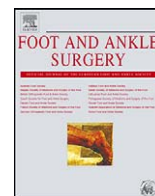


Contents lists available at [ScienceDirect](http://ScienceDirect.com)

Foot and Ankle Surgery

journal homepage: www.elsevier.com/locate/fas

A comparative study of radiation dose and screening time between mini C-arm and standard fluoroscopy in elective foot and ankle surgery

Edward J.C. Dawe MBBS, BSc(Hons), MRCS, Dip(SEM), Ernest Fawzy FRCS, MSc,
Jakub Kaczynski Mb ChB(Hons), MRCSEd, Phillip Hassman, Simon H. Palmer MBBS, FRCS(Eng),
FRCS(Tr and Orth), MSc, FFSEM*

Worthing and Southlands Hospitals, UK

ARTICLE INFO

Article history:

Received 11 August 2009
Received in revised form 2 January 2010
Accepted 5 January 2010

Keywords:

Mini C-arm
Dose area product (DAP)
Fluoroscopy

ABSTRACT

Background: Mini C-arm devices have gained popularity in extremity surgery. There is little evidence of the benefits of this technique in the clinical setting of foot and ankle surgery. We used dose area product (DAP) to compare radiation usage between mini C-arm and standard fluoroscopy.

Methods: We prospectively reviewed 127 cases requiring intra-operative screening during elective foot and ankle surgery.

Results: Mini C-arm was used in 55 patients and standard fluoroscopy in 72 patients. There was a statistically significant reduction in mean DAP using the mini C-arm, 3.46 Gy cm² vs 7.43 Gy cm² ($P = 0.0013$). There was no difference in screening time. The annual saving from using the mini C-arm could be £9391, saving the total cost of the device over 5 years.

Conclusion: The mini C-arm reduces radiation risk and costs when compared to standard fluoroscopy. We recommend its regular use in foot and ankle surgery.

© 2010 European Foot and Ankle Society. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Radiation exposure is hazardous in orthopaedic surgery however there is little awareness among surgeons and theatre staff regarding the effects of radiation and the means to minimise its harmful effects [1]. Intra-operative screening is crucial in foot and ankle surgery due to the anatomical complexity of this area. However, there could be potential challenges in the use of standard fluoroscopy for this task. These include radiographer availability, coordinating instructions from the surgeon to the radiographer, positioning of the C-arm unit and increased radiation exposure.

There may be some advantages to the regular use of a mini C-arm in foot and ankle surgery. It has been established that the mini C-arm reduces radiation dose in hand surgery [2–5]. The dose reduction could be explained by a smaller detector area, lower tube power, tighter beam collimation, and surgeon control of screening [6]. The operating surgeon has potentially better insight into the targeted views required, particularly during complex foot and ankle surgical procedures. Without the need for a radiographer, unnecessary and costly delays to theatre schedule are avoided. The

routine availability of a laser-pointing device on our mini C-arm greatly aided positioning of the foot for fluoroscopy. This should reduce the amount of exposure time wasted on inaccurate views. Laser pointing may not always be available during standard fluoroscopy. The pattern and degree of radiation scatter may differ between the foot and ankle and the hand, suggesting that the scattered dose to medical staff could be higher in foot and ankle surgery [7,8]. Several studies have compared the radiation exposure between the two devices [2,7–9]. According to our knowledge, no previous studies have compared the radiation dose used, screening time and cost implication in the real clinical setting of foot and ankle surgery.

Our null hypothesis is that there is no difference in radiation dose, exposure time and cost implication by using either technique.

The primary objective of this study is to compare the radiation dose delivered and screening times used between standard fluoroscopy and the mini C-arm during foot and ankle surgery. Our secondary objective is to estimate the cost implications of mini C-arm use.

2. Materials and methods

A total of 127 cases who required intra-operative screening during various elective foot and ankle procedures were prospectively reviewed. Mini C-arm was used in 55 cases and standard

* Corresponding author at: Worthing Hospital, Lyndhurst Road, Worthing BN11 2DH, United Kingdom. Tel.: +44 7979241026.

E-mail address: edwarddawe@doctors.org.uk (S.H. Palmer).

Table 1
Case-mix present in mini C-arm and standard fluoroscopy groups.

