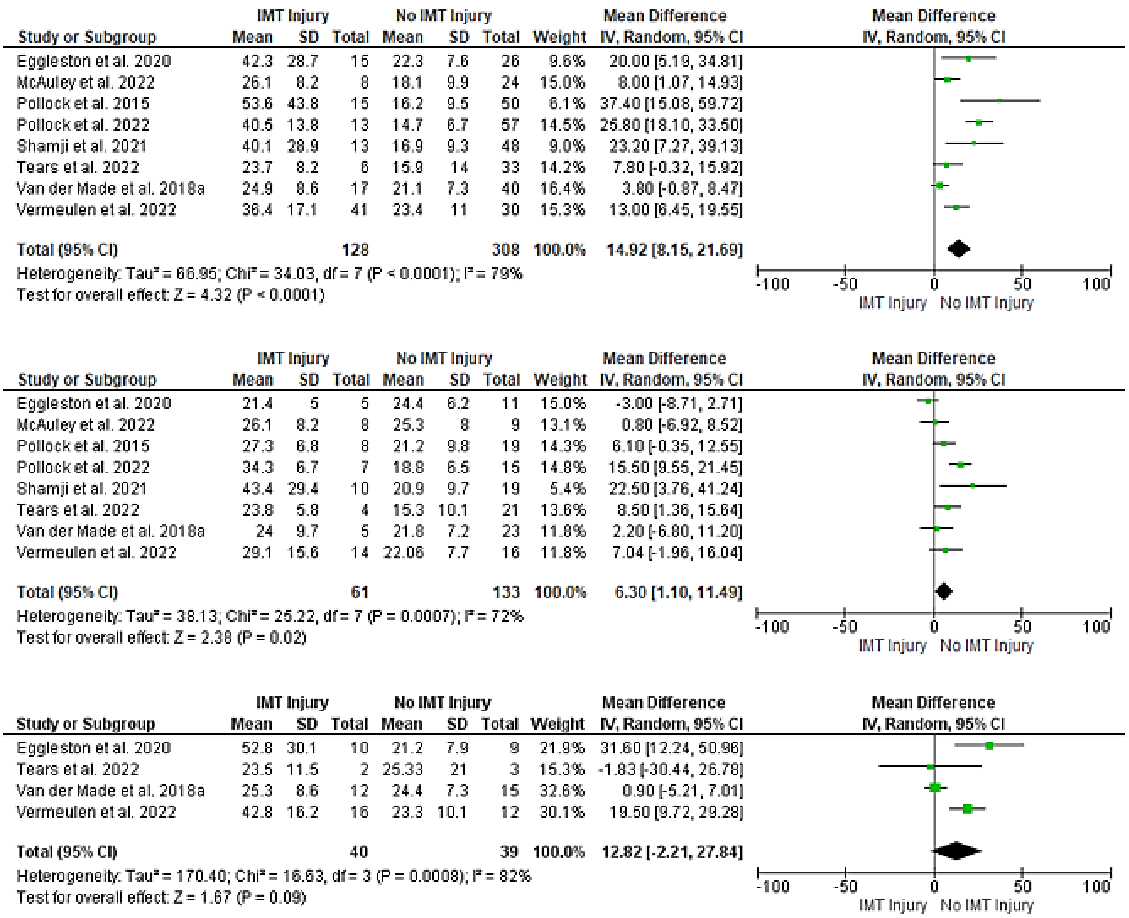

Figure 2. Forest plot comparing time to RTP (in days) for IMT and non-IMT injury irrespective of grade (top), BAMIC Grade 2 injuries (middle), and BAMIC Grade 3 injuries (bottom).

Re-injury

There were 68 reinjuries of which 31 occurred after IMT injuries. Five studies were pooled to compare re-injury rates (Figure 3) for index injuries with and without IMT injury. This analysis did not differentiate between injury grades. (OR = 2.98, 95%CI 0.93-9.59, Z = 1.83, *p* = .07).

Five studies (Figure 3) had enough data to pool for re-injury analysis for BAMIC grade 2 injuries (OR = 2.25, 95%CI 0.55-9.18, Z = 1.13, *p* = .26).

Due to insufficient data available for pooling, meta-analysis was not performed/undertaken for BAMIC grade 3 and 4 injuries; results were therefore reported narratively and displayed on forest plot (Figure 3).

