Original Article

PORTO BIOMEDICAL JOURNAL
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Intraoperative fluoroscopic radiation in orthopedic trauma: correlation with surgery type and surgeon experience

Luís Fabião[a,b], Ana Ribau[a,b], Carolina Lemos[b,c,d], Ricardo Rodrigues-Pinto[a,b]

ABSTRACT

Background: While fluoroscopy is widely used in orthopedic trauma surgeries, it is associated with harmful effects and should, therefore, be minimized. However, reference values for these surgeries have not been defined, and it is not known how surgeon experience affects these factors. The aims of this study were to analyze the radiation emitted and exposure time for common orthopedic trauma surgeries and to assess whether they are affected by surgeon experience.

Methods: Data from 1842 trauma orthopedic procedures were retrospectively analyzed. A total of 1421 procedures were included in the analysis. Radiation dose and time were collected to identify reference values for each surgery and compared for when the lead surgeon was a young resident, a senior resident, or a specialist.

Results: The most performed surgeries requiring fluoroscopy were proximal femur short intramedullary nailing (n = 401), ankle open reduction and internal fixation (ORIF) (n = 141), distal radius ORIF (n = 125), and proximal femur dynamic hip screw (DHS) (n = 114). Surgeries using higher radiation dose were proximal femur long intramedullary nailing (mean dose area [DAP]): 1361.35 $mGycm^2$), proximal femur DHS (1094.81 $mGycm^2$), and proximal femur short intramedullary nailing (891.41 $mGycm^2$). Surgeries requiring longer radiation time were proximal humerus and/or humeral shaft intramedullary nailing (02 mm:20 ss), proximal femur long intramedullary nailing (02 mm:04 ss), and tibial shaft/distal tibia intramedullary nailing (01 mm:49 ss). Senior residents required shorter radiation time when performing short intramedullary nailing of the proximal femur than young residents. Specialists required more radiation dose than residents when performing tibial nailing and tibial plateau ORIF and required longer radiation time than young residents when performing tibial nailing.

Conclusions: This study presents mean values of radiation dose and time for common orthopedic trauma surgeries. Orthopedic surgeon experience influences radiation dose and time values. Contrary to expected, less experience is associated with lower values in some of the cases analyzed.

Introduction

Since the 1980s, fluoroscopy has been increasingly used, particularly in orthopedic trauma surgeries.[1-3] In such surgeries, fluoroscopy can be used for anatomical localization, diagnosis, fracture reduction, intramedullary nailing, Kirshner wire/external fixator pin placement, and percutaneous hardware placement.[1] Despite its advantages, this technique can cause harmful, long-term side effects to the orthopedic surgeon and the team present in the operating theater because of the constant exposure to x-rays.[3,4] The maximum limit of exposure without a surgeon suffering harmful effects has not been precisely defined, but it is known that the greater the exposure, the higher the probability of being affected.[5-7] It is known that the deoxyribonucleic acid (DNA) double strand break is the most lethal injury induced by radiation, which contributes to cell death and increases the incidence of cancer.[7] The extremities, head, and neck are the most exposed areas, and the most sensitive organs to radiation are the eyes, thyroid, hands, and the gonads.[8,9] It is important to note that the incidence of cancer is five times greater in orthopedic surgeons compared with specialists in other areas.[10]

There are several factors that influence the time of exposure to radiation in the operating theater, such as the experience of the surgeon, the type of surgery being performed, and the type of imaging device used, as well as the time of the day at which the surgeon is operating.[5,11] Increasing the distance from the emission source of radiation, decreasing the exposure time, and using protective clothing are three proven ways to reduce the risk of exposure.[9,12] Protective clothing that may be worn consists of lead or similar light materials that attenuate scattered x-rays, such as aprons, thyroid shields, leaded eyewear, and lead-lined gloves.[9] In addition, a study has shown that good communication and the use of appropriate terminology between the surgeon and the radiology technician reduces the exposure time and the amount of radiation emitted.[13] Other studies have shown that surgeries performed with real-time dosimetry reduce the radiation to which the surgeon is exposed.[2,14] Physicians should follow the as low as reasonably achievable (ALARA) principle, which is based on minimizing the radiation emitted without reducing the quality of the image.[14,15]

