ORIGINAL RESEARCH

MRI-Detected Knee Ligament Sprains and Associated Internal Derangement in Athletes Competing at the Rio de Janeiro 2016 Summer Olympics

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Purpose: Describe the frequency and severity of knee ligament sprains diagnosed by MRI in athletes participating at the 2016 Summer Olympic Games, their association with certain sports and assess correlations with additional knee structural injury.

Patients and Methods: All knee MRIs performed in the Olympic Village and polyclinics during the 2016 Olympics were retrospectively, blindly reviewed for ligament sprains and associated knee injuries. In addition to the absence or presence of these abnormalities, athletes were stratified by age, gender and sport.

Results: 11,274 athletes participated in the 2016 Olympic Games: 113 athletes received at least one knee MRI with some having bilateral or repeat MRI on the same knee. Anterior cruciate and medial collateral ligament (ACL/MCL) sprains were most common, accounting for 32 of the 43 sprains (74.4%). Wrestling (10), hockey (7), athletics (7), and judo (5) accounted for over half of ligament sprains. ACL sprains showed a significant positive correlation with medial, lateral meniscal tears and bone contusions. The positive correlation between posterior cruciate ligament (PCL) sprains with MCL/lateral collateral ligament sprain, and popliteus tendon tear was statistically significant with 50% of total PCL sprains occurring in hockey. When athletes were stratified by gender, ligament sprains had a similar occurrence and distribution between men and women.

Conclusion: Knee ligament sprains, at the Rio 2016 Games, were most common in wrestling, hockey, athletics and judo with ACL and MCL sprains most frequent. Meniscal tears and bone contusions occurred often with ACL sprains. PCL sprains tended to be multi-ligamentous injuries. Sustained ligament sprains had similar occurrence between genders, while men had a peak incidence of sprains at a younger age and women at an older age.

Keywords: Olympics, knee, ligament, sprain, MRI

Introduction

The 2016 Rio de Janeiro Summer Olympic Games brought together worldwide, elite athletes at the height of their careers. Epidemiology and clinical-based information on sports injuries from the Olympic Games has been published, demonstrating the common nature of knee injuries among Olympic athletes.[1–6] The high intensity and volume of training undertaken by these athletes make them susceptible to overuse and traumatic (contact and noncontact) injuries. Acute injuries have been shown as more common during competition, though overuse injuries are not

infrequent.[4] The most common sports-related knee injuries associated with acute trauma are medial meniscal and anterior cruciate ligament tears.[7] However, low grade injuries including tendinitis and mild sprains were the most commonly described abnormalities at an Olympic training center.[5] Additionally, certain sporting activities are associated with higher occurrence of all types and number of injuries.[7]

In Olympic and other high-level athletes, knee pain from acute injury or repetitive microtrauma is not uncommon, and magnetic resonance imaging (MRI) is a highly specific tool for characterizing internal derangement and determining the severity with high sensitivity.[8,9] In addition to being a heavily utilized modality for diagnosing injuries, MRI serves a vital role in determining treatment and potentially impacting return to play.[1,10] During the Rio 2016 Olympic Games, new or recurring injury led to at least one day of missed sporting activity in 40% of athletes, and that 20% of injuries resulted in at least 7 days of missed time. Of all possible anatomical locations, the knee was the most common site of injury (n=130).[6]

Kompel et al previously demonstrated that ligament sprains were not infrequent in this same Olympic population, being the third most common abnormality on MRI after cartilage damage and meniscal tears. Additionally, wrestling, athletics (track and field), judo, and hockey were the sports with the highest number of ligament sprains.[11] However, the specific ligaments that were sprained and correlation with additional knee abnormalities were not analyzed. Given the relative high prevalence of ligament sprains in this population further detailed analysis is warranted to identify which athletes may be at highest risk.

The aim of our study is to describe the frequency of specific knee ligament sprains, diagnosed by MRI, in participating athletes at the Rio de Janeiro 2016 Summer Olympic Games. These injuries were then correlated with sport, other internal derangements of the knee and the age/gender of the athlete.