Surgery	Device			
	Standard Fluoroscopy		Mini C-arm	
	Frequency	Percentage	Frequency	Percentage
Forefoot procedures	21	29.6	19	34.5
Forefoot injection	16	23	17	31
EUA ankle	15	21	7	13
Hindfoot procedures	14	20	10	18
Subtalar arthrodesis	5	7	2	4
Total	71	100	55	100

fluoroscopy in 72 cases (Table 1). Both groups were comparable regarding the complexity of the procedures. Between June 2006 and September 2007, 72 patients were screened using standard fluoroscopy (Siremobil 2000, Siemens Medical Systems). The mini C-arm was introduced in September 2007. The remaining 55 patients were screened using the mini C-arm (Hologic, Insight) between September 2007 and March 2008. During each procedure screening time and radiation dose were prospectively recorded by the operator using readings from the dose area product (DAP) meters on both machines. These had been recently calibrated.

Standard fluoroscopy was conducted by one of the three on-site radiographers who were requested for screening giving radiographer 30 min notice. The mini C-arm is operated with sterile surgical drapes allowing use of a keyboard for editing images. There is a foot pedal, which is surgeon operated. This also allows accurate timing of the screening. Images taken may be exported on CD and then reviewed on the Picture Archiving and Communication System (PACS) as a permanent record of intra-operative events.

DAP was selected as a measure of radiation dose. This is a recommended method of comparing radiation usage during fluoroscopic procedures and may be used to assess dose-reduction strategies [10]. Results were analysed using a statistical analysis package (Medcalc V. 9.5.2.0).

3. Results

On comparing the radiation exposure between standard fluoroscopy and mini C-arm for all procedures we found that the mean DAP in the standard fluoroscopy group was 9.58 cGy cm² (SD 11.42) and 4.01 cGy cm² (SD 3.51) in the mini C-arm group (Fig. 1). The data was analysed using a Welch test (non-parametric two-tailed *t*-test for unpaired data).

We further compared DAP in each type of procedure between the two different devices using a Welch test (Table 2).

Screening time was compared using a similar *t*-test. The mean screening time was 13 s (SD 14.7) in the standard fluoroscopy

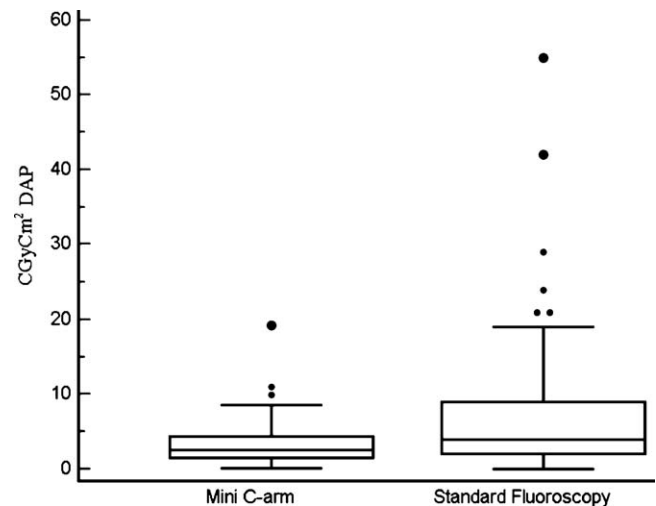


Fig. 1. A comparison of radiation dose (DAP, cGy cm²) between mini C-arm and standard fluoroscopy. Error bars represent 95% confidence intervals.

group and 14.5 s (SD 18.1) for the mini C-arm. There was no significant difference between screening times for the two devices ($P = 0.987$).

3.1. Cost-benefit analysis

All benefits and costs we have considered are expressed in financial terms and are adjusted to be correct as of April 2009. We considered the costs of standard fluoroscopy by calculating the cost of providing a radiographer to theatre as well as the cost of delays to theatre caused by radiographer in attendance.

The mean time of radiographer attendance was 22 min and the cost for this was £30/h as quoted by the trust. There was a delay to surgery as a result of radiographer in attendance in 19% of cases, with a mean delay of 4 min (range: 1–7 min). The mini C-arm cost £42,500 and three surgeons attended the IR(ME)R Course at a cost of £350 each. This allowed them to independently operate the mini C-arm. The cost of theatre time in a centre similar to our own is estimated at £15/min [11]. Our centre performs 350 extremity cases each year.

The saving associated with not using radiographers for extremity procedures is £5541 in radiographer delays and £3840 in radiographer salaries. This would equate to a total annual saving of £9391 if the mini C-arm were used for all extremity procedures.

4. Discussion

Intra-operative screening is required in many foot and ankle procedures due to the anatomical complexity of the areas. Our

Table 2
A comparison of dose area product (mGy cm²) in different foot and ankle surgeries using conventional fluoroscopy or mini C-arm.

