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Ultrasound-detected connective tissue involvement in acute muscle injuries in elite athletes and return to play: the French National Institute of Sports (INSEP) study.

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1 **Ultrasound-detected connective tissue involvement in acute muscle injuries in elite**
2 **athletes and return to play: the French National Institute of Sports (INSEP) study.**

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20 **Abstract**

21 **Objective:** Previous MRI studies showed that involvement of connective tissue in muscle
22 injuries may prolong recovery times. The relevance of ultrasound assessment of connective
23 tissue involvement as a prognostic factor is unknown. The aim was to test the hypothesis that
24 ultrasound-detected connective tissue involvement in acute muscle injuries are related to
25 longer recovery times.

26 **Design:** Cohort study.

27 **Methods:** Seventy consecutive elite athletes from the French National Institute of Sports
28 (INSEP) sustaining an acute muscle injury showing positive findings on ultrasound at
29 baseline were included. Ultrasound was systematically performed within 7 days after the
30 injury for the assessment of severity (grades 1-4) and type of injury in regard to the absence
31 (M injuries) or presence (C injuries) of connective tissue involvement. The differences in the
32 mean time needed to return to play (RTP) between the different grades and types of injury
33 were assessed using multiple non-parametric tests.

34 **Results:** When considering the overall grades independently of the type of injury (M or C), an
35 increase in the mean time needed to RTP was observed with the increase of grades
36 ($p < 0.0001$). The same relationship was found when considering grades from M and C injuries
37 separately, with higher grades of injuries exhibiting longer times needed to RTP ($p < 0.0001$).
38 Longer times needed to RTP were observed in athletes demonstrating C injuries in
39 comparison to the ones exhibiting M injuries overall ($p = 0.002$).

40 **Conclusion:** Ultrasound-detected connective tissue involvement in acute muscle injuries are
41 related to longer times needed to RTP, especially when disruption is detected.

42 **Key words:** muscle injuries; ultrasound, connective tissue injury; return to play

43 **Introduction**

44 Acute muscle injuries are responsible for a large part of time lost to competition in elite
45 athletes ¹⁻⁵. Current evidence regarding prediction of the time needed to return to play (RTP)
46 based on imaging features is mainly related to hamstring research, with studies suggesting
47 that a number of magnetic resonance imaging (MRI) findings are associated with the amount
48 of time needed before RTP ⁶⁻¹⁶. However, there are discrepancies in the literature regarding
49 the predictive effect of some MRI features, with the use of MRI being contested by previous
50 publications that could not reproduce the same results as previously published ¹⁷⁻²⁰.

51 Some studies shed light on the potential prognostic value of intramuscular connective tissue
52 involvement in acute muscle injuries. Two studies showed evidence that MRI-detected
53 intramuscular tendon involvement in hamstring injuries was associated with a delay in the
54 time needed to RTP ^{9,10}, and such feature was even included in a recent MRI classification
55 system of muscle injuries, the British Athletics Muscle Injury system ²¹. More recently, a
56 prospective MRI study demonstrated that mainly full-thickness disruption and waviness of the
57 intramuscular tendon in hamstring injuries was related to longer recovery times, but a limited
58 prognostic value was found if taking into account any intramuscular tendon involvement ¹².
59 Furthermore, another MRI study demonstrated that connective tissue involvement in calf
60 muscle injuries can be used to estimate the time needed to RTP ¹¹.

61 Compared to MRI, ultrasound is relatively inexpensive and easily accessible, being widely
62 used by many sports medicine teams in the diagnosis and follow-up of muscle injuries in elite
63 athletes. Ultrasound provides a greater spatial resolution than MRI, allowing for detailed
64 assessment of proximal and distal connective tissues in skeletal muscles, such as
65 intramuscular tendon as well as intra- and peri-muscular aponeurosis. Compared to MRI,
66 there is paucity of data regarding the clinical relevance of ultrasound findings in acute muscle

67 injuries, with controversial results regarding their prognostic value ^{8,22}. Furthermore, no
68 previous ultrasound studies attempted to specifically identify involvement of muscular
69 connective tissues in acute muscle injuries and its relationship with recovery times in athletes.