Methods
Subjects' MRIs
The methods, including the data collection and image analysis, are similar to those performed by Kompel et al.[11] We reviewed all knee MRI studies (GE Medical Systems) performed on athletes at the Rio 2016 Olympic Games while the Olympic Village was open (32 days), and were

obtained from the Radiological Information System (RIS) and Picture Archiving and Communication System (PACS). The MRIs were performed for either chronic/recurrent knee pain without trauma or an acute injury while at the Games. In order to prevent duplicate results, as some athletes were treated by both the Rio 2016 medical staff and the National Olympic Committee (NOC) for the same condition, the athlete accreditation number was used. For duplicate results, the NOC data was utilized. Our study and intent to publish the data was approved by the International Olympic Committee (IOC).

Confidentiality and Ethical Approval
Athlete accreditation numbers were used to search the IOC database for athletes who had a knee MRI and to record their nationality, gender, and age. The information remained confidential and was de-identified in the database following the query. The medical research ethics division committee of the Southeastern Norway Regional Health Authority approved our study (#S-07196C) and a second IRB was obtained from Boston University (#H-36593). The requirement for informed consent was waived, as the data in this study was de-identified and anonymized. The athletes' information was gathered, retained, and examined in strict adherence with data protection and confidentiality. The IOC consented to the review of the anonymized demographic data and imaging for publication.

Data Collection
In the Olympic Village, MRI's were performed at the official IOC clinics, using 3T Discovery MR750w and 1.5T Optima 450 MRw MR scanners (GE Healthcare, Brazil). As previously detailed, the MRI images were retrospectively gathered through RIS. Athletes' demographic data was anonymized and the information was stratified according to age, gender, country, sport-type, and specific internal knee derangement. MRI sequences performed included fat-suppressed proton density (intermediate-weighting) in multiple planes (axial, sagittal, and coronal), sagittal T2-weighted, and T1-weighted images in 1–3 planes (sagittal plane most commonly performed).

Imaging Analysis
A musculoskeletal (MSK) radiologist with board certification and 7-years MSK sub-specialization (AJK) blindly and independently analyzed every knee MRI without knowledge of the initial report or clinical history. The

MRIs were evaluated for abnormalities of all ligaments, menisci, cartilage, tendons and osseous structures, as well as the presence of an ACL graft.

Medial and lateral collateral ligament (MCL/LCL) sprains were graded based on their MRI characteristics including hyperintense signal superficial and deep to the ligament without discontinuity of the fibers (Grade 1), partial tearing of the fibers (Grade 2) or complete rupture of the ligament (Grade 3). All grades of ligament sprains were added together for analysis. Anterior and posterior cruciate ligament sprains (ACL/PCL) included partial and complete tears.[12] Diagnosis of a meniscal tear included a flap or displaced tear (abnormal meniscal morphology) or hyperintense linear signal extending to the articular surface on two consecutive MRI images.[13] Cartilage analysis followed the modified Outerbridge grading system with any cartilage loss (fraying/blistering to full thickness loss) included as cartilage abnormalities.[14] For this study, cartilage heterogeneity without thinning was not considered an abnormality (Grade1). Tendon injuries included both partial or complete tears.[15,16] Tendinosis was not included as an injury. Bone contusion was based on marrow edema on the fat-suppressed proton-density without circumscribed borders or fracture line.[17]

Statistical Analysis

Ligament sprains were grouped according to ligament involved (ACL, PCL, MCL, LCL). In addition, associated internal derangement (including other ligament sprains, meniscal tears, cartilage damage, tendon tears, and bone contusions) within the same knee was identified. To evaluate any significant correlation between the presence of a specific ligament sprain and associated internal derangement, a Pearson correlation coefficient (Pearson's r) was performed.

A second reader (AG) assessed 30 random cases for image interpretation reliability using prevalence-adjusted and bias-adjusted kappa (PABAK) and overall percent agreement (Appendix). A few of the MRI findings were not common/low prevalence, therefore, PABAK was used for assessment as kappa was described previously as being highly dependent on prevalence.

