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ORIGINAL ARTICLE

The Effect of Radiation Protection Provided by Lead Aprons in Orthopedic Theater

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ABSTRACT

Background: Orthopedic surgeons and operation staff are exposed to intraoperative radiation routinely because modern medicine is unthinkable without X-rays. Along with their advantages X-rays have also a harmful effect. This needs special care to be taken to protect from this radiation. Several factors that influence exposure risk have been identified including type of surgery, distance from radiation source, subspecialty practiced, and experience level of the surgeon. The aim of this study is to measure the effective protection provided by lead aprons and thyroid shields in orthopedic theater during surgical operations.

Methods: Radiation dose was measured during the use of a C-arm on an anthropomorphic lower thigh and proximal leg phantom on the operating table and scatter radiation exposure to multiple organs (thyroid, breast, gonads) and direct radiation exposure to the hands measured by Geiger Muller counter 300E plus (GMC300E plus) in different positions of the C arm and from different distances from radiation source.

Results: Scattered radiation exposure is higher when the C arm is in an inverted position and horizontal position when the Geiger is at the side of emitter and close to the C arm. Radiation exposure dose decreases as increasing the distance from the C arm. Lead aprons and thyroid shields decrease radiation exposure by approximately 90%.

Conclusion: The efficacy of radiation protection in orthopedic theaters is closely tied to the wearing of lead aprons, including thyroid shields, and the positioning of both the surgeon and the surgical staff in relation to the C-arm. Conversely, radiation exposure tends to increase when the C-arm is inverted or positioned horizontally.

Key words: Radiation exposure; Protective measures; C-arm positioning and scatter radiation

INTRODUCTION

The use of radiation in orthopedic operating theaters has raised concerns about the potential harmful effects of radiation exposure on medical staff. Several studies have focused on evaluating radiation exposure and the effectiveness of radiation protection measures in orthopedic theaters. The aim of these studies is to determine the amount of radiation exposure, assess the knowledge and practice of radiation safety among orthopedic surgeons and theater staff, and evaluate the effectiveness of radiation protection measures, such as lead aprons, in minimizing radiation exposure [1].

Understanding the Effects of Radiation is pivotal to appreciating the risks involved. Ionizing radiation can elicit pathologic effects categorized as deterministic or stochastic. Deterministic effects manifest as short-term responses, triggered only after a specific threshold of radiation exposure is reached. Examples include hair loss, skin erythema, burns, and cataract formation. Stochastic effects, on the other hand, exhibit an increase in incidence with exposure, particularly associated with issues like carcinogenesis and teratogenesis [2].

When it comes to orthopedic procedures involving intraoperative imaging, both surgical staff and patients are inevitably exposed to radiation. Direct radiation, absorbed as the beam projects from the source, predominantly affects the patient and surgeon. In contrast, scatter radiation, deflected off surfaces, becomes the primary source of exposure for operative staff positioned farther from the surgical table [2] .

Understanding the risks, the International Commission on Radiological Protection (ICRP) establishes recommended annual occupational exposure limits. For occupational exposure, the ICRP suggests a maximum average of 20 mSv per year over five years, with no exposure exceeding 50 mSv in a single year. For the general public, the limit is strictly set at a maximum average of 1 mSv per year over a 5-year period [3]. The World Health Organization recommends investigation when monthly exposure reaches specific levels for effective dose, the lens of the eye, or extremities [4].

To effectively reduce scatter radiation doses, three critical factors come into play: time of exposure, distance from the radiation source, and shielding. The most important among these factors is proper shielding [5] .

Lead aprons, typically 0.25 mm lead-equivalent, provide significant attenuation, with the most commonly used types attenuating 90% and 99% of radiation for 0.25-mm and 0.5-mm aprons, respectively [3]. Sterile radiation reduction gloves have been instrumental in reducing operator extremity dose during fluoroscopically guided procedures [6]. The principal disadvantage of leaded eyeglasses is their weight and discomfort [7].

Despite their weight and discomfort, wearing lead glasses is crucial to protecting the lens of the eye, the most radiation-sensitive part of the body [5].

In the pursuit of safety, the introduction of Geiger Muller counters provides a means of monitoring radiation exposure. Comprising a Geiger-Muller tube, high voltage supply, scalar, and timer, these counters offer a methodical approach to measuring and recording radiation levels [8]. This study aims to measure the effective protection provided by lead aprons and thyroid shields in the orthopedic theater during surgical operations.

