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Original Article

Challenges of Using C-Arm Fluoroscopy Systems: A Mixed Method Study Investigating Orthopedic Surgeons' Experience

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Abstract

Background: Intraoperative fluoroscopy systems are widely used nowadays, where their use allows a shorter duration of procedure time and better anatomical localization. The current study aims to investigate the most common challenges of C-arm fluoroscopy systems application.

Methods: This mixed-method study was carried out in February and March 2022. After the literature review, a qualitative study was designed using semi-structured interviews to find important themes and subthemes required to design a web survey. The web survey was completed by the Persian Orthopedic Trauma Association (POTA) event's international presenters.

Results: Nine orthopedic surgeons participated in interviews and 27 participants filled out the questionnaires. Five main themes including Physical Aspect, Mechanical Aspect, Software Options, Image Quality, and Radiation Exposure were extracted. Generally, over 80% of the web survey participants agreed that the size and shape of the base of C-arm fluoroscopy systems, C-arm diameter (space between tube and detector), and maneuvering and positioning of the C-arm fluoroscopy systems can interfere with surgical procedures. 100% of the participants agreed that providing two different views (*e.g.*, AP and lateral) from the surgical site with one shot can be beneficial. The effectiveness of real-time visualization of radiation exposure on exposure rate was acknowledged by more than 92% of the participants.

Conclusion: Although the C-arm fluoroscopy systems are widely used in surgical procedures, there are considerable issues regarding the application of this imaging modality in the operation room, and medical equipment companies should pay more attention to these issues to facilitate the use of these systems.

Keywords: C-arm fluoroscopy, Humans, Radiation exposure, Orthopedic surgery

Introduction

The trend toward minimally invasive procedures has led to increased use of intraoperative fluoroscopy systems (1,2). In the 1980s, mobile C-arm fluoroscopy systems became a widely accepted tool as an intraoperative aid (3). Today mobile C-arm fluoroscopy systems are well-established and commonly used pieces of equipment by surgeons in the operating room and play an important role in practical application in a wide variety of fields such as orthopedics, vascular, neurological, and cardiac procedures (4,5). Facilitation of the operation process, reduction of soft tissue trauma, reduction of the operation time, documentation of intraoperative images, and enhanced patient outcomes are the advantages of using this imaging modality (6-10).

Despite these advantages and wide range of applications, working with C-arm fluoroscopy systems in the operating rooms has been quite challenging for surgeons and does not seem to meet all the surgeon's expectations yet and since this equipment is not located in the main radiological facilities, less attention has been paid to it (11,12).

To the best of our knowledge, no study has evaluated the challenges of C-arm fluoroscopy systems application in operation rooms considering all aspects of the system including physical, software, radiation, *etc.*

The current study aims to investigate defects in the design of this imaging modality and the most common troubles and issues that surgeons deal with during working with C-arm fluoroscopy systems. The results of this mixed-method study will help medical equipment companies to design more user-friendly C-arm fluoroscopy systems.

The following article is in accordance with the COREQ reporting checklist.

Materials and Methods

The study consisted of three phases. First, a review of the literature was performed to identify previous publications related to the challenges of working with the C-arm fluoroscopy systems. A highly sensitive

Table 1. Main themes and sub-themes extracted from interviews and related quotes of the participants

Themes and Subthemes	Quotes
1. Physical Size Shape C-arm diameter Wire and cables	"Wires and cables of the machine are not well protected and susceptible to be damaged while being displaced." "The small diameter of C-arm is troublesome while capturing images from large anatomical sites of body (*e.g.*, sacroiliac fractures)."
2. Mechanical Movement of C-arm base Movement and positioning of C-arm Motorized movements Safety brakes C-arm locks	"Fracture tables are incompatible with the height of C-arm fluoroscopy system base due to being manufactured by separate companies." "Providing two different views (*e.g.*, AP and lateral) with one shot can save our time."
3. Image quality Spatial resolution Contrast Artifact Noise	"The image contrasts are not desirable and deteriorates in the second shot."
4. Software 3-D imaging Capacity of image storage Navigation systems Printing	"The ability to print selected images simultaneously in OR can be legally beneficial." "Without 3D technology many cases require postoperative adjustment." "Target pointer can facilitate pinning process." "Sometimes I lose view without saving the images."
5. Radiation exposure Wearing lead protection Radiation exposure data	"Wearing heavy lead protection is exhausting and intolerable."