Results

11274 athletes participated in the 2016 Olympic Games: 113 of these athletes received at least one knee MRI in the Olympic village, while 9 had bilateral knee MRIs or a repeat MRI on the same side. There was a total of 43 ligament sprains identified, with the highest number being complete ACL, Grade 1 MCL, and Grade 2 MCL sprains – 15, 9, and 6 respectively. When grouped, the total number of ACL and MCL sprains accounted for roughly 75% of all ligament sprains – 32 of 43 total. Wrestling, hockey, athletics, and judo together accounted for over half the total number of ligament sprains identified. A detailed overview of these results is presented in Table 1.

The positive correlation between grouped ACL sprains (partial and complete combined) was statistically significant with medial (r= 0.34) and lateral (r=0.32) meniscal tears, lateral femoral condyle (r=0.51), medial (r=0.38) and lateral tibial plateau (r=0.52) bone contusions. The positive correlation between grouped MCL sprains was

Table 1 Distribution of Ligament Sprain by Sport

	# Athletes with MRI	ACL Sprain	PCL Sprain	MCL Sprain	LCL Sprain
Aquatics - Swimming	2	1 (50%)	0	0	1 (50%)
Athletics	26	4 (15%)	0	3 (12%)	0
Badminton	2	2 (100%)	0	0	0
Fencing	4	1 (25%)	0	0	0
Gymnastics	3	1 (33%)	0	1 (33%)	1 (33%)
Handball	13	0	1 (8%)	1 (8%)	0
Hockey	8	1 (13%)	2 (25%)	4 (50%)	0
Judo	7	4 (57%)	0	0	1 (14%)
Taekwondo	1	1 (100%)	0	1 (100%)	1 (100%)
Volleyball	10	1 (10%)	0	0	0
Wrestling	9	1 (11%)	1 (11%)	5 (56%)	3 (33%)
Remaining sports combined	28	0	0	0	0
Total	113	17 (15%)	4 (4%)	15 (13%)	7 (6%)

Abbreviations: ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; MCL, medial collateral ligament; LCL, lateral collateral ligament.

statistically significant with PCL sprain (r=0.49), popliteus tendon tear (r=0.34), and lateral tibial plateau bone contusions (r=0.28). The positive correlation between grouped LCL sprains was statistically significant with ACL (r=0.31) and MCL sprains (r=0.33), tendon tears [semimembranosus (r=0.35) and popliteus (r=0.37)] and lateral femoral condyle bone contusion (r=0.31). Positive correlation between grouped PCL sprains was statistically significant with MCL (r=0.49) and LCL (r=0.28) sprains, semimembranosus (r=0.34), medial gastrocnemius (r=0.27), and popliteus tendon tears (r=0.49). There was no statistically significant correlation between grouped ligament sprains and cartilage damage (results summarized in Table 2).

When ligament sprains were stratified by age and sex, the overall prevalence of sprains between men and women are similar. In male athletes, ligament sprains occurred most frequently in ages 20–29 years old, with MCL and ACL injuries being the most common (17 of 23 ligament sprains, 11 of which were MCL or ACL injuries). Female athletes aged 20–29 also had the most identified ligament sprains (13 of 20 ligament injuries, 10 of which were MCL or ACL injuries). In both men and women, there were more sprains in the 30–39 age group than seen in the 15–19 age group (results summarized in Table 3).

Discussion

Our data showed that of the total number of knee MRIs performed at the 2016 Olympic village and polyclinics, over one third demonstrated some form of ligament sprain. The most common of these injuries were ACL and MCL sprains of various severity – more commonly complete disruption of the ACL and lower grade sprains (Grade 1 and 2) involving the MCL (Figure 1A and B). The sports in which these ligament sprains were detected the most – wrestling, hockey, athletics, and judo - have been shown to carry a greater than 10% risk of injury to participating athletes.[6,7,18,19]

Knee injuries in wrestling are common, with collateral ligament sprains occurring much more frequently than ACL sprains.[20,21] Our results support this literature by demonstrating that wrestling did not only have the most ligament sprains compared to other sports but also collateral ligament sprains outnumbered cruciate ligament tears. The mechanism of ligament injury is most often due to rotation on a planted foot with the leg in extension, usually during a takedown.[20,21] In hockey, lower extremity injuries are the most common with ACL and collateral ligament

