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Sports Injuries at the Rio de Janeiro 2016 Summer Olympics: Use of Diagnostic Imaging Services[1]

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Purpose: To describe the occurrence of imaging-depicted sports-related stress injuries, fractures, and muscle and tendon disorders during the 2016 Summer Olympic Games in Rio de Janeiro, Brazil.

Materials and Methods: Data on radiologic examinations were collected and retrospectively analyzed centrally by two board-certified musculoskeletal radiologists (with a third musculoskeletal radiologist acting as an adjudicator in case of discrepancies). Descriptive data on all imaging examinations by using radiography, ultrasonography (US), and magnetic resonance (MR) imaging were collected and analyzed according to imaging modality, country of origin of the athletes, type of sport, and type and location of injury.

Results: There were 1101 injuries that occurred in 11 274 (9.8%) athletes. A total of 1015 radiologic examinations were performed, including 304 (30.0%) radiographic, 104 (10.2%) US, and 607 (59.8%) MR examinations. Excluding 10 athletes categorized as refugees, athletes from Africa had the highest utilization rate (14.8%, 148 of 1001). Athletes from Europe underwent the most examinations with 103 radiographic, 39 US, and 254 MR examinations. Gymnastics (artistic) had the highest percentage of athletes who underwent imaging (15.5%, 30 of 194). Athletics (track and field) had the most examinations (293, including 53 radiographic, 50 US, and 190 MR examinations).

Conclusion: The overall occurrence of imaging used to help diagnose sports-related injuries at the Rio de Janeiro 2016 Summer Olympics was 6.4% of athletes. In these cases, MR imaging comprised 60% of imaging utilization.

Online supplemental material is available for this article.

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The 2016 Summer Olympic Games in Rio de Janeiro, Brazil (commonly known as Rio 2016) drew 11 274 athletes from 206 different countries and a team of 10 stateless refugees. In such a major international sporting event at an elite level, imaging diagnosis of sports-related injuries is essential to evaluate the type and severity of injury, which will in turn help to determine whether the affected athlete can continue to compete. Analyses of demand and use of radiology services were published for the London 2012 Summer Olympics, during which 1283 radiologic examinations were performed in athletes including 252 radiographic, 257 ultrasonographic (US), 674 magnetic resonance (MR) imaging, and 42 computed tomographic (CT) examinations, as well as 58 interventional procedures (1). However, only limited published data are available for previous games, to our knowledge (2–4). The aim of our study was to describe the occurrence of imaging-depicted sports-related stress injuries, fractures, and muscle and tendon disorders and to document the use of imaging with radiography, US, and MR imaging during the Rio de Janeiro Summer Olympics held in 2016.

Materials and Methods

GE Healthcare provided all imaging equipment according to an agreement with the International Olympic Committee and provided images for our study, but had no control over the contents of our article, nor provided any financial support toward our study.

Implications for Patient Care

- On-site radiologic services play an important role for the management of elite athletes with sports-related injuries and disorders during the Olympic Games.
- MR imaging comprised nearly 60% of all imaging performed for diagnosis of sports-related injuries at the Rio de Janeiro 2016 Summer Olympics.

Data Collection

Each athlete at the games was assigned an accreditation number; we used these numbers to query the International Olympic Committee athlete database for age, sex, and nationality of the injured athlete. We treated all information strictly confidentially, and de-identified our medical database after the games. Our retrospective study was reviewed by the medical research ethics committee of the South-Eastern Norway Regional Health Authority (file no. 2011/388) and was exempted from ethics committee approval. Informed consent was waived because all data in our study were anonymized and unidentifiable. The International Olympic Committee approved our use of anonymized imaging and demographic data for publication. Data were collected, stored, and analyzed in strict compliance with data protection and athlete confidentiality.

All National Olympic Committee medical teams reported the daily occurrence (or nonoccurrence) of injuries on a standardized medical report form. Concurrently, we retrieved the same information on all athletes treated for injuries in the official International Olympic Committee Olympic Village Polyclinic and all other medical venues by the Organizing Committee medical staff. We used the athlete accreditation number to track any athletes treated for the same condition by both the National Olympic Committee and the Rio 2016 medical staff. With duplicates, we retained the National Olympic Committee data.

The Polyclinic was open 24 hours a day, and the Imaging Center was open from 7 AM to 11 PM daily. In case of emergency situations requiring imaging examinations outside the opening hours of the Imaging Center or more complex injuries necessitating interventional procedures, the patients were referred to an outside referral hospital located 7.1 km (approximately 3.3 miles) away from the Olympic Village. Medical and imaging services were open for 32 days from the opening of the Olympic Village on July 24, through the period of the Olympic Games (August 5 to August 21), to the closing of the Olympic Village on August 24, 2016. Imaging was performed through the Polyclinic in Rio de Janeiro by using digital x-ray cameras (Discovery XR656 Advanced Digital Radiography System; GE Healthcare, Brazil), US machines (Logiq E9 XDClear and portable Logiq E; GE Healthcare), and MR imagers (3.0-T Discovery MR750w and 1.5-T Optima 450 MRw; GE Healthcare). Imaging data were collected retrospectively from the Centricity Radiological Information System and Picture Archiving and Communication System, both of which were provided by GE Healthcare. Demographic information was also collected for all athletes in an anonymized fashion. These data were stratified according to sex, age, participating country, type of sport, and body part.