70 In order to demonstrate the prognostic value of ultrasound in assessing acute muscle injuries,
71 we aimed to assess the relationships between ultrasound features of muscle injuries and the
72 time needed to RTP in a sample of elite athletes followed at the (blinded), including
73 ultrasound features of connective tissue involvement. We tested the hypothesis that muscle
74 injuries exhibiting connective tissue involvement are associated with longer recovery times
75 when compared to those without such involvement. Secondly, we also tested the hypothesis
76 that higher grades of ultrasound-detected injuries are related to longer recovery times.

77

78 **Methods**

79 Seventy consecutive elite athletes from several sports at (blinded) were retrospectively
80 included in our study from 2011 to 2014 if they sustained an acute muscle injury showing
81 positive findings on ultrasound at baseline. Ultrasound was systematically performed at the
82 department of radiology of (blinded) within 7 days after the injury. Clinically, we defined
83 acute muscle injuries as those where athletes complained of acute pain in a given muscle
84 group, which immediately prevented the athlete from any activity in training or competition.
85 Only muscle injuries from an indirect (intrinsic) mechanism were included in our study.
86 Athletes were excluded in case of history of previous injuries involving the same muscle
87 group affected by an acute injury. All athletes included had follow-up data regarding the
88 length of time to RTP after muscle injuries. Ethical approval was obtained from the local
89 Institutional Review Board which waived informed consent due to the retrospective nature of
90 the study.

91 All ultrasound examinations were performed by a single musculoskeletal radiologist with over
92 10 years experience in sports medicine imaging. Ultrasound of the muscle group affected by
93 injury was performed using an Aplio XG (Canon Medical Systems, Europe B.V.), with a 8-12
94 MHz linear probe. The region of interest (representing the region of maximal pain and
95 tenderness as identified by the athlete) was systematically examined using transverse and
96 longitudinal scanning with the involved muscle group fully relaxed (at rest). The radiologist
97 considered only the primary acute injury, the one exhibiting the greater extent and severity for
98 each athlete. Bilateral examination was systematically performed for all muscle injuries
99 detected. The longitudinal and transverse images demonstrating the greater severity of injury
100 were selected and saved in our Picture Archiving and Communication System (PACS). The
101 specific muscle involved (related to the images saved) was also recorded. For the purpose of
102 this study and to allow for a second independent assessment of ultrasound images, only
103 images acquired with muscles at rest were included for the assessments.

104 All muscle injuries detected on ultrasound were graded according to the (blinded)
105 classification system of acute muscle injuries²³. This system takes into account two distinct
106 types of intrinsic muscle injuries: “M” injuries, representing injury at the myo-connective
107 junction but the adjacent connective structures (intramuscular tendon, intra- or peri-muscular
108 aponeurosis) exhibit a normal ultrasound appearance; and “C” injuries, representing
109 involvement of the adjacent connective tissues. Since recent studies showed that the size
110 (extent) of muscle injuries does not represent a prognostic factor when adjusting for
111 confounders¹⁶⁻¹⁸, the size of ultrasound abnormalities was not taken into account in the
112 classification system used in this study. For each injury type detected on ultrasound (M or C),
113 three different grades (1 to 3) of severity are described in detail in **Table 1**. Grade 4 injuries
114 represent a complete detachment or rupture at the myo-connective junction with major
115 retraction, with no distinction between M and C injuries. Further, a second musculoskeletal

116 radiologist with over 30 years experience in sports medicine independently reviewed all
117 longitudinal and transverse ultrasound images saved initially in our PACS. The second reader
118 was blinded to the initial report including the classification of each muscle injury, and also
119 graded each injury according to the same scoring system.

120 All elite athletes included in our study followed the same treatment protocol at (blinded),
121 adapted for each muscle group involved. The rehabilitation program was considered as
122 successfully completed when sports-specific activities could be performed by the athlete
123 without any restriction or pain. For each athlete, the time needed to RTP was noted by the
124 sports medicine physician as the number of weeks between each acute muscle injury (day
125 zero) and the return to unrestricted activity in training or competition. The supervising sports
126 medicine physician gave the definite clearance for RTP.