MATERIALS AND METHODS

This experimental study was conducted at Baghdad Medical City/Nursing Home Hospital/center of Iraqi Board Education from September 2020 to October 2021.

The study focused on the use of C-arm fluoroscopy, specifically the OEC 9900 Elite manufactured in April 2018, housing model type 5335464/MX80 125 kV, located in the orthopedic operative theatre.

The chosen radiation detector sensor, GMC-300E Plus, manufactured in the USA, was deemed suitable for our measurements. To counteract radiation exposure, a lead apron (Mavic 0.25 mm thickness) and a thyroid shield (0.5 mm thickness) were employed, with a double layer of the lead apron for an enhanced lead equivalent of protection (0.5 mm

For the experimental setup, we utilized a phantom lower thigh and upper leg simulator filled with foam.

The radiation dose is measured by special radiation detector GMC-300E plus which is applied on trolley put on a measured levels and distances from C arm with and without using lead aprons

In the experimental setup where the C-arm is positioned vertically, two configurations were examined. In the first scenario, the radiation emitter (tube) was positioned downward, while the image intensifier (receiver) was elevated. The operational parameters included an operative table level of 100 cm, a simulator level of 130 cm, intensifier level from the ground at 140 cm, emitter level from the ground at 50 cm, Kv of 75, and mAm of 1.6.

In the second scenario, the tube was positioned upward, and the receiver was lowered. The operational parameters for this configuration were consistent with the previous setup, except for the intensifier level, which was at 80 cm, and the emitter level, which was at 160 cm.

To assess radiation exposure, measurements were taken using a Geiger counter at various levels, including the thyroid gland, xiphisternum, groin, and over the operative table for exposed hands **(Figure 1)**.

Two sets of readings were obtained: the first without a lead apron and the second with the application of a lead apron in front of the Geiger. Multiple readings were taken at each level, and the average was calculated. The results from the two groups were compared, and statistical analysis, using an unpaired t-test, was performed. The percentage of decreased radiation exposure was determined using the formula:

$$\text{\% of decreased radiation} = \frac{unprotected - protected}{unprotected} x100\%$$

Additionally, in the third scenario, radiation exposure was measured at different distances from the C-arm (one meter, two meters, three meters) with the Geiger placed on a special holder at the xiphisternum level **(Figure 2)**. The procedure was conducted both with the tube down/intensifier up and with the emitter up/intensifier down configurations. Measurements were taken initially without a lead apron and then repeated with the lead apron. Statistical analysis and percentage calculation were performed to compare the results.

In the case of C-arm horizontal positioning, two scenarios were examined: with the Geiger at the side of the image intensifier and with the Geiger at the side of the emitter. Operational parameters were consistent across both scenarios, and radiation exposure measurements were taken at different distances from the C-arm using a Geiger placed on a special trolley **(Figure 3)**. The procedure involved measurements without a lead apron and with a lead apron, and comparisons were made between the two groups.

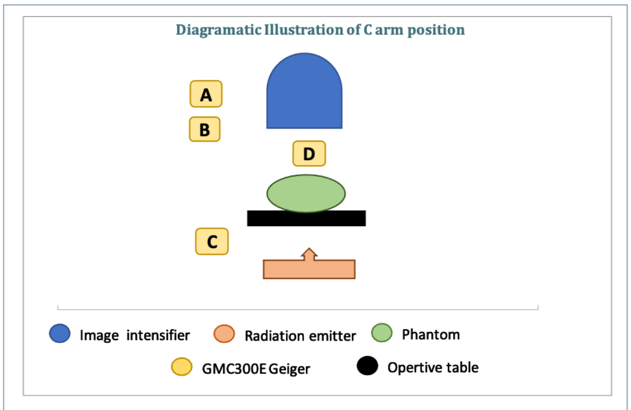

Figure 1. Diagramatic Illustration of position of C arm and Geiger C arm vertical, image intensifier up/emitter down. Geiger is close to C arm and at different levels for thyroid (A), xiphisternum (B), groin (C), hand (D).