While the use of fluoroscopy in trauma surgery is widespread, very few studies have analyzed the amount of radiation in common orthopedic trauma procedures, and therefore, no reference levels

[a] Spinal Unit (UVM) Department of Orthopaedics, Centro Hospitalar Universitário do Porto, Porto, Portugal, [b] ICBAS—Instituto de Ciências Biomédicas Abel Salazar, Universidade do Porto, Porto, Portugal, [c] UnIGENe, IBMC, Instituto de Biologia Molecular e Celular, Porto, Portugal, [d] i3S, Instituto de Investigação e Inovação em Saúde, Universidade do Porto, Porto, Portugal

Corresponding author: E-mail: address: luis.fabiao13@hotmail.com (L. Fabião).

Porto Biomed. J. (2023) 8:3(e218)

Received: 21 May 2023 / Accepted: 26 May 2023

http://dx.doi.org/10.1097/j.pbj.0000000000000218

have been defined. Furthermore, it is not clear whether the experience of the surgeon affects the amount of radiation used. The aims of this study were to (1) evaluate the amount of energy emitted and radiation time in common trauma orthopedic procedures and (2) to assess whether these factors are influenced by the surgeon experience.

Methods

All patients submitted to trauma orthopedic surgeries using fluoroscopy between June 2016 and June 2018 were included in the study. Clinical and surgical data were collected using the software SClínico v.2.3, and data regarding the amount of radiation (cumulative dose area product [DAP] and screening time [mm:ss]) were obtained from the software SECTRA version IDS7. The fluoroscopy C-arm used was a Philips BV Libra C-arm or equivalent.

During the period of analysis, 1842 surgeries were identified. Cases in which two or more surgeries requiring fluoroscopy were performed in the same surgical procedure were excluded because those were with insufficient information; additionally, hip and shoulder replacement surgeries performed in the context of trauma were also excluded because fluoroscopy here was only used to confirm prosthesis placement and not throughout the procedure. Hence, from and initial pool of 1846 cases, 1421 were analyzed.

For each surgical procedure, the amount of radiation and radiation time used were analyzed to understand which procedure required more time and dosage. To understand whether surgeon's experience influenced fluoroscopy use, the main surgeon was categorized into 3 groups: young residents (residents in their first 3 years of training), senior residents (residents in the last 3 years of training), and specialists.

Descriptive statistics were performed to characterize the sample. For statistical analysis, only surgical procedures with more than 30 cases were included. An one-way ANOVA test was used to analyze whether the experience of the surgeon influenced the mean values of amount of radiation and radiation time. A P-value <.05 was considered statistically significant difference. The statistical analyses were performed using IBM SPSS Statistics v.24.

This study was approved by the local ethic committee (Reference number: 2018.251 [221-DEFI/220-CES]) and was conducted in compliance with the standards of the Declaration of Helsinki.

Results

The 1421 surgeries included in the study represent 950 women and 471 men, with a mean age of 69 years. The most performed surgeries requiring the use of fluoroscopy were proximal femur short intramedullary nailing (n = 401), open reduction and internal fixation (ORIF) of ankle (unimalleolar, bimalleolar, or trimalleolar) fractures (n = 141), distal radius ORIF (n = 125), and proximal femur dynamic hip screw (DHS) (n = 114) (Table 1).

Eleven surgical procedures had more than 30 cases each, consisting of a total of 1155 cases. Surgeries using the greatest amount of radiation were proximal femur long intramedullary nailing with a mean DAP of 1361.35 mGycm^2, followed by proximal femur DHS (1094.81 mGycm^2) and proximal femur short intramedullary nailing (891.41 mGycm^2) (Table 1 and Fig. 1).

