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Title Page

Title of the article

Imaging at London 2012 Olympic Games: Analysis of demand and distribution of workload

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Abstract

Background

Very little data on provision of imaging services at the summer Olympic games has been published before. With 7.9 million Euros (£6.6 million, $11 million U.S) invested into setting up imaging equipment at the purpose built polyclinics for London 2012 Olympics, an ideal opportunity presented to study the demand and distribution of workload on imaging services at the Olympic Games.

Setting

Imaging services within polyclinics, London 2012 Olympic Games.

Aims

To analyse the demand and distribution of workload on radiology services at the London 2012 Olympic Games.

Methods

Data on Radiological investigations performed at London 2012 Olympic Games was retrieved from Radiology Integration System (RIS) picture archiving communication system (PACS) system and medical encounter database run by the games information system (ATOS) and analysed.

Results

The results show that 1711 diagnostic and interventional procedures were performed at the Stratford Polyclinic within the main games village. Of these 48.8% were Magnetic Resonance Imaging (MRI) scans, 20.2% were diagnostic Ultrasound (US) examinations,

23.6% were plain radiographs, 2.9% were Computerised Tomography (CT) scan and interventional procedures accounted for 4.3%. Nearly 75 % of imaging was performed on athletes while less than 5% of the services were utilised by the workforce. Demand on Radiology services peaked during week 2 of the Games.

Conclusion

Imaging played a substantial role in providing medical services at the London 2012 Olympics.

Main Text

INTRODUCTION

London 2012 Olympic was a memorable sporting spectacle, bringing together over 10,568 athletes from 204 different countries with around 6,000 team and International Olympic committee (IOC) officials and 70, 000 volunteer workforce. Dealing with injuries and illnesses in elite athletes at any major international sporting event can be challenging as medical needs of an athlete in competition are different from training injuries. Quick and safe return to competition, to give injured athletes the best chance of competing in what is often their only Olympic competition remains an important influence on every stage of management. It has been reported that 11% to 14% of athletes sustain sports injuries during Olympic games and further 7 % face constitutional illness. About 50% of these athletes undergo loss of time from sport [1-4]. The London Organising Committee of the Olympic and Paralympic games (LOCOG) set up medical services within the games villages to provide readily accessible medical treatment, minimising time out and inconvenience for the athletes. Limited data on imaging services at previous Olympic games has been published previously [5, 6]. We present comprehensive demographic data including volume and distribution of workload on radiology services at the London 2012 summer Olympics. Imaging data from Paralympic games does not form part of this study.

METHODS

Data on radiological investigations performed at London 2012 Olympic Games was prospectively collected analysed from integrated RIS-PACS, imaging software that enables radiologists to view scan images and issue reports and ATOS database, the official electronic games management system. Each entry was checked, to exclude duplicate entries. The list of accredited athletes for the competition was obtained from IOC. Data analysis included

category and modality wise breakdown of all radiological investigations and procedures, day wise breakdown of work load on imaging services, continent wise breakdown of per athlete utilisation of radiology resources and referral sources at London 2012 Olympics.

Imaging facilities

Medical and imaging services at the Olympic Games were provided through three purpose built polyclinics, with the major one located within the main games village at Stratford. The other two polyclinic facilities were located at Eton Dorney, the venue for rowing and Weymouth, which was the venue for sailing competitions. The polyclinic services opened 10 days before the start of the games and continued for 2 days after the closing ceremony.

Imaging facilities at Stratford polyclinic included a XR 656 wireless digital x-ray system (GE) for plain radiography, two US scanning machines (GE Logiq E9 scanners). Discovery 750 HD 64 slice multi-detector CT scanner (GE medical, Milwaukee), 3T and 1.5T wide bore MRI scanners (GE medical, Milwaukee). Eton Dorney and Weymouth polyclinics were equipped with 1 US scanner each (GE Logiq E9). Requests for plain radiography and cross-sectional imaging at these venues were sent to designated local radiology departments under a pay as you go contract. Handheld US devices were used both by the team doctors and LOCOG medical team at field of play and during consultation, although data on such investigations has not been included in our study.

