INTRODUCTION
Since Wilhelm Röntgen discovered x-rays in 1895, medicine has been using its benefits for diagnoses and therapy. In recent decades, ionizing radiation has been used more frequently, with the development of new diagnostic and therapeutic techniques. High quality images that allow quick and accurate diagnoses are considered indispensable nowadays in the clinical setting. The use of fluoroscopically-guided techniques in surgery has been increasing, and images in real time are now a vital tool for minimally invasive procedures. The International Commission on Radiological Protection states: “Interventional radiology offers to medicine in all countries, no matter the stage of development, the opportunity to treat a greater range of pathologies, in more patients and at lesser cost. Interventional techniques reduce the need for expensive operating suites and extended hospital in-patient admissions. They also reduce most of the risks to the patient by the use of minimally invasive techniques.

ABSTRACT
Objective: To evaluate the radiation dose received by staff in spine surgeries, including those who are not considered occupationally exposed workers. Methods: All spinal surgeries performed in the same department during a period of 12 months were evaluated with regard to the exposure of surgeons, scrub nurses, and auxiliary personnel working in the operating room to radiation from C-arm fluoroscopy. Radiation was measured by 15 film badge dosimeters placed on the professionals’ lapels, gloves, and room standardized sites. The films were analyzed in the dosimetry laboratory by collections per period. Results: During the 12 months, 81 spinal surgeries were performed by the same team, with surgical times ranging from 1 to 6 hours. The total radiation dose ranged from 0.16 mSv to 2.29 mSv depending on the dosimetry site. The most exposed site was the wrist of the main surgeon. Conclusion: The results showed that in the spinal surgeries in our setting, the radiation doses are low and within legal limits. Nevertheless, constant training of professionals is essential for radiation protection of medical staff and patients.

Keywords: Radiation. Absorption, Radiation. Radiation, Ionizing. Radiation Exposure. Radiation Dosage. Radiography.

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and through lesser requirements for general anesthesia.² As a consequence of the increasing use of imaging in the surgical setting, exposure times, and the radiation doses involved with the use of fluoroscopy, have been increasing too.³ It is known that frequent exposure to ionizing radiation can cause serious health effects. Therefore, the risk to which individuals are exposed during tasks involving ionizing radiation must be carefully considered by professionals who work with radiology, radiotherapy and nuclear medicine services.³⁵ In relation to the maximum amount of ionizing radiation to be used, there are principles that must be adhered to, in order to protect the patient. However, this dosage limitation does not apply to the exposure of medical staff to radiation. As a result, this exposure can be high in medical diagnosis, when compared with other medical procedures that use ionizing radiation. In fact, imaging exams are now the procedure that most contributes to radiation exposure.³ But there is a dose-response relationship between exposure to low doses of radiation and mortality, with significant increases in risk observed with doses of 100 to 200 mGy or higher.⁶ Ionizing radiation is used in a large number of procedures carried out in surgery centers. One such procedure is orthopedic surgery using the C-arm fluoroscope. The C-arm is essential in spinal surgeries, to guide the correct execution of the procedure. Despite the use of modern equipment with automatic control systems to limit exposure to radiation, which automatically adjust the voltage (kV), electrical current and exposure time (mAs) to compensate for variations in thickness and density of the tissues being observed, the resulting radiation dose is significant for the patient, and also for the staff involved in the surgical procedures.³⁴ Some studies have evaluated radiation doses in medical diagnoses and surgical centers, whether for patient, for occupationally exposed individuals (OIEs), or for the whole staff involved in the procedure. The majority of these studies either simulate surgical procedures or carry out the measurements during orthopedic or other procedures, in real time.⁷⁸ However, there are no studies in Brazil focused on surgeons’ exposure to ionizing radiation during surgical operations to the spine.