127 We tested if there were differences in the time needed to RTP (in weeks) between the
128 different grades of acute muscle injuries detected in our cohort using ultrasound. Further, we
129 tested if there were differences in RTP between “M” and “C” injuries detected, including data
130 on the whole sample of athletes, on the most common sport only, and on the most common
131 muscle group affected only. The non-parametric Mann-Whitney and Kruskal-Wallis tests
132 were used to assess the differences in RTP between the different groups and grades of muscle
133 injuries. The Bonferroni correction method was applied when multiple comparisons were
134 performed. The hypothesis log-rank test and Kaplan-Meier plots were used to compare the
135 means of time needed to RTP in the different groups and grades of injuries. The inter-reader
136 reliability of ultrasound assessments was evaluated using kappa statistics. Statistical
137 significance was set at 0.05. All analyses were performed using the SAS software version 9.4
138 (SAS Institute, Cary NC).

139

140 **Results**

141 Seventy elite athletes sustaining an acute muscle injury were included, one injury per athlete.
142 The mean age was 27.8 years (± 6.1 ; range 22 - 55) and 65.7% of athletes were male (N=46).
143 The majority of muscle injuries affected track and field athletes (N=25, 35.7%) followed by
144 rugby players (N=18, 25.7%), with a variety of sports related to the remaining athletes
145 including football (N=5), judo (N=5), basketball, pentathlon, and fencing (N=3 each), boxing,
146 tennis, and water polo (N=2 each), field hockey and jiu-jitsu (N=1 each). From 70 injuries
147 assessed on ultrasound, there were 31 hamstring injuries (44.3%), 11 calf injuries (15.7%), 10
148 quadriceps injuries (14.3%), 6 adductors injuries (8.6%), and 1 gluteus maximus injury
149 (1.4%), for a total of 59 injuries affecting muscles from the lower limbs (84.3%). Muscles
150 from the arm (N=5, 7.1%) and the abdominal wall (N=4, 5.7%) were the most commonly
151 affected by injuries outside the lower limbs.

152 Regarding the classification of muscle injuries on ultrasound, 52 were classified as type M
153 injuries (74.3%) and 18 as type C injuries (25.7%). There were no differences in age between
154 the athletes exhibiting M injuries (30.7 years ± 6.5) and those exhibiting C injuries (30.8 years
155 ± 4.5). However, a difference was observed in terms of gender, with 61.5% (N=31) males in
156 the "M injuries" group and 77.8% (n=14) males in the "C injuries" group. Twenty-four
157 injuries were classified as grade 1 (34.3%), 34 as grade 2 (48.6%), and 12 as grade 3 (17.1%).
158 No grade 4 injuries were found in our cohort. From 52 type M injuries, 24 were grade 1M
159 (34.3%), 22 were grade 2M (31.4%), and 6 were grade 3M (8.6%). From 18 type C injuries,
160 12 were grade 2C (17.1%) and 6 were grade 3C (8.6%). No grade 1C injuries were found. The
161 inter-reader reliability (kappa) for each specific injury grade was 0.45 ($p < 0.0001$), and for the
162 type of injury (M or C) was 0.65 ($p < 0.0001$).

163 When considering the overall grades (1 to 3) independently of the type of injury (M or C), an
164 increase in the mean time needed to RTP was observed with the increase of grades ($p < 0.0001$

165 for all comparisons performed; **Table 2; Appendix 1**). The same relationship was found when
166 considering grades from M and C injuries separately, with higher grades of injuries exhibiting
167 longer times needed to RTP ($p < 0.0001$ for all comparisons performed; **Table 2; Appendix 1**).
168 Longer times needed to RTP were observed in athletes demonstrating C injuries in
169 comparison to the ones exhibiting M injuries (all C injuries vs. all M injuries; $p = 0.002$; **Table**
170 **2; Appendix 1**). Although we observed a higher mean time needed to RTP for each grade of
171 C injuries when compared to each grade of M injuries (2C vs. 2M; 3C vs. 3M), these
172 differences were not statistically significant, and the standard deviation values obtained
173 indicate overlap (**Table 2**).

