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Mini c arm fluoroscopy: minimising radiation exposure for surgeons treating hand trauma patients

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Abstract

Aim
The adoption of Mini C-arm fluoroscopy in hand surgery represents a significant advancement, particularly for managing traumatic hand fractures. Traditional C-arms pose challenges due to limited manoeuvrability, often resulting in mispositioning and increased radiation exposure. Global acceptance of Mini C-arms underscores their versatility and cost-effectiveness across medical settings. However, the absence of established Diagnostic Reference Levels (DRLs) for Mini C-arm fluoroscopy presents safety challenges. This study aimed to assess the safety and efficacy of Mini C-arm fluoroscopy in hand trauma procedures.

Methods
Fifteen patients requiring surgical intervention for upper limb injuries were included. Radiation exposure was measured using dosimeters and Dose Area Product (DAP), while image quality was evaluated against national standards using the Xogragh Orthoscan TAU2020 Mini C-Arm.

Results
The average DAP was 0.373cGy.cm2, with patient doses averaging 0.007cGy. Surgeon exposure was minimal, with whole-body doses of 0.076uSv and eye doses of 0.187uSv per procedure. Compared to standard C-arms, Mini C-arms demonstrated significantly lower radiation exposure with preserved image quality, supporting safety and efficacy.

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Discussion
This study advocates for the routine use of Mini C-arm fluoroscopy in hand trauma surgery, highlighting safety and imaging benefits. Findings contribute to evidence-based guidelines, promoting safer surgical environments and enhancing patient care. Continued research and regulatory efforts are needed to establish DRLs for Mini C-arm fluoroscopy, ensuring consistent safety standards.

Introduction

The adoption of intra-operative fluoroscopy marks a significant shift in practice[1]. Traditional management of traumatic hand fractures has relied on the use of a radiographer-operated standard C-Arm fluoroscopy machine to achieve intra-operative indirect visualisation of the fracture site and its fixation. Some pitfalls associated with its routine use include its large size and poor manoeuvrability lending to frequent mispositioning for fluoroscopic screening - conventional management of traumatic hand fractures involve utilising a radiographer-operated standard C-Arm fluoroscopy machine for achieving intra-operative indirect visualisation of the fracture site and its fixation. Intra-operative fluoroscopy, a common occupational hazard in surgery, has significantly influenced the evolution of procedural techniques, inevitably resulting in larger doses of radiation exposure for both the patient and the surgeon[2].

The adoption of Mini C-Arm fluoroscopy machines as a global standard in various medical settings, including operating theatres, emergency departments, and outpatient clinics, underscores their widespread acceptance. Statistics reveal that Mini C-Arm machines have become the global standard of care, supported by numerous studies demonstrating their efficacy and safety across diverse healthcare scenarios - this international embrace of Mini C-Arm usage underscores their versatility and cost-effectiveness, leading to a shift in the global standard for intra-operative imaging procedures[3,4,5]. Initial cadaver and phantom studies demonstrated that the cumulative radiation hazard associated with using the Mini C-Arm machine was low and safe for routine use in upper limb procedures[6,7,8]. The total radiation also measured favourably when compared with the standard, large C-Arm machines in both cadaver and real-time surgical studies[9,10].

Considerable changes have taken place in Ireland in recent years within the regulatory landscape for safe radiation protection. In 2019, the European Basic Safety Standard (BSS) Directive 2013/59/EURATOM was transposed into Irish law with enactment of Statutory Instrument (SI) 256 and 30, as the Radiological Protection Act[11]. Among many new initiatives, a new emphasis has been placed on improved governance of radiation protection, education and training programmes, updated best practice guidelines and continued surveillance of current practices[12]. Responsibility for regulation has been delegated to the Health Information and Quality Authority (HIQA), who have been given inspection and enforcement powers[13].

Standard C-Arm machines have established Diagnostic Reference Levels (DRLs) for safe cumulative radiation exposure, aiding surgeons in maintaining safety standards. However, Mini C-Arm fluoroscopy lacks DRLs due to recent implementation and diverse manufacturers. Instituting specific DRLs for Mini C-Arms is crucial to ensure uniform safety standards and enable surgeons to understand radiation doses accurately. This addresses a critical gap in current practice and enhances safety protocols in plastic surgery, particularly regarding hand trauma procedures[14]. By quantifying radiation exposures, this study contributes to evidence-based guidelines, promoting patient safety and surgeon optimisation. Emphasising the reduction of occupational hazards aligns with broader efforts to improve doctor safety and enhance patient care, influencing guidelines and fostering continuous improvement in plastic surgery practice.