search in the PUBMED database was performed. Search headings were " C-arm", "fluoroscopy system", "C-arm fluoroscopy qualitative study", "intraoperative imaging", "intraoperative C-arm fluoroscopy", and "C-arm challenges". Subsequently, the distinct aspects of C-arm systems were identified. Secondly, semi-structured interviews were performed to design a web survey. Several orthopedic surgeons were recruited using a combination of purposive and snowball sampling. Recruitment ceased when saturation of themes was attained. Semi-structured interviews were done based on a predefined interview guide to collect our primary data. The participants received the interview guide by e-mail a week before the interview. Written informed consent was obtained from all the interviewees before the interview. All the participants were informed that they can withdraw at any time point or choose not to answer any of the questions. The interviews were conducted face to face by a female researcher who was experienced in qualitative research (Nastaran Maghbouli, MD-MPH); each lasted about 30 minutes. The main questions asked were about their personal experiences and the troubles that surgeons deal with during working with C-arm fluoroscopy systems. All the interviews were audio recorded, transcribed, coded, and analyzed after each session by the researchers. Important and recurrent themes and subthemes were identified and coded so that summarization of similar codes was applicable. The transcripts were reviewed by all the authors to reduce any bias. At this point, the interviewees were requested to review the findings of the mentioned qualitative analysis.

Finally, a web-based questionnaire (Google Form) was designed according to the semi-structured interviews. The questionnaire consisted of five main themes (Table 1) and took an average of 15 minutes to complete. In March 2022, a message was sent to the Persian Orthopedic Trauma Association (POTA) event presenters' group on WhatsApp application. POTA event was an international webinar and its presenters were orthopedic surgeons, gathered together from

Table 2. Likert questions and the level of agreements

	Strongly agree	Agree	Undecided	Disagree	Strongly disagree
In my opinion, size and shape of base of C-arm fluoroscopy systems can interfere with surgical procedure	33.34%	55.5%	3.7%	7.4%	0
In my opinion, C-arm diameter (space between tube and detector) can interfere with surgical procedure	29.63%	51.84%	7.41%	7.4%	3.7%
In my opinion, wire and cables of C-arm fluoroscopy systems can interfere with surgical procedure	18.52%	40.72%	14.81%	22.22%	3.7%
In my opinion, movement of C-arm base can be difficult during surgical procedure	29.63%	55.5%	3.7%	7.41%	3.7%
In my opinion, movement and positioning of C-arm can be difficult during surgical procedure	29.63%	55.5%	11.11%	3.7%	0%
In my opinion, providing two different views (*e.g.*, AP and lateral) with one shot can be beneficial	70.35%	29.64%	0%	0%	0%
In my opinion, 3-D imaging can be beneficial during surgical procedures	48.15%	33.34%	18.52%	0%	0%
In my opinion, low capacity of image storage can be problematic	18.52%	55.55%	7.4%	0%	0%
In my opinion, the ability to print selected images at the same time can be beneficial	29.63%	48.14%	11.11%	11.11%	0%
In my opinion, wearing lead protection during working with C-arm fluoroscopy systems can interfere with surgical procedures	55.55%	25.93%	7.4%	11.12%	0%
In my opinion, visualization of real time radiation exposure data can decrease radiation exposure	51.85%	40.74%	3.7%	3.7%	0%

9 different countries. The message contained an introduction to the survey and a link to the web-based survey tool. Twenty seven out of 60 presenters of the POTA event filled out the questionnaire.