174 Considering athletes from track and field only, the most common sport in our sample ($N = 25$,
175 35.7%), we found that longer times needed to RTP were observed in athletes exhibiting C
176 injuries (7.8 mean weeks \pm 3.8; 95%CI 5.6, 10.0) compared to those exhibiting M injuries
177 (4.8 mean weeks \pm 2.6; 95%CI 3.5, 6.1); $p = 0.03$. For the other sports related to the remaining
178 athletes included, the low number of athletes in each sport and consequently the lack of
179 statistical power do not allow for additional analyses regarding the relationship between the
180 types of injuries and recovery times.

181 Considering athletes exhibiting hamstring injuries only, the most common muscle group
182 affected by injury in our sample ($N = 31$, 44.3%), we found that longer times needed to RTP
183 were observed in athletes exhibiting C injuries (7.9 mean weeks \pm 4.9; 95%CI 5.3, 10.5)
184 compared to those exhibiting M injuries (4.1 mean weeks \pm 2.3; 95%CI 3.1, 5.1); $p < 0.01$. For
185 the other muscle groups affected, the low number of athletes and consequently the lack of
186 statistical power do not allow for additional analyses regarding the relationship between the
187 types of injuries and recovery times.

188

189 **Discussion**

190 In this sample of elite athletes sustaining an acute muscle injury assessed on ultrasound, we
191 found that higher grades of injury exhibited longer recovery times when considering the
192 general grades (1 to 3) as well as when comparing different grades of the same type of injury
193 (M or C). Furthermore, considering only the type of injury, we found that recovery times were
194 longer for athletes exhibiting C injuries in comparison with those having M injuries in
195 general. However, when specifically comparing the same grades from different types of injury
196 (2M vs. 2C and 3M vs. 3C), no significant differences were found in the time needed to RTP.
197 Finally, we report a moderate agreement between both radiologists when considering each
198 specific grade from the classification system of muscle injuries assessed on ultrasound.
199 However, a substantial agreement between radiologists was found when considering the type
200 of muscle injury (M or C).

201 Previous MRI studies highlighted the potential clinical relevance of muscle injuries affecting
202 connective tissues such as the intramuscular tendon involvement in hamstring injuries ^{9,10} and
203 rectus femoris injuries ¹⁵, as well as connective tissue involvement in calf injuries (tendon,
204 aponeurosis, and epimysium) ¹¹. These studies showed that injuries affecting connective
205 tissues demonstrated longer recovery times than those without such involvement, especially in
206 cases of disrupted and/or retracted connective structures. A recent prospective MRI study
207 evaluated the presence of intramuscular tendon involvement in hamstring injuries and the
208 relationship with the time needed to RTP ¹². The authors found that hamstring injuries
209 exhibiting full-thickness disruption of the intramuscular tendon and the presence of a
210 “waviness” pattern of the intramuscular tendon were associated with slightly longer recovery
211 times compared with injuries without intramuscular tendon involvement. However, the
212 authors found that partial-thickness disruption of the intramuscular tendon did not
213 substantially increase the time needed to RTP. Because the slight prolonged RTP and

214 considerable overlap between groups compared, the authors concluded that the clinical
215 relevance of intramuscular tendon involvement was limited in regard to prognosis ¹².

216 Ultrasound allows visualization of muscular architecture at in-plane resolutions of under
217 200µm and section thickness of 0.5-1.0mm, which exceeds current MRI ²⁴. Compared to
218 MRI, it also offers a number of distinct advantages: it is fast, relatively cheap, easier for
219 patients, and allows dynamic evaluations. Furthermore, ultrasound can demonstrate the
220 muscle structure and other relevant anatomy surrounding an injury that can often be obscured
221 by edema on MRI ⁸, including high-resolution assessment of intra- and peri-muscular
222 connective tissues, intramuscular tendon, and intramuscular aponeurosis. Previous studies
223 used ultrasound to evaluate features of acute muscle injuries and their relationship with RTP
224 ^{8,22}. A longitudinal study of acute hamstring injuries comparing ultrasound and MRI features
225 evaluated the correlations between imaging features and recovery times. The authors found
226 the cross-sectional area of the injury and the presence of an intramuscular hematoma depicted
227 on ultrasound were positively correlated to the time needed to RTP ⁸. Another study
228 evaluating the prognostic value of ultrasound features of hamstring injuries in soccer players
229 showed no significant differences in the time needed to RTP between athletes with and
230 without ultrasound abnormalities ²². Further, the same study found no correlation between the
231 length of injuries and the time needed to RTP.