Data Analysis

Two board-certified musculoskeletal radiologists (M.D.C. and M.J., with 10 years and 6 years of experience in musculoskeletal imaging, respectively) centrally, independently, and retrospectively reviewed radiographic, US, and MR examinations for the presence and type of injuries. For athletes with discrepancies in interpretations between the two radiologists, a third board-certified musculoskeletal radiologist (A.G.) acted as an adjudicator, and mutual consensus was reached following discussion. The radiologists were blinded to the radiographic and MR imaging reports, but not to the US reports, because of the necessity for meaningful interpretation of the US

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Conflicts of interest are listed at the end of this article.

Table 1

Number of Examinations Performed by Imaging Modality and Anatomic Location

Variable	Lower Limb	Upper Limb	Spine	Chest	Abdomen	Pelvis	Others	Total
Radiography	138	92	34	23	1	9	7	304
US	72	15	2	2	9	2	2	104
MR imaging	351	106	124	7	1	11	7	607
All modalities	561	213	160	32	11	22	16	1015

Figure 1

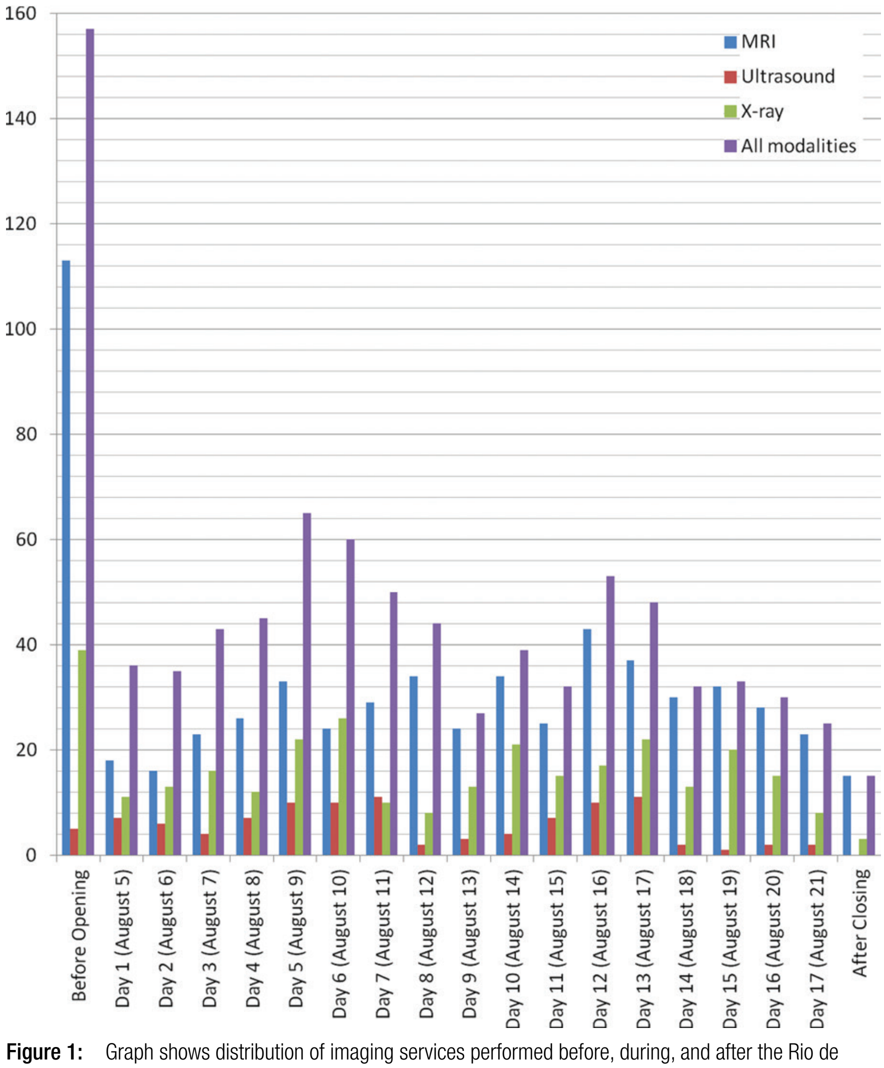


Figure 1: Graph shows distribution of imaging services performed before, during, and after the Rio de Janeiro 2016 Summer Olympic Games.

images in a retrospective fashion. All on-site US scanning was performed by on-site radiologists. All collected data were entered into a spreadsheet to document the occurrence of all radiologic examinations. Details as to how we interpreted images for the presence of stress injuries, fractures, and muscle and tendon injuries are described below.

Fractures and Stress Injuries (Including Stress Fractures and Stress Reactions)

All radiographs were reviewed for the presence of fractures, which were diagnosed radiographically by the presence of sclerosis, periosteal reaction and/or elevation, cortical thickening, and/or a fracture line at the site of bone pain. Those without a relevant history of acute trauma were considered stress fractures and were included in the category of stress injuries. Bone stress reaction, also included in the category of stress injuries, was defined as an ill-defined area of T2 hyperintensity at MR imaging representing marrow edema at a symptomatic site with no definite demonstrable fracture at radiography or MR imaging (5).