The study was in accordance with the Ethical Committee of Tehran University of Medical Sciences (Approval ID: IR.TUMS.DDRI.REC.1401.032).

Results

Nine orthopedic surgeons participated in the interviews. The themes and subthemes of the interview results and some of the related quotes of the interviewees are demonstrated in table 1.

Forty five percent of the POTA presenters (27 presenters) filled the designed questionnaire. Likert questions and the level of agreement are shown in table 2.

Discussion

The current study aimed to detect and clarify the most common troubles and issues that surgeons deal with during working with C-arm fluoroscopy systems to reduce adverse outcomes by decreasing OR time, improving teamwork, and further minimizing unnecessary radiation exposure.

Physical aspect

The main explored physical challenge associated with working with C-arm fluoroscopy systems was the size and shape of the device, which can make it difficult to position the C-arm in the optimal location leading to increased wasted time during surgery. One of our interviewees mentioned that a reduction in the size of C-arm fluoroscopy can ease the surgical procedure. Due to its smaller size and overall practicality, the mini C-arm could be a suitable choice to solve the problem of difficult movement (13,14). Gieroba TJ *et al* demonstrated that since the surgeon can easily operate mini C-arm without a radiographer, it reduces surgery delays and saves about 4 minutes of operation time per surgery (15). Although the mini C-arm fluoroscopy device has been promoted mainly due to its easy mobility, decreased cost, and its usage in taking images from smaller parts of the body in the operation room or emergency department (16,17), recently van Rappard JRM *et al* indicated that the image quality is significantly better for the mini C-arm in comparison with the standard C-arm in hand surgeries (18).

Mechanical aspect

About 85% of our study subjects had difficulty positioning C-arm fluoroscopy systems. The studies mentioned below have provided solution for this problem.

Stroh *et al* proposed a standardized terminology for C-arm movements to improve communication between orthopedic surgeons and radiologic technologists in operating room (19). Kausch *et al* designed an automated repositioning procedure for the C-arm to reduce wasted time and radiation exposure due to repeated fluoroscopy during manual positioning of the device. They tested their procedure on a human cadaver simulating the clinical case, which showed improvements in positioning accuracy, therefore it could be capable of clinical use (20). Haliburton *et al* proposed a tracking system that was armed with a single downward-facing camera mounted to the base of a C-arm. This tracking system was able to track motion using relative motion tracking and absolute position recovery algorithms. The system achieved clinically relevant accuracies and had the potential to reduce OR time and harmful radiation exposure to patients and surgical staff (21).

De Silva *et al* reported that a virtual fluoroscopy system, utilizing three key advances, robust 3D2D registration to a preoperative CT, real-time forward projection on GPU, and a motorized mobile C-arm with encoder feedback on C-arm orientation, had the potential of reducing time and dose spent in C-arm using (22).

Software aspect

The majority of our study participants (approximately 80%) agreed that 3D imaging can be beneficial during surgical procedures. Banat *et al* conducted a study to evaluate the efficacy of intra-operative 3D imaging with a C-arm fluoroscopy system in comparison to post-operative CT imaging in the spine screw implant surgery for 94 patients. They found out that 97.5% of the screws were implanted accurately with intra-operative 3D imaging through C-arm devices, therefore this could be an effective approach (23). Takao *et al* investigated the accuracy of a C-arm device's 3D fluoroscopic navigation system through

a geometric phantom made of a cube and stimulation of the hip joint surgery using a set of dray pelvic and femoral bones. Their results suggested that the accuracy of the 3D navigation system was appropriate for clinical use (24). C-arm fluoroscopy system with a feature of providing two different views (AP and lateral) from the surgical site simultaneously, was one of the most important and prevalent demands of our study participants regarding software theme, which have not been addressed before to our knowledge.

Radiation exposure aspect

Approximately 90% of our study participants agreed that real-time radiation exposure visualization would help them reduce the OR staff and the patients' radiation exposure. Seibert also listed the possible efforts to reduce radiation amount; for instance, encouraging strict collimation, pulsed fluoroscopy, last frame hold, using devices such as DAP meters for all fluoroscopy units, establishing guidelines and procedures for determining patient dose, and ensuring the periodic maintenance and calibration of fluoroscopy equipment (25).