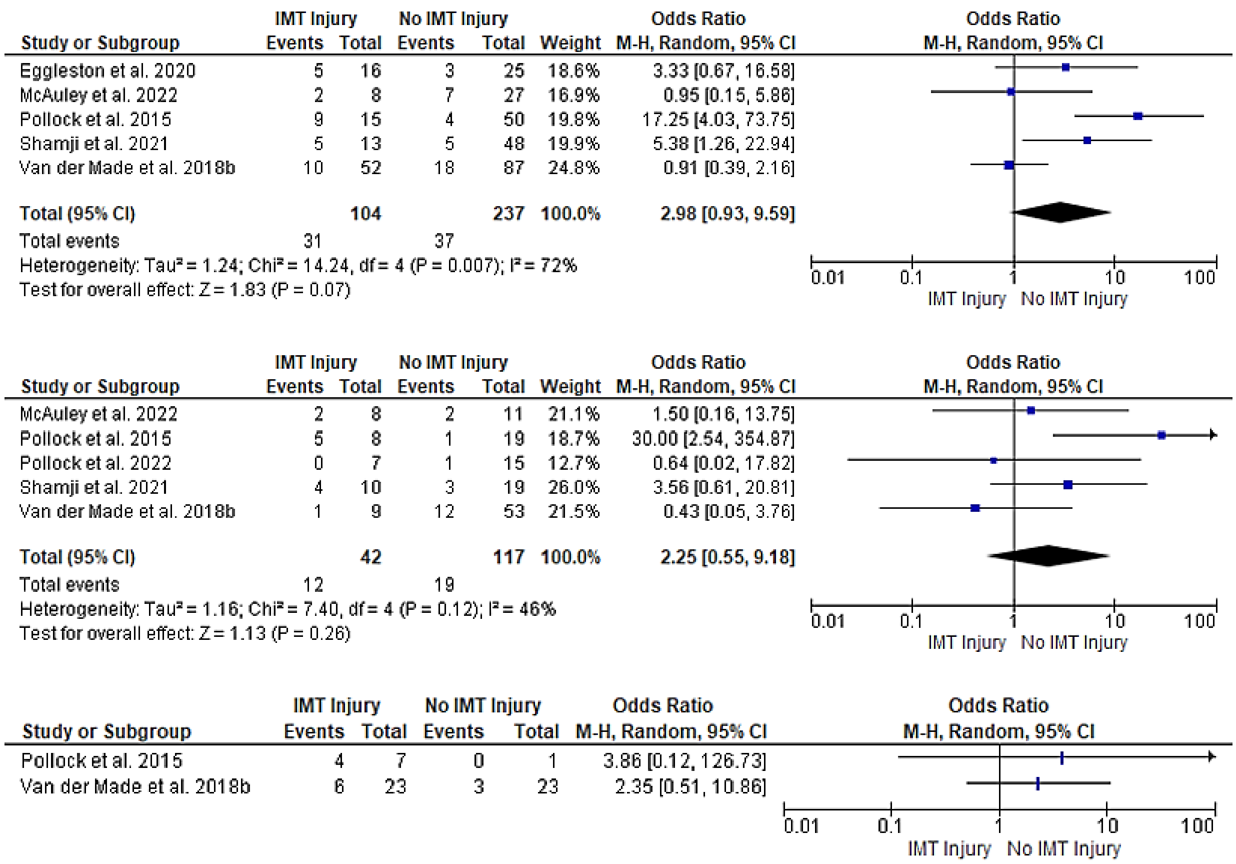

Figure 3. Forest plot illustrating the odds of reinjury for IMT and non-IMT injury irrespective of grade (top) BAMIC Grade 2 injuries (middle) and BAMIC Grade 3 injuries (bottom).

Certainty of evidence

The studies included in this review were initially considered "*low*" certainty of evidence. This was further downgraded based on the quality assessment, inconsistency (heterogeneity) and imprecision as depicted by the large confidence intervals around the pooled estimates for return to play and odds of re-injury. The overall certainty of evidence was therefore considered as "*very low*". A summary of findings tables can be found in Appendix 2.

DISCUSSION

This systematic review was undertaken to examine whether IMT involvement equates to a more significant hamstring injury and has negative consequences when considering time to RTP and re-injury rates compared with non-IMT injuries. The overall very low quality of the included studies gravely impacts conclusions that may be drawn regarding comparisons of time to RTP and re-injury rate. Despite it being commonly accepted that hamstring injuries involving the IMT require a longer RTP and have a higher re-injury risk, we have found limited evidence to support this.

Our analysis of the available data found that when grade (numerical) is not taken into account, any injury to the IMT increases overall RTP time by approximately 15 days. There were no clear differences in odds of re-injury following hamstring injury with or without IMT involvement. While being a notably smaller between-group difference in RTP than previously reported in individual studies, this two-week difference can be regarded as clinically relevant given the competitive and financial implications of athletes being unavailable for selection in professional or elite sport.

Our results suggest a significantly shorter extension in RTP in comparison with some individual studies included in our analysis (Pollock et al., 2021, 2016). There are also large between-study differences in both RTP and re-injury rate across the studies in the analysis, with some studies showing significantly less RTP extension and re-injury risk associated with IMT injuries than others (Van Der Made, Almusa, Reurink, et al., 2018; Van Der Made, Almusa, Whiteley, et al., 2018).

There are several potential reasons why hamstring IMT injuries may require an extended RTP including physiological, histological and biomechanical characteristics of the IMT. However, the most important findings were that the majority of the papers investigating outcomes following hamstring IMT injury are of poor methodological quality, have a low certainty of evidence and lack blinding of clinicians making RTP decisions. Therefore, the clinical importance hamstring IMT injury remains unclear.