Methods

This study was a prospective case series performed by the Plastics and Reconstructive Surgery Department in a university teaching hospital, St. Vincent's Hospital, Dublin. This study was carried out over a three-month period, commencing in August 2021. Trauma patients who had sustained hand fractures distal to the carpal bones, that required operative intervention were assessed for inclusion in this study. Due to the study's specific operational constraints and scheduling limitations, certain patients had to be excluded from participation. Exclusion criteria are summarised in Table 1. Patients were identified from the Plastics Surgery Trauma Assessment Clinic each morning and consented for inclusion in the study.

Exclusion Criteria
Patients under 18 years of Age
Non-operative management; including splinting
Severe co-morbid patients unsuitable for GA
Contra-Indication for radiation Exposure
Fracture Fixation under direct vision w/o need for fluoroscopy

Table 1: Exclusion Criteria for Patients in this Study

This study utilised the Xogragh Orthoscan TAU2020 Mini C-Arm (Xograph healthcare, Gloucestershire, GL10 2LU, UK) exclusively. A single surgeon conducted all procedures in the main operating theatre using this Mini C-Arm. A radiographer, trained specifically in its operation, assisted throughout the trial due to its recent implementation in the hospital. The surgeon adhered to safety protocols, including wearing personal protective equipment such as a Xenolight Lead apron, lead thyroid shields, and lead glasses.

Radiation exposure was assessed using dosimeters and the Dose Area Product (DAP) of the Mini C-Arm, measured in grays per square centimetre (cGy/cm2) (14). The surgeon wore electronic personal dosimeters (EPD) and real-time badge dosimeters (RaySafe i2, Philips; Eindhoven, Netherlands) above and below the lead apron, measuring whole-body radiation in micro-Sieverts (uSv). Ring and eye dosimeters were also worn to monitor hand and eye exposure. Data from each case were securely stored in a password-protected database.

The physical image quality was evaluated using Leeds test object phantoms, imaged by the Xograph Mini C-Arm and three other C-Arm machines available in the hospital: Siemens Varic 1, Siemens Varic 2, and Ziehm RFD. Resolution and low contrast sensitivity were compared against national X-Ray image quality standards[15].

Results

15 patients met the inclusion criteria for this study. All patients had sustained an upper limb injury that required surgical intervention. The average age of the participants was 46 (23 – 58). There were 11 male and 4 female patients included.

Dose Area Product (DAP)

The average DAP delivered to these patients by the Mini C-Arm was 0.373cGy.cm^2 (0.060 – 1.4 cGy.cm^2). The average radiation dose that patients were exposed to was 0.007cGy (0.0002 – 0.005cGy). The average fluoroscopy screening time in seconds that each patient was exposed to was 16.8 seconds (1 – 42s). A summary of these findings is shown in [Table 2].

In comparison, the diagnostic reference levels , in this hospital, for radiation exposure delivered by the standard C-Arm showed that the average DAP delivered to patients for hand procedures was 4cGy.cm^2.

Case Number	DAP	Dose	Screening Time (s)	Procedure

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1	0.0377	0.002	4	ORIF of 5th MC
2	0.174	0.033	11	K Wire insertion
3	0.3629	0.021	42	Cannulation of 1st MC
4	0.3047	0.022	26	ORIF of 5th MC
5	0.4919	0.017	23	ORIF of 5th MC
6	1.21	0.0072	32	ORIF of 3rd MC
7	0.1135	0.0006	5	ORIF of 3rd MC
8	0.2814	0.001	12	ORIF of 3rd MC
9	1.414	0.004	22	ORIF of 1st MC
10	0.1854	0.0017	18	K Wire insertion
11	0.1813	0.0021	19	K Wire insertion
12	0.0626	0.0005	8	ORIF of 1st MC
13	0.3699	0.003	16	ORIF of 1st MC
14	0.0603	0.0002	1	ORIF of 3rd MC
15	0.3489	0.002	14	ORIF of 3rd MC
Average	0.3732	0.00782	16.8667	

