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ORIGINAL ARTICLE

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Assessment of orthopedist exposure to occupational doses of radiation in foot and ankle surgeries

Avaliação da exposição do ortopedista a doses ocupacionais de radiação em cirurgias do pé e tornozelo

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ABSTRACT

Objective: To measure the doses of occupational radiation to which a physician who performs orthopedic surgery of the foot and ankle using a fluoroscopy device is exposed during work and to compare those doses with the values provided in the current legislation and propose measures of radioprotection.

Methods: Thermoluminescent dosimetry (TLD) was used to measure radiation in critical target areas (whole-body, lens, thyroid, right and left hands) of the surgeon's body during all the surgical procedures performed by him between 12/19/2017 and 2/5/2018. From the mean dose values obtained for the procedures, the dose of annual radiation exposure was estimated for each of the regions analyzed and compared with the current legislation.

Results: The estimate of the annual radiation dose received by the surgeon to the chest region, above the lead apron, was 5 times higher than that established by the national legislation. However, considering the use of the lead apron, the dose was acceptable. Estimates of equivalent doses for the limbs and thyroid had results within the levels required by the current legislation. The equivalent dose for the lens, on the other hand, was 4 times higher than that established by the legislation.

Conclusion: During the workday, the foot and ankle orthopedic surgeon is exposed to doses of radiation higher than those considered acceptable. The data corroborate the need to wear radiological protective clothing, especially a lead apron and goggles.

Level of Evidence IV; Prognostic Study; Case Series.

Keywords: Orthopedic surgeons; Absorption, radiation; Radiation dosage.

RESUMO

Objetivo: Medir as doses de radiação ocupacional às quais um médico, que realiza cirurgias ortopédicas do pé e tornozelo utilizando aparelho de fluoroscopia está exposto em sua jornada de trabalho, bem como comparar as doses obtidas com os valores previstos na legislação em vigor e propor medidas de radioproteção.

Métodos: Por meio de dosimetria do tipo termoluminescente (TLD), foram obtidas respostas para pontos alvo-críticos (corpo-inteiro, cristalino, tireoide, mãos direita e esquerda) no corpo do cirurgião, durante todos os procedimentos cirúrgicos realizados por ele entre os dias 19/12/2017 e 05/02/2018. A partir dos valores de dose médios obtidos para os procedimentos, estimou-se a dose de exposição à radiação anual em cada uma das regiões analisadas e comparou-se com a legislação vigente.

Resultados: A estimativa da dose anual de radiação recebida pelo cirurgião para a região do tórax, por cima do avental de chumbo, teve resultado cinco vezes mais alto do que a legislação nacional preconiza. Entretanto, considerando-se o uso do avental plumbífero, a dose torna-se adequada. As estimativas de doses equivalentes para as extremidades e tireoide tiveram resultados compatíveis com as exigências das legislações vigentes. A dose equivalente para o cristalino, por outro lado, teve resultado quatro vezes mais alto do que o indicado na legislação.

Work performed at the Hospital XV, Curitiba, PR, Brazil.

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Conclusão: O cirurgião ortopedista especialista em pé e tornozelo está exposto, em sua jornada de trabalho, a doses de radiação superiores àquelas consideradas adequadas. Os dados corroboram a necessidade do uso de vestimentas de proteção radiológica, especialmente avental e óculos plumbíferos.
Nível de Evidência IV; Estudos Prognósticos; Série de Casos.

Descritores: Cirurgiões ortopédicos; Absorção de radiação; Dose de radiação.

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INTRODUCTION

The discovery of ionizing radiation occurred in 1895 by the physicist Wilhelm Conrad Röntgen[1].

Since its discovery, ionizing radiation has been applied in several areas, including the food, civil, and mechanical industries and medical sector. In health, its use has gained prominence in the diagnosis and treatment of diseases through the use of radiography, tomography, nuclear medicine, and radiotherapy, among others[1].

As the use of radiation increased, its deleterious effects on human health became evident, such as burns, poisoning, and carcinogenic effects[2,3].

The use of radiation through fluoroscopy plays a key role in the treatment of various surgical orthopedic diseases. Radiation doses to which medical staff are exposed during surgical procedures have been reported in other studies[4,5].