Table 2 Correlation Between Specific Knee Ligament Sprains and Other Internal Derangement

Ligament Sprained	ACL		PCL		MCL		LCL		Medial Meniscus		Lateral Meniscus		Cartilage		Tendons		Bone Contusion	
	Intact	Sprained	Intact	Sprained	Intact	Sprained	Intact	Sprained	Intact	Torn	Intact	Torn	Normal	Abnormal	Intact	Injured	Absent	Present
ACL	0	17	17	0	13	4	14	3	9	8[a]	9	8[a]	4	13	17	0	10	7[a]
PCL	4	0	0	4	0	4[a]	3	1[a]	2	2	3	1	0	4	3	1[b]	3	1
MCL	11	4	11	4[a]	0	15	12	3	9	6	12	3	2	13	13	2[c]	10	5[a]
LCL	4	3[a]	6	1	4	3[a]	0	7	5	2	5	2	4	3	6	1[d]	4	3[a]

Notes: [a] p < 0.05; [b] p < 0.05 for semimembranosus, medial gastrocnemius, popliteus tendons; [c] p < 0.05 for popliteus; [d] p < 0.05 for semimembranosus, popliteus.
Abbreviations: ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; MCL, medial collateral ligament; LCL, lateral collateral ligament.

**Table 3** Age and Gender Stratification of Ligament Sprains

Gender	Age Group	ACL Sprain		PCL Sprain		MCL Sprain		LCL Sprain		# Athletes with Any Ligament Sprain	
		N	% (ACL Sprain/# MRIs Performed	N	% (PCL Sprain/# MRIs Performed	N	% (MCL Sprain/# MRIs Performed	N	% (LCL Sprain/# MRIs Performed)	N	% (Any Ligament Sprain/# MRIs Performed
Men	15–19	1	50.0%	0	0	0	0	1	50.0%	1	50.0%
	20–29	4	11.1%	3	8.3%	7	19.4%	3	8.3%	11	30.6%
	30–39	3	13.6%	0	0	1	4.5%	0	0	4	18.2%
Women	15–19	0	0	0	0	0	0	0	0	0	0.0%
	20–29	7	15.2%	1	2.2%	3	6.5%	2	4.3%	11	23.9%
	30–39	2	14.3%	0	0	4	28.6%	1	7.1%	4	28.6%

Abbreviations: ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; MCL, medial collateral ligament; LCL, lateral collateral ligament.

sprains, caused by non-contact maneuvers including "cutting" and deceleration.[22–24] Athletics encompasses many different types of running, jumping and throwing events in various combinations and distances. Injuries almost always are caused by overuse or non-contact trauma, and the lower extremity is the most commonly involved anatomical region with knee injuries representing a relatively high percentage of these lower extremity injuries.[25–27] While tendinosis, tibial stress, and patellofemoral syndrome are more common injuries and related to overuse, acute ligament sprains can result from non-contact, especially in events requiring quick bouts of acceleration including sprinting, hurdles, jumping, and multi-event

athletes.[27,28] Judo had the 4th most ligament sprains composed mostly of ACL sprains. ACL rupture has been shown to not only be a frequent injury in Judo but also the most common severe type injury leading to months of recovery and decreased performance.[7,19,29] The risk of ACL and MCL sprains in judo has been shown to significantly increase to the athlete being attacked rather than attempting to attack, certain leg techniques (such as osoto-gari), and with opponents having different grip styles.[19,30]