Muscle Injuries

All US and MR imaging from athletes with muscle injuries triggered in the Radiological Information System were reviewed for their presence and anatomic location. Only athletes with muscle injuries with positive findings at imaging were included in our descriptive analysis. The anatomic location was defined by isolating the specific muscle or muscle group (ie, hamstring, quadriceps, adductors, etc), with the most extensive injury depicted at imaging. US images were reviewed in conjunction with the original reports extracted from the Radiological Information System. The US examinations in the Polyclinic were conducted by eight musculoskeletal radiologists who had between 6 years and 22 years of experience in diagnosing sports injuries. Muscle injuries were considered present when imaging with US and/or MR imaging showed intrasubstance edema, distortion of muscle fibers and/or tear, or total muscle rupture with or without retraction (6) (Figs E1, E2 [online]).

Tendon Injuries

All US and MR images were reviewed for the presence of tendon injuries. Tendon abnormalities were graded at fluid-sensitive MR imaging, according to morphologic changes and other

Table 2

Utilization of Imaging per Athlete by Continent

Variable	Africa	Americas	Asia	Europe	Oceania	Refugee	Total
Radiography	58	81	47	103	14	1	304
US	31	28	4	39	2	0	104
MR imaging	114	131	74	254	33	1	607
All modalities	203	240	125	396	49	2	1015
Athletes who underwent imaging*	148 (14.8)	157 (6.2)	83 (3.8)	286 (5.6)	42 (5.6)	2 (20.0)	718 (6.4)
All athletes	1001	2539	2165	4805	754	10	11274

*Data in parentheses are percentages.

Table 3

Number of Athletes Who Underwent Imaging in Each Sport

Sport	No. of Examinations	X-ray	US	MR Imaging	Athletes Who Underwent Imaging in Each Sport*	All Athletes in Each Sport
Aquatics (diving)	18	7	0	11	11 (8.1)	135
Aquatics (open water swimming)	1	0	1	0	1 (2.0)	51
Aquatics (swimming)	26	9	3	14	23 (2.6)	901
Aquatics (synchronized swimming)	6	4	0	2	3 (2.9)	104
Aquatics (water polo)	19	13	0	6	14 (5.4)	258
Archery	2	1	0	1	2 (1.6)	128
Athletics	293	53	50	190	208 (8.8)	2367
Badminton	7	1	0	6	7 (4.1)	172
Basketball	24	9	3	12	19 (6.6)	287
Beach volleyball	17	4	0	13	13 (13.5)	96
Boxing	27	9	1	17	18 (6.3)	286
Canoe (slalom)	5	3	0	2	3 (3.6)	83
Canoe (sprint)	3	1	0	2	2 (0.8)	248
Cycling (motorcross)	10	7	2	1	6 (12.5)	48
Cycling (mountain biking)	8	4	1	3	6 (7.5)	80
Cycling (road)	13	7	0	6	9 (4.3)	211
Cycling (track)	9	5	1	3	5 (2.7)	182
Equestrian	4	1	0	3	3 (1.5)	200
Fencing	19	8	1	10	12 (5.9)	204
Football	28	9	0	19	21 (4.2)	503
Gymnastics (artistic)	57	18	4	35	30 (15.5)	194
Gymnastics (rhythmic)	9	3	1	5	5 (5.2)	96
Gymnastics (trampoline)	6	2	0	4	2 (6.3)	32
Handball	58	16	7	35	44 (13.1)	335
Hockey	32	13	0	19	29 (7.6)	384
Judo	64	22	3	39	42 (10.8)	390
Modern pentathlon	3	2	0	1	3 (4.2)	72
Racquetball	1	0	1	0	1 (0.0)	0
Rowing	9	3	2	4	8 (1.5)	546
Rugby	28	10	1	17	22 (7.6)	291
Sailing	4	0	1	3	3 (0.8)	380
Shooting	14	4	1	9	11 (2.8)	390
Table tennis	7	2	3	2	6 (3.5)	172
Taekwondo	22	16	3	3	18 (14.2)	127
Tennis	30	3	6	21	22 (11.1)	199
Triathlon	9	5	0	4	6 (5.5)	109
Volleyball	44	11	2	31	26 (9.0)	288
Weightlifting	43	4	5	34	31 (12.1)	256
Wrestling	36	15	1	20	28 (8.0)	349

*Data in parentheses are percentages.

Table 4

Muscle Injuries, Osseous Stress Injuries, and Fractures and Tendon Injuries by Body Region and Sport