In foot and ankle surgeries, the advancement of minimally invasive techniques and percutaneous surgeries has resulted in an increased need for fluoroscopy.

This study aims to measure the doses of occupational radiation to which a physician who performs orthopedic surgery of the foot and ankle using a fluoroscopy device is exposed during work and to compare those doses with the values provided in the current legislation and propose measures of radioprotection.

METHODS

This study was approved by the Research Ethics Committee with registration in the Brazil Platform under CAAE number: 78449517.9.3003.5529 and complied with all requirements related to human rights.

The study included 1 orthopedist who was a foot and ankle expert and who was exposed to occupational doses of radiation during surgical activities. The physician agreed to participate in the study and signed a free and informed consent form.

An evaluation of the professional's workday, bibliographic research, and legislation provided the methodological basis for monitoring 5 (5) critical target areas (Figure 1): right hand and left hand (dose at the limbs), neck (thyroid), forehead (lens) and thorax (total body). The points selected were monitored outside the personal radiological protection equipment (lead apron with 0.50mm lead (Pb) equivalent from NMartins®) used by the professional so that the dosimeter could sense a significant amount of radiation. Radiological protection equipment was not used on the hands, neck or eyes.

Figure 1. Critical target areas (highlighted in red) for monitoring the physician.
Source: Authors' personal archive.

Monitoring was performed with a LiF:Mg,Ti thermoluminescent dosimeter (TLD) supplied by the Laboratory of Applied Nuclear Physics to measure the cumulative dosage.

Dosimeter kits were prepared and calibrated by the laboratory, i.e., irradiated with an X-ray source by applying a 56kVp voltage (mean voltage applied in the procedures) with increasing current-time (mAs), as shown in table 1. In this calibration step, an ionization chamber was used, which verified the radiation dose at each exposure.

The TLD readings were corrected by individual calibration factors, which were previously determined. In addition, background (BG) dosimeters were used to quantify natural radiation. The value assessed by these BG dosimeters was subtracted from the values of all irradiated dosimeters. The result of this subtraction provided the "Actual Reading".

A calibration curve with error was elaborated with these results to obtain a factor relating the dose received by each dosimeter with the dosimeter reading. This curve (Figure 2) generated the equation $y = (0.00138 \pm 0.00005).x$, in which "y" represents the radiation dose and "x" represents the dosimeter reading, deducted from the BG value.

Kits were provided to the physician for the chosen target areas. The kits contained duplicate dosimeters for each point, in addition to the background kit stored outside the surgical area.

For monitoring, the physician placed the dosimeters before asepsis. Dosimeter use control was performed using records for each fluoroscope used in the surgeries, called device A and B, both of the Siemens® brand, which were handled by a radiology technician. The fluoroscopes were calibrated according to the regulations in Ordinance 453/1998 of the Health Ministry[6].

The physician was instructed to record the following data for each procedure: date of surgery, surgical procedure, number of images taken, exposure time, and voltage and intensity of the fluoroscope.

Table 1. Data for the preparation of the calibration curve

Actual reading of each dosimeter	Radiation Dose (milligray - mGy)	Milliampere-second (mAs)
243.6	0.3	3.2
606.6	0.5	5
852	1	10
1341	1.3	13.2
1653.3	2	20
1871.5	2.5	25
2744.8	4	40

Source: Prepared by the author based on the research results.

After data collection between 12/19/2017 and 02/05/2018, the dosimeters were sent for laboratory evaluation.

From the results, the annual radiation dose to which the professional is exposed at each measurement point was estimated for comparison with the current legislation.

RESULTS

Table 2 shows the data recorded in all fluoroscopic surgical procedures performed by the orthopedist between 12/19/2017 and 02/05/2018, which were monitored by dosimetry. In total, the orthopedist performed 16 procedures, of which 14 were performed with device A and 2 were performed with device B. The recorded exposure times ranged from 0 to 60 seconds(s).

The mean voltage, current-time product, number of images and exposure time, considering the 2 devices, were 55kVp (maximum voltage), 2mAs (current-time), 18 images and 23s, respectively.

Table 3 shows the cumulative doses in milligray (mGy) and TLD errors to which the professional was exposed in the 14 procedures performed with device A. The highest cumulative dose was to the right hand, followed by the thorax and left hand and, finally, the forehead.