Our data also highlights associations within ligamentous sprains, and between ligament injury and other internal derangement diagnosed by MRI. The most pronounced correlation was between ACL sprains, meniscal tears, and
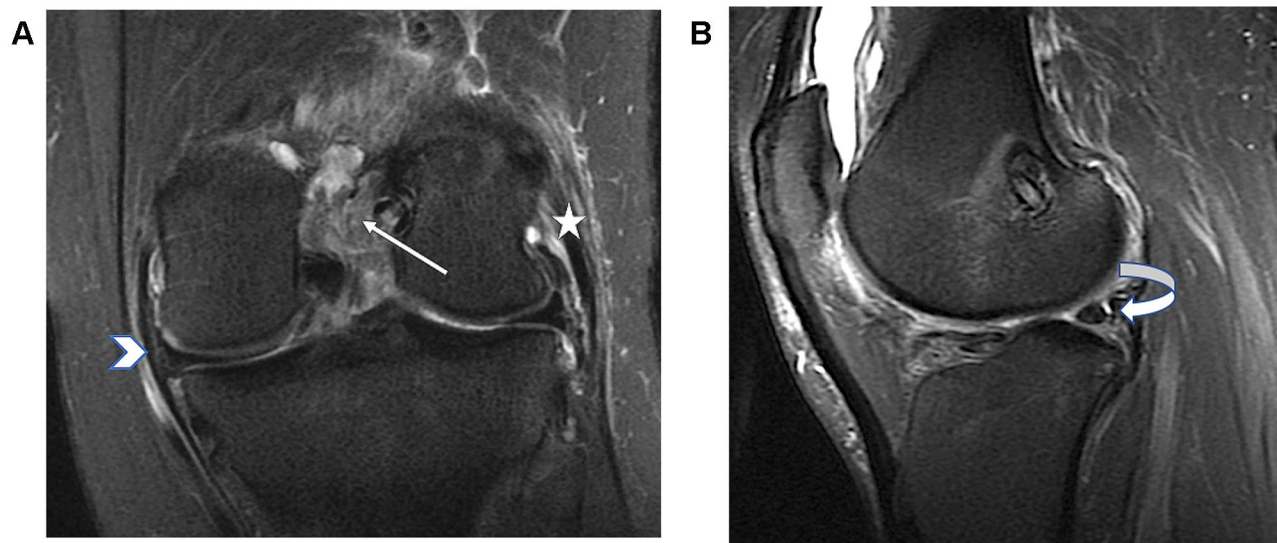
Figure 1 (**A**) Coronal and (**B**) sagittal proton-density fat-saturated magnetic resonance images of the left knee. 33-year old female taekwondo competitor demonstrates a ruptured anterior cruciate ligament graft (arrow), Grade 2 lateral collateral (star) and grade 1 medial collateral ligament sprains (arrowhead). There is a vertical tear of the posterior horn lateral meniscus (curved arrow).
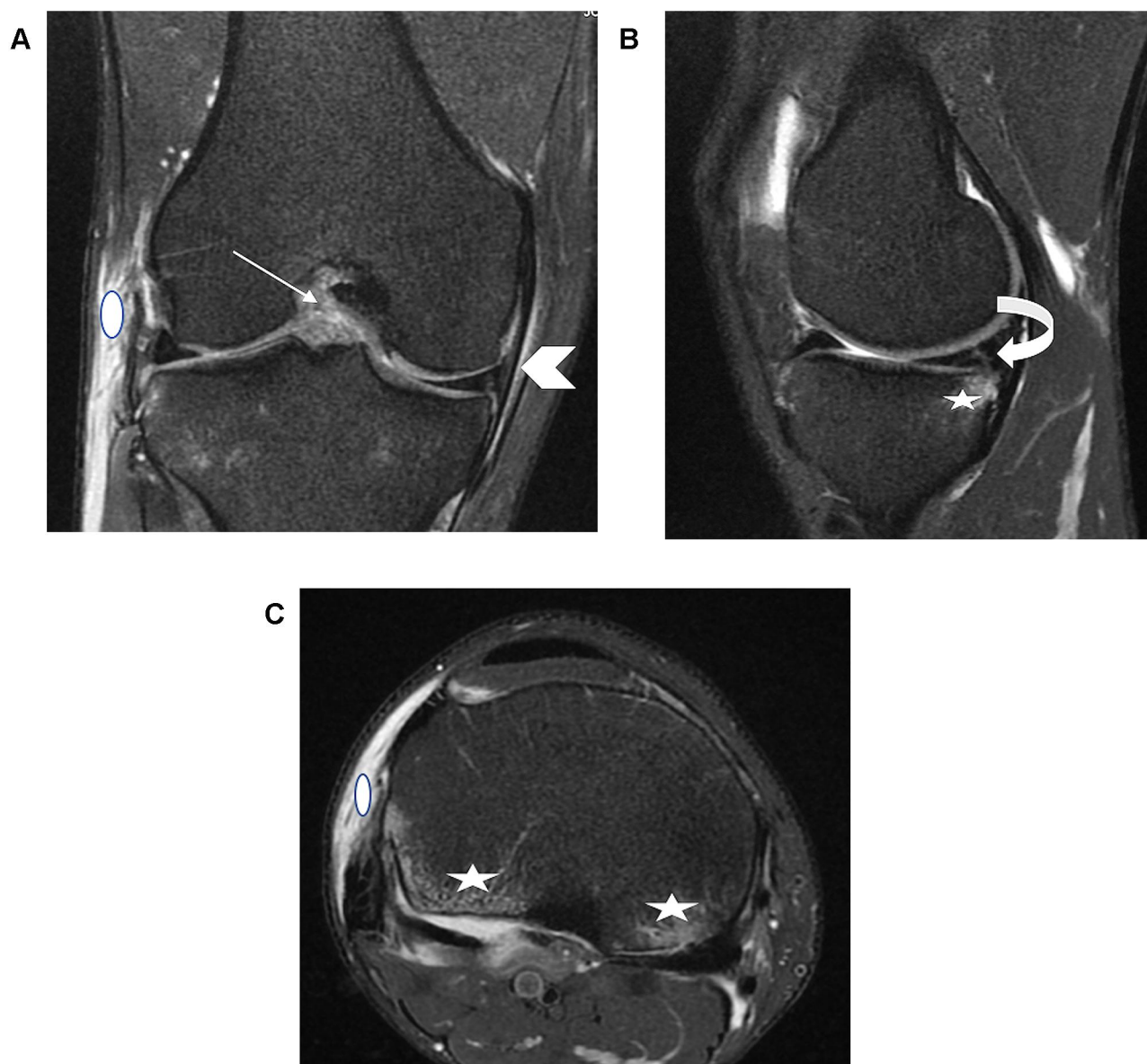
Figure 2 (**A**) Coronal, (**B**) sagittal and (**C**) axial proton-density fat-saturated magnetic resonance images of the right knee. 25-year old male gymnast shows a ruptured anterior cruciate ligament (arrow), grade 1 medial collateral ligament sprain (arrowhead), vertical tear of the posterior horn medial meniscus (curved arrow), posterior tibial plateau bone contusions (star), and lateral soft tissue contusion (oval).

