Radiation dose to surgeons in theatre

Article *in* South African journal of surgery. Suid-Afrikaanse tydskrif vir chirurgie · May 2012

Source: PubMed

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SAJS

General Surgery

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Summary

Objectives. To evaluate the effects of ionising radiation and radiation limits, and measure radiation doses received by surgeons in theatre.

Design. Thermoluminescent dosimeter measurements of accumulated dose to specific anatomical regions of a neurosurgeon, gastroenterologist and orthopaedic surgeon performing fluoroscopy on 39 patients undergoing treatment for back pain, 7 for endoscopic retrograde cholangiopancreatography procedures, and 48 for orthopaedic operations respectively.

Results. Radiation dose levels with the X-ray tube above the table during back pain procedures exceeded the occupational annual recommendation to the neurosurgeon's hands. The protocol regarding the orientation of the C-arm was changed. Convincing evidence of the importance and effectiveness of lead shielding was recorded.

Conclusions. Constant revision of protocols should apply the as-low-as-reasonably-achievable principle in every unique setting. The ideal is to position the image intensifier above the theatre table. The longest possible distance from the source will lower radiation risk. Full-body protection of 0.35 mm lead equivalence during fluoroscopy is mandatory.

S Afr J Surg 2012;50(2):

Stochastic radiation effects such as carcinogenesis cannot be ruled out at low levels of exposure. The lower the level of exposure, the lower the probability of cancer induction; however, the severity of the cancer is independent of the dose that caused it.[1] Owing to the cumulative effect of radiation, personnel who are chronically exposed to low doses of radiation are vulnerable.[2] Radiation workers should therefore apply at all times the as-low-as-reasonably-achievable (ALARA) principle to ensure the lowest possible radiation dose to patients and staff. The aim was to determine whether the radiation dose received by surgeons during surgical procedures fell within the limits set by the International Commission of Radiological Protection (ICRP),[3] and to apply this finding to current protocols for achieving the ALARA principle.

Effects of radiation

For radiation protection purposes, the threshold dose for the occurrence of biological damage is referred to as the effective dose, and is expressed in Sievert (Sv). This figure reflects potential biological damage.[4] The main biological effects caused by ionising radiation are stochastic and deterministic (non-stochastic) effects; stochastic effects **may** occur while deterministic effects **will** occur.[1]

Deterministic effects occur when cells are killed; this will be clinically visible above a certain threshold dose. The effects may lead to erythema, hair loss or cataract formation.[5] Stochastic effects may result when irradiated cells are modified rather than killed. The first sign of the presence of a stochastic effect is induced cancer.[4] The average latent period for development of leukaemia is 7 years, and 20 years for other cancers.[6] The second sign of a stochastic effect is genetic, where ionising radiation may damage genes and chromosomes in germ cells. Although lower ionising radiation doses result in lower occurrence of genetic changes, slight physical or functional impairment may be passed on to future generations. Reducing ionising radiation in theatre is imperative because the chance of genetic and carcinogenic effects 'is always higher than zero'.[1]

Radiation limits

By setting dose units below the thresholds, radiological protection aims to avoid deterministic and stochastic effects.[7] The effective dose limit for medical exposure recommended by the ICRP for the public is 1 mSv per year, and not exceeding 5 mSv over 5 years. The population on average receives a natural radiation dose of 3 mSv per year from natural radiation sources.[8] The recommended effective dose limit for radiation workers is 20 mSv per year, not to exceed 100 mSv over 5 years, and not exceeding 50 mSv in one year. The dose limit for the skin is 500 mSv, while that for the eyes was lowered to 20 mSv in November 2011.[3] The South African Department of Health accepted these international recommendations,[9] resulting in local radiation workers being monitored by means of a monthly dosimeter issued by the Radiation Protection Service.[10]

The South African Department of Health, Directorate Radiation Control, accepted the conditions stated by the ICRP, Publication 57, paragraph 174, which states that any person within 1 m of an X-ray source or patient when the machine is operated at 100 kV, should wear a protective apron of at least 0.35 mm lead (0.35 mm Pb) equivalence,[9] and that other staff in theatre should wear at least 0.25 mm lead aprons as a means of protection during such procedures. The recommendation that the lead apron closer to the patient be thicker is because the primary source of radiation is scatter from the patient.[11] The inverse square law applies; 'doubling the distance from the radiation source decreases the radiation level by a factor of four'.[12] Maximum distance from the source of radiation is important but varies according to every unique situation in the theatre. For instance, during back pain or endoscopic procedures, it was observed by the researcher that the surgeon needs to be very close to the X-ray source in order to administer the injectate. Orthopaedic and neurosurgeons visualise the placement of a needle or screws by means of fluoroscopy while their hand is holding the instruments directly in the path of the beam. For surgeons close to the table, a 0.35 mm lead apron is mandatory.