All imaging services were offered between 7 AM to 11 PM, while out of hours services were restricted to plain radiography accessed via polyclinic casualty. Referrals for imaging were accepted directly from team physicians who were provided with temporary registration with the General Medical Council (GMC). Referrals were also received from sports medicine doctors, casualty doctors, general practitioners, physiotherapists, podiatrists within the polyclinic and from the venue medical doctors. All referrals were made through either printed

or electronic request forms providing athletes details along with clinical information and nature of investigation requested. Each request was processed and entered into the electronic RIS-PACS, software electronically without the need for film printing.

27 Musculoskeletal (MSK) radiologists, 56 radiographers, and 23 radiographic assistants and 4 trained Ultrasonographers were involved in providing radiology services for the duration of the Olympic Games. All reporting MSK radiologists were FRCR trained and had at least 8 years working experience at Consultant level. The staff worked in two shifts every day, each shift lasting about 8 hrs. During the peak period, each shift was covered by 5 MSK radiologists, 5 radiographers, 4 radiographic assistants and 1 ultrasonographer. US services at Eton Dorney and Weymouth were conducted by 1 MSK radiologist at each site.

The turnaround time between receiving the request for imaging to performing the investigation for plain radiography and CT on an average was less than 2 hrs. The waiting period for MRI and US was however variable. Even at peak demand during the competitions, the turnaround was still on an average less than 24hrs for these modalities. The printed report along with a copy of the scan images on a DVD format were issued within 1 hr of the examination being performed in most cases. Conference room with projector facilities were available for team doctors intending to discuss the scan images with the radiologists in private.

Statistics

Numerical data, except for Resource utilisation per athlete has been rounded off to nearest one decimal. Given the extremely small values, Resource utilisation per athlete was worked up to the nearest third decimal for greater accuracy.

RESULTS

Imaging at Stratford Polyclinic within the main games village

Volume of workload handled

A total of 1711 radiological investigations and interventional procedures were performed at the Stratford Polyclinic. Please refer to **Table 1** for individual modality breakdown.

Table 1 Modality wise breakdown of all radiological investigations performed at Stratford Polyclinic

Modality	**No. (%)**
MRI	835(48.8)
Diagnostic US	347 (20.3)
Plain films	405 (23.7)
Diagnostic CT	50 (2.9)
US Guided Injections	45 (2.6)
CT Guided Injections	29 (1.7)
Total no. of investigations	**1711**

Of the 1711 investigations, 1283 (75%) investigations were performed on athletes, 347 (20.3%) on team and IOC officials and 81 (4.7%) investigations were performed on the volunteer workforce **(Table 2, Fig 1)**.

Table 2 Category and modality wise breakdown of all radiological investigations at Stratford Polyclinic

Modality wise breakdown of Radiological investigations in each category			
	Athlete scans (AS)	**Team Official scans (TOS)**	**Workforce scans(WFS)**
Modality (M)	No. (% of AS)	No. (% of TOS)	No. (% of WFS)
MRI	674 (52.5)	147 (42.4)	14 (17.3)
Diagnostic US	257 (20)	72 (20.8)	18 (22.2)
Plain film	252 (19.6)	108 (31.1)	45 (55.6)
Diagnostic CT	42 (3.3)	7 (2)	1 (1.2)
US Guided Injections	36 (2.8)	7 (2)	2 (2.5)
CT Guided Injections	22 (1.7)	6 (1.7)	1 (1.2)
Subtotal (% of T)	**1283 (75)**	**347 (20.3)**	**81 (4.7)**
Total No. of Investigations (T)	**1711**		

Radiological investigations in Athletes

1283 radiological investigations were performed on 825 athletes, of which over 35 % of the investigations were performed on track and field athletes. The next highest number of investigations was performed in Hockey (6.2%), closely followed by handball, basketball, Judo and weightlifting **(Table 3)**.