bone contusions to the lateral femoral condyle, medial tibial plateau, and lateral tibial plateau (Figure 2A–C). Bone contusions associated with ACL sprain have been documented to have prevalence of up to 70% and more commonly occur than the traditional "unhappy triad" confluence of ACL, MCL, and medial meniscal tear.[31] The significant correlation between ACL sprains with medial and lateral meniscal tears is in agreement with prior reports of meniscal tears (medial/lateral or both) occurring with an ACL sprain in 59–79% of cases, with the meniscal tears being nearly split evenly between medial and lateral.[32,33] Additionally, while not a statistically significant correlation (p = 0.13), about a quarter of athletes with ACL sprains did have a concomitant MCL sprain indicating a trend for these injuries to occur together and percentage-wise comparable to previous literature.[34]

Multi-ligamentous knee injury is defined as involving at least 2 of the 4 major knee ligaments usually with at least one of these ligamentous being completely ruptured.[35] Multi-ligamentous knee injuries have been shown to involve up to 11% of knee ligament sprains presenting for treatment with combined ACL/MCL sprains most frequent.[35,36] While ACL/MCL combined injury was

observed in this Olympic population, there was a significant correlation with PCL sprains occurring with MCL and/or LCL sprains and popliteus tendon tears, indicating injury to the posterolateral corner (Figure 3A–C). Although PCL sprains are much less common than ACL injuries, PCL sprains are known to commonly occur with other ligament (up to 95% of cases) and posterolateral corner knee injuries potentially related to the mechanism of injury or higher energy trauma required to injure the PCL.[37–39] Therefore, if there is suspicion for PCL injury, the likelihood of concomitant internal derangement should be highly suspected, and MRI is highly accurate in diagnosing all related injuries.[39,40] While isolated PCL

injuries, especially low-to-moderate grade sprain, can be treated non-operatively, complete rupture or avulsion of the PCL and associated ligamentous/posterolateral corner injuries commonly require surgical intervention. Correct diagnosis of these injuries is critically important to the surgical planning, to ensure post-operative stability to the knee.[38,41,42]