Certainty of evidence

The body of evidence available for this review was limited with only 9 studies suitable for inclusion, 5 of which were retrospective. Although the included studies were rated 'fair or good' with respect to methodological quality they were considered to be of a 'very low' certainty of evidence. This was due to the methodological quality, heterogeneity of the pooled data and imprecision supported by the large confidence intervals.

Lack of blinding

There was a lack of blinding of treating clinicians and patients for MRI findings in 6 out of 9 included studies. This lack of blinding introduces considerable risk of bias, reducing the validity of the studies included and therefore the ability to formulate conclusions and evidence-based recommendations. However, the current evidence available is all that is available to clinicians who are expected to provide accurate injury prognosis to athletes and stakeholders. There is the possibility that, even without the use of a (current or later developed) specific classification system, the knowledge of a 'seemingly substantial injury' on imaging might have delayed the athlete's progression through rehabilitation. This may be further influenced by the therapist's knowledge regarding differences between muscle and tendon healing.

Therapists caution regarding prognosis is relevant in elite sports where exacerbations and (early) re-injury can have substantial performance and financial consequences as well as ramifications for the medical professionals involved in the rehabilitation process. Some authors address this limitation and discuss how physiotherapists claimed to not be biased by the tendon involvement on the MRI and instead relied on their athlete reaching a pre-defined criterion (Eggleston et al., 2020). However, in a systematic review, a disparity was highlighted between implicit and explicit beliefs amongst health care professionals (Fitzgerald & Hurst, 2017). Although these therapists claimed not to be influenced by the presence of an IMT injury, their implicit biases and external pressures may have affected their clinical judgement which effected injury outcomes.

In a retrospective analysis, it is impossible to determine whether a between-group difference is based on healing response and biomechanical demand on the IMT, a prolonged rehabilitation due to knowledge of imaging findings, or both. While we appreciate that this methodological hurdle is difficult to overcome in an elite sports setting, blinding remains paramount to overcome the risk of a "*self-fulfilling prophecy*" (Gustaaf Reurink et al., 2015). Future research investigating outcomes following hamstring IMT injuries should employ blinding and a prospective study design as the continued publication of retrospective analysis of IMT injury outcomes will not achieve any deeper understanding of these injuries.

IMT injury healing

The delay of tendon healing in comparison to muscle is mentioned frequently as potential reason for an extended RTP following IMT injury (Brukner & Connell, 2016; Pollock et al., 2021, 2016) . This is hypothesised due to vascular supply and structural cellular differences between muscle and tendon (Brukner & Connell, 2016). The delay in healing is suggested to be why the IMT may also be more susceptible to early re-injury than other injuries (Pollock et al., 2016). Much of this research is based on free tendons rather than IMTs. Although it has been proposed that IMTs have a similar healing mechanism to free tendons, there are certain differences in its function, such as its stiffness, which suggests it has a different purpose (Brukner et al., 2018). Further research is required to evaluate these theories.

Re-injury definition

Our analysis did not find an overall difference in re-injury rate between IMT and non-IMT injuries. The same applied to BAMIC grade 2 injuries (OR: 2.25, 95% CI 0.55-9.18). Due to insufficient numbers of reinjuries in the different subgroups, no formal meta-analysis could be performed for BAMIC grades 3 and 4. The number of re-injuries in this systematic review would realistically only allow for strong associations to be identified, and that for small to moderate associations about 200 reinjuries would be required (Bahr, 2003).

There were notable differences in reported re-injury rates, and duration of follow-up between different papers across different sports for IMT injuries, which make comparisons between papers difficult to interpret. A disparity exists in defining re-injuries across the studies included in this review. Several studies that reported elevated re-injury rates following IMT injury included exacerbations throughout the rehabilitation process as separate re-injuries (Pollock et al., 2016). Part of this definition was that the athlete's involvement in training or rehabilitation was altered for greater than 48 hours. Forty-eight hours could be considered a relatively short time frame and therefore the inclusion of exacerbations in reinjury rates may overestimate any effect of IMT involvement in reinjury risk. Furthermore, presence of 'new' acute tissue damage was not confirmed nor ruled out by MRI. Other studies with lower re-injury rates excluded exacerbations in their reinjury analysis, following recommendations by Fuller et al. This difference in recording of re-injury may explain some of the between-study differences in re-injury rate. Future research investigating re-injury rate following IMT injury should exclude exacerbations as a re-injury as per consensus guidelines on injury surveillance (Fuller, Bahr, Dick, & Meeuwisse, 2007).

