C-Arm orientation during back pain procedures

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Abstract: This study attempted to determine radiation dose levels around the operating theatre table, on either side of the C-Arm, in order to establish if the radiation dose received by staff during back pain procedures fell within the limits set by the International Commission of Radiological Protection (ICRP). The question that arose from this goal was whether the stance of staff, in relation to the x-ray tube side of the C-Arm, influenced radiation dose levels. In order to apply the 'As-Low-As-Reasonably-Achievable' (ALARA) principle, the possibility of lowering the radiation dose in the neurological operating theatre was explored. The methodology of the study was twofold: measurements were executed by means of thermoluminescent detectors (TLD) as well as with an ionisation chamber. The measurement values resulted in a proposed protocol in terms of positioning of staff and orientation of the C-Arm in order to apply the ALARA principle during back pain procedures. Constant revision of protocols is the responsibility of the radiographer in order to guarantee that the ALARA principle is implemented in every unique situation.

Keywords: ALARA, back pain management, ionising radiation protection, back pain fluoroscopy protocol.

Introduction

Having worked as a radiographer in an operating theatre of a private hospital during the course of the last four years, the investigator observed that some of the staff members, namely the neurosurgeons, nurses, assistant nurses and the anaesthetists in theatre, were reluctant to make use of protective clothing against radiation during fluoroscopy procedures. Despite the fact that they are aware that wearing a lead (Pb) rubber apron during fluoroscopy is a legal requirement, whenever the matter of protection against radiation exposure was mentioned, the immediate response was that studies in the past have shown the radiation during fluoroscopy to be insignificant. However the opposite of this is documented in the literature. For example, due to the cumulative effect of ionising radiation, staff members who are chronically exposed to low doses of radiation are vulnerable to the stochastic effect of radiation [1]. Some staff members preferred the risk of exposure to radiation to the backache caused by the heavy lead rubber aprons [2]. Those who were willing to wear lead rubber aprons chose only half body protection because they were of the opinion that the full body aprons were too bulky and heavy.

The current study was conducted to determine the ionizing radiation level distribution during fluoroscopy. In addition, confirmation that the C-Arm operation maintains radiation dose to staff within the safe limits according to the international standards as set by the International Commission of Radiological Protection (ICRP), was sought. The objective was to propose specific protocols in a neurological operating theatre during back pain management procedures with regard to the position of the C-Arm in relation to the neurosurgeon and other staff to apply the 'As-Low-As-Reasonably-Achievable' (ALARA) principle.

Sampling, statistical analysis, method of the research and the importance of protection against ionising radiation, are discussed in this paper.

- Sampling: Staff members exposed to radiation dose during fluoroscopy back pain procedures in the operating theatre in this study included two neurosurgeons, two nurses, two nursing assistants, two anaesthetists and two radiographers. The aim was to include 40 patients undergoing treatment for back pain by means of fluoroscopic interventions in the study.
- Statistical analysis: Biostatisticians of the Department of Biostatistics, University of the Free State (UFS), analysed data by means of the computer software package, SAS 9.1.3 Service pack 3. A comparison between the doses received by the neurosurgeon on each side of the C-Arm, namely tube or image intensifier (II), were analysed.
- Ethical aspects: Consent from the patient was not required since the patient-related information was confidential. The study did not influence the radiation dose to patients in any way as the standard imaging protocols were adhered to. The ethics committee of the UFS confirmed that the ethical principles of the extended study fell within the accepted standards (ETOVS NR 155/06). Permission from the hospital management, the operating theatre management, the neurosurgeon and staff in the specific theatre, was obtained.
- Protocol design background: The measured radiation distribution, together with guiding principles from literature, were used to propose a protocol for C-Arm orientation and staff positioning during back pain management procedures for this specific theatre.