The highest number of ligament sprains was observed in both male and female athletes aged 20–29, which can be expected given this age group has the largest number of competitors. Additionally, ligament sprains were nearly equally distributed between men and woman in terms of number and location of the sprain. Previous research
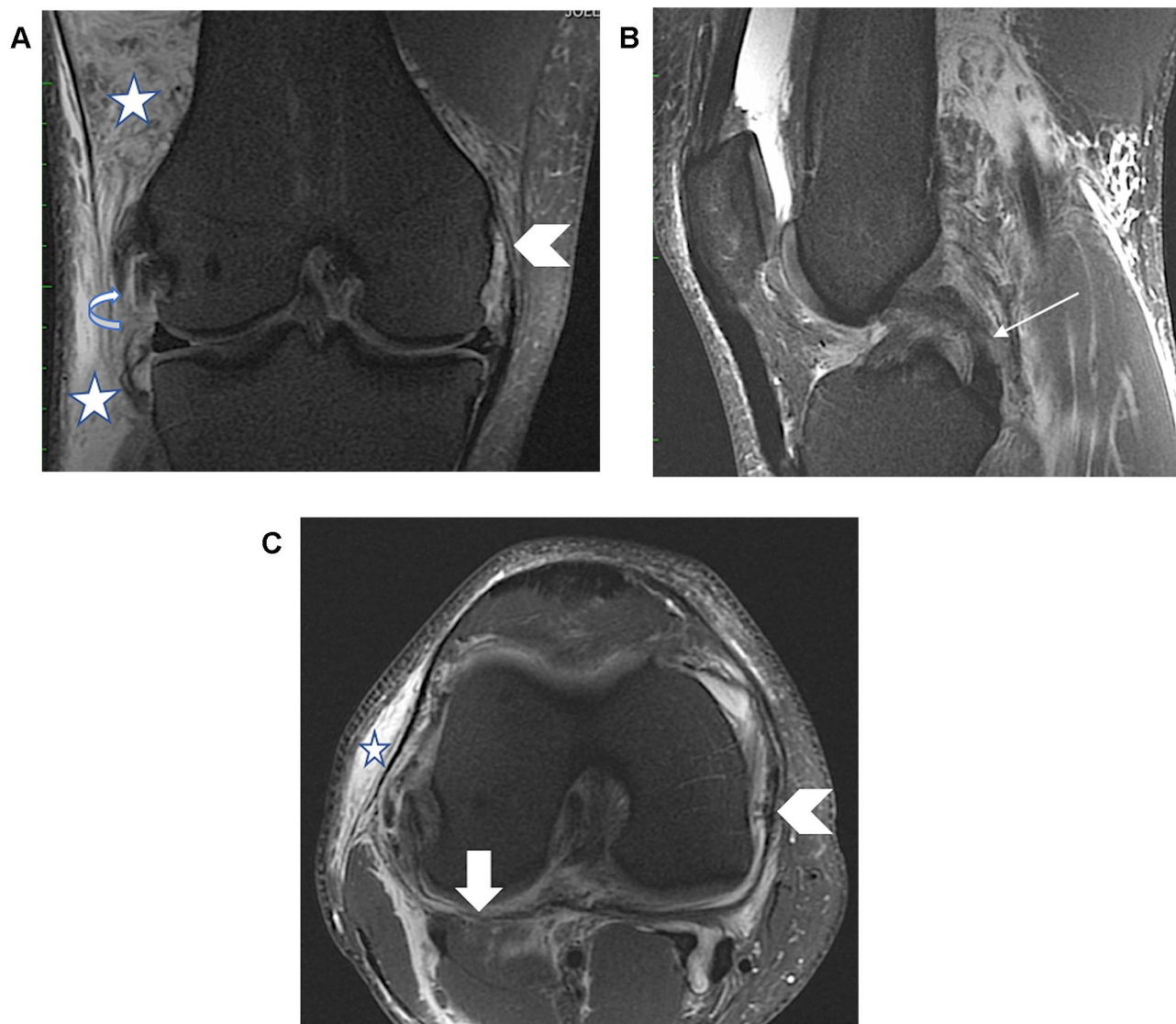
Figure 3 (**A**) Coronal, (**B**) sagittal and (**C**) axial proton-density fat-saturated magnetic resonance image of the right knee. 29-year old male wrestler demonstrates a grade 3 lateral collateral ligament sprain (curved arrow), grade 2 medial collateral ligament sprain (arrowhead), partial posterior cruciate ligament tear (arrow), and posterolateral capsular injury (block arrow) with overlying soft tissue contusion (star).