Table 2: Presents Radiation Exposure to the Patient from the Mini C-Arm machine. DAP = Dose Area Product. cGy.cm^2 = Grays per centimetre squared. cGy = Grays representing the dose of radiation. S = seconds.
ORIF = Open reduction internal fixation
MC = Metacarpal

Surgeon Exposure

Whole-body dosimeter readings were worn both over and under the lead apron for all 15 cases. The minimum sensitivity for these dosimeters is 0.01uSv. The whole-body surgeon exposure calculated by the dosimeter worn over the lead apron was 0.16uSv per procedure. The whole-body exposure calculated by the dosimeter under the lead apron was 0.03uSv per procedure. The cumulative dose that the surgeon received after performing all 15 cases was 2.72uSv over the lead apron and 0.51uSv under the lead apron. The surgeon operated in a seated position for the duration of the cases with an average distance of 30cm from the centre of the radiation field. These results are summarised in Table 3.

Exposure to Eyes

Dosimeters were worn both over and under the lead glasses. Readings from these dosimeters is available for all 15 patients. The average exposure to the surgeons' eyes using the mini C-arm was calculated to be 0.187uSv/ procedure over the lead glasses. The average exposure to the surgeon calculated by the dosimeter worn under the lead glasses was 0.075uSv/ procedure. These results are summarised in table 3.

Case No.	Dosimeter Reading Outside Lead Apron (uSv)	Dosimeter Reading Under Lead Apron (uSv)	Dosimeter Reading over lead Glasses (uSv)	Dosimeter Reading under lead Glasses (uSv)
1	0	0	0	0
2	1	0.2	0.4	0.1
3	3	0.6	1.6	0.6
4	0	0	0	0
5	0	0	0	0
6	0	0	0.1	0
7	0	0	0	0
8	0	0	0	0.1
9	0.2	0.04	0.1	0.1
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0.3	0.1	0.2	0.2
15	1	0.2	0.4	0.1
Average	***0.367***	**0.076**	**0.187**	**0.075**

Table 3: Presents whole-body and eye measured radiation doses emitted to the surgeon during fluoroscopy. uSv = MicroSeiverts.

Exposure to Hands

Readings from the ring dosimeter worn on the surgeon's hand during the operations was only available for 7 cases. This was due to the ring dosimeter becoming misplaced. The total exposure received by the surgeon to the hand from these 7 cases was 1.47uSv. The average exposure sustained to the hand of the surgeon was 0.21uSv/ procedure and therefore the estimated total exposure to the surgeon's hand for all 15 cases was calculated as 3.57uSv. These readings are summarised in table 4.

Case No.	Ring Dosimeter Readings (uSv)
1	0.4
2	0
3	0.2

4	0
5	0.3
6	0
7	0.57
Average	***0.21***

Table 4: Presents Hand radiation doses emitted to the surgeon during fluoroscopy. uSv = MicroSeiverts.

Image quality

The resolution of X-Ray images was assessed using Leeds test object phantoms. The resolutions were assessed for the Mini C-Arm and three different standard C-Arm machines that were available (Siemens Varic1, Siemens Varic2, Ziehm Ortho C-Arm). The image resolution was assessed in full field view and 2X magnification (Mag2X). The resolution for the Mini C-Arm was 2lp/mm in full field view and 2.5lp/mm in Mag2X. The resolution for the Siemens Varic1 C-arm in full field view was 2lp/mm and 2.5lp/mm in Mag2X. The resolution for the Siemens Varic2 C-arm in full field view was 2.24lp/mm and 2.8lp/mm in Mag2X. The resolution for the Ziehm Ortho C-arm in full field view was 2.5lp/mm and 2.8lp/mm in Mag2X. These results are summarised in Table 5.

Test	Expected	Siemens Varic1 C-Arm	Siemens Varic2 C-Arm	Ziehm Ortho C-Arm	Xograph TAU2020 Mini C-Arm
Low Contrast sensitivity (noise)	**< 4%**	**0.84%**	**1.5%**	**1.93%**	**3.22%**
Limiting Resolution Full Field Mag 1	**≥ 1.6 lp/mm ≥ 2.0 lp/mm**	**2 2.5**	**2.24 2.8**	**2.5 2.8**	**2 2.5**

Table 5: Image Quality Assessment using Test Objects. Lp/mm = line pairs per millimetre (a measurement of resolution)

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Discussion

In investigating radiation exposure during flat panel mini C-Arm fluoroscopy for hand fractures, this study reveals consistently lower levels for both patients and surgeons – compared to the standard C-Arm, establishing the Mini C-Arm as a safe alternative with preserved image quality. The average patient dose of 0.007cGy.cm2, surgeon's whole-body dose of 0.076uSv, and eye dose of 0.075uSv highlight the machine's safety. Comparable findings in previous studies and adherence to Irish radiation standards further support the Mini C-Arm's safety. The study's shift in practice towards Mini C-Arm usage showcases its efficiency and potential applications.