430 (52.1%) of the 825 athletes imaged were male and 613 (47.9%) were female. Given that 5892 (55.8%) of the total athlete population were male and 4675 (44.2%) female, only a marginal variation in ratio of imaged to total athletes is observed for each gender. This ratio is 0.13 for female athletes as compared to 0.11 for male. Age wise breakdown of investigations in athletes is shown in **Figure 2**.

Table 3 Sport wise distribution of radiological investigations on athletes at Stratford Polyclinic

Sport	No.of Investigations	% of Total Radiological investigations in Athletes
Athletics- Track and field	451	35.2
Hockey	79	6.2
Handball	76	5.9
Basketball	69	5.4
Judo	67	5.2
Weightlifting	62	4.8
Gymnastics artistic	54	4.2
Swimming	53	4.1
Taekwondo	48	3.7
Boxing	39	3.0
Wrestling	35	2.7
Volleyball	28	2.2
Football	27	2.1
Triathlon	22	1.7
Fencing	20	1.6
Others	153	12

Distribution of workload at various stages of the competition

Imaging services were busiest during the second week of the competitions, when the games schedule was at its busiest with the maximal number of residents within the games village **(Table 4, Figure 3)**. The volume of workload started gently decreasing during the last few of days of service. In total 81.4% of all investigations were performed during the actual competition and 18.2% pre-competition. Limited services were provided for two days following the games, during which only 7 (0.4%) investigations were performed selectively in cases where there was an element of urgency.

Table 4 Modality wise breakdown of all radiological investigations during competitions

	No. of Investigations for Athletes, Team Officials and Workforce combined during each day of competitions																
Modality	**27th July Day 1**	**28th July Day 2**	**29th July Day 3**	**30th July Day 4**	**31st July Day 5**	**1st Aug Day 6**	**2nd Aug Day 7**	**3rd Aug Day 8**	**4th Aug Day 9**	**5th Aug Day 10**	**6th Aug Day 11**	**7th Aug Day 12**	**8th Aug Day 13**	**9th Aug Day 14**	**10th Aug Day 15**	**11th Aug Day 16**	**12th Aug Day 17**
MRI	27	27	29	32	41	42	43	45	45	50	52	54	49	43	37	40	28
Diagnostic US	12	15	10	21	16	17	18	15	20	16	21	24	14	20	10	11	12
Plain film	12	11	21	24	18	18	23	16	20	18	18	20	19	29	33	22	16
Diagnostic CT	1	1	1	3	3	1	4	2	2	2	3	5	4	4	4	1	3
US Guided Intervention	0	2	2	3	1	2	2	5	3	2	1	1	2	2	2	2	1
CT Guided Intervention	3	4	1	1	2	2	3	3	0	0	0	3	0	0	0	0	0
Subtotal	**55**	**60**	**64**	**84**	**81**	**82**	**93**	**86**	**90**	**88**	**95**	**107**	**88**	**98**	**86**	**76**	**60**
Total Investigations	**1393**																

Breakdown of investigation modalities

MRI

445 of the 674 (66%) MRIs performed on athletes were on the lower extremity, majority of which were knees, 112 (16.6%) on upper extremity and 104 (15.4%) were performed on the spine **(Table 5)**. One MRCP for suspected biliary pathology, 3 MRI brains following head injuries were among the other scans performed on the athletes. Within the team officials' category, about 80 % of the MRIs performed were on Knees, spines and shoulders.

MRI was performed as a second line investigation to US in 40 athletes. MRI demonstrated pathology in 5 cases where US was normal. 3 of these were labral tears in hip and shoulder and the rest included subtle muscle tear in an athlete and tear of the anterior talo-fibular ligament within the ankle joint, which was difficult to appreciate on US due to extensive soft tissue swelling and joint effusion.