232 None of the previous ultrasound studies specifically assessed connective tissue involvement in
233 muscle injuries and its relationship with RTP. To the best of our knowledge, our study is the
234 first to take into account ultrasound features of connective tissue involvement in muscle
235 injuries as prognostic factors. The classification system used in our study ²³ distinguishes
236 injuries exhibiting ultrasound involvement of intra- and perimuscular connective tissues (C
237 injuries) from those without such involvement (M injuries). Considering all grades of injuries
238 detected in our sample, we found that athletes with C injuries exhibited longer (mean)

239 recovery times than those with M injuries (3.7 weeks mean time longer for C injuries). This
240 supports the existing evidence from previous MRI studies^{9-12,15}, reinforcing the idea that
241 connective tissue involvement in muscle injuries has some prognostic value. Longer recovery
242 times related to C injuries were also demonstrated when considering athletes from track and
243 field only (most common sport in our sample), as well as when considering athletes exhibiting
244 hamstring injuries only (most common muscle group affected in our sample), with the global
245 mean recovery times for different grades of C injuries being comparable to the ones from a
246 previous study including only track and field athletes with hamstring injuries¹⁰. We also
247 demonstrated that injuries with disruption of the involved connective tissue (grade 3C; **Figure**
248 **1**) exhibited even longer recovery times when compared with those without disruption of the
249 involved connective tissue (grade 2C) (6.4 weeks mean time longer for 3C injuries). This also
250 supports the results from previous MRI studies, which demonstrated that injuries exhibiting
251 disruption and/ or retraction of the involved connective tissue were related to longer mean
252 times needed to RTP¹⁰⁻¹². When directly comparing the same grades of different types of
253 injuries, we found a slight increase in the mean time needed to RTP for C injuries (1.3 weeks
254 mean time difference between 2C and 2M; 1.6 weeks mean time difference between 3C and
255 3M). However, the standard deviation values found indicate overlap between these groups,
256 and such differences are difficult to interpret. Higher grades of ultrasound-detected injuries
257 were related to longer recovery times considering M injuries only, as well as the overall
258 grades regardless of the type of injuries.

259 Connective tissue involvement in muscle injuries, mainly connective tissue disruption, seems
260 to be the one morphological feature exhibiting some clinical relevance in terms of recovery
261 times of athletes and our study demonstrated that ultrasound assessment of muscle injuries is
262 capable of depicting such involvements, which lead to longer recovery times in our sample.
263 Injuries affecting muscular connective tissues such as the intramuscular tendon, the

264 perimuscular aponeurosis, or the intramuscular aponeurosis seem to lead to a dysfunction in
265 its biomechanics, as such tissues act not only as an anatomical support to the muscular tissue
266 but also in transmitting both tensile and shear loads generated by muscles, transmitting force
267 from a segment to another^{25,26}. Thus, alterations in the structure of such tissues (mainly
268 disruption) would impair these important biomechanical functions, which could explain why
269 connective tissue involvement in muscle injuries is related with longer recovery times.
270 Compared to MRI, ultrasound may be easily implemented in sports medicine facilities, even
271 within the field, and be used to evaluate connective tissue integrity in acute muscle injuries,
272 providing thus some prognostic input to athletes and physicians.