MATERIALS AND METHODS

This experimental study was conducted in the Spine Surgery Department of a large, public, university hospital in Brazil. The protocol was approved by the local ethics committee and all the participants (surgeons, technicians, nurses and auxiliary staff) involved signed informed consent forms for the radiation dose evaluations and inclusion in the study. All the spinal surgeries performed in the department over a twelve-month period were evaluated. The same fluoroscopy equipment was used in all the procedures. Radiation film badge dosimeters were attached to fifteen standard sites, and kept in operation throughout the surgery:

1. Standard
2. Surgical center 1 – operating room wall
3. Surgical center 2 – opposite wall of the operating room
4. Below the operating room table
5. Surgeon 1 - attached to the lapel, over the lead apron
6. Surgeon 1 - attached to the lapel, under the lead apron
7. Surgeon 1 - wrist
8. Surgeon 2 - attached to the lapel, over the lead apron
9. Surgeon 2 - attached to the lapel, under the lead apron
10. Surgeon 2 - wrist
11. Instrumentator (scrub nurse) - attached to the lapel
12. Resident - attached to the lapel
13. C-arm operator - attached to the lapel, over the lead apron
14. C-arm operator - attached to the lapel, under the lead apron
15. Auxiliary - in the C-arm

The C-arm operator and the surgeons 1 (main surgeon) and 2 (auxiliary surgeon) used two badges attached to the lapel, one over the lead cover and another underneath it, and one attached to the wrist, under the surgical glove. Care was taken to leave the movements of the hands and arms free. Figure 1 shows how the film badge dosimeters were attached to the staff members, and Figure 2 shows the operating room table and the attachment of the dosimeter to the wall. After each study period, the film badges were developed and analyzed in a radiology laboratory, and the following variables were recorded: date, procedure type and duration, voltage and electrical current of the C-arm, and the distances between the main beam of the C-arm and the professionals. These data were recorded on a filing card, as shown in Figure 3.

RESULTS

During the twelve-month period, 81 spinal surgeries were performed. The mean distances from the professionals to the radiation emission site during the procedures were almost the same in all procedures (Table 1). Table 2 shows data relating to the duration of surgery, and the voltage and electric current registered in the C-arm, which varied according to the type of surgery performed. The radiation doses recorded in the dosimeter devices over periods ranging from one to three months were grouped and analyzed in the laboratory. The results of each period are presented in Table 3. The total radiation doses varied from 0.16 mSv (under the lead apron) to 2.29 mSv (on the wrist of the main surgeon). The last column of Table 3 shows the cumulative dose for the entire study period of about a year. The highest estimated dose was indicated for the badge dosimeters placed over the lead cover of surgeons 1 and 2, the professionals who are positioned closest to the primary beam and the patients. In such cases the dose to the professional is lower due to the protection offered by the lead apron, as indicated by the dosimeters positioned below this protective covering.

Figure 1. Attachment of film badge dosimeters to staff member body: A: lapel; B: lapel under lead apron; C: lapel over lead apron; D: inside the surgical glove; E: under sterile surgical glove; F: position on the wrist.
DISCUSSION AND CONCLUSIONS

Exposure to radiation can be a cause of concern in spinal surgeries, which is a complex procedure usually involving six professionals in our service and lasting from one to six hours. Handling the fluoroscope potentially exposes surgeons to a radiation dose higher than the annual recommendation in orthopaedic procedures. A study on different types of surgery using fluoroscopy has shown that the total dose in orthopaedic procedures can reach 2.92 mGy/m², with an effective dose of 58.4 mSv. As pointed out by Anupam Mahajan et al., orthopaedic surgeons are not considered as to be workers exposed to radiation, and radiation is usually seen as an additional secondary occupational hazard for them. Still, there are non-surgeon personnel in the operating room, and these should receive monitoring and protection. An experimental study using phantom anthropometric figures and simulating the spinal surgery setting showed that scatter radiation

Table 1. Medium distance from the professionals to the radiation emission site during the procedures.

| Professional | Surgeon 1 | Surgeon 2 | Instrumentist | Resident | C-arm operator | Auxiliary |
|--------------|-----------|-----------|---------------|----------|----------------|-----------|
| Distance (cm)| 40        | 40        | 60            | 100      | 100            | 120       |

