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**Imaging-Detected Acute Muscle Injuries in Athletes Participating in the Rio de Janeiro 2016 Summer Olympic Games**

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**Abstract**

**Background:** Acute muscle injuries in elite athletes are responsible for a large portion of time loss injuries.

**Aim:** To describe the frequency, the anatomic distribution, and severity, of imaging-detected acute muscle injuries among athletes who competed in the Rio de Janeiro 2016 Summer Olympics.

**Methods:** We recorded all sports injuries reported by the National Olympic Committee (NOC) medical teams and the Organizing Committee medical staff during the 2016 Summer Olympics. Imaging of acute muscle injuries was performed at the International Olympic Committee's polyclinic within the Olympic Village, using ultrasound and 3.0T and 1.5T MRI scanners. The assessment of images was performed centrally by three musculoskeletal radiologists. The distribution of injuries by anatomic location and sports discipline and the severity of injuries were recorded.

**Results:** In total, 11274 athletes from 207 teams were included. A total of 1101 injuries were reported. Central review of radiological images revealed 81 acute muscle injuries in 77 athletes (66% male, mean age: 25.4 years, range 18-38 years). Athletics' (track and field) athletes were the most commonly affected (N=39, 48%), followed by football players (N=9, 11%). The majority of injuries affected muscles from lower limbs (N=68, 84%), with the hamstring being the most commonly involved. Most injuries were grade 2 injuries according to the Peetrons classification (N=44, 54%), and we found 18 injuries exhibiting intramuscular tendon involvement on MRI.

**Conclusion:** Imaging-detected acute muscle injuries during the 2016 Summer Olympics affected mainly thigh muscles in athletics disciplines.

## Introduction

Acute muscle injuries represent a major challenge for elite athletes with considerable and non-negligible prevalence when considering all sports-related injuries in competitions, as described in previous reports [1-5]. Muscle injuries are responsible for a large part of time lost to competition in elite athletes [6-9].

Although the relevance of imaging in regard to prognosis of acute muscle injuries is contested by some authors [10], the use of imaging modalities in major competitions has increased in the past years [1,11]. Protection of athletes' health is a clearly articulated mission of the International Olympic Committee (IOC) [12]. Medical surveillance during the games plays an important role in prevention and management of sports-related injuries in Olympian athletes. The IOC has instituted injury and illness surveillance systems to increase detection of risk factors and determine mechanisms of injuries in elite athletes [2,13-17], including muscle injuries.

We aimed to describe the frequency, the anatomic distribution, and the severity of imaging-detected acute muscle injuries involving athletes during the Rio de Janeiro 2016 Summer Olympic Games.

## Methods

This is a retrospective study of imaging data collected at the Rio 2016 Summer Olympic Games from the Radiological Information System (RIS) and Picture Archiving and Communication System (PACS). Medical and imaging services were open for 32 days from the opening of the Olympic Village on 24th July 2016, through the period of the Olympic Games (5 to 21 August) to the closing of the Olympic Village on 24th August 2016.

All National Olympic Committee (NOC) medical teams reported the daily occurrence (or non-occurrence) of injuries on a standardized medical report form [17]. We also retrieved the same information on all athletes treated for injuries in the polyclinic and all other medical venues by the Organizing Committee of the Rio de Janeiro 2016 medical staff. We used the athlete accreditation number to control for injuries being treated by both groups. With duplicates, we retained the NOC data. Our study and intent to publish the data were approved by the International Olympic Committee.

### *Confidentiality and ethical approval*

Our retrospective study was reviewed by the Medical Research Ethics Committee of the South-Eastern Norway Regional Health Authority (2011/388) and was exempted from Ethics Committee approval. Informed consent was waived since all data in our epidemiological study were anonymized and unidentifiable. We obtained approval from the Internal Olympic Committee (IOC) to use anonymized imaging and demographic data for publication. Data were collected, stored and analyzed in strict compliance with data protection and athlete confidentiality.

### *Data collection*

Diagnostic imaging was performed through the official IOC polyclinic within the Olympic Village, using 3T Discovery MR750w and 1.5T Optima 450MRw magnetic resonance imaging (MRI) scanners, and Logiq E9 XD Clear and portable Logiq E ultrasound machines (all machines GE Healthcare, Brazil). MRI protocols consisted of 3 plane acquisition of fluid-sensitive images (including fat-suppressed T2-weighted and/or fat-suppressed proton densityweighted), and T1-weighted images in at least one plane as appropriate for each anatomical location. We finally retained data exclusively on imaging-detected acute muscle injuries retrospectively collected from the original reports generated in the Radiological Information System (RIS) at the polyclinic. Demographic information was also collected for all athletes diagnosed with acute muscle injuries on ultrasound and/or MRI, in an anonymized fashion. These data were stratified by gender, age, sport discipline, and anatomical region.