273 Our study has some limitations. As we included only elite athletes, the results of our study
274 may not reflect the general population. Also, the supervising sports medicine physicians
275 responsible for the definite clearance for RTP were not blinded to the results from the initial
276 ultrasound performed. This included knowledge about the presence or absence of connective
277 tissue involvement. However, at the time of the inclusion period (2011 to 2014), there was no
278 strong evidence that general connective tissue involvement in different muscle groups was
279 associated with longer recovery times in athletes, with only one publication available
280 assessing the intramuscular tendon involvement in the hamstring⁹. The time needed to RTP
281 could also be influenced by the athlete's motivation to RTP and pressure to compete exerted
282 by the teams. Further, we acknowledge that the time needed to RTP may vary during
283 preseason, season, and postseason. Although the initial treatment protocol for muscle injuries
284 was similar among the athletes included, the rehabilitation program was further adapted for
285 each muscle group affected and sport-specific activities were implemented during the
286 program, which might have influenced our results. The inter-reader reliability assessment was
287 not performed following a second and independent real repeated examination but rather a re-
288 reading of the images documented in the first place. Finally, we included injuries from

289 different muscle groups from elite athletes practicing various sports, and since each muscle
290 group has different anatomy and function related to sport-specific activities, this might have
291 played a role in the results.

292

293 **Conclusion**

294 Ultrasound-detected connective tissue involvement in acute muscle injuries of elite athletes
295 are related to longer times needed to RTP, especially when a disrupted connective tissue
296 (intramuscular tendon or aponeurosis) is detected, which is in accordance to previous MRI
297 studies. Radiologists performing ultrasound in acute muscle injuries should drive their
298 attention to the connective tissue integrity near areas of injury, which may potentially estimate
299 the duration of rehabilitation in elite athletes. Further prospective studies applying ultrasound
300 in injuries of specific muscle groups and specific sports are necessary to confirm the
301 prognostic value of ultrasound-detected connective tissue involvement.

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311 **Practical Implications**

- 312 - Overall, muscle injuries exhibiting connective tissue involvement depicted using
313 ultrasound (C injuries) are related to longer times needed to RTP in comparison with
314 injuries without such involvement (M injuries).
- 315 - Considering only muscle injuries with connective tissue involvement seen on
316 ultrasound (C injuries), those exhibiting discontinuity of the involved connective
317 tissue are related to longer recovery times than those without discontinuity.
- 318 - Our study supports the existing limited evidence that connective tissue involvement in
319 muscle injuries are related to longer recovery times, and such involvement might be
320 detected using ultrasound, which is relatively inexpensive and easily accessible
321 compared to MRI.

322

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332 **References**

- 333 1. Ekstrand J, Hagglund M, Walden M. Epidemiology of muscle injuries in professional
334 football (soccer). *Am J Sports Med* 2011; 39(6):1226-1232.
- 335 2. Elliott MC, Zarins B, Powell JW, et al. Hamstring muscle strains in professional
336 football players: a 10-year review. *Am J Sports Med* 2011; 39(4):843-850.
- 337 3. Engebretsen L, Soligard T, Steffen K, et al. Sports injuries and illnesses during the
338 London Summer Olympic Games 2012. *Br J Sports Med* 2013; 47(7):407-414.
- 339 4. Soligard T, Steffen K, Palmer D, et al. Sports injury and illness incidence in the Rio de
340 Janeiro 2016 Olympic Summer Games: A prospective study of 11274 athletes from 207
341 countries. *Br J Sports Med* 2017; 51(17):1265-1271.
- 342 5. Feddermann-Demont N, Junge A, Edouard P, et al. Injuries in 13 international
343 Athletics championships between 2007-2012. *Br J Sports Med* 2014; 48(7):513-522.
- 344 6. Ekstrand J, Healy JC, Walden M, et al. Hamstring muscle injuries in professional
345 football: the correlation of MRI findings with return to play. *Br J Sports Med* 2012;
346 46(2):112-117.
- 347 7. Askling CM, Tengvar M, Saartok T, et al. Acute first-time hamstring strains during
348 high-speed running: a longitudinal study including clinical and magnetic resonance imaging
349 findings. *Am J Sports Med* 2007; 35(2):197-206.
- 350 8. Connell DA, Schneider-Kolsky ME, Hoving JL, et al. Longitudinal study comparing
351 sonographic and MRI assessments of acute and healing hamstring injuries. *AJR Am J*
352 *Roentgenol* 2004; 183(4):975-984.
- 353 9. Comin J, Malliaras P, Baquie P, et al. Return to competitive play after hamstring
354 injuries involving disruption of the central tendon. *Am J Sports Med* 2013; 41(1):111-115.
- 355 10. Pollock N, Patel A, Chakraverty J, et al. Time to return to full training is delayed and
356 recurrence rate is higher in intratendinous ('c') acute hamstring injury in elite track and field