demonstrates that woman have a higher rate of non-contact ACL tears which is thought to be related to underlying bone geometry, more specifically a shortened and rounded tibial plateau and increased tibial slope.[43,44] However, when evaluating ACL sprains resulting from contact and non-contact causes and the sport involved, there are similar rates of ACL tears between genders.[45,46] In terms of age, the sport and gender of the athlete have potential impact on spraining a knee ligament.[47] For men, the rate of ligament sprain decreased with increasing age, which could represent younger athletes competing in sports with a higher risk of knee sprain compared to the older athletes.[48] Additionally, previous research supports that the incidence of isolated ACL tears in men significantly decreases as age increases.[49] For women, the rate increased with increasing age which could be related to sport. However, previous studies have shown that males have a peak incidence of ACL rupture in their early twenties and women have a second peak occurrence in their forties with an overall advanced age compared to men for when the sprain occurs.[50] This increased risk for ligament sprain in older athletes is thought to be related age-dependent changes in connective tissue possible related to impaired healing capacity and vascular supply.[51] Independent of the cause, this data should guide sports medicine personnel to the potential increased risk in older athletes, especially woman, and implement injury prevention mechanisms.

This study included all MRIs performed at the Olympic village and polyclinics however, if an athlete was transferred to an outside hospital for treatment, likely for more serious injuries, any MRIs at that hospital and the athlete's knee injuries were not included in this analysis. The clinical context for obtaining an MRI was not known in this retrospective review. This includes the indication for the MRI (acute injury during the games, recurrent injury or pain present while at the Games without a trauma), physical exam findings, mechanism of injury (if a trauma occurred), treatment, and any return to play timeline. Also, the overall sample size is small, including 130 athletes who were clinically diagnosed with a knee injury and 113 athletes had an MRI performed in the Olympic village/polyclinics.

These results show that ligament sprains in Olympians align with other high-performing athletic populations and associated internal knee derangement is consistent with previously described patterns. Given the volume and intensity levels these athletes train, knowing which athletes and

sports may be more susceptible can lead to increased surveillance and potential injury mitigation training techniques. Additionally, performing this analysis over multiple Olympic Games will further delineate significant associations between knee ligament sprains, concomitant internal derangement and the association with certain sports and athletes' demographics.

Conclusion

Ligament sprains are the third most common knee lesion in this Olympic population after cartilage damage and meniscal tears. Certain sports are more commonly associated with knee ligament sprains including wrestling, hockey, athletes and judo. ACL and MCL sprains were detected most frequently and could result from contact and non-contact mechanisms depending on the sport. In support of the literature, ACL sprains commonly have associated injuries including medial and/or lateral meniscal tears and bone contusion. PCL sprains, though much less common, are usually multi-ligamentous injuries, including the posterolateral corner, and frequently require surgical intervention. When evaluating ligament sprains based on gender and age, the overall rate of occurrence is similar between gender when including contact and noncontact sports.

Author Contributions

All authors contributed to data analysis, drafting or revising the article, have agreed on the journal to which the article will be submitted, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

Disclosure

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