MR arthrography was hardly ever requested during the games. Acute traumatic dislocation of shoulders presented with joint effusion which provided for adequate joint distension. Besides tiny risk of infection, intra-articular injection can result in discomfort that could affect athletes' participation. Hence, this was not an investigation of choice for labral tears in hip, most of which would be treated conservatively during the competition. High resolution images from 3T MRI to an extent reduced the need for arthrographic examinations of the joints [5]. Gadolinium enhanced MRI had to be used in only 2 cases for the entire duration of the games.

Table 5 Summary of MRI procedures based on body area scanned

Body area scanned	Athletes	Team Officials	Workforce	Total (%)
Lower Limb	445	78	7	530 (63.5)
Spine	104	51	4	159 (19)
Upper Limb	112	16	3	131 (15.7)
Chest & Abdomen	10	2	0	12 (1.4)
Others	3	0	0	3 (0.4)
Total No. of Procedures	**674**	**147**	**14**	**835(100)**

Diagnostic US

347 diagnostic US examinations were performed on athletes, team officials and workforce combined, of which 284 (81.8%) were MSK and 63 (18.2%) were non-MSK/general examination **(Table 6)**. The majority of the MSK USs performed on athletes (66.9%) were for lower limb complaints, while a much smaller percentage of scans performed on upper extremities (17.1%). Sonographic evaluation of Achilles tendon, ankles for ligament injuries and foot for evaluation of plantar fascia made up for a significant proportion of scans performed. Abdominal and pelvic US in athletes' category and US for suspected Deep vein thrombosis (DVT) in the team officials' category were the most commonly performed general US investigations. Torted ovary in an athlete requiring partial oopherectomy was among the acute emergencies diagnosed on US.

Table 6 Diagnostic US procedures breakdown

Body area scanned	Athletes	Team Officials	Workforce	Total (%)
MSK US				
Lower Limb	172	32	12	216 (62.3)
Upper Limb	44	14	3	61 (17.6)
Others	7	0	0	7 (2)
No. of MSK US Procedures	**223**	**46**	**15**	**284 (81.8)**
General US				
US Abdomen	14	6	1	21 (6.1)
US Doppler Leg	1	8	2	11 (3.2)
US Pelvis	5	6	0	11 (3.2)
US Abdomen and pelvis	7	1	0	8 (2.3)
US Renal	4	2	0	6 (1.7)
US Head & Neck (Thyroid, salivary glands)	2	2	0	4 (1.2)
US Testes	1	1	0	2 (0.6)
No. of General US Procedures	**34**	**26**	**3**	**63 (18.2)**
Total No. of US Procedures (T)	**258**	**71**	**18**	**347**

Diagnostic CT

50 Diagnostic CTs were performed in total, 42 of which were performed on competing athletes **(Table 7)**. 17 of the diagnostic CTs were performed as second line investigations following MRI examinations in athletes. 13 of these were to evaluate suspected stress fractures on MRI and 12 of them were positive on CT. The other indication for performing CT following MRI was to confirm avulsion fractures suspected on MRI.

Table 7 Diagnostic CT procedures breakdown

Body area scanned	Athletes	Team Officials	Workforce	Total (%)
Lower Limb	17	0	0	17 (34)
Spine	10	1	0	11 (22)
Others	8	2	0	10 (20)
Chest & Abdomen	4	4	1	9 (18)
Upper Limb	3	0	0	3 (6)
Total No. of Procedures (T)	**42**	**7**	**1**	**50**

Plain radiography

405 plain radiographic examinations performed, of which 252 (62.2%) were performed on athletes **(Table 8)**. Plain x-rays of the foot was the most commonly requested investigation among athletes, accounting for 31(12.3%) examinations. X-rays of knees (21.3%) were performed in highest number, followed by chest x-rays (17.6%) within the team officials' category. Plain radiographs performed on workforce accounted for 11.1% of all plain x-ray examinations performed. This figure is considerably higher in comparison to other modalities (1.7% for MRI and 5.2 % for US), suggesting that plain films were more utilised for imaging workforce.