Table 4 shows the TLD results regarding dose (mGy) and errors obtained using fluoroscope B. The highest cumulative dose was found in the thorax, followed by the right hand, then by the forehead, neck, and left hand.

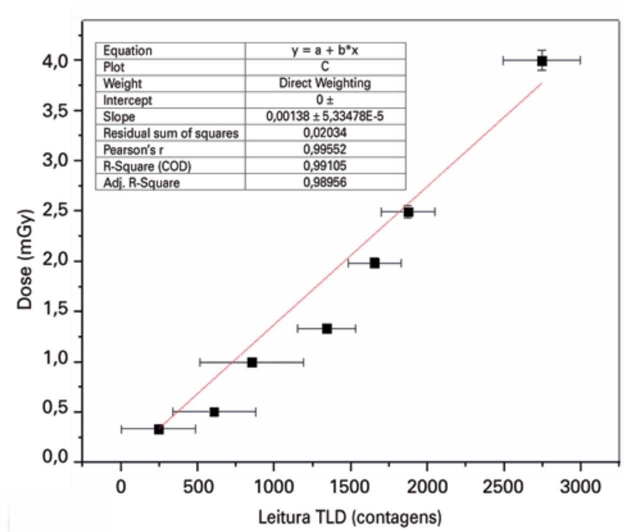

Figure 2. Calibration curve and error generated for the dosimeters. **Source:** Prepared by the author based on the results of the research.

Table 2. Data collection in Hospital 1.

Date	Procedure	N	T (s)	kVp	mAs
19/12/2017	Unilateral hallux valgus	15	----	52	5.2
19/12/2017	Claw toe	30	----	46	----
02/01/2018	Removal of screws + tibial rod removal attempt	40	----	61	10
02/01/2018	Dislocation fracture	----	42	55	----
06/01/2018	Bilateral hallux valgus and left tailor's bunion	22	18	57	0.8
09/01/2018	Subtalar arthrodesis + arthroscopy	20	60	50	----
09/01/2018	Triple arthrodesis + arthroscopy	36	18	50	----
09/01/2018	Calcaneus fracture	23	12	51	----
16/01/2018	Arthroscopy and reconstruction of the ligament	16	----	58	----
20/01/2018	Ankle fracture	12	----	67	----
23/01/2018	Calcaneus fracture	13	0	64	1.1
23/01/2018	Ankle fracture	11	----	65	----
23/01/2018	Fracture of the distal tibia	30	----	56	----
27/01/2018	Loss of redug. of fracture and calcaneus	24	18	48	0.5
27/01/2018	Ankle fracture	13	18	58	0.3
05/02/2018	Bilateral percutaneous hallux valgus	15	----	54	----

Source: Prepared by the author based on the research results.

"N": number of images; "T": time of exposure to radiation in seconds (s); "KVp": voltage in kilovoltage; "mAs": current-time product in milliampere-second.

Table 3. Dose per critical target area, device A.

Device 1A	Cumulative daily dose for 14 workdays (milligray - mGy)	Cumulative dose error for 14 procedures (mGy)	Dose for 1 procedure (mGy)	Dose error for 1 procedure (mGy)
Forehead	0.8	1.2	0.06	0.08
Thorax	1.3	1.2	0.1	0.08
Left hand	1.3	1.2	0.09	0.09
Right hand	1.7	1.2	0.13	0.09

Source: Prepared by the author based on the research results.

The maximum acceptable doses established by law are measured at a given tissue depth (no more than 1mm). Thus, the actual dose values in the professional are slightly lower than those obtained.

For the comparison with current legislation, an estimation was made considering a total of 16 procedures in 49 monitored days. By extrapolating the results for 1 year of work (without counting 30 days of vacation), 109 surgeries would have been performed; the doses obtained are provided in table 5. The results are presented in millisievert (mSv) (the conversion factor between mGy and mSv is equal to 1) for comparison with the annual limits established in the legislation.

Considering the annual dose estimation, the highest dose observed was in the chest region, followed by the limbs (right and left hands), lens and thyroid.