Sport	No. of Injuries	Lower Extremities	Upper Extremities	Chest	Pelvis	Lumbar Spine	Head and Face
	Muscle Injuries (n = 81)						
Athletics	39 (48.1)	38 (46.9)	1 (1.2)	0	0	0	0
Aquatics (diving)	1 (1.2)	0	0	0	1 (1.2)	0	0
Basketball	1 (1.2)	1 (1.2)	0	0	0	0	0
Boxing	1 (1.2)	0	1 (1.2)	0	0	0	0
Cycling (road)	1 (1.2)	1 (1.2)	0	0	0	0	0
Cycling (track)	1 (1.2)	1 (1.2)	0	0	0	0	0
Football	9 (11.1)	8 (9.9)	0	0	1 (1.2)	0	0
Gymnastics (artistic)	1 (1.2)	0	1 (1.2)	0	0	0	0
Gymnastics (rhythmic)	2 (2.5)	1 (1.2)	0	0	1 (1.2)	0	0
Handball	4 (4.9)	4 (4.9)	0	0	0	0	0
Judo	2 (2.5)	0	1 (1.2)	1 (1.2)	0	0	0
Rugby	4 (4.9)	3 (3.7)	0	0	1 (1.2)	0	0
Table tennis	1 (1.2)	1 (1.2)	0	0	0	0	0
Tennis	2 (2.5)	0	0	2 (2.5)	0	0	0
Volleyball	3 (3.7)	3 (3.7)	0	0	0	0	0
Weightlifting	5 (6.2)	5 (6.2)	0	0	0	0	0
Wrestling	4 (4.9)	2 (2.5)	2 (2.5)	0	0	0	0
Total	81	68 (83.9)	6 (7.4)	3 (3.7)	4 (4.9)	0	0
	Stress Reaction and Stress Fracture (n = 25)						
Athletics	11 (44.0)	10 (40.0)	0	0	0	1 (4.0)	0
Fencing	2 (8.0)	2 (8.0)	0	0	0	0	0
Gymnastics (artistic)	3 (12.0)	2 (8.0)	1 (4.0)	0	0	0	0
Gymnastics (rhythmic)	1 (4.0)	1 (4.0)	0	0	0	0	0
Handball	1 (4.0)	1 (4.0)	0	0	0	0	0
Triathlon	1 (4.0)	1 (4.0)	0	0	0	0	0
Volleyball	4 (16.0)	4 (16.0)	0	0	0	0	0
Weightlifting	2 (8.0)	0	0	0	1 (4.0)	1 (4.0)	0
Total	25	21 (84.0)	1 (4.0)	0	1 (4.0)	2 (8.0)	0
	Fractures (n = 43)						
Aquatics (synchronized swimming)	1 (2.3)	1 (2.3)	0	0	0	0	0
Aquatics (water polo)	2 (4.7)	0	1 (2.3)	0	0	0	1 (2.3)
Athletics	5 (11.6)	2 (4.7)	3 (7.0)	0	0	0	0
Badminton	1 (2.3)	1 (2.3)	0	0	0	0	0
Beach volleyball	1 (2.3)	1 (2.3)	0	0	0	0	0
Boxing	2 (4.7)	0	0	2 (4.7)	0	0	0
Cycling (motorcross)	2 (4.7)	1 (2.3)	1 (2.3)	0	0	0	0
Cycling (road)	4 (9.3)	0	2 (4.7)	2 (4.7)	0	0	0
Fencing	1 (2.3)	1 (2.3)	0	0	0	0	0
Football (soccer)	2 (4.7)	2 (4.7)	0	0	0	0	0
Gymnastics (artistic)	2 (4.7)	1 (2.3)	1 (2.3)	0	0	0	0
Handball	3 (7.0)	2 (4.7)	1 (2.3)	0	0	0	1 (2.3)
Hockey	5 (11.6)	3 (7.0)	2 (4.7)	0	0	0	0
Judo	3 (7.0)	1 (2.3)	2 (4.7)	0	0	0	0
Rugby	2 (4.7)	0	2 (4.7)	0	0	0	0
Taekwondo	1 (2.3)	0	1 (2.3)	0	0	0	0
Tennis	2 (4.7)	0	2 (4.7)	0	0	0	0
Volleyball	3 (5.9)	0	3 (5.9)	0	0	0	0
Weightlifting	1 (2.3)	0	1 (2.3)	0	0	0	0
Total	43	16 (37.2)	21 (48.8)	4 (9.3)	0	0	2 (4.7)

Table 4 (*continues*)

Table 4 (*continued*)

Muscle Injuries, Osseous Stress Injuries, and Fractures and Tendon Injuries by Body Region and Sport

Sport	No. of Injuries	Lower Extremities	Upper Extremities	Chest	Pelvis	Lumbar Spine	Head and Face
			Tendon Injuries (n = 156)				
Aquatics (swimming)	5 (3.2)	0	5 (3.2)	0	0	0	0
Aquatics (water polo)	2 (1.3)	0	2 (1.3)	0	0	0	0
Athletics	54 (34.6)	47 (30.1)	5 (3.2)	0	2 (1.3)	0	0
Basketball	6 (3.8)	4 (2.6)	2 (1.3)	0	0	0	0
Beach volleyball	4 (2.6)	3 (1.9)	1 (0.6)	0	0	0	0
Boxing	3;(1.9)	0	3 (1.9)	0	0	0	0
Cycling (mountain biking)	1 (0.6)	1 (0.6)	0	0	0	0	0
Cycling (road)	1 (0.6)	0	1 (0.6)	0	0	0	0
Fencing	1 (0.6)	0	1 (0.6)	0	0	0	0
Gymnastics (artistic)	12 (7.7)	3 (1.9)	9 (5.8)	0	0	0	0
Handball	6 (3.8)	4 (2.6)	2 (1.3)	0	0	0	0
Hockey	3 (1.9)	2 (1.3)	1 (0.6)	0	0	0	0
Judo	15 (9.6)	1 (0.6)	13 (8.3)	1 (0.6)	0	0	0
Rugby	3 (2.2)	1 (0.6)	2 (1.3)	0	0	0	0
Shooting	2 (1.3)	0	2 (1.3)	0	0	0	0
Taekwondo	3 (1.9)	2 (1.3)	1 (0.6)	0	0	0	0
Tennis	9 (5.8)	1 (0.6)	8 (5.1)	0	0	0	0
Triathlon	2 (1.3)	2 (1.3)	0	0	0	0	0
Volleyball	11 (7.1)	5 (3.4)	6 (3.8)	0	0	0	0
Weightlifting	10 (6.4)	5 (3.2)	5 (3.2)	0	0	0	0
Wrestling	3 (1.9)	1 (0.6)	1 (0.6)	1 (0.6)	0	0	0
Total	156	82 (52.6)	70 (44.9)	2 (1.3)	2 (1.3)	0	0