- 357 athletes: clinical application of the British Athletics Muscle Injury Classification. *Br J Sports*
358 *Med* 2016; 50(5):305-310.
- 359 11. Prakash A, Entwisle T, Schneider M, et al. Connective tissue injury in calf muscle
360 tears and return to play: MRI correlation. *Br J Sports Med* 2018; 52(14):929-933.
- 361 12. van der Made AD, Almusa E, Whiteley R, et al. Intramuscular tendon involvement on
362 MRI has limited value for predicting time to return to play following acute hamstring injury.
363 *Br J Sports Med* 2018; 52(2):83-88.
- 364 13. Slavotinek JP, Verrall GM, Fon GT. Hamstring injury in athletes: using MR imaging
365 measurements to compare extent of muscle injury with amount of time lost from competition.
366 *AJR Am J Roentgenol* 2002; 179(6):1621-1628.
- 367 14. Gibbs NJ, Cross TM, Cameron M, et al. The accuracy of MRI in predicting recovery
368 and recurrence of acute grade one hamstring muscle strains within the same season in
369 Australian Rules football players. *J Sci Med Sport* 2004; 7(2):248-258.
- 370 15. Cross TM, Gibbs N, Houang MT, et al. Acute quadriceps muscle strains: magnetic
371 resonance imaging features and prognosis. *Am J Sports Med* 2004; 32(3):710-719.
- 372 16. Cohen SB, Towers JD, Zoga A, et al. Hamstring injuries in professional football
373 players: magnetic resonance imaging correlation with return to play. *Sports Health* 2011;
374 3(5):423-430.
- 375 17. Crema MD, Godoy IRB, Abdalla RJ, et al. Hamstring Injuries in Professional Soccer
376 Players: Extent of MRI-Detected Edema and the Time to Return to Play. *Sports Health* 2018;
377 10(1):75-79.
- 378 18. Moen MH, Reurink G, Weir A, et al, Goudswaard GJ. Predicting return to play after
379 hamstring injuries. *Br J Sports Med* 2014; 48(18):1358-1363.

- 380 19. Reurink G, Brilman EG, de Vos RJ, et al. Magnetic resonance imaging in acute
381 hamstring injury: can we provide a return to play prognosis? *Sports Med* 2015; 45(1):133-
382 146.
- 383 20. Jacobsen P, Witvrouw E, Muxart P, et al. A combination of initial and follow-up
384 physiotherapist examination predicts physician-determined time to return to play after
385 hamstring injury, with no added value of MRI. *Br J Sports Med* 2016; 50(7):431-439.
- 386 21. Pollock N, James SL, Lee JC, et al. British athletics muscle injury classification: a new
387 grading system. *Br J Sports Med* 2014; 48(18):1347-1351.
- 388 22. Petersen J, Thorborg K, Nielsen MB, et al. The diagnostic and prognostic value of
389 ultrasonography in soccer players with acute hamstring injuries. *Am J Sports Med* 2014;
390 42(2):399-404.
- 391 23. Brasseur JL, Renoux J. Echographie du muscle. Paris, France: Sauramps Medical
392 2016:130-166.
- 393 24. Van Holsbeeck M, Introcasco J. Sonography of Muscle. In:Musculoskeletal
394 Ultrasound. St Louis, MI. Mosby 2001.
- 395 25. Stecco C, Pavan P, Pachera P, et al. Investigation of the mechanical properties of the
396 human crural fascia and their possible clinical implications. *Surg Radiol Anat* 2014;36(1):25-
397 32.
- 398 26. Pavan PG, Stecco A, Stern R, et al. Painful connections: densification versus fibrosis
399 of fascia. *Curr Pain Headache Rep* 2014;18(8):441.