Surgeries using the longest radiation time were proximal humerus and/or humeral shaft intramedullar nailing with a mean screening time of 02 mm:20 ss, followed by proximal femur long intramedullary nailing (02 mm:04 ss) and tibial shaft/distal tibia intramedullary nailing (01 mm:49 ss) (Table 1 and Fig. 2).

TABLE 1

Type of trauma operations requiring fluoroscopy use with respective frequency, including mean dose area product and screening time for trauma cases where n >30

Surgery	n	Mean DAP (mGycm^2)	Mean screening time (mm:ss)
Proximal femur short intramedullary nailing	401	891.41	00:58
Ankle (unimalleolar, bimalleolar, or trimalleolar) ORIF	141	133.01	00:37
Distal radius ORIF	125	50.79	00:37
Proximal femur DHS	114	1094.81	01:01
Proximal femur long intramedullary nailing	84	1361.35	02:04
Proximal humerus and/or humeral shaft ORIF	82	338.28	00:55
Phalanges and/or metacarpals ORIF	53	43.10	00:36
Tibial plateau ORIF	44	317.60	00:55
Proximal humerus and/or humeral shaft intramedullary nailing	43	666.65	02:20
Tibial shaft/distal tibia intramedullary nailing	35	317.64	01:49
Patella ORIF	33	105.87	00:20

DAP, dose area product; DHS, dynamic hip screw; ORIF, open reduction and internal fixation.

To understand whether surgeon's experience influenced the amount and radiation time, the main surgeon was categorized into young resident, senior resident, and specialist. Within the 11 most performed surgeries, the mean radiation of young residents was 662.13 mGycm^2, for senior residents was 581.48 mGycm^2 and, for specialists was 597.14 mGycm^2. The mean radiation time was 01 mm:01 ss when the surgery was performed by a young resident, 00 mm:59 ss when the surgery was performed by a senior resident, and 01 mm:03 ss when the surgery was performed by a specialist (Table 2).

Finally, the experience of main surgeon was analyzed in specific surgeries. Proximal femur short intramedullary nailing required a longer period of radiation exposure when the surgery was performed by young residents (01 mm:02 ss) compared with the older ones (00 mm:55 ss) (P=.027). Tibial shaft/distal tibia intramedullary nailing required shorted exposure to radiation when it was performed by younger residents (01 mm:29 ss) than specialists (02 mm:28 ss) (P=.022); when the same procedure was performed by specialists, the amount of radiation emitted was higher (544.80 mGycm^2) when compared with senior residents (324.72 mGycm^2) and with young residents (189.91 mGycm^2) (P=.002). Finally, tibial plateau ORIF required more radiation emitted when the surgery was performed by specialists than when it was performed by senior residents (447.27 mGycm^2 vs 259.46 mGycm^2, P=.019) (Table 3).

Discussion

As aforementioned, radiation exposure is an occupational hazard affecting orthopedic surgeons to a much higher extent than other physicians, placing them at greater chance of developing cancer.[10] The International Commission on Radiological Protection recommends a maximum effective exposure of 20 milliSievert (mSv) (20 mGy) per year averaged over a defined periods of 5 years (100 mSv in 5 years, not exceeding 50 mSv in a year).[16] For a better understanding of the value of mSv, an airport backscatter x-ray screen corresponds to 0.05 microSievert (μSv).[17] Therefore, it is important to understand the amount of radiation emitted in