***Imaging interpretation***

All MRIs and ultrasound images from cases of acute muscle injuries triggered in the RIS were reviewed for the presence, anatomic location, and severity by three board-certified musculoskeletal radiologists, centrally and independently. We defined acute muscle injuries as those where athletes complained of acute pain in a given muscle compartment with imaging features of acute muscle injury. Specifically, imaging of an acute muscle injury on MRI included at least an ill-defined hyperintensity area within the muscle on fluid sensitive sequences; on ultrasound, injuries exhibiting at least an ill-defined hyperechogenicity area within the muscle. The anatomic location was defined by isolating the specific muscle or muscle group (hamstring, quadriceps, adductors, etc.) exhibiting the greatest extent of injury depicted on imaging. Any difference in opinion was adjudicated through mutual consensus by all radiologists following discussion.

Because ultrasound is a real-time examination and highly operator-dependent, ultrasound images were reviewed in conjunction with the original reports extracted from the RIS. Ultrasound examinations in the polyclinic during the games were performed by musculoskeletal radiologists experienced with imaging of sports injuries. The severity of muscle injuries on ultrasound was assessed using the Peetrons classification [18], as grade 1 (no abnormalities or focal/diffuse bleeding – ill-defined hyperechogenicity – with no or fiber disruption less than 5%), grade 2 (well-defined hypoechogenicity indicating partial rupture with more than 5% of muscle involved, with or without fascial injury), and grade 3 (complete rupture with retraction).

For a global and uniform evaluation of the severity of all muscle injuries included in this study, the severity of injuries depicted on MRI was initially assessed using a modified Peetrons classification system [7], as grade 1 (ill-defined hyperintensity on fluid sensitive sequences indicating oedema without architectural distortion of muscle fibers or macroscopic tear), grade 2 (architectural distortion of muscle fibers or well-defined hyperintensity on fluid sensitive sequences indicating partial muscle tear), and grade 3 (total muscle or tendon rupture with retraction).

Finally, using only the injuries depicted on MRI, we assessed the location and severity of injuries using the British Athletics Muscle Injury classification[19,20]. Muscle injuries were graded as 0 a/b: normal/normal or patchy high signal changes (HSC) on fluid sensitive sequences throughout one or more muscles; 1 (1a=myofascial; 1b=myotendinous): HSC <10% extension; craniocaudal (CC) length <5 cm; may note fiber disruption < 1cm); 2 (2a=myofascial; 2b=myotendinous): HSC of cross-sectional area (CSA) between 10% - 50% at maximal site; CC length >5 and <15 cm; architectural fiber disruption < 5 cm; 3 (3a=myofascial; 3b=myotendinous): HSC of CSA of >50% at maximal site; CC length of >15 cm; architectural fiber disruption >5 cm; and 4: complete discontinuity of the muscle with retraction. In addition to myofascial (a) and myotendinous (b) locations, injuries with intramuscular tendon involvement (“c” injuries) were scored as grade 2c: longitudinal length of tendon involvement <5 cm; CSA of tendon involvement <50% of maximal tendon CSA; no loss of tension or discontinuity within the tendon; grade 3c: longitudinal length of tendon involvement >5 cm; CSA of tendon involvement >50% of maximal tendon CSA; may be loss of tendon tension; no discontinuity is evident; grade 4c: complete discontinuity of the tendon with retraction. “C” injuries represent muscle injuries at the myotendinous junction that involved the adjacent intramuscular tendon; these were not injuries that affected the “free” proximal or distal tendon (outside the muscle, near the insertion sites). Injuries affecting the “free” proximal or distal tendon were not included in this study.

## Results

A total of 11274 athletes (5089 women (45%), 6185 men (55%)) from 207 Olympic teams participated in the IOC’s surveillance study [17]. NOC and Rio de Janeiro 2016 medical staff reported 1101 injuries. Our centralized review of images included 81 acute muscle injuries (7.4% of all injuries) in 77 athletes (aged from 18 to 38 years; mean age 25.4 ± 4.7; 66.2% male) from 21 different disciplines. Sixty-eight (83.9%) injuries affected lower limb muscles, 6 (7.4%) upper limb muscles, three (3.7%) the chest wall, and four (4.9%) the pelvis.