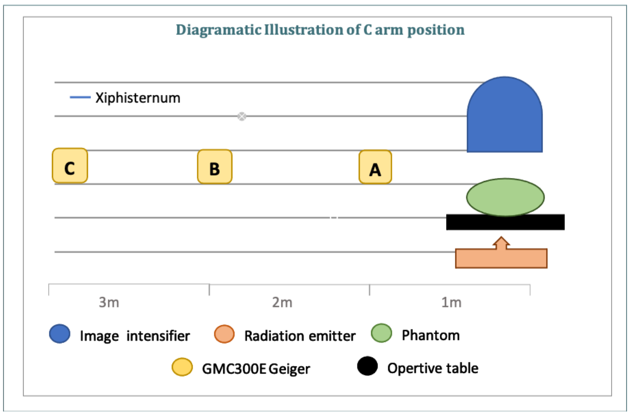

Figure 2. C arm vertical and Geiger at different distances

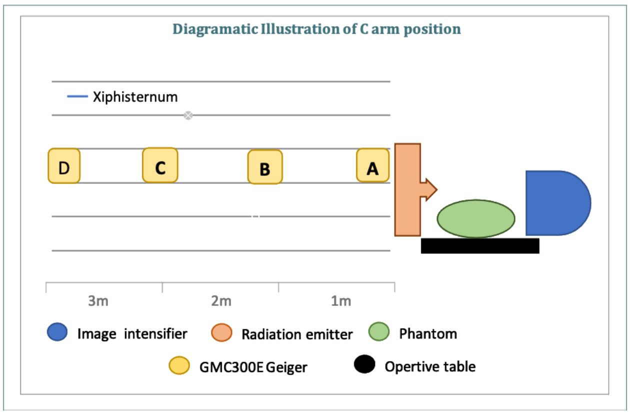

Figure 3. C arm horizontal/Geiger at different distances from C arm

†Unpaired t test
*hands unprotected by lead apron because lead impregnated gloves not available in the hospital. N/A=not applicable

RESULTS

When the C arm is vertical (intensifier up / emitter down) radiation dose measured with and without lead apron, A high radiation exposure measured when unprotected, especially for the hands level which are under the path of radiation beam and exposed to direct radiation.

After applying a lead apron in front of Geiger the radiation exposure decreased significantly by 89% but this is not applicable for hands because lead impregnated gloves are not available in our hospital **(Table 1)**.

Inverting the position of the C arm resulted in higher radiation exposure when Geiger is close to the C arm. But the exposure decreased significantly by 90% - 92% after application of lead apron **(Table 2)**.

When the C arm is horizontal and the Geiger is at the side of emitter, there was significant increase in radiation exposure while without protection and decreased by 90% after application of lead apron **(Table 3)**.

Increasing the distance between C-arm and Geiger which is fixed at xiphisternum level, a significantly decreased radiation exposure was measured in spite of without protection, for both vertical and horizontal positions **(Tables 3, 4)**.

Table 1. Average radiation values in different positions with and without a lead apron during C-arm vertical orientation (emitter down/intensifier up).

Levels	Average of radiation exposure Without lead apron in μSv	Average of radiation exposure with lead apron in μSv	Percentage of decreased radiation exposure	P value †
Thyroid	0.95	0.10	89.4%	**<0.001**
Xiphisternum	0.87	0.09	89.6%	**<0.001**
Hand*	2.24			N/A
Groin	0.86	0.11	87%	**<0.001**

†Unpaired t test
*Hands unprotected by lead apron because lead-impregnated gloves were not available in the hospital. N/A=not applicable

Table 2. C arm vertical/tube up-receiver down/ Geiger close to the C arm.

levels	Average of radiation exposure Without lead apron in uSv	Average of radiation exposure with lead apron in uSv	Percentage of decreased radiation exposure	P value †
Thyroid	1.90	0.17	91%	**< 0.001**
Xiphisternum	1.96	0.18	90%	**<0.001**
Hand*	3.15			N/A
Groin	1.78	0.13	92 %	**<0.001**

†Unpaired t test
*hands unprotected by lead apron because lead impregnated gloves not available in the hospital. N/A=not applicable

Table 3. C arm horizontal/Geiger at the side of emitter(tube), at the level of xiphisternum, from different distances .

Distance In meter	Average of radiation exposure Without lead apron in uSv	Average of radiation exposure with lead apron in uSv	Percentage of decreased radiation exposure	P value †
Close	3.52	0.40	88%	**<0.001**
1 m	1.84	0.21	89%	**<0.001**
2 m	0.85	0.08	90%	**<0.001**
3 m	0.44	0.04	91%	**<0.001**

†Unpaired *t* test

Table 4. Variations in C-arm vertical orientation, tube down, intensifier up, and Geiger position at xiphisternum level across different C-arm distances.