DISCUSSION

Comparison of the results obtained with standard CNEN 3.01[7] shows that the estimate of the effective dose for the whole body (thorax) (109±86mSv/year) was approximately 5 times higher than that recommended by the national legislation (20.0mSv/year). However, considering that the professional worked using a lead apron, which reduces the dose by 99.94% when functioning optimally, the estimated dose decreased to 0.07±0.05mSv/year, which is acceptable.

Expectations of equivalent doses for the limbs, observed in the left and right hands (79±55mSv/year) and thyroid (neck measurement with 61±99mSv/year), showed results within the current legislation (500 and 300mSv/year, respectively), even when the professional was not using a protective device. In turn, the equivalent dose for the

Table 4. Dose per critical target area, device B.

Device 1B	Cumulative dose for 2 workdays (milligray - mGy)	Cumulative dose error for 2 procedures (mGy)	Dose for 1 procedure (mGy)	Dose error for 1 procedure (mGy)
Forehead	1.3	1.2	0.66	0.58
Neck	1.1	1.8	0.56	0.9
Thorax	1.8	1.6	0.9	0.78
Left hand	1.1	1.2	0.54	0.58
Right hand	1.4	1.6	0.68	0.81

Source: Prepared by the author based on the research results.

Table 5. Annual dose estimation.

Area	Area (CNEN 3.01)	Dose	Dose estimation (millisievert – mSv/year)	Error (mSv/year)	Limit (mSv/year)
Thorax	Whole Body	Effective dose	109	86	20
Forehead	Lens	Equivalent dose	79	64	20
Neck	Thyroid	Equivalent dose	61	99	300
Left hand	Hands	Equivalent dose	70	64	----
Right hand	Hands	Equivalent dose	88	89	----
Limbs	----	Equivalent dose	79	55	500
CNEN (2014)[7]					

Source: Prepared by the author based on the research results.

lens (measured at the forehead), 79±64mSv/year, was 4 times higher than that indicated in the legislation (20.0mSv/year), and currently, physicians use no radiological protective device for the eyes.

Radiation doses to which medical staff are exposed during surgical procedures have been reported in other studies[4,5]. Palácio et al.[4] studied radiation exposure during surgical treatment of transtrochanteric fractures and concluded that the anatomical regions below the waistline were those that received the most ionizing radiation. Their results highlight the importance of the use of biosafety devices. Soares et al.[8] indicated that the use of a curtain-type lead protector on the sides of the operating table may reduce the radiation dose to the lower limbs by 64%. The present study did not evaluate the exposure to radiation in regions below the waistline; however, it showed that the thorax was the region exposed to the highest radiation, followed by the right (dominant) hand. It is believed that the dominant hand of the surgeon receives greater radiation exposure because it is in prolonged contact with the operating field and holds the patient's limb to obtain radiological images. Similarly, the thorax is closer to the radiation apparatus at the time of imaging.

Smith et al.[9] evaluated doses of ionizing radiation to the eyes, body and hands during orthopedic trauma surgeries. Their results showed that the maximum recommended dose did not exceed the recommendations in any area of the body. Torres-Torres et al.[10] also reported doses of radiation exposure during various orthopedic surgeries, with results below the recommended limit; however, the authors emphasized the need for the use of radiation protection measures, especially in the hands and eyes. Singh et al.[11] evaluated the annual radiation dose exposure (12 months) in the hands of orthopedists (foot and ankle specialists) and concluded that the doses were much lower than those considered safe by the legislation. This result is consistent with that found in the present study, in which the doses obtained at the limbs were approximately one-sixth of the stipulated limit. Leite et al.[12] reported that the estimated annual radiation exposure for orthopedists who operate close to the radiation beam was of 20.63 to 68.75mSv (gonads), 4.95 to 16.50mSv (lens) and 8.25 to 27.50mSv (hands). However, the authors concluded that the radiation levels to which physicians are exposed during orthopedic surgeries is considerable, which allows classifying these professionals as being exposed to unhealthy levels. This justifies the mandatory use of individual dosimetry and the adoption of radioprotection measures. In the present study, the doses to the hands of the surgeon were higher than those in the study cited above but still within normal limits. However, the dose to the lens was much higher, exceeding the recommended limits.