(i) C-Arm orientation

Fluoroscopy training recommends positioning of the x-ray tube with the image intensifier (II) above the table [3]. The American Association of Physicists in Medicine (AAPM) report also indicated that the radiation dose on the II side during the lateral view might have a five times lower value than on the x-ray tube side. The difference can be ascribed to the three times higher scatter radiation from the patient on the entrance surface than from the exit surface of the patient [4]. It is also important that the II is positioned as close to the table and thus to the patient, as possible [5]. In the theatre that was utilized for the current study, however, the theatre table did not accommodate the x-ray tube positioning under the table comfortably during back pain management procedures. The main reason was that, with the available theatre table, the x-ray tube was close to the patient if positioned under the table, causing a magnified view of the spine. To address the magnification, the table had to be elevated. However, due to the increased table height, it became rather challenging for the neurosurgeon to administer spinal injections. The bulkiness of the II above the table then obscured comfortable viewing of the monitor. The II was not positioned close to the patient because the neurosurgeon preferred the space for the sterile needle placement with resulting magnification of the spinal image. The C-Arm adjustment from the AP position to the lateral position was time-consuming because the C-Arm had to slide through the arc under the table. The table had to be raised to an even higher level to make adjustments under the table possible for the lateral position. Adjustment of the C-Arm over the patient into the lateral position as a second option meant that the C-Arm had to be removed from under the table and the table had to be lowered again. Besides the fact that this maneuver was time consuming, the sterile area was, as a result of this, a point of concern. These circumstances resulted in the x-ray tube, prior to this study, being routinely positioned above the table (over couch) which was not in keeping with recommendations.

(ii) Positioning of the staff

It is important to note that it was difficult for the neurosurgeon to position himself close enough to the patient on the console side of the C-Arm in the AP/PA or oblique position due to the space occupied by the arc of the C-Arm on the console side. The neurosurgeon preferred to stand opposite the radiographer, away from the console side of the C-Arm because there was more space on the opposite side for the sterile trolley with the syringes and needles positioned close to him. According to theatre protocol, the radiographer also needed space to alter the C-Arm position and had to be at a distance of 30cm from the sterile trolley. It was thus not only more comfortable, but practical to have the neurosurgeon opposite the console side.

The custom-manufactured screening table accommodated the movement of the C-Arm through its arc underneath the table. With the placement of the II above the table during the AP view, the x-ray tube side was altered to the lateral position underneath the table; the x-ray tube was on the neurosurgeon's side during the lateral view. For the duration of the study the neurosurgeon remained on the x-ray tube side of the C-Arm without walking around to the II side when the x-ray tube was adjusted in the lateral position. The TLD dose to the neurosurgeon's hand and body was still lower, considering his position close to the x-ray tube in the lateral position, than with the x-ray tube above the patient during the PA views. It would however be ideal to minimise the dose to the neurosurgeon in total by changing his position to the other side of the table during the single injection in the lateral position. The dose is lower in the lateral position on the II side, as confirmed by the lateral measurements of the ionisation chamber.

(iii) Why protect against radiation?

The goal of radiation protection is to keep exposures set in accordance with ALARA. The reason is based on the assumption that risks of radiation increase with dose and there is no threshold dose below which risks cease to exist [6]. Stochastic (probabilistic) effects cannot be ruled out at low levels of radiation exposure. This statement implies that there is no safe dose below which the stochastic effect cannot appear. It means that any radiation dose will amplify the cancer risk thus all radiation must be kept to a minimum [7].

There are several advisory bodies that issue recommendations regarding radiation protection. The two most widely known agencies are the National Council on Radiation Protection (NCRP) and the ICRP [4]. The South African Department of Health (DoH), Directorate Radiation Control, accepted the conditions, stated by the ICRP regarding the policy on protective clothing [8]. The conditions stated by the ICRP Publication 57, paragraph 174 (1998), dictate that workers should wear a protective apron of at least 0.25 mm lead equivalence when in the area where the x-ray machine is operated. Any person standing within one metre of the x-ray tube when the machine is operated at tube voltages above 100 kV should wear a protective apron of at least 0.35 mm lead equivalence.