Table 2. Data collected during the procedures. Periods refer to the time taken for each batch of film badges to be taken to laboratory analysis.

| Procedure                  | Duration (h, min) | Electric tension (kV) | Electric current (mA) |
|----------------------------|-------------------|-----------------------|-----------------------|
| Period A: two months       |                   |                       |                       |
| Scoliosis                  | 1h10              | 75                    | 0.9                   |
| Lumbar arthrodesis         | 0h40              | 80                    | 0.9                   |
| Lumbar arthrodesis         | 2h20              | 80                    | 0.4                   |
| Period B: November, one month |               |                       |                       |
| Lumbar arthrodesis         | 1h10              | 82                    | 1.1                   |
| Lumbar arthrodesis         | 1h30              | 80                    | 1.3                   |
| Cervical arthrodesis       | 2h10              | 80                    | 1.1                   |
| Period C: one month        |                   |                       |                       |
| Lumbar arthrodesis         | 2h10              | 86                    | 1.4                   |
| Period D: one month        |                   |                       |                       |
| Lumbar arthrodesis         | 2h10              | 72                    | 2.0                   |
| Lumbar arthrodesis         | 2h50              | 72                    | 1.8                   |

Figure 2. Operating room bed, under which a film badge dosimeter was placed and the operating room wall with a dosimeter badge attached.

Figure 3. Filling card used to record the data.

C1 = Surgeon 1; C2 = Surgeon 2; INSTR. = Instrumentator (scrub nurse); RESID. = Resident; OPER. = C-arm operator; AUX. = Auxiliary.
Table 3. Results from radiation doses measurements per period (as indicated in Table 2); periods refer to the time interval for each batch of film badges to be taken to laboratory analysis.

| Professional | Dose (mSv) per period |
|--------------|-----------------------|
|              | A  | B  | C  | D  | E  | F  | G  | H  | Total |
| Standard     |    |    |    |    |    |    |    |    |       |
| Surgical center 1 – operating room wall | 0.06 | 0.03 | - | - | - | 0.08 | - | 0.17 |
| Surgical center 2 – operating room wall | - | - | 0.05 | 0.03 | - | - | 0.09 | 0.11 | 0.28 |
| Below patient bed | - | - | 0.8 | 0.44 | - | - | 0.19 | - | 1.43 |
| Surgeon 1 - attached to the lapel, over the lead apron | 0.15 | 0.13 | 0.05 | 0.08 | 0.03 | 0.05 | 0.41 | 0.29 | 1.19 |
| Surgeon 1 - attached to the lead apron | 0.02 | - | 0.02 | - | - | - | 0.03 | 0.09 | 0.16 |
| Surgeon 2 - attached to the lapel, over the lead apron | 0.02 | 0.07 | 0.05 | 0.21 | 0.06 | - | 0.29 | 0.12 | 0.82 |
| Surgeon 2 - attached to the lead apron | 0.02 | - | 0.02 | 0.04 | - | - | 0.06 | 0.60 | 0.74 |
| Instrumentator (scrub nurse) | - | - | - | - | - | - | 0.02 | 0.09 | 0.12 |
| Resident | 0.06 | - | 0.02 | - | - | - | 0.09 | 0.10 | 0.27 |
| C-arm operator - attached to the lapel, over the lead apron | 0.06 | - | 0.02 | 0.09 | - | - | 0.04 | 0.08 | 0.29 |
| C-arm operator - attached to the lapel, under the lead apron | - | - | - | - | - | 0.03 | 0.04 | 0.09 | 0.16 |
| Auxiliary | - | - | - | - | 0.07 | - | 0.13 | 0.04 | 0.24 |
| Surgeon 1 - wrist | 1.43 | - | 0.81 | - | - | - | 0.05 | 2.29 |
| Surgeon 2 - wrist | 0.10 | - | 0.13 | 0.07 | 0.02 | 0.02 | 0.03 | 0.59 |

Doses not mentioned are below the minimum detectable level (0.02 mSv).

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