Prior research by Van Rappard et al echoes the findings of this study, showcasing consistently low radiation exposure levels. Their investigation reveals an average whole-body radiation exposure of 0.29uSv to the surgeon and 0.12uSv at the thyroid level during real-time surgical cases involving flat panel Mini C-Arm fluoroscopy [(10).] Significantly, their conclusion emphasises the Mini C-Arm's superiority, attributing it to the flat panel intensifier that enhances image quality and the machine's compact design, which improves ergonomics. Over the extensive 5-month study duration, the surgeon using the mini C-Arm reached a mere 3% of their annual radiation dose, supporting its exceptional safety and efficacy.

This study examined real-time fluoroscopy and radiation exposure in hand trauma cases, revealing consistently low levels of exposure. These minimal radiation levels ensure safety for both surgeon and patient, suggesting feasibility for numerous cases yearly without compromising safety standards. Initial phantom studies confirmed the Mini C-Arm's low radiation exposure for patients and surgeons. Giordano et al's study showed diverse radiation levels depending on proximity to the machine's intensifier[16]. Recent legislative changes in Ireland, implementing the European Basic Safety Standard (BSS) Directive, categorise hand surgeons under general public radiation safety recommendations[11]. HIQA's regulatory role ensures protection for frontline staff, highlighting the Mini C-Arm's importance[12].

The Mini C-Arm adoption transformed practice within this unit, reducing operative screening time and mispositioned images. The heightened manoeuvrability, coupled with a streamlined single-machine setup, significantly cut down operative screening time, thereby minimising patient exposure to anaesthesia. It's important to note the absence of comparative data in this article to substantiate these claims While acknowledging the study's limitations, including its nature as a single surgeon case series involving only 15 patients without comparative data, the findings suggest that the Mini C-Arm serves as a potentially safe alternative for patients and surgeons. This suggests potential for increased surgical capacity without radiation-related concerns. However, it's important to temper our conclusions to align with the data presented.

There were some limitations to this study. Like many studies in this area, the dosimeters have a minimum level of radiation needed for detection and therefore many do not give any value for the dosage. This study assesses multiple body areas in a single surgeon and shows different levels associated with the use of personal protective equipment. However, given that this study utilised a single surgeon, the difference in techniques used for the machines was not evaluated. Surgeons have a unique relationship with fluoroscopy given that they hold the patient's limb in close proximity to the radiation source to attain adequate images. Therefore, exposure doses at the surgeon's hand would be indicative of the highest level of radiation exposure sustained. The ring dosimeter was misplaced during the study and therefore the data for the hand exposure was incomplete for a certain number of the patients in this study.

This study establishes the Mini C-Arm as a safe and low-exposure alternative for both patients and surgeons. The findings affirm that surgeons can operate efficiently with enhanced safety, achieving better outcomes for hand trauma patients. The low radiation doses recorded not only permit surgeons to perform more surgeries without apprehension of reaching radiation limits but also contribute significantly to the broader objective of minimising radiation exposure in orthopedic procedures. This is crucial for ensuring the long-term safety of both patients and surgeons who frequently encounter radiation during these procedures. Importantly, the study demonstrates that the use of Mini C-Arm does not compromise image quality, showcasing comparable resolution levels to standard machines. Institutions bear the responsibility of ensuring the highest levels of safety for both their employees and patients. The adoption of Mini C-arms can serve as a crucial measure in fulfilling this responsibility by minimising radiation exposure risks for surgeons while enhancing patient safety during procedures. Based on these compelling results, the authors strongly advocate for the routine use of the Mini C-Arm in hand trauma operations involving fluoroscopy, highlighting its dual benefits of enhanced safety, and maintained imaging quality.

Declarations of Conflicts of Interest:
None declared.

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