Methods

Measurements of the ionising radiation doses in a specific theatre were taken to verify that radiation falling on the surgeon during fluoroscopic procedures was within ICRP safety limits. Measurements were taken in close proximity to the patient on the theatre table, and the X-ray tube. Dose measurements were recorded at different body heights of the surgeon to determine possible areas of lower radiation distribution around the theatre table.

Initial measurements were done with the co-operation of a neurosurgeon and later a gastroenterologist and an orthopaedic surgeon. Measurements were established for each surgeon before the next study. The practice-based research included surgeons whom the researcher had the privilege to 'screen with' in theatre. The measurement approach differed for each discipline:

- The differences in dose to the neurosurgeon with the X-ray tube either above or under the table were compared. These differences could lead to confirmation of the correct protocol for positioning the C-arm tube.
- The average dose in mSv per patient was calculated for the gastroenterologist because of the long screening times (>10 minutes) normally recorded during endoscopic retrograde cholangiopancreatography (ERCP) procedures. This value could assist in predicting the potential dose that the surgeon may accumulate per patient.
- The accumulated dose to the orthopaedic surgeon over a period of 2 months could provide an estimation of the dose he may receive over 12 months. Placement of thermoluminescent detectors (TLDs) under the lead apron could indicate the effectiveness of the lead apron.

Target group

Measurements were conducted on the basis of availability of patients booked for each surgeon. The neurosurgeon study was of 39 patients over a period of 6 months undergoing treatment for back pain. The dose accumulated by the gastroenterologist during 7 ERCP interventions was over 2 months. The 48 orthopaedic cases that reflected the orthopaedic surgeon's dose were operated on over 2 months.

Biostaticians of the Department of Biostatistics, University of the Free State (UFS), analysed data for the neurosurgeon to calculate median dose values, and determine *p*-values. The Ethics Committee of the UFS approved the study (ref. ETOVS NR 155/06).

Equipment

TLDs were used to collect data in the form of counts that could be translated into radiation dose received per surgeon. To prepare the TLDs (lithium fluoride chips TLD-100), each group of TLDs was initially annealed in an oven and irradiated with a 90Sr/90Y radioactive source to the same dose. It was read in a TLD reader (Toledo 654, Vinten Instruments). The annealing and irradiation procedures were repeated 5 times to determine the reproducibility and standard deviation (SD) of each TLD. Individual reproducibility was >5%, and SD <1%. The sensitivity uncertainty of the total set of TLDs was estimated to be 1%. The calibration factor per batch was obtained by irradiating 7 TLDs in a 100 kV orthovoltage beam that had been calibrated against a secondary standard dosimeter. The TLDs were calibrated at 100 kV, as this was the nearest available energy to the average kV for the lateral projection in this study. TLDs were marked, placed in protective sachets, and used as described in the next section.

Seven TLDs were calibrated to ensure accurate measurements as well as for measuring background radiation. During each procedure, TLDs were placed over the specified anatomical regions of the surgeon performing the procedure for its entire duration. On completion of the procedure, the radiographer placed all TLDs back into the appropriate containers so as to be kept away from radiation. The TLDs were read by a TLD reader, and a physicist calculated the values to present the radiation doses in millisievert (mSv).

The C-arm fluoroscopic system (Instrumentarium Imaging, Ziehm 8000, manufactured October 2003) with a filtration of 4 mm Al and maximum 100 kV, was operated in automatic brightness control mode. Exposure factors (kV, mA and screening duration) were recorded for each patient.

Placement of TLDs

TLDs were placed in different anatomical regions of each surgeon to cover the dose measurement in areas most likely to be exposed to radiation. Placement of the TLDs was as follows:

- **Neurosurgeon** (during back procedures). Two TLDs were placed in the pelvis area opposite the umbilicus, 2 on the right upper corner of the theatre shirt pocket, and 1 on the proximal phalanges of the index finger holding the needle in the path of the beam. The distance from the floor to this surgeon's umbilicus was 110 cm, and to the chest 133 cm. It was noted that the surgeon did not face the patient directly; he was left-handed, and his right side was closer to the X-ray tube. The chest TLDs were placed on his right side rather than the left pocket, to be close to the X-ray source during the injection.
- **Gastroenterologist** (during ERCP procedures). Two TLDs were placed on the left knee closest to the X-ray tube under the table (not covered by the lead apron), 2 on the left elbow close to the image intensifier (II), 2 on the shoulder closest to the II, and 1 on the thyroid, protected by the thyroid shield.
- **Orthopaedic surgeon** (during operations requiring screening). Two TLDs were placed on the umbilicus under the lead apron, 2 on the umbilicus above the lead apron, and 1 on the thyroid above the thyroid shield.