Note.—Data in parentheses are percentages.

associated features. At US, tendon injuries were considered present when there was abnormal tendon morphology or echogenicity, partial tear, or complete tear. At MR imaging, tendon injuries were considered present when there was intratendinous T2 hyperintensity, tendon thickening with or without irregular contour, partial tear, or complete tear (7) (Fig E3 [online]).

Results

Volume of Imaging Services

In total, 11 274 athletes (5089 women [45%] and 6185 men [55%]) from 207 Olympic teams (206 National Olympic Committees and a team of athletes categorized as refugees) participated in our study. National Olympic Committee and Rio 2016 medical staff reported 1101 injuries during the games. They performed 1015 radiologic examinations. Table 1 summarizes the modality breakdown by body region. A total of 718 athletes reported injuries. Of note, 140 (19%) athletes had two or more injuries, and 103 (14%) athletes underwent more than one imaging examination for the same structure (bone or joint).

Distribution of Imaging Utilization at Different Stages of the Olympic Games

Of 1015 radiologic examinations, 157 (15.5%; 39 radiographic, five US, and 113 MR imaging) were performed prior to the start of the games on August 5, 2016 (Fig 1). Overall, 82.8% (840 of 1015) of radiologic examinations were performed during the games (day 1 through day 17) with two peaks, the first on day 5 (August 9, 2016) and the second on day 12 (August 16, 2016). Only 18 imaging examinations (1.8%; 15 MR imaging and three radiographic) were performed after the end of the games on August 21, 2016.

Utilization of Imaging per Athlete by Continent

As shown in Table 2, athletes from Europe underwent the highest number of imaging examinations with 103 radiographic, 39 US, and 254 MR examinations, totaling 396 examinations. Other than a very small number of athletes categorized as refugees, athletes from Africa had the highest utilization rate (14.8%, 148 of 1001 athletes). Imaging utilization rates were similar among athletes from the Americas, Europe, and Oceania (5% to 6%). Athletes from Europe underwent the most radiologic examinations (286 examinations), although Europe also had the largest number of participants (4805 participants) among all continents. Athletes from Asia had

Figure 2

Figure 2: Images in a sprinter with acute anterior thigh pain sustained while training. **(a)** Longitudinal US image of anterior thigh shows complete rupture of proximal myotendinous junction of rectus femoris muscle (arrowheads) with major distal retraction (arrows). Origin of proximal tendon (arrowheads) is located at anterior inferior iliac spine (*). **(b)** Sagittal and coronal fat-suppressed T2-weighted fast spin-echo MR imaging demonstrates distal retraction of proximal myotendinous junction of rectus femoris muscle (arrows). 3.0-T MR imaging parameters: sagittal T2 (2830/77 [repetition time msec/echo time msec]; field of view, 48 × 48 cm; matrix, 416 × 256; echo train length, 16; section thickness, 6 mm) and coronal T2 (4974/86; field of view, 44 × 44 cm; matrix, 320 × 192; echo train length, 16; section thickness, 6 mm).

the lowest number of examinations in all modalities and the lowest utilization rate of all.

Utilization of Imaging by Type of Sport

Table 3 summarizes utilization of radiologic examinations by type of sport. The highest percentage of athletes who underwent imaging were in gymnastics (artistic) (15.5%, 30 of 194), followed by Taekwondo (14.2%, 18 of 127) and beach volleyball (13.5%, 13 of 96). Athletics (track and field) had the most examinations (293, including 53 radiographic, 50 US, and 190 MR examinations).

Distribution of Injuries by Type of Injury, Sport, and Body Region

We recorded the frequency of imaging-depicted muscle injuries, bony stress injuries including stress fractures and stress reactions, fractures, and tendon injuries and stratified them according to body region (Table 4). Of note, no injuries were seen in the abdomen or the neck.

Muscle Injuries

Sixty-eight (83.9%) injuries affected muscles from the lower extremities, six (7.4%) (Fig 2) from the upper extremities, three (3.7%) from the chest, and four (4.9%) (Fig 3) from the pelvis. The sports most prone to muscle injuries were athletics (track and field) (n = 39; 48.1%), football (n = 9; 11.1%), and weightlifting (n = 5; 6.2%).