Distance In meter	Average of radiation exposure Without lead apron in uSv	Average of radiation exposure with lead apron in uSv	Percentage of decreased radiation exposure	P value †
1 m	0.68	0.07	89.9 %	**<0.001**
2 m	0.48	0.05	89.9 %	**<0.001**
3 m	0.34	0.03	91.3 %	**<0.001**

†Unpaired *t* test

DISCUSSION

The use of fluoroscopy in orthopedic surgery exposes medical staff to radiation, making the use of lead aprons a crucial protective measure. In this study, we conducted a thorough evaluation of radiation exposure levels at various anatomical locations, including the thyroid, xiphisternum (thymus), groin, and hands, during orthopedic operations utilizing C-arm fluoroscopy. Our assessment, performed using a radiation dosimeter (GMC-300E plus), aimed to not only measure exposure levels but also explore the efficacy of radiation protection provided by lead aprons in the orthopedic operating theater.

In current study when the C arm set in vertical position and the emitter down/image intensifier up, without application of lead apron, the thyroid, xiphisternum, and groin are exposed to scattered radiation while the hand position (on operative table) exposed to direct radiation and a high radiation dose levels measured by the Geiger specially for hand level and this is comparable with Martin et al study [9]. When the lead apron applied in front of the Geiger, the radiation dose exposure decreased significantly for scattered radiation but not to hand level which is exposed to direct radiation because the hands are positioned through the path of radiation beam and unprotected by lead apron because lead impregnated gloves not available in our hospital, this finding comparable with the study of Ivanova et al [10] .

Concerning radiation exposure in the orthopedic operative theater, the surgeon experienced higher radiation exposure compared to the assistant. This discrepancy arises from the surgeon's close proximity to the C-arm, in contrast to the considerable distance maintained by the assistant. Our study revealed that increasing the distance to one meter from the C-arm did not result in a significant change in radiation exposure. However, extending the distance to two meters led to a noteworthy decrease in radiation exposure, even without the use of a lead apron. This finding aligns with previous studies by [11–13], Furthermore, upon the application of a lead apron, there was a highly significant reduction in radiation exposure for both one-meter and two-meter distances. This observation is consistent with the findings of Roman A. et al

[14] .

When the C arm in horizontal position and the Geiger at the side of emitter at the level of the xiphisternum and close to the C arm there was a very high measures of radiation detected when no lead apron was applied, and this is comparable with Rhea et al [15]. In our study, after application of lead apron there was 88% decrease of radiation exposure.

Roman A. et al study [14] found that a surgeon or operative staff standing at the site of emitter are exposed to radiation by four to eight fold than standing at the side of intensifier and this is comparable with our study in which 3.52 uSv measured when the Geiger was at the side of the emitter and 0.84 uSv when the Geiger at the side of the intensifier without protection, and 0.4 uSv,0.1 uSv respectively after protection with lead apron.

When the C-arm is inverted (emitter up/intensifier down) with the Geiger close to the C-arm, the Geiger measures a high radiation dose for all levels when unprotected by a lead apron. This indicates increased exposure to scattered radiation, aligning with findings from Lee et al's study [16], which reported decreased scatter radiation with the emitter positioned below the torso.

Pancholy SB et al [17] identified a strong relationship between the object's distance from the X-ray source and radiation exposure burden, supporting our own findings. Similarly, Zuguchi et al [18] and Goodman et al [19] focused on the three-point policy of radiation protection for staff: reducing exposure time, increasing distance from the radiation source, and using radiation shielding, which is consistent with our study.

Maghrabi et al [20] discovered that the effectiveness of a protective garment lies in its ability to balance the needs of the individual and its required functionality, a conclusion that aligns with our study.

CONCLUSION

The efficacy of radiation protection in orthopedic theaters is closely tied to the wearing of lead aprons, including thyroid shields, and the positioning of both the surgeon and the surgical staff in relation to the C-arm. Conversely, radiation exposure tends to increase when the C-arm is inverted or positioned horizontally.

ETHICAL DECLARATIONS

- **Acknowledgements**

None.

- **Ethics Approval and Consent to Participate**

Not required.

- **Consent for Publication**

Not applicable.

- **Availability of Data and Material**

No patient data are presented in the study.

- **Competing Interests**

The authors declare that there is no conflict of interest.

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- **Authors' Contributions**

All stated authors contributed significantly, directly, and intellectually to the work and consented it to be published.

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