Results

The results for each discipline are presented separately. Radiographic projections and orientation of the C-arm are mentioned for referencing purposes.

Dose to neurosurgeon during back procedures

The dose levels to the neurosurgeon were measured on both sides of the C-arm, X-ray tube (tube) or image intensifier (II). Different orientation of the C-arm is possible by altering the C-arm position: for one set of measurements, the tube was positioned above the table and, for the other set, under the table. The 39 procedures mostly comprised lumbar facet combined with sacro-iliac (SI) and a caudal injection. C-arm orientation was in the anterior posterior (AP) and both oblique positions. The lateral position of the C-arm was required for the caudal injection. The X-ray tube was routinely placed above the table (over couch X-ray source) during the procedures to satisfy the protocol at the time. Another set of measurements was conducted for the neurosurgeon with the X-ray tube under the table. The differences in dose to the neurosurgeon with the X-ray tube above or under the table were compared.

The median values of the radiation doses to the neurosurgeon's chest were 2.02 mSv, with the X-ray tube above the table, and 0.48 mSv with the tube under the table (p=0.02). The median radiation doses to the neurosurgeon's pelvis area were 2.3 mSv with the tube above, and 0.96 mSv with the II above, the theatre table (p=0.12). The dose to the neurosurgeon's hand (Fig. 1) confirmed a lower dose on the II side of the C-arm than on the tube side.

The median value of the radiation dose to the finger of the neurosurgeon was 65.68 mSv with the X-ray tube above the theatre table, and 0.84 mSv with the tube under the table (i.e. II above the table (p=0.12).

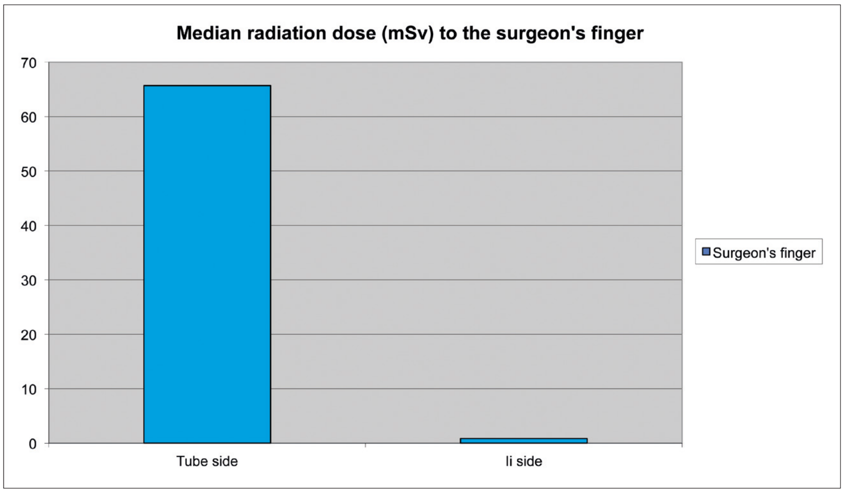

Fig. 1. Finger dose values to the neurosurgeon with X-ray tube under and above theatre table.

Dose to gastroenterologist during ERCP procedures

The 7 procedures in this project mostly made use of fluoroscopy to place the endoscope and to visualise the flow of contrast media. C-arm orientation was predominantly in the AP position. Oblique projections were used minimally. The II was routinely placed above the table during procedures. Fig. 2 displays the distribution of the dose to the different anatomical areas of the surgeon.

The average equivalent dose to the surgeon expressed in mSv per patient, were as follows: 0.03 mSv at the shoulder, 0.3 mSv at the elbow, 0.02 mSv under the thyroid collar, and 0.4 mSv at knee level. The reader is reminded that the ICRP limit for radiation to the skin is 500 mSv per year.