Method

The first part of the measurement entailed the utilization of thermoluminescent detectors (TLD) to determine the dose that the neurosurgeon, the radiographer and the patient received. TLDs were placed on the pelvis, chest and finger in the beam of the neurosurgeon during back pain procedures. TLDs on the chest and pelvis of the radiographer determined radiation levels close to the x-ray source opposite the neurosurgeon. TLDs on the patient recorded the radiation dose to the area of the patient which was irradiated. Exposure factors, patient size and the number of injections (hits) were recorded for future reference.

The second sets of measurements utilized an ionization chamber and a phantom to simulate a patient. Radiation dose was measured around the x-ray source and fluoroscopic table by placing the ionization chamber at fixed 25 cm intervals around the table, altering the height of the chamber to 110 cm and 133 cm respectively from the floor. The ionization measurements were repeated with the C-Arm in the anteriorposterior (AP), the oblique and the lateral positions. The phantom, simulating a patient, was positioned in a prone position.

Results

The procedures of this current study mostly consisted of lumbar facet injections with the C-Arm in the PA and both oblique positions combined with a lateral position during the caudal injection of thirty-nine patients. However, the injections differ for each patient. The neurosurgeon, for instance, may determine that for the specific patient's pathology, the radio frequency option is the procedure of preference. During radio frequency procedures for neurosurgeon #1 no caudal injection was administered. The C-Arm was only positioned in the PA position because no lateral view was necessary. The radio frequency routine of neurosurgeon #2 comprise PA, oblique and lateral projections routinely combined with sacrum-iliac (SI) joints injections. This work routine resulted in more hits, namely three for each SI joint and one for the caudal, per patient.

Median dose values of the staff with the x-ray tube and II respectively above the theatre table measured with the TLDs are presented below.

- The median values of the radiation doses to the neurosurgeon's chest (Figure I) were 2.02mSv (0.2mSv per patient), with the x-ray tube positioned above the table and 0.48mSv (0.04mSv per patient) with the II above the table (p-value=0.02). The median radiation doses to the pelvis areas were 2.3mSv (0.23mSv per patient) with the x-ray tube above and 0.96mSv (0.09mSv per patient) with the II above the theatre table (p-value=0.12).
- The radiographer was positioned on the console side of the C-Arm. The median value of the radiation dose to the radiographer's chest area was 0.14mSv with the x-ray tube side above the table and 0.29mSv with the II above the table (p-value=0.77). The median value of the radiation dose to the radiographer's pelvis was 0.29mSv with the x-ray tube above the table and 0.28mSv with the II above the table (p-value=0.7).
- The dose to the neurosurgeon's hand, as indicated in Figure 2, confirmed a lower dose on the II side of the C-Arm. The median value of the radiation dose to the neurosurgeon's finger was 65,68mSv with the x-ray tube positioned above the theatre table and 0.84mSv with the II positioned above the table (p-value=0.12).
- Due to the sample size, the p-values < 0.15 could be an indication of statistical significance. The radiation dose to the hand is of importance during the PA and oblique views because, with the lateral view, the hand was not directly positioned in the x-ray beam, as was the case with the PA and oblique views. The median ionizing radiation dose to the neurosurgeon's hands was 78 times less on the II side if values of 6.6mSv per patient on the x-ray tube side of the C-Arm, were compared to 0.08mSv to the hand on the II side of the C-Arm.
- The median dose values of the neurosurgeon's finger, pelvis and chest area are a confirmation that during back pain management procedures the x-ray tube side of the C-Arm must be positioned under the theatre table to lower radiation to the neurosurgeon.