Injuries were diagnosed on MRI alone in 65 cases, on ultrasound alone in 13 cases, and on MRI and ultrasound in three cases. The incidence proportion of imaging-detected acute muscle injuries for each discipline during the 2016 summer Olympics is presented in **Table 1**.

**Table 1.** Incidence of imaging-detected acute muscle injuries during the 2016 Olympics for each discipline.

| **Disciplines** | **Number of Athletes** | **Number of imaging-detected acute muscle injuries** | **Incidence proportion (%)** |
|---|---|---|---|
| Gymnastic - Rhythmic | 96 | 2 | 2,08 |
| Weightlifting | 256 | 5 | 1,95 |
| Football | 503 | 9 | 1,79 |
| Athletics | 2367 | 39 | 1,64 |
| Rugby | 291 | 4 | 1,37 |
| Handball | 335 | 4 | 1,19 |
| Wrestling | 349 | 4 | 1,15 |
| Volleyball | 288 | 3 | 1,04 |
| Tennis | 199 | 2 | 1,01 |
| Aquatics - Diving | 135 | 1 | 0,74 |
| Table Tennis | 172 | 1 | 0,58 |
| Cycling - Track | 182 | 1 | 0,54 |
| Gymnastic - Artistic | 194 | 1 | 0,52 |
| Judo | 390 | 2 | 0,51 |
| Cycling - Road | 211 | 1 | 0,47 |
| Boxing | 286 | 1 | 0,35 |
| Basketball | 287 | 1 | 0,35 |
| **All disciplines** | **11274** | **81** | **0,71** |

### ***Distribution of acute muscle injuries in Athletics (Track and Field) disciplines***

The distribution of acute muscle injuries in athletics disciplines depicted using all imaging modalities is presented in **Table 2**. A total of 39 acute muscle injuries were depicted (8 on ultrasound and 31 on MRI). The majority of lesions were diagnosed in sprinters – short distance (N=25, 64.1%). Hamstring injuries were the most common including 18 injuries (46.2%) of which 12 affected the biceps femoris (30.8%). Chronic changes (scars) adjacent to acute muscle injuries were depicted on MRI in three hamstring and three rectus femoris injuries. Among injuries depicted in sprinters (N=25), a total of 15 injuries affected the hamstring (60%) with 9 biceps femoris injuries (36%) and 7 rectus femoris injuries (28%).

**Table 2.** Distribution of muscle injuries in athletics disciplines by anatomical location. N = number of injuries; FDS = flexor digitorum superficialis; MG = medial gastrocnemius; SM = semimembranosus; ST = semitendinosus.

| | adductor longus | anterior tibial | biceps femoris | FDS | gluteus maximus | MG | quadratus femoris | rectus femoris | SM | soleus | ST | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Athletics** | **N** | **N** | **N** | **N** | **N** | **N** | **N** | **N** | **N** | **N** | **N** | **N** | **%** |
| Short distance | 1 | 0 | 9 | 0 | 1 | 0 | 1 | 7 | 2 | 0 | 4 | 25 | 64,1 |
| Middle and long distance | 0 | 1 | 3 | 1 | 3 | 1 | 0 | 0 | 0 | 1 | 0 | 10 | 25,6 |
| Decathlon | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 5,1 |
| Javelin | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2,6 |
| Long jump | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2,6 |
| TOTAL | 2 | 1 | 12 | 1 | 6 | 1 | 1 | 8 | 2 | 1 | 4 | 39 | 100 |

### *Distribution of acute muscle injuries in other disciplines*

The distribution of acute muscle injuries in other disciplines using all imaging modalities is presented in **Table 3 (Web appendix)**. A total of 42 acute muscle injuries were depicted (8 on ultrasound and 34 on MRI). The majority of lesions were diagnosed in football players (N=9, 21.4%), followed by weightlifting athletes (N=5, 11.9%). Hamstring injuries were the most common with 11 injuries (26.2%), of which 6 affected the biceps femoris (14.3%). Of all hamstring injuries depicted in other disciplines, five (45.5%) were seen in football players.