Stress Injuries Including Stress Fractures and Stress Reactions

Twenty-one of 25 stress injuries were seen in the lower extremities (84.0%) (Fig 4; Figs E4, E5 [online]). Two athletes had stress injuries in the lumbar pedicle (8.0%), one in the upper extremity (4.0%) (Fig E6 [online]), and one in the pelvis. Stress injuries were most commonly seen in athletics (n = 11; 44%), followed by volleyball (n = 4; 16.0%), artistic gymnastics (n = 3; 12.0%), fencing (n = 2; 8.0%), and weightlifting (n = 2; 8.0%). Rhythmic gymnastics, triathlon, and handball had one athlete each (4.0%).

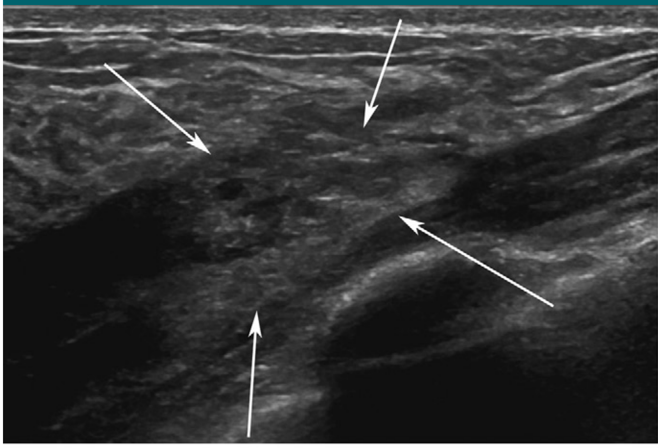
Fractures

Fractures were most commonly found in athletics and hockey (n = 5; 11.6%), followed by road cycling (n = 4; 9.3%). The incidence of fractures was less than 7% in other types of sports. Upper extremity fractures were most common (n = 21; 48.8%) (Fig E7 [online]) among all body regions, closely followed by lower extremity fractures (n = 16; 37.2%) (Fig E8 [online]). Two chest wall fractures were seen each in road cycling (Fig 5) and boxing (4.7%). One head and facial fracture occurred each in aquatics (water polo) and handball (2.3%).

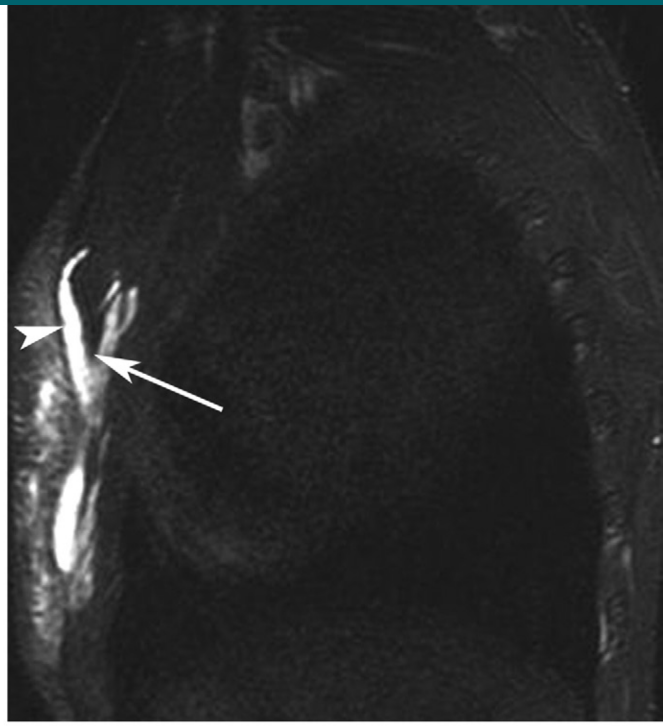
Tendon Injuries

Tendon injuries were most commonly found in athletics (n = 54; 34.6% of all tendon injuries), followed by judo (n = 15; 9.6%), gymnastics (n = 12; 7.7%), volleyball (n = 11; 7.1%), tennis (n = 9; 5.8%), and weightlifting (n = 10; 6.4%). The frequency of tendon injuries was less than 5.0% for all other disciplines. Lower extremity injuries were the most common (n = 82; 52.6%) (Figs E9, E10 [online]) among all body regions, closely followed by upper extremity injuries (n = 70; 44.9%) (Fig 6). Only 1.3% of all

Figure 3



a.



b.

c.

Figure 3: Images in a tennis player with acute pain at anterior chest wall after a match. **(a)** Longitudinal US image of right anterior chest wall shows substantial architectural distortion and hyperechogenicity of proximal aspect of pectoralis major muscle (arrows). **(b)** Coronal short inversion time inversion-recovery and **(c)** axial T2-weighted fast spin-echo MR imaging was performed in addition to US, and shows major disruption of pectoralis major muscle fibers with intramuscular fluid collection (hematoma, arrowheads) and muscle fibers retraction (arrows). 3.0-T MR imaging parameters: axial T2 (5725/105 [repetition time msec/echo time msec]; field of view, 42 × 42 cm; matrix, 320 × 224; echo train length, 16; section thickness, 5 mm) and sagittal T2 (5945/102; field of view, 34 × 34 cm; matrix, 320 × 320; echo train length, 25; section thickness, 5 mm).

tendon injuries were noted in the pelvis and chest.