In the present study, the mean exposure to radiation was 23 s. La Salvia et al.[13] found a mean radiation exposure time of 61s in several orthopedic surgeries. According to the authors, the procedures involving intramedullary devices were those that required the most radiation. Crawley and Rogers[14] evaluated surgeries involving the internal fixation of ankle fractures and obtained an average time of fluoroscopy use of approximately 33s. Anatomical site, type and complexity of the surgery, quality of the fluoroscopy device and level of experience of the surgeon directly influence the time of surgical exposure to radiation. Thus, it is difficult to compare the radiation exposure time results from this study with those from other studies in the literature.

There is strong evidence of the deleterious effects of radiation on human health, including burns, poisoning and carcinogenic effects[1,3]. Although Mahajan et al.[5] found occupational doses within the allowed limits in their prospective study, they warned that nothing can be concluded about the stochastic effects of radiation. In another study, Noriega et al.[15] found alterations in thyroid-stimulating hormone levels during orthopedic spine surgery after 1 year of routine radiation exposure. Zadeh et al.[16] found higher levels of congenital malformations in children of doctors than in the remainder of the population. The authors, however, did not directly correlate these changes with X-ray exposure, reporting that other factors may be associated. There are probably deleterious effects of radiation on the human body that have not yet been discovered or proven. This fact reinforces the importance of using appropriate radioprotection materials and the need to follow recommended safety measures.

Given the risks associated with exposure to radiation, there is growing interest in new technologies capable of reducing radiation exposure without compromising surgical outcomes. Dawe et al.[17] compared the use of conventional fluoroscopy with mini C-arm in foot and ankle surgeries and concluded that its use reduces radiation emission and costs; they recommended its routine use. Giordano et al.[18] evaluated the use of the mini C-arm in upper limb surgeries and concluded that the medical team receives minimal doses of radiation when the device is used, unless a member of the team is in the direct trajectory of the radiation beam. Panchbhavi et al.[19] evaluated the use of fluoroscopy with the aid of a laser sight system in foot and ankle surgeries and concluded that the system increases the accuracy of intraoperative imaging, reducing radiation exposure.

Several authors have suggested protective measures to reduce the exposure of surgeons to radiation. Mesbahi et al.[20] reported that the exposure of the orthopedic surgical team was minimal when their distance from the enhancer was greater than 20cm. Singh et al.[11] suggested that the experience of the surgeon and the X-ray technician are important factors for reducing radiation exposure. As measures to reduce radiation exposure, Singer et al.[21] cited reduced time of use, increased distance from the X-ray beam, use of a lead apron, thyroid collar, lead gloves and goggles, beam collimation, use of a lower dose setting on the device, inversion of the side of the fluoroscope, and surgeon's control of the fluoroscope. As a protective measure, Herscovici et al.[22] suggested regularly calibrating the device, increasing the distance between health professionals and the X-ray beam, using radioprotection devices, and following radiological protection guidelines. Kalem et al.[23] evaluated the physical properties of fluoroscopy devices, such as the size of the enhancer and maneuverability, and concluded that these factors altered the surgical time and radiation exposure time during proximal femur fracture surgeries. Mechlenburg et al.[24] evaluated orthopedist exposure to radiation during periacetabular osteotomy surgeries. The authors concluded that the use of a lead collar reduced the incidence of radiation in the thyroid region but that the use of gloves with lead did not increase the protection of surgeons' hands. Another author, however, advocates the mandatory use of protective gloves because of a reduction of 75% of the dose to the hands when the surgeon is protected[25]. The data obtained in this study do not support the use of protective gloves because the radiation exposure levels at the limbs were well below the recommended limits.

In the present study, it was possible to verify that foot and ankle surgeons may be exposed, in their daily practice, to radiation levels above those recommended by the Brazilian legislation. The data obtained reiterate the need for the use of appropriate radioprotection attire during surgery as well as compliance with established health standards.

CONCLUSION

The results show that orthopedic surgeons who specialize in the foot and ankle are exposed, in their workday, to radiation doses higher than those considered acceptable, especially in the chest and eyes. The data corroborate the need for the use of radiological protective clothing, especially a lead apron and glasses. Radiological protection for the limbs does not seem to be necessary.

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