**Table 3 (Web appendix).** Distribution of muscle injuries in other Olympic disciplines regarding the anatomical location. N = number of injuries; LG = lateral gastrocnemius; MG = medial gastrocnemius; SS = supraspinatus; ST = semitendinosus.

| | adductor brevis | adductor magnus | brachialis | biceps femoris | deltoid | gluteus maximus | iliacus | iliopsoas | LG | MG | obturator externus | pectineus | pectoralis major | posterior tibialis | quadratus femoris | rectus femoris | SS | ST | teres minor | vastus intermedius | vastus lateralis | vastus medialis | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | % |
| Aquatics - Diving | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2,4 |
| Basketball | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2,4 |
| Boxing | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2,4 |
| Cycling - Road | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2,4 |
| Cycling - Track | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2,4 |
| Football | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 9 | 21,4 |
| Gymnastics - Artistic | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2,4 |
| Gymnastics - Rhythmic | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4,8 |
| Handball | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 | 9,5 |
| Judo | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4,8 |
| Rugby | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 4 | 9,5 |
| Table tennis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2,4 |
| Tennis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4,8 |
| Volleyball | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 7,1 |
| Weightlifting | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 5 | 11,9 |
| Wrestling | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 4 | 9,5 |
| TOTAL | 1 | 1 | 1 | 7 | 2 | 3 | 2 | 1 | 1 | 2 | 1 | 1 | 3 | 1 | 1 | 4 | 1 | 4 | 1 | 1 | 2 | 1 | 42 | 100 |

### *Severity of acute muscle injuries according to the Peetrons' classification*

Most injuries depicted on ultrasound were grade 1 (N=8; 50%), of which four affected the hamstring. Five muscle injuries were grade 2 (31.3%; various muscles – **Figure 1**) and 2 were grade 3 (12.5%; both affecting the rectus femoris). One injury affecting the semitendinous muscle was diagnosed on ultrasound as delayed onset of muscle soreness, since the symptoms were observed in a sprinter 48 hours after competition. On MRI, there were 17 grade 1 injuries (26.2%), 39 grade 2 injuries (60%), and 7 grade 3 injuries (10.8%). Two injuries could not be graded due to an incomplete assessment of the extent of injuries in the available sequences. Considering all acute muscle injuries evaluated on both ultrasound and MRI using the 3-grade system (Peetrons and modified Peetrons), we found one injury corresponding to delayed onset muscle soreness (1.2%), 25 grade 1 injuries (30.9%), 44 grade 2 (54.3%), and 9 grade 3 injuries (11.1%).

### *Severity of acute muscle injuries according to the British Athletics Muscle Injury system (MRI assessment)*

Two injuries could not be graded due to an incomplete assessment of the extent of injuries in available sequences. In regard to the extent of injuries, 12 injuries (18.4%) were grade 1, 38 (58.5%) were grade 2, 7 (10.8%) were grade 3, and 6 (9.2%) were grade 4. Regarding location of injuries, "a" injuries (myofascial junction) were found in 20 cases (30.8%), "b" injuries (myotendinous junction without intramuscular tendon involvement) in 25 cases (38.4%), and "c" injuries (tendon involvement) in 18 cases (27.7%) (**Figure 2**). The hamstring (N=7), the quadriceps (N=5), and the medial gastrocnemius and gluteus maximus muscles (N=2 each) were the most commonly affected by myofascial ("a") injuries. Gluteus maximus (N=6), the hamstring (N=4), and the adductors muscles (N=3) were the most frequently affected in myotendinous junction injuries without tendon involvement ("b" injuries). The hamstring (N=8) and the quadriceps (rectus femoris only) muscles (N=4) were the most commonly affected by muscle injuries associated with intramuscular tendon injuries ("c" injuries).

**Discussion**

This is the most comprehensive study of the frequency, distribution, and classification of imaging-detected acute muscle injuries in elite athletes during the summer Olympic Games. The 81 acute muscle injuries imaged in 77 athletes represented 7.4% of all injuries reported by NOCs and Rio de Janeiro 2016 medical staff. Such frequency is likely underestimated as we did not have access to data on imaging services offered at the field of play (e.g., ultrasound), data from participating teams' own medical set-ups (e.g,. ultrasound), as well as any imaging performed outside the imaging center in the Olympic Village (likely minimal). As this was an imaging study we did not include muscle injuries diagnosed clinically but not assessed using imaging.