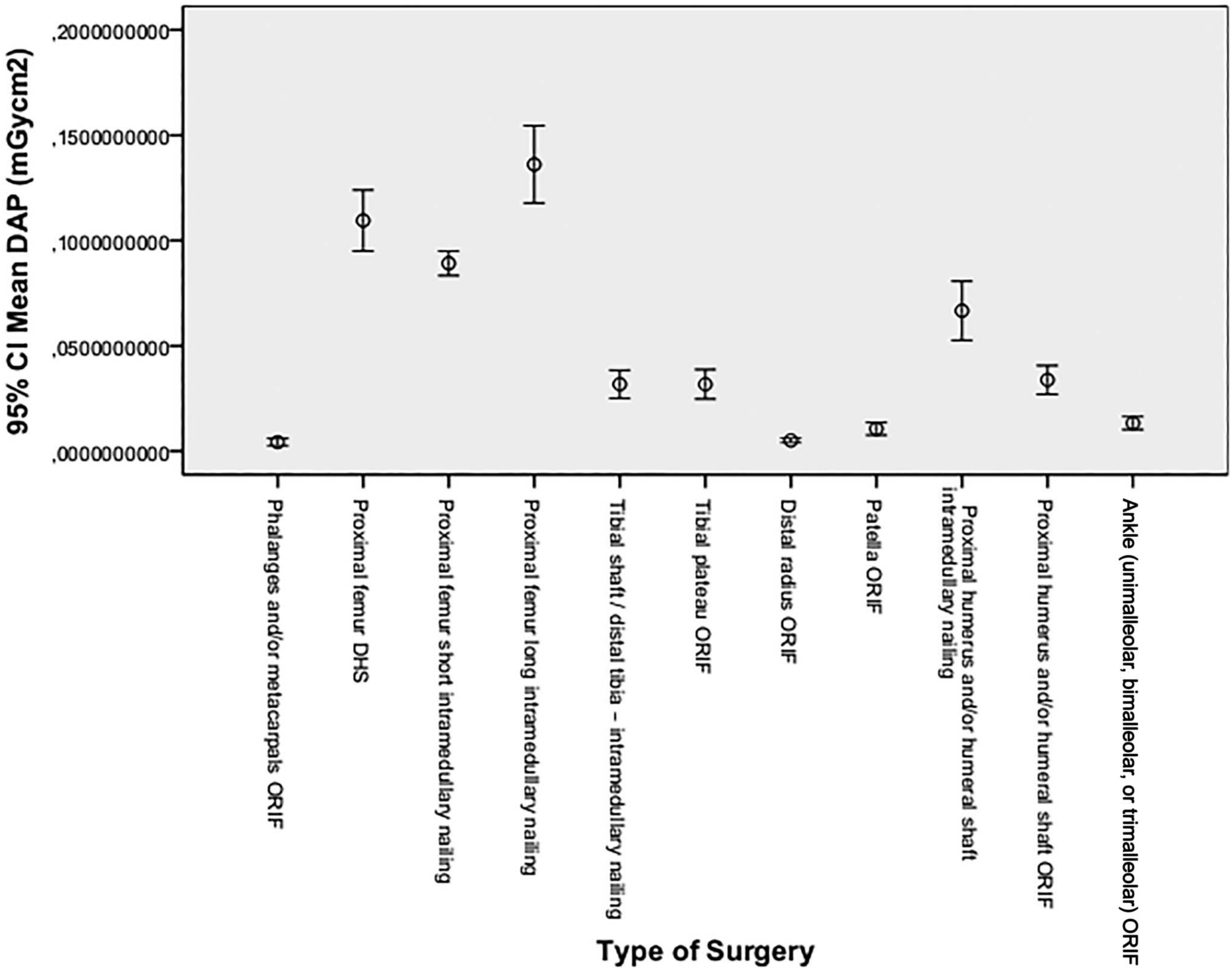

Figure 1. Mean dose area product by type of trauma operations requiring fluoroscopy use. 95% CI, 95% confidence interval; DAP, dose area product; DHS, dynamic hip screw; ORIF, open reduction and internal fixation.

each surgery and whether it changes according to the surgeon experience.

This is, to the best of our knowledge, the largest study analyzing radiation dosage and exposure time in common orthopedic trauma procedures. It demonstrates that long intramedullary nailing of the proximal femur required the highest dosage of radiation. This is in agreement with the results published by Rashid et al.[3] While femoral nailing is a very common procedure and relatively a quick procedure, placement of the distal screw—which is performed without a guide—may account for the larger dosage of radiation needed. While distal targeting devices have been developed and have shown to reduce radiation exposure, even in long intramedullary nailing, their use is not widespread.[18-20]

The three surgeries in which more radiation dosage was used were all femur fractures—proximal short and long nailing and DHS. One possible reason for this higher dosage needed may be related to the surface area of this anatomical region compared with others such as the wrist, forearm, phalanxes, and others. This larger surface area requires higher radiation to penetrate the tissues and to allow for adequate bone visualization. Further confirming this is the fact that proximal/diaphyseal humerus nailing required the longer radiation time but was only the forth with regard to radiation dosage suggesting that while humeral nailing requires more images, this can be achieved with a lower dosage.