Athletics Vs field sports

Some of the studies included in this analysis that show the largest between-group differences are studies with track and field athletes. Unfortunately, there was insufficient data for a separate track and field meta-analysis. Field sports were analysed independently (Appendix 3). When considering time to RTP and re-injury risk following any injury, the type of activity the athlete is aiming to return to must be considered and is likely relevant to inform the rehabilitation process (Ardern et al., 2016). Sprinting speed and volume of high-speed running are two factors associated with hamstring injury risk (Duhig et al., 2016). Overall, similar maximal speeds of approximately 32 kilometres per hour (kph) are reached in AFL and football (Abbott, Brickley, & Smeeton, 2018; Janetzki, Bourdon, Norton, Lane, & Bellenger, 2021). However, these speeds are lower than those reached by track and field athletes where elite 100m sprinters can reach 44 kilometres per hour (Čoh, Hébert-Losier, Štuhec, Babić, & Supej, 2018). A detailed comparison between the athletic demands of AFL, football and athletics is beyond the scope of this analysis. However, in track and field, participants are exposed to much higher running speeds than field sports (Abbott et al., 2018; Čoh et al., 2018).

Furthermore, in field sports, intensity can be regulated by tactical awareness. This is supported by who demonstrated that high speed running (HSR) distances are suppressed after return to play following a hamstring injury (Whiteley et al., 2021). These authors found that 50% of the players examined experienced a reduction in HSR performance on return from a hamstring injury. This highlights the possibility that a field sport player can adjust sprinting intensity while competing in their sport. However, this is not feasible for competitive sprinters seeking to perform to their potential in competition and therefore this may result in an extended RTP and risk of re-injury (Pollock et al., 2021, 2016). The apparent differences in sporting demands observed on our forest plots might partly explain the range in RTP times and re-injury rates for IMT seen across the studies included in our analysis. However, it must be noted a formal analysis was not undertaken due to sample size issues.

BAMIC

The design and widespread implementation of the BAMIC has played a significant role in increasing the awareness of IMT injury both in research and clinical practice. This grading system uses the anatomical location (a, b, or c) in the cases of large injuries to the musculotendinous unit in addition to a numerical grade (0-4). Injuries to the IMT can occur to the longitudinal length or the cross-sectional area (CSA) of the tendon. Recent research has suggested that extent of tendon injury CSA is more likely associated with outcomes than the longitudinal length (Eggleston et al., 2020). This may be associated with a loss of tension to the IMT which can be noted as waviness on an MRI (Vermeulen et al., 2021b). Furthermore, it has been suggested that the IMT may undergo more lateral expansion with transverse strain rather than longitudinal strain (Farris, Trewartha, McGuigan, & Lichtwark, 2013). Therefore, a greater amount of CSA involvement may result in increased compliance in a structure designed for stiffness than longitudinal disruption.

This caveat regarding orientation of IMT tissue disruption is something not distinguished between when using BAMIC grading in isolation. For instance, a grade 3 hamstring injury with a 10% tendon CSA involvement is considered a 3c, as is an injury involving >50% tendon CSA. These two injuries may be grouped together as 'c–injuries' despite a greater tendon disruption to the second example. This may partially explain the large variation in outcomes following IMT injury observed across the studies. Future research should consider using a grading system with more weighting on the extent and direction of tendon disruption in order to guide clinical practice.

Limitations

Analysis was not possible on some subgroups due to insufficient sample sizes for some of the subgroups (i.e. high-grade injuries). These included RTP analysis for BAMIC grade 4 injuries, reinjury analysis for BAMIC grade 3 and 4 injuries, a separate analysis for track and field athletes, and a comparison between recreational and competitive/elite athletes.

Some studies had a larger number of high-grade injuries included in their analysis than others (Van Der Made, Almusa, Reurink, et al., 2018; Van Der Made, Almusa, Whiteley, et al., 2018; Vermeulen et al., 2022). This may be due to a difference in recruitment as these studies recruited injured players at a hospital rather than observing injury trends with a squad over time increasing the risk of selection bias.

There was heterogeneity between sports and rehabilitation approaches in our study population. Together with methodological limitations of the included studies, this heterogeneity may reduce the robustness of the results.

Implications for clinical practice and future research directions

Our analysis of the current body of evidence suggests that the presence of an IMT injury extends RTP by 2 weeks and does not increase risk of re-injury. However, this is not generalisable to other cohorts based on methodological limitations in most studies reporting differences in RTP time and re-injury risk introducing substantial risk of bias. Despite the knowledge of the presence of IMT injury, the variance in time to RTP for these injuries renders an accurate prediction of RTP for the individual injured athlete virtually impossible.