The ionization chamber measurements were executed with the x-ray tube above the table; the C-Arm x-ray tube side was routinely placed above the patient, that is PA, during back pain management procedures before the current study. The ionization chamber measurements with the C-Arm in the PA position indicated that the values were higher closer to the x-ray source at the 133 cm height from the floor than at the 110 cm height. The radiation dose measured on the x-ray tube side, during the oblique views, was higher at the x-ray tube side of the C-Arm compared to the II side. Since the x-ray tube was positioned above the table, the higher values were recorded at the 133 cm height, when the x-ray tube was closer to the neurosurgeon's chest with the C-Arm in the oblique position. It should be noted however that the dose values will change when the C-Arm is adjusted through the arc to the other side. The ionization chamber measurements, with the x-ray tube in the lateral position, indicated a difference of less than five times on the II side. For the lateral views, the values were higher on the height of 110 cm from the floor compared to the 133 cm height. In order for the neurosurgeon to be able to execute injections into the facet or SI joints he is positioned close to the x-ray tube and the patient during back pain management procedures. Application of the ALARA principle underpins the placement of the neurosurgeon in relation to the II side of the C-Arm and is a matter of meticulous thought and planning. The researcher's opinion is that the

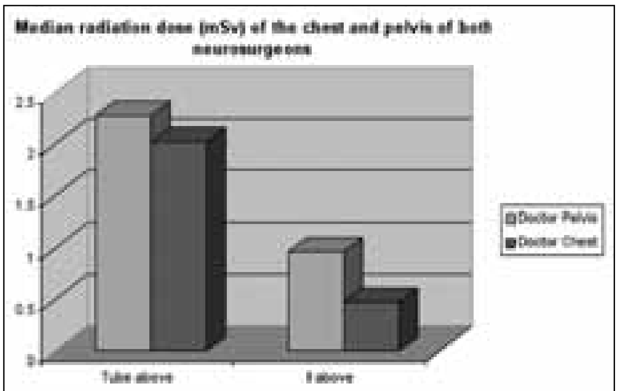

Figure 1: The pelvis and chest dose values of the neurosurgeons with x-ray tube and image intensifier (II) respectively above the table

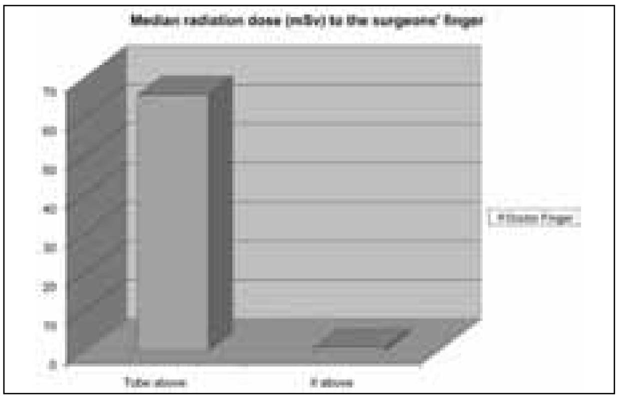

Figure 2: The finger dose values of the neurosurgeons with the x-ray tube and II respectively above the table

neurosurgeon who monitors injections with fluoroscopy cannot totally avoid ionizing radiation during back pain management procedures due to the close proximity of the x-ray source and patient.

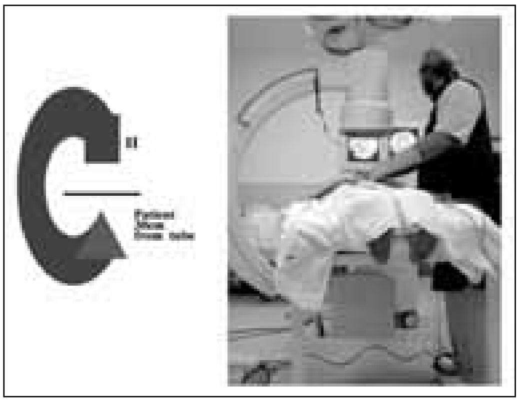

Figure 3: Ideal AP positioning of the C-Arm with the II above the theatre table

Discussion

A special fluoroscopy table, specifically for back pain procedures, was manufactured as an initiative by the nursing staff in this theatre. This table allowed effortless movement of the C-Arm arc under the table and ease of positioning of the x-ray tube under the patient. The table height was fixed throughout the procedure, saving time while adjusting positions for the purpose of this study. The sterile area was not compromised. The table made it possible to position the x-ray tube under the table during back pain procedures.