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403 **Tables**

404 **Table 1.** The (blinded) ultrasound classification of muscle injuries including severity (grades
 405 1-4) and type (M or C) of injuries.

Type of Injury	M injuries (normal ultrasound appearance of the adjacent connective tissues)	C injuries (abnormal ultrasound appearance of the adjacent connective tissues)
Grades		
1	Intramuscular ill-defined areas of increased echogenicity without architectural distortion at the myo-connective junction	Connective tissue exhibiting thickening and ill-defined contours without architectural distortion at the myo-connective junction. No connective tissue discontinuity.
2	Ill-defined areas of increased echogenicity with architectural distortion at the myo-connective junction, no visible detachment of muscle fibers, no adjacent hematoma	Connective tissue exhibiting thickening and ill-defined contours with architectural distortion at the myo-connective junction. No connective tissue discontinuity.
3	Partial detachment of muscle fibers at the myo-connective junction with adjacent hematoma	Partially ruptured connective tissue with or without adjacent hematoma
4	Complete detachment or rupture at the myo-connective junction with major retraction	

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411 **Table 2.** Differences in the mean time needed to return to play (RTP) when considering the
 412 overall grades (1 to 3) and each grade for each type of injury (M or C) detected on ultrasound
 413 ($p < 0.0001$ for all statistical comparisons performed for the overall grades and for grades
 414 within each type of injury). Differences in RTP between all M injuries vs. all C injuries were
 415 statistically significant ($p = 0.002$).

Overall grades	RTP (weeks) Mean \pm SD	Min-Max	95%CI
1 (n=24)	2.2 \pm 1.1	0-4	1.7, 2.6
2 (n=34)	4.6 \pm 1.9	2-9	3.9, 5.2
3 (n=12)	11.1 \pm 3.6	6-17	9.1, 13.1
M Injuries	RTP (weeks) Mean \pm SD	Min-Max	95%CI
Grades			
1 (n=24)	2.2 \pm 1.1	0-4	1.7, 2.6
2 (n=22)	4.1 \pm 1.6	2-8	3.4, 4.8
3 (n=6)	10.2 \pm 3.8	6.7-17	7.2, 13.2
All M injuries (n=52)	3.9 \pm 1.4	0-17	3.5, 4.3
C Injuries	Mean \pm SD	Min-Max	
Grade			
2 (n=12)	5.4 \pm 2.3	3-9	4.1, 6.7
3 (n=6)	11.8 \pm 3.6	6-16	8.9, 14.7
All C injuries (n=18)	7.6 \pm 2.9	3-16	6.3, 8.9

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417 **Figure 1' Legend**

418 **A.** Ultrasound-detected grade 3C injury at the proximal myo-tendinous junction of the long
419 head of the biceps femoris muscle in a 21-year-old male sprinter. Partial disruption of the
420 intramuscular tendon is depicted (arrows), exhibiting ill-defined margins, hypoechogenicity
421 and focal central thinning consistent with focal partial discontinuity. **B.** A normal ultrasound
422 appearance of the tendon in another elite athlete for comparison, exhibiting well-defined
423 margins and high echogenicity, with preserved thickness at the proximal myotendinous
424 junction (arrows). **A and B:** transverse views.

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427 **Appendix 1' Legend**

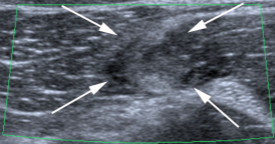
428 Corresponding curve plots for the differences in the mean time needed to RTP when
429 considering the overall grades independently of the type of injury ($p < 0.0001$ for all
430 comparisons performed), when considering the grades for M or C injuries specifically
431 ($p < 0.0001$ for all comparisons performed), and when considering all M injuries vs. all C
432 injuries ($p = 0.002$).

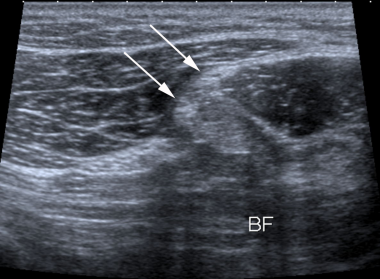
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