To inform prognosis more large, prospective, blinded research is required to establish whether IMT injury indeed confers an extended RTP timeframe and increased re-injury risk in sport-specific settings. Firstly, future studies should consider blinding therapists and athletes to MRI results to reduce bias on those making a RTP decision. Understandably, this would be difficult to undertake in elite sport. Secondly, it may be helpful if more studies considered the direction and the extent of IMT injury in the prognosis of the athlete rather than relying on a BAMIC grading in a clinical setting and in research. This would require communication with radiologists regarding reporting style which may not always be possible. Without this communication and reporting style the role of MRI in the management of hamstring IMT injury may not be justified as there is little evidence to suggest MRI findings influence outcomes (G. Reurink et al., 2015). Crema et al., (2017) determined that the presence of an IMT injury cannot be detected by clinical examination and that MRI is required. If it was demonstrated that IMT involvement did not influence outcomes, this may reduce the financial burden on sporting organisations to MRI muscle injuries. This may be an important factor to consider for sporting organisations whose financial resources are limited. Future research may use an alternative classification system such as the one proposed by Eggleston et al., (2020) which provides more context to the extent of IMT involvement in the injury.

CONCLUSION

There is very low quality evidence to guide prognosis for hamstring injuries involving the IMT. Based on the available body of evidence, IMT injuries may have an extended RTP duration of approximately two weeks compared to non-IMT injury. No between-group differences were found in re-injury rate. The overall very low quality of the included studies impacts conclusions that may be drawn regarding comparisons of time to RTP and re-injury rate. However, the evidence available is all clinicians have to guide their prognosis. Ultimately, we consider our papers strongest conclusion to be a call to arms to attempt to complete high quality blinded research investigating outcomes following IMT injury. In order to provide evidence-based RTP timeframes, re-injury rates, and informed treatment/rehabilitation decisions for injuries with and without intramuscular tendon involvement, high-quality prospective studies with blinding of MRI findings are paramount. We argue that further publication of unblinded retrospective analysis will not add any new information to guide clinicians working with athletes with these injuries.

Perspective

Over the last 10 years the role of IMT involvement in hamstring injury outcomes has been a popular topic in sports medicine. The creation and the implementation of the BAMIC has been instrumental in increasing awareness of this anatomical region within a musculotendinous unit. However, to date the available studies vary in outcomes following this type of hamstring injury. To the authors knowledge this the first systematic review and meta-analysis examining hamstring IMT injury RTP and re-injury outcomes. Despite our findings of an extended RTP for these injuries, the clinical relevance of this is questionable due to the majority of studies being of moderate quality.

Providing an estimation of RTP following hamstring injury is a difficult task for a clinician. Perhaps the involvement of an IMT should not be considered a yes or no answer when attempting to provide a prognosis. Evidence suggests that extent of tendon CSA disruption is more associated with outcomes than longitudinal length (Eggleston et al., 2020). However, IMT involvement is only one piece of the puzzle and other factors need to be considered such as history of injury, age and level of sport they are returning to (Green, Bourne, Van Dyk, & Pizzari, 2020). More caution may be required with athletes with large IMT CSA disruption. Ultimately, further high quality research with adequate blinding is required to provide more guidance on management of these injuries.

AUTHOR CONTRIBUTIONS

Michael O'Sullivan was the lead author who conceptualised the idea for a review on this topic. He was responsible for screening papers, writing drafts and liaising with co-authors to reach a final draft. Karen Mullins was involved in the search, screening and methodology. Karen also created the tables in which the results are displayed. Anne van der Made, as an author who has already published in this area provided key feedback to the drafts. Anne suggested changes to the discussion when needed and also helped with putting the abstract together. Mr. Patrick Carton, as a renowned hip surgeon and author provided feedback to the group around writing and contributed greatly to the structure of the discussion, results and conclusion. All authors contributed greatly to this project in their own way.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REGISTRATION AND DEVIATIONS FROM PROTOCOL

This systematic review adhered to the planned protocol which was registered at PROSPERO (ID CRD42022303455). In our original proposal we had planned to compare outcomes between recreational and competitive/elite athletes. Lack of data made this impossible.

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APPENDIX 1. SEARCH STRATEGY.

Search strategy

Muscle	Tendon	Injury	RTP	Re-injury
Hamstring	Intra-muscular tendon	Injury	RTP	Re-injury
Posterior Thigh	Central Aponeurosis	Strain	Recovery	Recurrence
Biceps Femoris	Intra-aponeurosis	Tear	Return to full training	Exacerbation
Semimembranosis	Intramuscular connective tissue	Disruption	Return to sport	
Semi-tendinosis		Avulsion	Return to competition	