No additional pads for patient comfort were placed between the patient and the table, except sponge pillows. The proposed protocol focuses on the position of the C-Arm, recommended areas for staff in theatre and, radiation protection measures.

- AP position : the ideal is to position the II above the patient, as close as possible to the patient without hampering needle placement into the facets of the spine. It is important to make sure that the x-ray tube is at a distance of 30 cm from the patient under the table. In view of the height of the customized table in this specific theatre, the x-ray tube can be placed at a 30 cm distance from the patient. Figure 3 indicates the position of the neurosurgeon, the monitor and the C-Arm position. The nurse is not close to the table. The position of the C-Arm refers to the x-ray tube over couch (PA) or x-ray tube under couch position (AP). The II must be positioned above the patient during back pain management procedures for the AP and oblique positions.
- Oblique position: the ideal is to position the II above the patient, as for the AP view. The neurosurgeon stands as close to the II as possible. In this specific theatre both oblique views were used during the procedure. It was impractical to make the neurosurgeon move over to the opposite side when the II was altered so as to be further away from the neurosurgeon. The neurosurgeon in this specific theatre remained on one side but the dose values were still lower than with the x-ray tube above the table. Figure 4 illustrates the oblique position of the C-Arm, as well as the respective positions of the neurosurgeon, the radiographer and the monitor. The II is positioned as close to the patient as possible.
- Lateral position: The ideal position of the radiographer and the neurosurgeon in relation to the C-Arm during lateral views is shown in Figure 5. The neurosurgeon must be on the II side of the C-Arm so as to adhere to the ALARA principle. During procedures such as laminectomy or spinal fusion operations, fluoroscopy is utilised to determine the level of operation or screw placement. Only lateral views are normally required and the radiographer must plan in advance to position the C-Arm with the II side closest to the neurosurgeon and the scrub nurse.

Figure 4: Ideal oblique positioning of C-Arm with the II above the theatre table

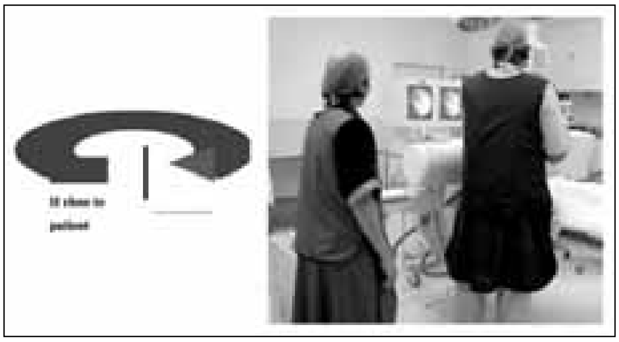

Figure 5: Ideal lateral positioning of the C-Arm with staff on the II side

Recommendations

(i) Areas for staff in theatre

The ideal is to place the radiographer and the surgeon on the console side of the C-Arm but the sterile trolley and arc of the C-Arm make this positioning impractical, as discussed previously. The neurosurgeon may operate on the side opposite the console in the AP and oblique views and, during the time taken for the radiographer to position the C-Arm in the lateral from the AP, the neurosurgeon can walk around for the lateral injection.

The anaesthetist is normally placed at the head of the table in order to monitor the patient. It is possible to position the anaesthetist and corresponding equipment closer to the II side of the C-Arm during back pain management procedures. Another option would be to position the anaesthetist behind the ventilation machine or to place an extra lead barrier, in the form of a lead rubber apron hanging over a drip stand, between the anaesthetist and the x-ray source, as shielding from the x-ray radiation.