	Device				Comparison by two-tailed <i>t</i> -test <i>P</i> -value
	Standard fluoroscopy		Mini C-arm		
	Frequency	DAP	Frequency	DAP	
Forefoot procedures	21	2.9	19	2.36	0.44
Steroid injection	16	7.56	17	3.87	0.04
Examination under anaesthesia of ankle	15	4.75	7	2.77	0.18
Hindfoot procedures	14	16.9	10	4.40	0.01
Subtalar arthrodesis	5	6.60	2	8.14	0.54
All procedures	71	5.90	55	3.32	0.0013

results suggest that the mini C-arm facilitates foot and ankle surgery whilst reducing radiation dose.

Radiation exposure is hazardous, so the ALARA principle (As Low As Reasonably Achievable) is used to govern its safe use. When this principle is applied, radiation is used in appropriate procedures and with minimum possible dose. ALARA also considers the cost implications of any reduction in radiation dose. In extremity surgery this helps to minimise the risks of the two types of radiation-induced conditions: deterministic and stochastic. Deterministic conditions occur above a threshold level of radiation exposure. The risk in foot surgery is of radiation dermatitis, which may occur above a threshold of 3–5 Gy. It would be very rare to exceed this during examination of the foot and ankle. Other deterministic effects include eye-lens opacity and permanent sterility. Stochastic conditions occur with increasing probability as a person's total lifetime radiation dose increases. These include leukaemia and cancers, which may develop following the accumulation of radiation dose over time [12]. Current international guidelines recommend limiting radiation exposure to a total yearly effective dose of 20 mSv and a yearly dose maximum of 500 mSv to the hands and feet [13]. By limiting the radiation dose during fluoroscopy we limit both the direct dose to the patient and the scattered radiation dose to the surgeon and theatre staff. A prerequisite of using the mini C-arm in our hospitals is attending a course on the safe use of ionising radiation and limb fluoroscopy.

DAP is a measure of the amount of radiation released by the X-ray source on each device. This has been shown to be proportional to both absorbed dose to the patient and to scattered radiation [10,14]. One important factor in our study was ensuring that the extremity being examined was held in contact with the image intensifier and not allowed to approach the source. This was essential in order to achieve reproducible results using DAP as our measure of exposure. This also ensured the minimum absorbed dose to the patient [8]. DAP has provided us with a useful comparison between low-dose examinations and highlights the superiority of the mini C-arm in our study.

There is a statistically significant reduction in mean DAP between standard fluoroscopy 9.58 cGy cm² (SD 11.42) and mini C-arm 4.01 cGy cm² (SD 3.51) ($P = 0.0013$). Whilst it is possible to make exact measurements of absorbed dose and scattered radiation by using artificial set-ups, we argue that measuring DAP in the clinical setting is a more useful method of comparing dose-reduction strategies [15].

The dose reduction when using the mini C-arm may be a result of several factors. Firstly the mini C-arm can easily be used inverted, placing the extremity on the detector. Tremains et al. showed that inversion of a C-arm significantly reduced radiation exposure to the patient and surgeon ($P < 0.0001$) [4]. They also allayed concerns that inversion of the C-arm would increase the radiation dose to the thyroid of the operating surgeon, as this was only 67% of the dose from a C-arm in the standard position. The smaller radius of the mini C-arm allows a lower beam power to be used and greater collimation of the beam. The detector size in the mini C-arm is less than half the diameter of that of the standard device. As the incident rays are more parallel to the detector in the mini C-arm we would expect a lower proportion of the radiation to be scattered around the theatre. The surgeon-operated foot pedal on the mini C-arm allows the patient may be more easily positioned for correct views and is likely to reduce the radiation dose to the patient [15]. The presence of a laser-pointing device on the mini C-arm has not been shown to effectively reduce dose in extremity surgery but we found this a helpful aide to screening [16,17]. Intra-operative image editing also allows post-exposure adjustment of the image so the surgeon may adjust the brightness or

contrast of an incorrectly exposed image instead of taking another.

Whilst both machines adjust the voltage and current used by the X-ray tube automatically, the surgeon or radiographer retains control of the total screening time. Interestingly we found no statistically significant difference between screening time for mini C-arm and standard fluoroscopy ($P = 0.987$). This contradicts the results of White et al. who found screening time was increased when using the mini C-arm [5]. We would expect a reduction in screening time using the mini C-arm given the advantages of laser pointing, automatic beam power adjustment and surgeon operation of the unit. However, there is a learning curve to using the mini C-arm that could initially contribute to a longer screening time. We feel that both average screening times and DAP could be reduced with greater experience of using the mini C-arm.