The boolean term OR was used within categories, AND was used between categories

Search: (((((((Hamstring) OR (posterior thigh)) OR (semitendinosus)) OR (semimembranosus)) OR (bicep femoris)) AND ((((injury) OR (strain)) OR (tear)) OR (disruption))) AND ((intramuscular tendon) OR (central tendon))) AND ((((((((return to play) OR (recovery)) OR (return to training)) OR (return to sport)) OR (return to competition)) OR (reinjury)) OR (recurrence)) OR (Exacerbation))
("hamstring muscles"[MeSH Terms] OR ("hamstring"[All Fields] AND "muscles"[All Fields]) OR "hamstring muscles"[All Fields] OR "hamstring"[All Fields] OR "hamstrings"[All Fields] OR (("posterior"[All Fields] OR "posteriors"[All Fields]) AND ("thigh"[MeSH Terms] OR "thigh"[All Fields] OR "thighs"[All Fields] OR "thigh s"[All Fields])) OR ("hamstring muscles"[MeSH Terms] OR ("hamstring"[All Fields] AND "muscles"[All Fields]) OR "hamstring muscles"[All Fields] OR "semitendinosus"[All Fields]) OR ("hamstring muscles"[MeSH Terms] OR ("hamstring"[All Fields] AND "muscles"[All Fields]) OR "hamstring muscles"[All Fields] OR "semimembranosus"[All Fields]) OR ("hamstring muscles"[MeSH Terms] OR ("hamstring"[All Fields] AND "muscles"[All Fields]) OR "hamstring muscles"[All Fields] OR ("bicep"[All Fields] AND "femoris"[All Fields]) OR "bicep femoris"[All Fields])) AND ("injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[MeSH Subheading] OR "injuries"[All Fields] OR "wounds and injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "wounds and injuries"[All Fields] OR "injurious"[All Fields] OR "injury s"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields] OR ("sprains and strains"[MeSH Terms] OR ("sprains"[All Fields] AND "strains"[All Fields]) OR "sprains and strains"[All Fields] OR "strain"[All Fields] OR "strains"[All Fields] OR "strain s"[All Fields]) OR ("tears"[MeSH Terms] OR "tears"[All Fields] OR "tear"[All Fields] OR "lacerations"[MeSH Terms] OR "lacerations"[All Fields]) OR ("disrupt"[All Fields] OR "disrupted"[All Fields] OR "disrupter"[All Fields] OR "disrupters"[All Fields] OR "disrupting"[All Fields] OR "disruption"[All Fields] OR "disruptions"[All Fields] OR "disruptive"[All Fields] OR "disruptiveness"[All Fields] OR "disrupts"[All Fields])) AND (("intramuscular"[All Fields] AND ("tendinopathy"[MeSH Terms] OR "tendinopathy"[All Fields] OR "tendonitis"[All Fields] OR "tendon s"[All Fields] OR "tendonous"[All Fields] OR "tendons"[MeSH Terms] OR "tendons"[All Fields] OR "tendon"[All Fields])) OR (("central"[All Fields] OR "centrally"[All Fields] OR "centrals"[All Fields]) AND ("tendinopathy"[MeSH Terms] OR "tendinopathy"[All Fields] OR "tendonitis"[All Fields] OR "tendon s"[All Fields] OR "tendonous"[All Fields] OR "tendons"[MeSH Terms] OR "tendons"[All Fields] OR "tendon"[All Fields]))) AND ("return to sport"[MeSH Terms] OR ("return"[All Fields] AND "sport"[All Fields]) OR "return to sport"[All Fields] OR ("return"[All Fields] AND "play"[All Fields]) OR "return to play"[All Fields] OR ("recoveries"[All Fields] OR "recovery"[All Fields]) OR (("return"[All Fields] OR "returned"[All Fields] OR "returning"[All Fields] OR "returns"[All Fields]) AND ("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields])) OR ("return to sport"[MeSH Terms] OR ("return"[All Fields] AND "sport"[All Fields]) OR "return to sport"[All Fields]) OR (("return"[All Fields] OR "returned"[All Fields] OR "returning"[All Fields] OR "returns"[All Fields]) AND ("competition"[All Fields] OR "competitions"[All Fields] OR "competitive"[All Fields] OR "competitively"[All Fields] OR "competitiveness"[All Fields])) OR ("reinjuries"[MeSH Terms] OR "reinjuries"[All Fields] OR "reinjury"[All Fields]) OR ("recurrance"[All Fields] OR "recurrence"[MeSH Terms] OR "recurrence"[All Fields] OR "recurrences"[All Fields] OR "recurrencies"[All Fields] OR "recurrency"[All Fields] OR "recurrent"[All Fields] OR "recurrently"[All Fields] OR "recurrents"[All Fields]) OR ("exacerbate"[All Fields] OR "exacerbated"[All Fields] OR "exacerbates"[All Fields] OR "exacerbating"[All Fields] OR "exacerbation"[All Fields] OR "exacerbations"[All Fields] OR "exacerbator"[All Fields] OR "exacerbators"[All Fields]))