Nurses in the room must be positioned on the II side during the lateral view and also at a distance not closer than 2 m to the x-ray source with a 0.25 mm lead (Pb) equivalent apron. The nurse closest to the table should make use of a lead rubber apron with a 0.35 mm Pb equivalent during back pain management procedures.

(ii) Radiation protection measures

Radiographers should encourage only the necessary staff to be present during the fluoroscopy procedures in theatre to adhere to the ALARA principle. Staff need to comprehend the principle of no minimum safe dose [7]. The staff present should wear full body lead rubber aprons (0.25 mm Pb equivalent) and thyroid shields, as stipulated by law. Since a difference in dose measured to different heights varied with the altering of the C-Arm position, half-body protection is not negotiable. Each permanent worker in the theatre must be issued with a TLD. Lead rubber gloves will give extra protection to the neurosurgeon's hand close to the x-ray field but may not be practical to use due to the weight of glove as well as the need for sterility of the injection area during the procedure. For these specific cases, sterile, flexible gloves (with a lead equivalent) are available in the market. Pulsed fluoroscopy can be considered during placement of the needle to lower the dose to the hand.

(iii) Fluoroscopy

The principles of radiation safety are time, distance and shielding [6]. The most effective way to reduce patient exposure to ionising radaition is to use less fluoroscopic time. This will benefit all because the dose to the staff is reduced when the dose to the patient is reduced [6]. Fluoroscopy machines are equipped with a timer and an alarm which sound at the end of every five minutes fluoroscopic usage [9]. Radiation dose can be lowered by limiting exposure times [4]. Exposure rate from a point source or radiation decreases as the distance from the source is squared [6]. The inverse square law is of the utmost importance during fluoroscopy since doubling the distance from the radiation source decreases the radiation level by a factor of four. Scattered radiation from the patient and tabletop are also sources of radiation exposure. The radiation intensity is 0.1% when the neurosurgeon is placed one meter from the patient at 90 degrees to the incident beam. Staff should be as far as possible from the x-ray source. Verbal warnings must be given that fluoroscopy is in progress before the fluoroscopy button is activated so that staff are aware that precautions should be taken to reduce unnecessary dose.

Several factors should be considered when implementing the proposed protocol in order to lower the fluoroscopy radiation dose during back pain management procedures. Image detail, for example, can be improved by increasing kV, decreasing the distance between the patient, the II and the x-ray beam collimation. Higher kilovotage (kV) values produce brighter fluoroscopy images. Radiographers should remember that the clearest images may produce the highest doses, but with an increase in kV and with lower miiliamperes (mA), the same quality may be produced at a lower dose. Radiographers and surgeons must learn to work with imperfections which still allow the needed clinical outcome as 'noise is good' [10]. High kV and low mA are preferred in fluoroscopy to produce acceptable images with low patient radiation exposure [4].

The x-ray tube current (mA setting) controls the quantity of x-rays produced per unit of time. When mA is doubled, the exposure to the patient and the staff will double. Patient size should be taken into account: larger patients receive higher doses [11]. All fluoroscopic parameters and radiation duration must be recorded at all times. One should calibrate the monitor conditions for the specific environment due to the fact that good lighting for surgical needs must be balanced with imaging considerations [9]. Patient dose can also be reduced by other factors, such as filtration in the unit. Filtration can remove the low energy x-rays before they reach the patient since the low energy x-rays do not contribute to the image [4].

According to Manchikanti [12] the primary source of radiation is scatter from the patient. Scattered radiation occurs due to the Compton effect when an incident x-ray interacts with a loosely bound outer-shell electron of an atom deflecting the x-ray from its original path. The protection from the scattered x-rays emanating out of the patient is therefore necessary [4]. Applying certain principles during fluoroscopy can lower scatter, for example: maintaining maximum distance from the source of x-rays; utilizing shielding material; minimizing exposure time; applying intermittent fluoroscopy; applying last image holding and applying electronic collimation and adjustment of beam quality [12].