In addition, surgeries performed with open reduction and internal fixation, in which direct visualization of bone and its reduction is possible, generally required lower radiation than those in which reduction was closed. It is, therefore, important to weigh the advantages of closed reduction against the disadvantages of higher radiation; this is especially important in cases of minimally invasive surgery, which also generally require larger radiation doses.

TABLE 2

Mean dose area product and mean screening time by grade of the lead surgeon, with respective frequency, for trauma cases where n >30

Grade of lead surgeon	Total	Mean DAP (mGycm^2)	*P*	Mean screening time (mm:ss)	*P*
Young resident	428	662.13		01:01	
Senior resident	544	581.48	.159	00:59	.637
Specialist	183	597.14		01:03	

DAP, dose area product.

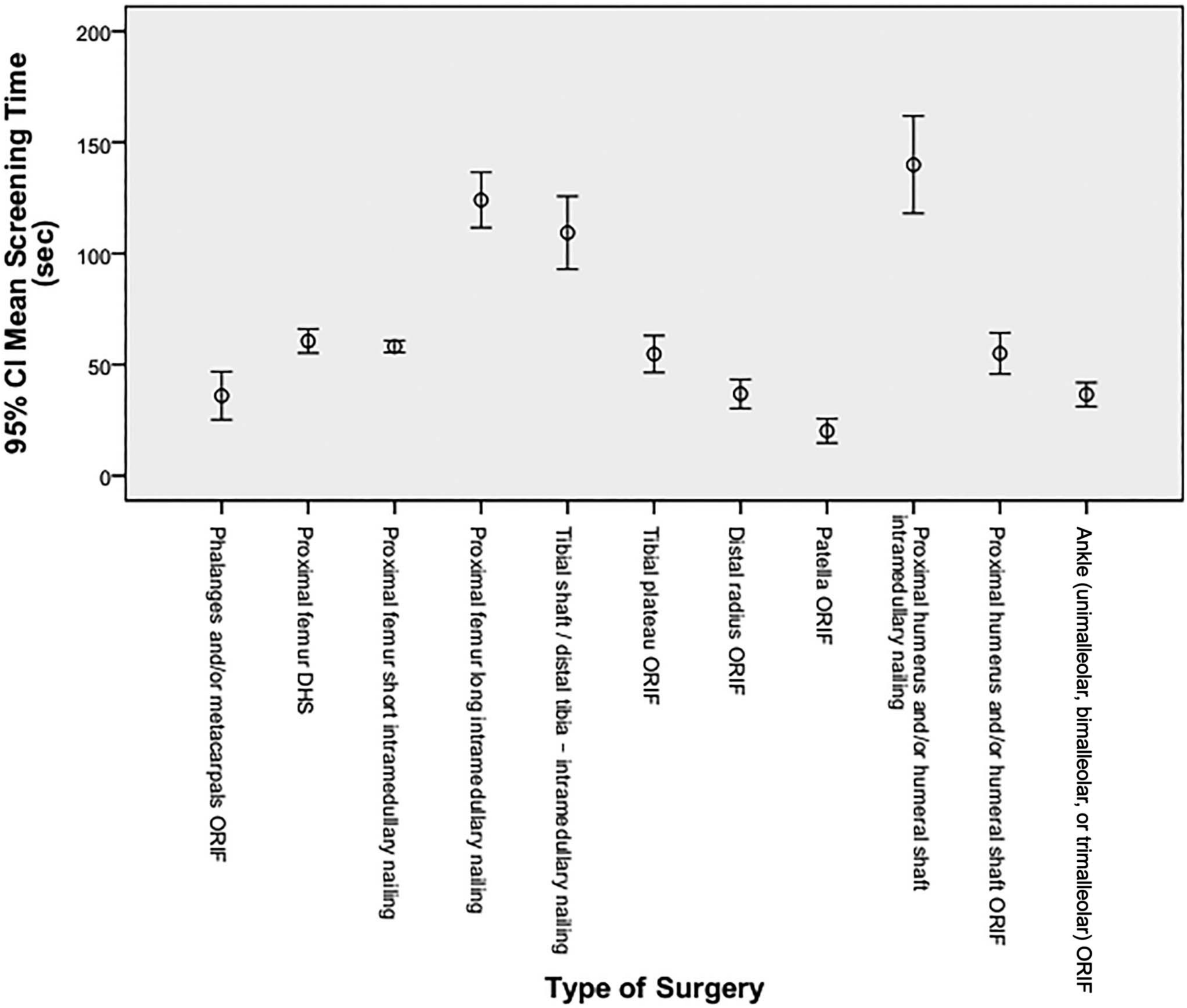

Figure 2. Mean screening time by type of trauma operations requiring fluoroscopy use. 95% CI, 95% confidence interval; DHS, dynamic hip screw; ORIF, open reduction and internal fixation.

When considering the 11 surgeries with more than 30 procedures, no significant differences were found when comparing the mean radiation dosage and time between young residents, senior residents, and specialists. When analyzing specific surgeries, young residents required longer radiation times to perform proximal femur short intramedullary nailing when compared with senior residents. This is possibly because young residents are more inexperienced and may need longer to adequately reduce and stabilize the fractures. However, when performing intramedullary nailing of the tibia, specialists required more radiation and longer radiation times than residents. Similarly, when performing tibial plateau ORIF, specialists required more radiation dosage than senior residents. The fact that residents