Translations

Hamstring: "hamstring muscles"[MeSH Terms] OR ("hamstring"[All Fields] AND "muscles"[All Fields]) OR "hamstring muscles"[All Fields] OR "hamstring"[All Fields] OR "hamstrings"[All Fields]
posterior: "posterior"[All Fields] OR "posteriors"[All Fields]
thigh: "thigh"[MeSH Terms] OR "thigh"[All Fields] OR "thighs"[All Fields] OR "thigh's"[All Fields]
semitendinosus: "hamstring muscles"[MeSH Terms] OR ("hamstring"[All Fields] AND "muscles"[All Fields]) OR "hamstring muscles"[All Fields] OR "semitendinosus"[All Fields]
semimembranosus: "hamstring muscles"[MeSH Terms] OR ("hamstring"[All Fields] AND "muscles"[All Fields]) OR "hamstring muscles"[All Fields] OR "semimembranosus"[All Fields]
bicep femoris: "hamstring muscles"[MeSH Terms] OR ("hamstring"[All Fields] AND "muscles"[All Fields]) OR "hamstring muscles"[All Fields] OR ("bicep"[All Fields] AND "femoris"[All Fields]) OR "bicep femoris"[All Fields]
injury: "injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[Subheading] OR "injuries"[All Fields] OR "wounds and injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "wounds and injuries"[All Fields] OR "injurious"[All Fields] OR "injury's"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields]
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tear: "tears"[MeSH Terms] OR "tears"[All Fields] OR "tear"[All Fields] OR "lacerations"[MeSH Terms] OR "lacerations"[All Fields]
disruption: "disrupt"[All Fields] OR "disrupted"[All Fields] OR "disrupter"[All Fields] OR "disrupters"[All Fields] OR "disrupting"[All Fields] OR "disruption"[All Fields] OR "disruptions"[All Fields] OR "disruptive"[All Fields] OR "disruptiveness"[All Fields] OR "disrupts"[All Fields]
tendon: "tendinopathy"[MeSH Terms] OR "tendinopathy"[All Fields] OR "tendonitis"[All Fields] OR "tendon's"[All Fields] OR "tendonous"[All Fields] OR "tendons"[MeSH Terms] OR "tendons"[All Fields] OR "tendon"[All Fields]
central: "central"[All Fields] OR "centrally"[All Fields] OR "centrals"[All Fields]
tendon: "tendinopathy"[MeSH Terms] OR "tendinopathy"[All Fields] OR "tendonitis"[All Fields] OR "tendon's"[All Fields] OR "tendonous"[All Fields] OR "tendons"[MeSH Terms] OR "tendons"[All Fields] OR "tendon"[All Fields]
return to play: "return to sport"[MeSH Terms] OR ("return"[All Fields] AND "sport"[All Fields]) OR "return to sport"[All Fields] OR ("return"[All Fields] AND "play"[All Fields]) OR "return to play"[All Fields]
recovery: "recoveries"[All Fields] OR "recovery"[All Fields]
return: "return"[All Fields] OR "returned"[All Fields] OR "returning"[All Fields] OR "returns"[All Fields]
training: "education"[Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train's"[All Fields] OR "trained"[All Fields] OR "training's"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]
return to sport: "return to sport"[MeSH Terms] OR ("return"[All Fields] AND "sport"[All Fields]) OR "return to sport"[All Fields]
return: "return"[All Fields] OR "returned"[All Fields] OR "returning"[All Fields] OR "returns"[All Fields]
competition: "competition"[All Fields] OR "competitions"[All Fields] OR "competitive"[All Fields] OR "competitively"[All Fields] OR "competitiveness"[All Fields]
reinjury: "reinjuries"[MeSH Terms] OR "reinjuries"[All Fields] OR "reinjury"[All Fields]
recurrence: "recurrance"[All Fields] OR "recurrence"[MeSH Terms] OR "recurrence"[All Fields] OR "recurrences"[All Fields] OR "recurrencies"[All Fields] OR "recurrency"[All Fields] OR "recurrent"[All Fields] OR "recurrently"[All Fields] OR "recurrents"[All Fields]
Exacerbation: "exacerbate"[All Fields] OR "exacerbated"[All Fields] OR "exacerbates"[All Fields] OR "exacerbating"[All Fields] OR "exacerbation"[All Fields] OR "exacerbations"[All Fields] OR "exacerbator"[All Fields] OR "exacerbators"[All Fields]

Warnings

((((((Hamstring) OR (posterior thigh)) OR (semitendinosus)) OR (semimembranosus)) OR (bicep femoris)) AND ((((injury) OR (strain)) OR (tear)) OR (disruption))) AND ((intramuscular tendon) OR (central tendon))) AND ((((((((return to play) OR (recovery)) OR (return to training)) OR (return to sport)) OR (return to competition)) OR (reinjury)) OR (recurrence)) OR (Exacerbation))

APPENDIX 2. SUMMARY OF FINDINGS TABLES.