It is a legal requirement that staff should wear physical secondary radiation protection. Lead rubber aprons may be considered cumbersome and heavy when worn during lenghty procedures. Lead rubber aprons should be well-designed and tailored to distribute the weight across an individual's shoulders sparing the spine from the full weight of the apron [11]. Prudent use of collimators lowers the radiation that the patient receives, since less patient tissue is in the radiation beam. Collimation restricts the field size [6]. A collimated beam means that radiation workers receive less radiation as scattered radiation is minimised. Apart from increasing absorbed dose to patients and staff scatter radiation impacts on image quality since radiographic contrast decreases.

'Last image hold' avoids unnecessary patient and staff exposure due to the image being available for reference. Intermittent, or pulsed fluoroscopy, will reduce exposure when compared to continuous fluoroscopy [12].

C-Arm fluoroscopic units may cause problems for patients, especially when the radiographer allows the x-ray tube to be positioned very close to the patient's skin. This should be avoided. Radiographers should make sure that the x-ray tube is as far from the patient as possible with the image intensifier (II) as close as possible [11].

Attention to detail, increased kV, increased filtration and the tabletop transmission, namely silicon pads on the tabletop, can result in a 78% reduction in patient dose [10].

In summary, time, distance and shielding are the best ways to protect against radiation [11]. Implementing all these factors is a constant challenge for any radiographer and a lifelong responsibility to make sure that a culture of radiation protection prevails in the operating theatre during back pain management procedures.

Conclusion

In the present study, the difference in radiation dose measured to the hands and the body of the neurosurgeon with the x-ray tube under the table compared to the doses with the x-ray above the table, already has played a role in convincing the neurosurgeons to modify the C-Arm positioning protocol for back pain procedures. The enforcement of the C-Arm positioning protocol, namely II above, for back pain management procedures during the course of the study was implemented and accepted in the specific theatre though minor adjustments were required. The special fluoroscopy (screening) table made the positioning of the II above the table and, the application of the ALARA principle, practical. The customized screening table allowed for easier positioning of the arc of the C-Arm. The theatre layout was changed to position the C-Arm monitor above the patient's head in order to make visualization effortless. The anaesthetic equipment was moved slightly to the side. The II was positioned closer to the sterile area compared to the distance with the x-ray tube above the table: the distance between the II and the patient gave the neurosurgeon enough space to work in a sterile environment. Magnification due to the II patient distance was acceptable and preferred above the higher dose levels of the PA view. Magnification of the image, due to the II distance from the patient to provide space for the injection area, is only applicable with overweight patients.

The study was initiated out of concern due to the dose levels that neurosurgeons received during back pain procedures. The possibility to lower radiation dose to the neurosurgeons needed investigation. The objectives of the study were attained: determining the radiation dose to the neurosurgeon on the x-ray tube side and II side of the C-Arm, as well as pointing out working areas for the theatre staff so as to maximize radiation protection during fluoroscopy. TLD and ionisation chamber measurements at two heights, as well as different distances from the x-ray tube, provided a clear picture of the radiation distribution during back pain management procedures. The final objective was achieved with the implementation of the proposed protocol.

In order to improve the workplace or ourselves, radiographers should have the right to explain why extra attention is given to one's environment. To ask the question: "How can I improve what I am doing?" is the only way to influence social change [13]. The research resulted in changing of the protocol (x-ray tube above table) in the theatre used in this study, with improved ionising radiation protection during fluoroscopy. Lower radiation levels to staff imply lower radiation levels to the patient. Thus the creation of a safer work environment for staff and patients in this specific neurological operating theatre has the possibility to improve the quality of life for the patient as well as the staff.

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