Imaging-confirmed acute muscle injuries can prevent elite athletes from training and competition. During the London 2012 Summer Olympic Games, 38 of 174 (22%) injuries that prevented athletes from participating in competition or training for more than a week, were muscle injuries [14]. Some of those injuries were also diagnosed clinically so it cannot be compared directly with our findings.

*Which imaging modality is most suitable?*

MRI is considered the reference imaging method to assess the morphology of muscles in athletes due to its capability to visualize soft tissues with excellent contrast, providing high-resolution and multiplanar assessment of muscles [21]. Several grading systems of muscle injuries using MRI are available, with previous studies showing adequate reliability of MRI systems when scoring acute hamstring injuries [22,23].

Compared to MRI, ultrasound is relatively inexpensive and easily accessible (superior portability), has a greater spatial resolution allowing for assessment of superficial muscle groups, as well as for dynamic imaging while mobilizing the injured limb, which increases the sensitivity in the detection of fiber disruption, and to assess muscle injury healing. Compared to MRI, there is paucity of data regarding the clinical relevance of ultrasound findings in acute muscle injuries of the lower limbs, with controversial results regarding the prognostic value of ultrasound findings in acute muscle injuries [24,25].

*Which sports were most affected by acute muscle injuries?*

The majority of imaging-detected acute muscle injuries in our study affected elite athletes from athletics disciplines (48.1% of all muscle injuries), with the majority of injuries affecting sprinters (64.1%). Although exhibiting one of the higher incidence rates of imaging-detected muscle injuries, other disciplines showed higher incidence rates of such injuries than the athletics' such as gymnastic – rhythmic, weightlifting, and football. Excluding the athletics disciplines, the majority of imaging-detected muscle injuries were observed in football players, followed by weightlifters, handball players, rugby players, and wrestling athletes.

*Which muscles were affected?*

Most injuries in athletics disciplines in our study involved the hamstring (46.2%), especially in sprinters (60%), with the quadriceps (rectus femoris) being the second most involved muscle. Such frequencies are supported by previous reports which demonstrated sprinters are particularly at risk for acute thigh muscle injuries (hamstring or quadriceps not specified in those studies) [26,27]. A previous work evaluating injuries in 13 athletics competitions in elite athletes demonstrated that thigh strain injuries were the most common among time-loss injuries (28.2%), being more prevalent among short distance runners [27]. Furthermore, previous studies have demonstrated the prognostic impact of imaging-detected hamstring injuries in sprinters as well as in other athletics' disciplines, as they are responsible for time-loss in training and competition [8,20]. A variety of muscles were affected by acute injury in various other disciplines in our study, with the majority of injuries also located in the lower limbs, mainly in the thigh (hamstring and quadriceps were the most commonly affected).

*What does imaging tell us about severity of acute muscle injuries?*

Regarding the overall severity of imaging-detected acute muscle injuries during the Olympic Games (using the 3-grade system), the majority of injuries were grade 2 (54.3%), followed by grade 1 injuries (30.9%), and grade 3 injuries (11.1%). There is some evidence that a linear and positive relationship exists between imaging grades of hamstring injuries and time to return to play when clinical factors (pain, strength, range of motion) were not included in the models [7,20]. However, reports that included clinical predictors suggested that MR imaging appearance of hamstring explained little of the variance in return to play times [10,28,29]. As we do not have return to play data we cannot add to that discussion but it could be an aim for future IOC studies.

There has been an argument that MRI-detected hamstring injuries with intramuscular tendon involvement (especially discontinuity of tendon) are associated with longer recovery times in athletes when compared to injuries without tendon involvement [20,30]. For this reason and for all injuries depicted on MRI, severity of acute muscle injuries was assessed according to the British Athletics Muscle Injury system, which allows the evaluation of intramuscular tendon involvement ("c" injuries) [19]. We found that 27.7% of all MRI-detected muscle injuries occurring during the 2016 Summer Olympic Games represented "c" injuries, which more commonly affected the hamstring and the rectus femoris muscles in athletes. The sports medicine community should be aware of the relevant frequency of "c" injuries as it may affect prognosis, as they are responsible for longer recovery times. We contend this highlights the usefulness of imaging services during major competitions such as the Olympic Games, as clinical examination cannot depict intramuscular tendon involvement in muscle injuries [31]. However, we acknowledge the controversy relating to prognosis of these intramuscular hamstring tendon injuries.