Discussion

During the Rio de Janeiro 2016 Summer Olympic Games, a total of 1015 radiologic examinations were performed in participating athletes. This number is fewer than those recorded during the London 2012 Summer Olympics (1150 examinations, including 252 radiographic, 224 US, and 674 MR examinations [1]), although there were a similar number of participants (11 274 athletes in Rio de Janeiro and 10 568 athletes in London). However, care should be taken when comparing data from the London Olympics, because their data included diagnostic imaging of non–sports-related injuries and disorders. Our data included only sports-related injuries, with or without a triggering traumatic event, and did not include imaging (eg, chest radiograph) for "general illnesses."

In Olympic athletes, the cost of imaging is not a limiting factor, and thus radiography is not necessarily the first imaging examination performed to evaluate musculoskeletal pain. Indeed, all imaging examinations, particularly the relatively more expensive MR examinations, were provided free of charge to

Figure 4

a.

b.

Figure 4: Images in a long-distance runner with left foot pain without a triggering acute traumatic event. **(a)** Anteroposterior radiograph of left foot shows fine lucent line in distal diaphysis of third metatarsal representing stress fracture, surrounded by marked periosteal reaction (arrow). **(b)** Sagittal fat-suppressed proton density–weighted MR image of left foot confirms fracture line and periosteal reaction (arrow), and also shows diffuse hyperintensity of entire metatarsal confirming acute nature of stress fracture. 3.0-T MR imaging parameters as follows: 2522/48 (repetition time msec/echo time msec); field of view, 15 × 15 cm; matrix, 384 × 256; echo train length, 11; section thickness, 3 mm.

the athletes in the Olympic Village. Two MR imagers were available from 7:00 AM to 11:00 PM daily. In these circumstances physicians were, presumably, more likely to request MR imaging and/or US without an initial radiograph.

By continent, Africa continued to have the highest percentage of athletes who used imaging services. This trend persisted from the London 2012 Summer Olympics (1), and should be cause for concern if the reason is lack of access to adequate health care at home, including medical imaging services.

The lower limb was the most common anatomic location of imaging-depicted sports-related injuries overall, and the highest number of examinations were performed for imaging of lower extremities in all modalities. The second most common location was the upper limb. This is to be expected, given the nature of musculoskeletal injuries related to sports played during the summer months, and is in line with previous publications from past sporting events, particularly the Summer Olympics in 2008 and 2012, the Glasgow 2014 Commonwealth Games, and the 2009 International Association of Athletics Federations World Athletics Championships (1,8–11).

Use of imaging services peaked twice during Rio 2016, first on day 5 and then on day 12. The second peak may be because the athletics, or track and field events—which had the most imaging-depicted injuries among all sports—were scheduled in the latter half of the games (from day 8 to day 17). Similarly, the first peak may be because judo, which had the second most imaging-depicted injuries among all sports, was scheduled in the first half of the games (from day 2 to day 8). This trend of having two peaks of imaging utilization is different from previous reported sports events such as the London 2012 Summer Olympics (1), which showed small fluctuations throughout the competition, with the biggest peak on day 12, and the 2014 Glasgow Commonwealth Games (8), which showed a single peak halfway through the games. Overall high

Figure 5

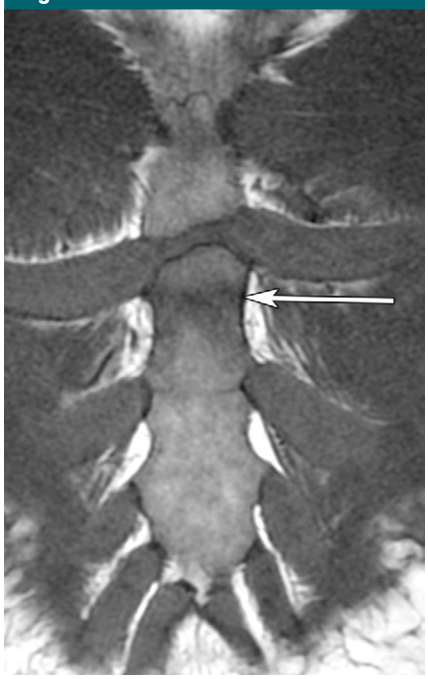
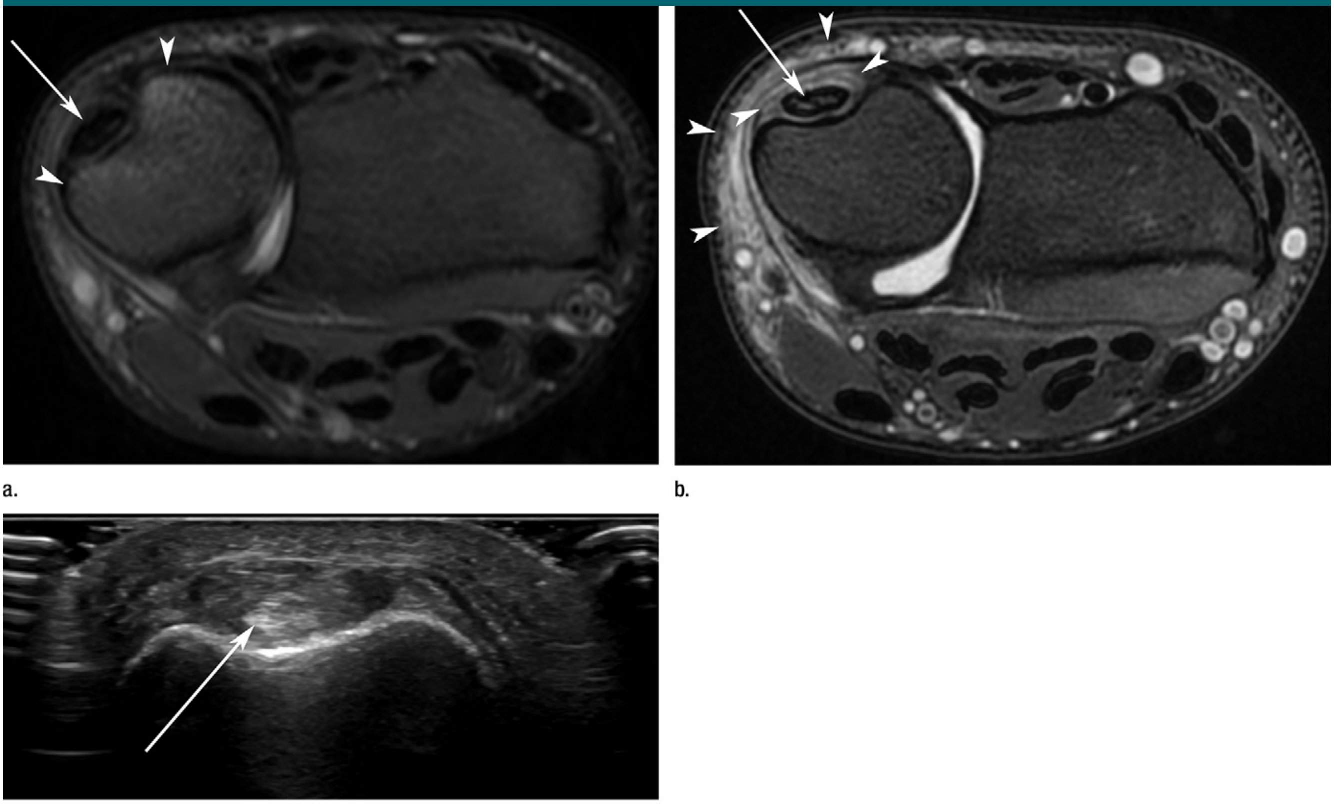