Certainty assessment							№ of patients		Effect		Certainty	Importance
№ of studies	**Study design**	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other considerations**	**IMT Involvement**	**No IMT Involvement**	**Relative (95% CI)**	**Absolute (95% CI)**		
RTP for IMT Versus No IMT												
8	non-randomised studies	very serious[a]	serious[b]	not serious	serious[a,b]	none	128	308	-	MD **14.92 higher** (8.15 higher to 21.69 higher)	⊕◯◯◯ Very low	CRITICAL
RTP for BAMIC 2												
8	non-randomised studies	very serious[a]	serious[b]	not serious	serious	none	61	133	-	MD **6.3 higher** (1.1 higher to 11.49 higher)	⊕◯◯◯ Very low	CRITICAL
RTP for BAMIC 3												
4	non-randomised studies	very serious[a]	serious[b]	not serious	serious	none	40	39	-	MD **12.82 higher** (2.21 lower to 27.84 higher)	⊕◯◯◯ Very low	CRITICAL
Reinjury all IMT Versus Non IMT												
5	non-randomised studies	very serious[a]	serious[b]	not serious	serious	none	31/104 (29.8%)	37/237 (15.6%)	**OR 2.98** (0.93 to 9.59)	**199 more per 1,000** (from 9 fewer to 483 more)	⊕◯◯◯ Very low	CRITICAL
Reinjury Rate BAMIC 2												
5	non-randomised studies	very serious[a]	serious[b]	not serious	serious[a,b]	none	12/42 (28.6%)	19/117 (16.2%)	**OR 2.25** (0.55 to 9.18)	**141 more per 1,000** (from 66 fewer to 478 more)	⊕◯◯◯ Very low	CRITICAL
Reinjury Rate BAMIC 3												
2	non-randomised studies	very serious[a]	serious[b]	not serious	serious[a,b]	none	10/30 (33.3%)	3/24 (12.5%)	not pooled	see comment	⊕◯◯◯ Very low	CRITICAL

Notes. CI: confidence interval; MD: mean difference; OR: odds ratio. Explanations: a. Most studies did not blind physiotherapist to MRI results. b. Heterogeneity.

APPENDIX 3. SUB-ANALYSIS.

RTP and reinjury in Field sports

When pooling data from field sports only, the mean difference between injuries with and without IMT was 9.93 days (95%CI 4.93-14.94, p = .0001, Z = 3.89). There was no difference in the odds of reinjury in field sports between injuries with and without IMT injury (OR = 1.83, 95% CI 0.73-4.61, p = .20, Z = 1.28).

Due to insufficient number of reinjuries in the track and field studies, we could not repeat the analyses for track and field studies in a similar manner to field sports.

	IMT Injury			No IMT Injury				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Eggleston et al. 2020	42.3	28.7	15	22.3	7.6	26	8.5%	20.00 [5.19, 34.81]
McAuley et al. 2022	26.1	8.2	8	19	9.8	22	19.9%	7.10 [0.10, 14.10]
Shamji et al. 2021	40.1	28.9	13	16.9	9.3	48	7.6%	23.20 [7.27, 39.13]
Tears et al. 2022	23.7	8.2	6	15.9	14	33	17.6%	7.80 [-0.32, 15.92]
Van der Made et al. 2018a	24.9	8.6	17	21.1	7.3	40	25.5%	3.80 [-0.87, 8.47]
Vermeulen et al. 2022	36.4	17.1	41	23.4	11	30	21.0%	13.00 [6.45, 19.55]
Total (95% CI)			**100**			**199**	**100.0%**	**9.93 [4.93, 14.94]**

Heterogeneity: Tau² = 19.93; Chi² = 11.42, df = 5 (P = 0.04); I² = 56%
Test for overall effect: Z = 3.89 (P = 0.0001)

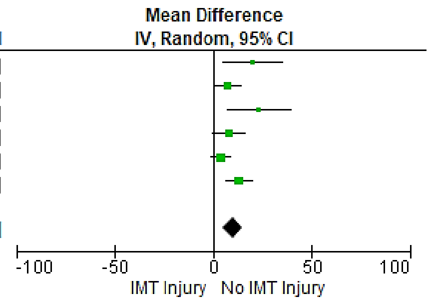

Figure 5. Forest plot comparing time to RTP (in days) for IMT and non-IMT injury in field sports irrespective of grade.

	IMT Injury		No IMT Injury			Odds Ratio
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Eggleston et al. 2020	5	16	3	25	20.9%	3.33 [0.67, 16.58]
McAuley et al. 2022	2	8	7	27	17.7%	0.95 [0.15, 5.86]
Shamji et al. 2021	5	13	5	48	23.6%	5.38 [1.26, 22.94]
Van der Made et al 2018b	10	52	18	87	37.8%	0.91 [0.39, 2.16]
Total (95% CI)		**89**		**187**	**100.0%**	**1.83 [0.73, 4.61]**
Total events	22		33			

Heterogeneity: Tau² = 0.39; Chi² = 5.43, df = 3 (P = 0.14); I² = 45%
Test for overall effect: Z = 1.28 (P = 0.20)

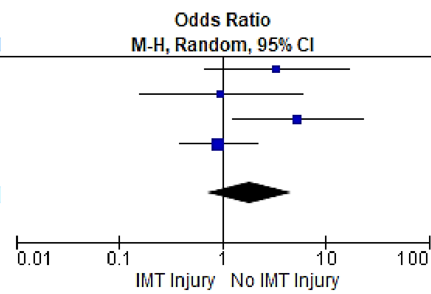

Figure 6. Forest plot comparing odds of re-injury for IMT and non-IMT injury in field sports irrespective of grade.