## Conclusion

Imaging services helped clinicians diagnose muscle injuries and MRI assessment detected a large number of injuries that exhibited intramuscular tendon involvement ("c" injuries). The results of our study may help the sports medicine community involved in the Olympic Games to develop preventive strategies to decrease the incidence of muscle injuries in future competitions. Further, it reinforces the usefulness of imaging services in major sports events in regard to detection and severity assessment of muscle injuries.

**What are the new findings:**

- 81 acute muscle injuries (7.4% of all injuries) in 77 athletes were depicted on imaging studies at the medical polyclinic during the 2016 summer Olympic Games.
- The overall incidence proportion of imaging-detected acute muscle injuries was 0.71%.
- Hamstring injuries were the most common; Considering all acute muscle injuries that could be evaluated using the 3-grade system we found 25 grade 1 injuries (31%), 44 grade 2 (54%), and 9 grade 3 injuries (11%). One injury corresponded to delayed onset muscle soreness (1.2%).

**How might it impact on clinical practice in the near future:**

- We identified which sports have higher incidence rates of imaging-detected muscle injuries.
- Helps provide a focus for preventive efforts – which muscles injuries in which sports?
- Imaging services during major competitions such as the Olympic Games permit accurate diagnosis of intramuscular tendon involvement; this cannot be done confidently by clinical assessment alone.

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**Authorship statement:** All coauthors of our manuscript have fulfilled the following criteria:

- Substantial contributions to the conception or design of the work, or the acquisition, analysis or interpretation of data.
- Drafting the work or revising it critically for important intellectual content.
- Final approval of the version published.
- Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

**Conflict of interest**

Ali Guermazi is the President of Boston Imaging Core Lab (BICL), LLC, and a Consultant to MerckSerono, AstraZeneca, Pfizer, GE Healthcare, OrthoTrophix, Sanofi and TissueGene. Frank Roemer and Michel Crema are shareholders of BICL, LLC. Lars Engebretsen is a consultant to Arthrex and Smith and Nephew. Other authors have nothing to disclose.

## References


1. Guermazi A, Hayashi D, Jarraya M, et al. Imaging-detected sports-related stress injuries, fractures, muscle and tendon pathology at Rio de Janeiro 2016 Summer Olympic Games: Retrospective analysis of utilization of diagnostic imaging services. *Radiology* (Accepted)
2. Junge A, Engebretsen L, Mountjoy ML, et al. Sports injuries during the Summer Olympic Games 2008. *Am J Sports Med* 2009;37:2165-72.
3. Orchard J, Seward H. Epidemiology of injuries in the Australian Football League, seasons 1997-2000. *Br J Sports Med* 2002;36:39-44.
4. Darrow CJ, Collins CL, Yard EE, et al. Epidemiology of severe injuries among United States high school athletes: 2005-2007. *Am J Sports Med* 2009;37:1798-1805.
5. Ekstrand J, Hagglund M, Walden M. Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med* 2011;39:1226-32.
6. Elliott MC, Zarins B, Powell JW, et al. Hamstring muscle strains in professional football players: a 10-year review. *Am J Sports Med* 2011;39:843-50.
7. Ekstrand J, Healy JC, Walden M, et al. Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play. *Br J Sports Med* 2012;46:112-7.
8. Askling CM, Tengvar M, Saartok T, et al. Acute first-time hamstring strains during high-speed running: a longitudinal study including clinical and magnetic resonance imaging findings. *Am J Sports Med* 2007;35:197-206.
9. Askling CM, Tengvar M, Saartok T, et al. Proximal hamstring strains of stretching type in different sports: injury situations, clinical and magnetic resonance imaging characteristics, and return to sport. *Am J Sports Med* 2008;36:1799-1804.

10. Wangensteen A, Almusa E, Boukarroum S, et al. MRI does not add value over and above patient history and clinical examination in predicting time to return to sport after acute hamstring injuries: a prospective cohort of 180 male athletes. *Br J Sports Med* 2015;49:1579-87.

11. Bethapudi S, Budgett R, Engebresten L, et al. Imaging at London 2012 summer Olympic Games: analysis of demand and distribution of workload. *Br J Sports Med* 2013;47:850-6.

12. International Olympic Committee. https://stillmed.olympic.org/Documents/olympic_charter_en.pdf.

13. Engebretsen L, Steffen K, Alonso JM, et al. Sports injuries and illnesses during the Winter Olympic Games 2010. *Br J Sports Med* 2010;44:772-80.