Figure 5: Coronal T1-weighted MR image in road cycling athlete with anterior chest wall pain following direct trauma shows nondisplaced fracture line of sternum (arrow), surrounded by bone marrow edema. 1.5-T MR imaging parameters as follows: 686/13 (repetition time msec/echo time msec); field of view, 30 × 30 cm; matrix, 320 × 256, echo train length, 3; section thickness, 2.5 mm.

Figure 6



a.

b.

c.

Figure 6: Images in a tennis player with pain at ulnar side of wrist without a triggering acute traumatic event. **(a)** Axial fat-suppressed T2-weighted MR imaging shows minimal thickening of extensor carpi ulnaris tendon (arrow) with underlying bone marrow edema of ulna (arrowheads). 1.5-T MR imaging parameters: axial proton density–weighted fat-suppressed (3533/53 [repetition time msec/echo time msec]; field of view, 15 × 15 cm; matrix, 288 × 224; echo train length, 10; section thickness, 2.8 mm). **(b)** Axial fat-suppressed T2-weighted MR imaging 5 days later shows worsening of intratendinous hyperintensity (arrow) with surrounding synovitis and soft-tissue edema (arrowheads) and worsening of effusion within distal radioulnar joint. 1.5-T MR imaging parameters: axial proton density–weighted fat-suppressed (3081/59; field of view, 15 × 15 cm; matrix, 288 × 224; echo train length, 10; section thickness, 2.5 mm). **(c)** Additional same-day US image in transverse plane shows thickening of extensor carpi ulnaris tendon (arrow) with tenosynovitis.

utilization of US and MR imaging during the Olympic Games implies that organizers of future Olympic and non-Olympic sporting events should ensure wide availability of these imaging modalities.

There were limitations of our study. Our study focused specifically on diagnostic imaging based on radiography, US, and particularly MR imaging. Imaging with CT was not included in our analysis because there were no CT scanners in the Olympic Village. We do, however, recommend having an on-site CT scanner because stress fractures may be better diagnosed with CT rather than MR imaging (1). We did not have access to information on imaging services offered at the field of play, participating teams' own medical setups, and imaging performed outside the Olympic Village Imaging Center; hence, such data could not be included in our analysis. Data on clinical symptoms and other nonradiologic data on epidemiology of sports-related injuries at the games were outside the scope of our study. That data, covering all participants (12), as well as specific to the German National Team (13), are available in the literature at the time of writing. Our study is a utilization analysis without analysis of "value" of imaging, and what it added compared with clinical history and physical examination. Last, we did not have a possibility to easily work out how many injuries were imaged with more than one modality. The choice of imaging modality was based on the referrer's preference, and most athletes would have underwent primarily only one image modality to assess a given injury.

In conclusion, diagnostic imaging was used to help diagnose sports-related injuries during the Rio de Janeiro 2016 Summer Olympic Games as part of medical care offered to athletes. Use of MR imaging was high, comprising nearly 60% of all imaging performed for diagnosis and evaluation of sports-related injuries. On-site radiologic services were highly used by elite athletes with sports-related injuries and disorders during the 2016 Summer Olympics.

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