Table 8 Plain films breakdown

Body area scanned	Athletes	Team Officials	Workforce	Total (%)
Lower Limb	81	60	20	161 (39.8)
Upper Limb	105	20	21	146 (36.1)
Chest & Abdomen	38	20	3	61 (15.1)
Spine	18	8	1	27 (6.7)
Others	10	0	0	10 (2.5)
Total No. of Procedures (T)	**252**	**108**	**45**	**405**

Imaging guided intervention

Imaging guided interventional procedures were carried out following clinico-radiological discussion of the athletes' medical problem. This was in most cases preceded by a diagnostic evaluation of the affected body part. A total of 74 imaging guided interventional procedures were performed **(Tables 9, 10)**. Most of the imaging guided injections in extremities were performed under US guidance, while spinal intervention was exclusively performed under CT guidance.

Within the upper extremity, US guided intra bursal injection of the shoulder was the most commonly performed procedure, while local anaesthetic and corticosteroid injections for indications such as tendinopathy, tenosynovitis were most commonly performed procedures on the lower extremities. Platelet rich plasma, dextrose injections and hyaluronic acid injections were among the interventional procedures performed under US guidance. No direct complications following interventional procedures were reported during the games.

Table 9 CT Guided Procedures Breakdown

Body area scanned	Athletes	Team Officials	Workforce	Total (%)
CT Guided Epidural Injection	11	4	1	16 (55.2)
CT Guided Facet Joint Injection	8	1	0	9 (31.0)
CT Guided Nerve Root Block	3	1	0	4 (13.8)
Total No. of Procedures (T)	**22**	**6**	**1**	**29**

Table 10 US guided procedures breakdown

Body area	Athletes	Team Officials	Workforce	Total (%)
Lower Limb	26	4	1	31 (68.9)
Upper Limb	10	3	1	14 (31.1)
Total No. of Procedures(T)	**36**	**7**	**2**	**45**

Referral sources

Majority of the referrals for imaging in both Athletes and team officials were received from National Olympic Committee (NOC) team doctors, accounting for 62% and 49% of the referrals respectively. 17 % of imaging referrals within team officials' category originated from GPs as compared to 0.6 % in athletes, as general medical illnesses were more commonly encountered in this group. Within the workforce category, most of the imaging referrals came through casualty doctors and GPs, accounting for 82% of referrals in this group**.**

Imaging at Eton Dorney and Weymouth

Compared to Stratford polyclinic, far less imaging was handled at the other two sites, due to fewer sporting events and competing athletes. 47 US examinations were performed at Weymouth polyclinic, of which 22 (46.8 %) were performed on athletes, 20 (42.6%) on workforce and 5 (10.6%) on team officials. At Eton Dorney 18 US examinations were performed in total, of which 14 (78 %) were on workforce and a mere 4 (22 %) examinations were on actual athletes. Significantly higher percentage of scans was performed on workforce at both Weymouth and Eton Dorney sites, compared to the Stratford polyclinic.

Continent wise breakdown of radiological investigations and resource utilisation per Athlete

Resource utilisation per registered athlete at the games was highest for Africa at 0.294 as compared to an overall average of 0.169 **(Figure 4)**. Notably, about 70 % of all examinations performed on African athletes were on the lower extremities and nearly 50 % of those scanned competed in track and field events. Almost 50 % of all radiological procedures performed in this group were MRI scans. Given that only 4 athletes represented IOA and only 1 radiological investigation performed, not much can be deduced in this category.