Our cost calculation is generated by adding the cost of providing a radiographer to theatre to the cost of theatre delays. This saving would be enough to pay for the C-arm device and surgeon training over 5 years in a centre similar to our own performing around 350 extremity procedures each year. The saving might be still greater if the mini C-arm were used in other areas such as in the orthopaedic outpatient clinic where appropriate [18].

5. Conclusion

The use of a mini C-arm during elective foot and ankle surgery gave a significant reduction in radiation use when compared to standard fluoroscopy.

Interestingly, we find no statistically significant difference between the screening times for the two groups.

The introduction of a mini C-arm reduces the cost and we recommend its routine use in foot and ankle surgery.

Competing interests

The authors have no competing interests to declare regarding this paper.

References

- [1] Finestone A, Schlesinger T, Amir H, Richter E, Milgrom C. Do physicians correctly estimate radiation risks from medical imaging? *Arch Environ Health* 2003;58(January (1)):59–61.
- [2] Athwal G, Bueno R, Wolfe S. Radiation exposure in hand surgery: mini Versus standard C-arm. *J Hand Surg* 2005;30(6):1310–6.
- [3] Badman BL, Rill L, Butkovich B, Arreola M, Griend RA. Radiation exposure with use of the mini-C-arm for routine orthopaedic imaging procedures. *J Bone Joint Surg Am* 2005;87(January (1)):13–7.
- [4] Tremains MR, Georgiadis GM, Dennis MJ. Radiation exposure with use of the inverted-C-arm technique in upper-extremity surgery. *J Bone Joint Surg Am* 2001;83(May):674–8.
- [5] Singer G. Occupational radiation exposure to the surgeon. *J Am Acad Orthop Surg* 2005;13(January–February (1)):69–76.
- [6] White SP. Effect of introduction of mini C-arm image intensifier in orthopaedic theatre. *Ann R Coll Surg Engl* 2007;89(April ()):268–71.
- [7] Shoaib A, Rethnam U, Bansal R, De A, Makwana N. A comparison of radiation exposure with the conventional versus mini C arm in orthopedic extremity surgery. *Foot Ankle Int* 2008;29(January (1)):58–61.
- [8] Athwal GS, Bueno Jr RA, Wolfe SW. Radiation exposure in hand surgery: mini versus standard C-arm. *J Hand Surg Am* 2005;30(November (6)):1310–6.
- [9] Giordano BD, Baumhauer JF, Morgan TL, Rectine 2nd GR. Patient and surgeon radiation exposure: comparison of standard and mini-C-arm fluoroscopy. *J Bone Joint Surg Am* 2009;91(February (2)):297–304.
- [10] Crawley MT, Rogers AT. Dose-area product measurements in a range of common orthopaedic procedures and their possible use in establishing local diagnostic reference levels. *Br J Radiol* 2000;73(July (871)):740–4.
- [11] NHS Institute for Innovation and Improvement. <http://www.institute.nhs.uk> [accessed 10.05.09].
- [12] Singer G. Radiation exposure to the hands from mini C-arm fluoroscopy. *J Hand Surg Am* 2005;30(July (4)):795–7.
- [13] The 2007 Recommendations of the International Commission on Radiological Protection. *Ann ICRP* 2007;37(2–4):1–332 [ICRP Publication 103].

- [14] Williams JR. The interdependence of staff and patient doses in interventional radiology. *Br J Radiol* 1997;70(May (833)):498–503.
- [15] Nordeen MHH, Shergill N, Twyman RS, Cobb JP, Briggs T. Hazards of ionising radiation to trauma surgeons: reducing the risk. *Injury* 1993;24:562–4.
- [16] Harris I, Walker PM, Trieu L. Radiation exposure using laser aiming guide in orthopaedic procedures. *Aust NZ J Surg* 2002;72(May (5)):349–51.
- [17] Conn KS, Hallett JP. A simple laser guide to reduce the screening time during the insertion of dynamic hip screws. *Injury* 1998;29(September (7)):539–41.
- [18] Hasham S, Burke FD, Evans SJ, Arundell MK, Quinton DN. An audit of the safe use of the mini C-arm image intensifier in the out-patient setting. An audit of the safe use of the mini C-arm image intensifier in the out-patient setting. *J Hand Surg Eur* 2007;32(October (5)):563–8 [Epub 2007 May 31].