14. Engebretsen L, Soligard T, Steffen K, et al. Sports injuries and illnesses during the London Summer Olympic Games 2012. *Br J Sports Med* 2013;47:407-14.

15. Soligard T, Steffen K, Palmer-Green D, et al. Sports injuries and illnesses in the Sochi 2014 Olympic Winter Games. *Br J Sports Med* 2015;49:441-7.

16. Steffen K, Moseid CH, Engebretsen L, et al. Sports injuries and illnesses in the Lillehammer 2016 Youth Olympic Winter Games. *Br J Sports Med* 2017;51:29-35.

17. Soligard T, Steffen K, Palmer D, et al. Sports injury and ilness incidence in the Rio de Janeiro 2016 Olympic Summer Games: a prospective study of 11274 athletes from 207 countries. *Br J Sports Med* 2017;51:1265-71.

18. Peetrons P. Ultrasound of muscles. *Eur Radiol* 2002;12:35-43.

19. Pollock N, James SL, Lee JC, et al. British athletics muscle injury classification: a new grading system. *Br J Sports Med* 2014;48:1347-51.

20. Pollock N, Patel A, Chakraverty J, et al. Time to return to full training is delayed and recurrence rate is higher in intratendinous ('c') acute hamstring injury in elite track and field athletes: clinical application of the British Athletics Muscle Injury Classification. *Br J Sports Med* 2016;50:305-10.

21. Crema MD, Yamada AF, Guermazi A, et al. Imaging techniques for muscle injury in sports medicine and clinical relevance. *Curr Rev Musculoskelet Med* 2015;8:154-61.

22. Hamilton B, Whiteley R, Almusa E, et al. Excellent reliability for MRI grading and prognostic parameters in acute hamstring injuries. *Br J Sports Med* 2014;48:1385-7.

23. Wangensteen A, Tol JL, Roemer FW, et al. Intra- and interrater reliability of three different MRI grading and classification systems after acute hamstring injuries. *Eur J Radiol* 2017;89:182-90.

24. Connell DA, Schneider-Kolsky ME, Hoving JL, et al. Longitudinal study comparing sonographic and MRI assessments of acute and healing hamstring injuries. *AJR Am J Roentgenol* 2004;183:975-84.

25. Petersen J, Thorborg K, Nielsen MB, et al. The diagnostic and prognostic value of ultrasonography in soccer players with acute hamstring injuries. *Am J Sports Med* 2014;42:399-404

26. Alonso JM, Edouard P, Fischetto G, et al. Determination of future prevention strategies in elite track and field : analysis of Daegu 2011 IAAF Championships injuires and illnesses surveillance. *Br J Sports Med* 2012;46:505-14.

27. Fedderman-Demont N, Junge A, Edouard P, et al. Injuries in 13 international Athletics championships between 2007-2012. *Br J Sports Med* 2014;48:513-22.

28. Moen MH, Reurink G, Weir A, et al. Predicting return to play after hamstring injuries. *Br J Sports Med* 2014;48:1358-63.

29. Jacobsen P, Witvrouw E, Muxart P, et al. A combination of initial and follow-up physiotherapist examination predicts physician-determined time to return to play after hamstring injury, with no added value of MRI. *Br J Sports Med* 2016;50:431-9.

30. Comin J, Malliaras P, Baquie P, et al. Return to competitive play after hamstring injuries involving disruption of the central tendon. *Am J Sports Med* 2013;41:111-5.

31. Crema MD, Guermazi A, Reurink G, et al. Can clinical examination depict intramuscular tendon involvement in acute hamstring injuries? *Orthop J Sports Med* (In print)

## Figures' Legends

**Figure 1**. Ultrasound-detected grade 2 rectus femoris injury in a 20-year-old male sprinter, according to the Peetrons classification. Partial rupture of fibers is seen as a focal well-defined hypoechogenicity (arrows) surrounded by an ill-defined hyperechoic area (arrowheads). Note the architectural distortion of fibers around the rupture.

**Figure 2**. MRI-detected biceps femoris injury in a 23-year-old female sprinter. Axial fat-suppressed T2-weighted image shows high signal changes around the proximal myotendinous junction of the right long head of biceps femoris muscle, with focal and partial intratendinous discontinuity (arrow). As the longitudinal length of tendon involvement was less than 5 cm, this injury was graded as "2c" according to the British Athletics muscle injury system. Note the normal tendon at the proximal myotendinous junction of the left long head of biceps femoris muscle for comparison (arrowhead).