Limitations

Although the study subject has only been surveyed in one region, by reviewing available studies, it can be concluded that globally, surgeons and OR staff have similar difficulties while working with C-arm fluoroscopy systems, and more investigations and improvements are needed to meet their expectations.
Recruiting exclusively orthopedic surgeons was a limitation of the current study. The small number of samples was another limitation of this study. Furthermore, the results cannot be generalized to other personnel categories as the study was exclusively conducted among surgeons. The result of the present study is not capable of generalized interpretation for all countries but sheds light for the first time on some challenging aspects of C- arm application.

Conclusion

Although the C-arm fluoroscopy systems are widely used in practice and have facilitated surgical procedures in the past few years, there are considerable issues in the application of this imaging modality for orthopedic surgeons regarding size and shape, positioning, and software options, and yet this imaging modality does not seem to meet all their needs. We attempted to bring to the fore some of the most prevalent issues and difficulties to help medical equipment companies to manufacture more efficient and user-friendly devices. Reducing the size of the body of these systems, widening the space between the detector and the tube, improving the software options to provide 3-D images and navigation systems, enhancement of the image quality and storage capacity, adding device features such as real-time visualization of radiation exposure data, capturing two different views of the surgical site with one shot, printing the desired shots can optimize the use of this device. Further studies with a wholesome point of view to other surgical fields may be helpful to identify the issues and challenges of working with this imaging modality.

Reporting Checklist

The present study is in accordance with the COREQ eporting checklist. The authors have completed the COREQ reporting checklist.

Ethical Statement

The study was in accordance with the Ethical Committee of Tehran University of Medical Sciences (Approval ID: IR.TUMS.DDRI.REC.1401.032).
Informed consent was taken for recording discussions. The participants were aware of the objectives of the study and participation in this study was completely voluntary. The participants were also assured that the recorded contents and the questionnaire answers would be confidential.

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None.

Conflict of Interest

The authors have no conflicts of interest to declare.

References

1. Liu C, Pan LK. Advances in minimally invasive surgery and clinical measurement. Comput Assist Surg (Abingdon) 2019 Oct;24(sup1):1-4.

2. Rehani MM, Ciraj-Bjelac O, Vañó E, Miller DL, Walsh S, Giordano BD, et al. Radiological protection in fluoroscopically guided procedures performed outside the imaging department. Ann ICRP 2010 Dec;40(6):1-102.

3. Opreanu RC, Kepros JP. Patient and surgeon radiation exposure: comparison of standard and mini-C-arm fluoroscopy. J Bone Joint Surg Am 2009 Aug;91(8):2044-5; author reply 2045.

4. Kerr IH. Patient dose reduction in diagnostic radiology. Clin Radiol 1991 Jan;43(1):2-3.

5. Goldstone KE, Wright IH, Cohen B. Radiation exposure to the hands of orthopaedic surgeons during procedures under fluoroscopic X-ray control. Br J Radiol 1993 Oct;66(790):899-901.

6. Mahabir RC, DeCroff CM, Thurgood L, Harrop AR. Closed reduction internal fixation rates and procedure times for metacarpal fractures treated in a minor surgery area before and after the introduction of a mini C-arm unit. Can J Plast Surg 2008 Fall;16(3):162-4.

7. Lee MC, Stone III NE, Ritting AW, Silverstein EA, Pierz KA, Johnson DA, et al. Mini-C-arm fluoroscopy for emergency-department reduction of pediatric forearm fractures. J Bone Joint Surg Am 2011 Aug 3;93(15):1442-7.

8. Tsalafoutas IA, Tsapaki V, Kaliakmanis A, Pneumaticos S, Tsoronis F, Koulentianos ED, et al. Estimation of radiation doses to patients and surgeons from various fluoroscopically guided orthopaedic surgeries. Radiat Prot Dosimetry 2008;128(1):112-9.