require lower fluoroscopy dosage/time is relatively surprising but can possibly be justified by the fact that the specialists may be lead surgeons in the most complex surgeries, and that, owing to the intrinsic complexity of the fracture, they require more radiation dosage and longer radiation times.

Reduction of radiation exposure is paramount to protect not only the orthopedic surgeons but also the radiology technicians and the rest of the team in the operating theater. For these methods to succeed, the professionals (orthopedic surgeons and radiology technicians) and the institutions should follow certain recommendations.

Orthopedic surgeons should maintain adequate distance from the C-arm because it is one of the fundamental concepts to minimize the exposure to radiation; increasing the distance from 1 meter to 2 meters from the power source reduces the intensity of the x-rays by a factor of four.[21] Complex procedures may need to be performed more by specialists to minimize exposure to radiation to all people involved. Specialists should assist residents in cases of complicated fractures because there is evidence that the most inexperienced surgeons, in these situations, use more radiation.[21,22] Radiology technicians should use techniques that help minimize exposure, such as magnification and inversion of the C-arm; the use of image intensifier memory and image storage facilities, rather than additional exposures; in complicated situations, a more experienced radiology technician should be called.[21,23] Finally, institutions should provide all the necessary materials for the protection of their employees, such as lead gowns, thyroid shields, and eye goggles, and conduct audits, to

TABLE 3

Variation of mean dose area product and mean screening time between grades of lead surgeon for trauma cases where n >30