DISCUSSION

MRI, US and interventional facilities were well utilised by the athletes throughout the games. US was used for diagnosing muscle tears and injuries to superficial tendons, ligaments and plantar fascia. MRI was used for diagnosing subtle muscle tears difficult to visualise on US for defining complete extent and morphology of high grade muscle tears. Suspected pathology to soft tissue such as meniscus, labrum, deep tendons and ligaments, spine, sacro-iliac joints and anatomical areas difficult to assess on US were also investigated with MRI. MRI was performed as a second line investigation to US in few cases, for further evaluation of pathology identified on US or when US findings were inconclusive.

Previous study reported 21.1% incidence of stress fractures in track and field athletes alone, with majority occurring within the tibia [7]. CT is useful in diagnosing bone stress fractures [8-11] and served as a second line investigation for evaluation of bone stress response seen on MRI. Diagnosing such injuries with accuracy, gave the athletes better information on true extent of risk involved in competing with the injury, thereby helping them make better

informed choices. Avulsion fractures difficult to appreciate on plain films were also diagnosed on CT.

The major indication for plain film imaging in athletes was to rule out bony injuries following acute trauma, although a significant number of chest and knee radiographs were performed, particularly in team officials' category, for general illnesses and chronic pain respectively.

Injuries to lower extremities were much more commonly imaged at the games than any other body part, accounting for nearly 66% of all MRIs and USs performed in athletes. This matches the results from previous studies on injury surveillance conducted on elite athletes at major international sporting events [2, 4, 12, 13]. Nearly 35% of imaging performed on athletes was in track and field category. Our data on sport wise breakdown of imaging in athletes **(Table 3)** matches the distribution of injuries in various sports reported at Beijing 2008 [2].

Events and schedules on each day influenced the nature of requests for radiological investigations. This is based on the fact that sport specific injuries occurred more commonly on the days such events were being held in the sporting arena. For example: elbow injuries, peaked during judo and weightlifting events, the two Olympic sports most commonly prone for elbow injuries. Similarly the bulk of the imaging requests for suspected plantar fascia, Achilles tendon pathology and muscle tears within lower limbs coincided with the period when track and field events were scheduled.

Continent wise breakdown of utilisation of radiology resources, suggest that Africa has the highest ratio of per athlete consumption of imaging resources. If similar trends are observed consistently and lack of access to adequate imaging facilities is an attributing factor, this information should be fed back to the respective NOCs for review of existing medical infrastructure and access to imaging facilities.

LIMITATIONS

While all efforts were made to ensure accuracy, manual entry of radiological investigation type on to the RIS system, makes this liable for an element of human error. The Team Officials category includes investigations performed on both team and IOC officials. It was a deliberate attempt not to classify these groups as this was interchangeably used on occasions during entry into the ATOS and RIS systems and hence classification could invite an element of error.

Access to information on imaging services offered at field of play, participating teams' medical set-ups and imaging performed outside the polyclinics was not available on the ATOS medical encounter system and hence not included.

CONCLUSION

The demand for MRI services, which accounted for nearly 50% of all Radiological examinations, justified the setting up of 2 MRI scanners within the main games village polyclinic. Despite having 2 MRI scanners and 2 US units within the main games village, the demand for these services was continuous and at times extremely busy, particularly during the games period. Both US guided extremity and CT guided spinal intervention were in demand from the athletes and having such facilities on site can contribute to quick and effective management of athletes medical problems, where indicated. Recording use of portable US imaging on field and during consultation by sports physicians as separate investigation into the main ATOS medical encounter system at future events can provide easy access to this information. Such information can contribute positively towards data analysis.

SUMMARY (WHAT ARE THE NEW FINDINGS?)

- Breakdown of imaging demographic data and volume of workload on radiology services at various stages of 2012 summer Olympics.
- Use of imaging services including diagnostic and interventional procedures by athletes, team officials and work force
- Per athlete utilisation of imaging resources based on continent

Impact on Clinical practice in Future

- The data is a guide for anticipating demand on imaging services and when used in conjunction with the existing injury and illness surveillance data, serves useful lessons towards planning imaging infrastructure tailored to the needs and demands of the events at similar international sporting events.

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Competing interests

None

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