9. Giachino AA, Cheng M. Irradiation of the surgeon during pinning of femoral fractures. J Bone Joint Surg Br 1980 May;62-B(2):227-9.

10. Singer G. Radiation exposure to the hands from mini C-arm fluoroscopy. J Hand Surg Am 2005 Jul;30(4):795-7.

11. Tuohy B, Marsh DM, O'reilly G, Dowling A, Cooney P, Malone JF. Quality assurance programme applied to mobile C-arm fluoroscopy systems. Eur Radiol 1997;7(4):534-41.

12. Stirton JB, Savage AD, Pally EM, Kreder HJ, Mooney M. A standard universal C-arm language: assessing its need and its likelihood of acceptance. J Orthop 2018 Dec 20;16(1):61-63.

13. FluoroScan mini C-arm unit. Health Devices 1995 Feb;24(2):44-70.

14. Kaplan DJ, Patel JN, Liporace FA, Yoon RS. Intraoperative radiation safety in orthopedics: a review of the ALARA (As low as reasonably achievable) principle. Patient Saf Surg 2016 Dec 12:10:27.

15. Gieroba TJ, Williams N, Antoniou G, Cundy PJ. Mini C-arm: faster, cheaper, safer? ANZ J Surg 2017 Apr;87(4):282-6.

16. Chapman T, Martin DP, Williamson C, Tinsley B, Wang ML, Ilyas AM. Mini C-arm fluoroscopy: does its configuration matter for radiation exposure to the surgeon? Hand (N Y) 2018 Sep;13(5):552-7.

17. White SP. Effect of introduction of mini C-arm image intensifier in orthopaedic theatre. Ann R Coll Surg Engl 2007;89(3):268-71. doi:10.1308/003588407X155770

18. van Rappard JRM, Hummel WA, de Jong T, Mouës CM. A comparison of image quality and radiation exposure between the mini C-arm and the standard C-arm. Hand (N Y). 2019 Nov;14(6):765-769. doi: 10.1177/1558944718770210. Epub 2018 Apr 17. PMID: 29661071; PMCID: PMC6900691.

19. Stroh DA, Ashie A, Muccino P, Bush C, Kaplan D, DiPasquale T. A proposal for a standardized nomenclature of the C-arm movements. J Am Acad Orthop Surg Glob Res Rev 2020 Feb 18;4(2):e20.00008.

20. Kausch L, Thomas S, Kunze H, Privalov M, Vetter S, Franke J, et al. Toward automatic C-arm positioning for standard projections in orthopedic surgery. Int J Comput Assist Radiol Surg. 2020 Jul;15(7):1095-105.

21. Haliburton L, Esfandiari H, Guy P, Anglin C, Hodgson A. A visual odometry base-tracking system for intraoperative C-arm guidance. Int J Comput Assist Radiol Surg 2020 Oct;15(10):1597-609.

22. De Silva T, Punnoose J, Uneri A, Mahesh M, Goerres J, Jacobson M, et al. Virtual fluoroscopy for intraoperative C-arm positioning and radiation dose reduction. J Med Imaging (Bellingham) 2018 Jan;5(1):015005.

23. Banat M, Wach J, Salemdawod A, Domurath L, Scorzin J, Vatter H. Can postoperative CT imaging in spine surgery be replaced by intraoperative 3D rotation with the C-Arm?: results of a prospective single center cohort study. Front Surg 2021 Jul 14:8:692189.

24. Takao M, Yabuta K, Nishii T, Sakai T, Sugano N. Accuracy of a 3D fluoroscopic navigation system using a flat-panel detector-equipped C-arm. Comput Aided Surg 2011;16(5):234-239.

25. Seibert JA. Vertebroplasty and kyphoplasty: do fluoroscopy operators know about radiation dose, and should they want to know? Radiology 2004 Sep;232(3):633-4.