	Total	Mean DAP (mGycm^2)	*P*	Mean screening time (mm:ss)	*P*
Proximal femur short intramedullary nailing					
Young residents	174	936.64	.406	01:02	.027
Senior residents	188	855.86		00:55	
Specialists	39	860.95		00:55	
Ankle (unimalleolar, bimalleolar, or trimalleolar) ORIF					
Young residents	62	122.26	.819	00:30	.065
Senior residents	58	143.28		00:43	
Specialists	21	136.31		00:38	
Distal radius ORIF					
Young residents	47	57.02	.570	00:39	.602
Senior residents	57	49.20		00:38	
Specialists	21	41.16		00:30	
Proximal femur DHS					
Young residents	52	993.60	.277	01:01	.289
Senior residents	50	1131.67		00:58	
Specialists	12	1379.83		01:13	
Proximal femur long intramedullary nailing					
Young residents	27	1457.11	.548	02:14	.171
Senior residents	36	1243.61		01:51	
Specialists	21	1440.05		02:15	
Proximal humerus and/or humeral shaft ORIF					
Young residents	13	265.58	.282	00:53	.905
Senior residents	44	315.34		00:57	
Specialists	25	416.47		00:53	
Phalanges and/or metacarpals ORIF					
Young residents	9	47.21	.380	00:46	.672
Senior residents	33	34.96		00:36	
Specialists	11	64.17		00:30	
Tibial plateau ORIF					
Young residents	4	194.75	.019	00:50	.209
Senior residents	25	259.46		00:50	
Specialists	15	447.27		01:05	
Proximal humerus and/or humeral shaft intramedullary nailing					
Young residents	14	783.50	.319	02:28	.129
Senior residents	21	661.14		02:32	
Specialists	8	476.63		01:34	
Tibial shaft/distal tibia – intramedullary nailing					
Young residents	10	189.91	.002	01:29	.022
Senior residents	20	324.72		01:48	
Specialists	5	544.80		02:28	
Patella ORIF					
Young residents	16	101.39	.253	00:23	.588
Senior residents	12	88.49		00:17	
Specialists	5	161.88		00:20	

DAP, dose area product; DHS, dynamic hip screw; ORIF, open reduction and internal fixation.

avoid excessive radiation exposure of the operating team. In addition to the previously mentioned, the staff in the operating theater should be restricted to the number strictly necessary.[3]

Good communication, with a predefined language between the orthopedic surgeon and radiology technicians, reduces the exposure time and possibly the radiation emitted. The knowledge of how fluoroscopy works can also improve the communication efficiency between them.[24] It has been shown that when orthopedic surgeons are aware of the radiation that is emitted in the operating theater, they change their behavior and the amount of energy emitted is lower, so the use of dosimeters in the operating theater is strongly recommend, as well as the daily recording of the radiation to which the surgeon has been exposed.[2] In this way, the surgeon may have a sense of the radiation he has been exposed to in that day and take more precautions on the following days, until a reasonable radiation value is reached.

While fluoroscopy is used worldwide to assist in trauma orthopedic surgeries, very few studies have performed and analysis such as this presented here. This study provides values that can be used as reference for surgeons and institutions and help to audit adequate radiation exposure and also in reducing it. In this study, radiation intensity and time were recorded and analyzed. Radiation intensity is, however, influenced by factors unrelated to the surgeon, such as body mass index (BMI) of the people being operated. Radiation time, however, depends on the number and duration of exposures, which can be more attributed to the surgeon and the technician.[6]

In the clinical setting at which this study took place, which is a university teaching hospital, the importance of following all recommendations to avoid excessive exposure to radiation should be emphasized because these recommendations will be followed by the surgeons in training and will have great influence as they should be role models for future doctors.

This study has some limitations. Most of the surgeries performed by residents, both in the first three years and in the last three, were supervised by a specialist, who may help in more complex parts of the surgery, and therefore, the values obtained when the surgery was being performed by residents may be biased. Conversely, residents may also feel pressured by the presence of a specialist and, to prevent mistakes, they may ask for more images. The experience of the radiology technician and the complexity of the fractures in each group were also not considered, which can affect the results. Data such as the age of the person being operated, their bone density, and their BMI were not analyzed; this, as aforementioned, may also influence the results obtained.

In conclusion, in this study, which includes the largest number of cases to date, the radiation time, and dosage were analyzed for common orthopedic trauma surgeries. This provides reference values for each surgery that can be used to assess fluoroscopy use and also to implement measures to reduce radiation dosage and time. Contrary to expected, more inexperienced surgeons do not require more radiation dosage and time for the most common procedures.

Conflicts of interest

None.

Presentation: free paper in 39º Congresso Nacional de Ortopedia e Traumatologia.

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