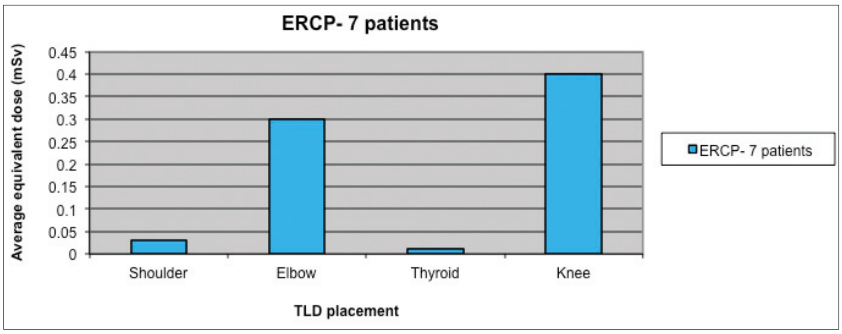

Fig. 2. mSv values during ERCP procedures.

Dose to orthopaedic surgeon during operations requiring fluoroscopy

The total of 48 operations requiring fluoroscopy included: 17 hand/wrist operations, 11 foot/ankle operations, 14 shoulder/tib/fib operations and 6 femur/hip operations. The X-ray tube was placed either above or under the table to adhere to sterile requirements that differ for each operation. The total mSv values accumulated by the surgeon per placement area are shown in Table 1.

The ionising radiation levels accumulated by the surgeon over the 2-month period were 5.98 mSv at the umbilical region on the outside of the lead apron, 0.34 mSv at the umbilical region under the apron, and 1.87 mSv at the thyroid. These data are displayed in Fig. 3.

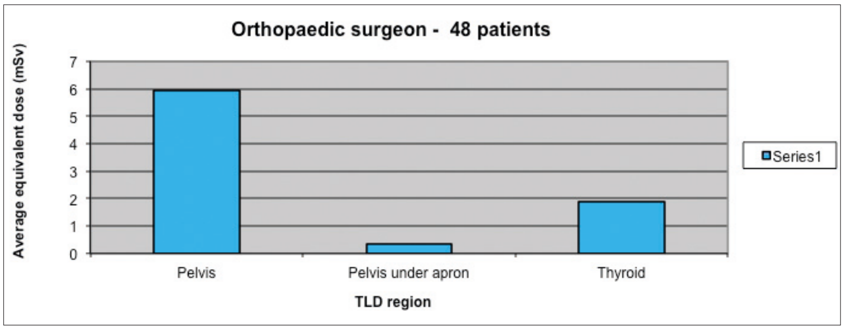

Fig. 3. mSv values from TLDs placed on the surgeon during 48 random orthopaedic procedures.

The difference in the dose to the surgeon's pelvis area above and under the lead apron clearly indicates the effectiveness of the lead protection. The value of 5.98 mSv at the surgeon's pelvis over 2 months indicates that 3 mSv radiation exposure per month to the surgeon is possible. The implication is that the dose limit of 20 mSv per year to the body can be exceeded within 6 months without lead protection. The radiation exposure limit to the thyroid has the potential of being exceeded within a year without lead protection.

Reluctance was observed on the part of surgeons and personnel to acknowledge, or demand protection against, the risk of exposure to radiation during fluoroscopy procedures with a C-arm. The assertion that radiation doses during fluoroscopy are insignificant was not uncommon. Staff who are willing to wear protective clothing prefer only half-body protection.

Discussion

Positioning of the X-ray tube during fluoroscopic procedures needs meticulous focus. The comparative results during back pain procedures confirmed that the radiation dose on the II side during the lateral view might have a 5 times lower value than on the X-ray tube side. The hand convincingly received a 78 times lower dose. The measurement values recorded in the neurological theatre indicated that the dose to the neurosurgeon was lower at the chest, pelvis and finger with the X-ray tube

TABLE 1. TOTAL mSv VALUES ACCUMULATED BY THE SURGEON PER PLACEMENT AREA

TLD placement	mSv
Pelvis	5.98
Pelvis under apron	0.34
Thyroid	1.87

under the table than with the tube above the table. The II must therefore be placed above the table at all times during back pain management procedures. The surgeon must also be positioned at the II side of the C-arm during the lateral views when the C-arm is in a horizontal position.

Personnel should be located as far as possible from the X-ray source. The high dose to the knees of the gastroenterologist can be ascribed to greater proximity to the X-ray tube. The high dose to the surgeon's elbow, although closer to the image intensifier than to the X-ray tube, may be an indication of high scatter levels from the patient.

Radiation dose can be lowered by limiting exposure times. Fluoroscopy machines are equipped with a timer and an alarm which sounds after every 5-minute fluoroscopic session. During ERCP procedures with generally longer screening times, intermittent fluoroscopy is highly recommended owing to the complicated positioning of the scope.

The effectiveness of the lead apron is indisputable. The radiation dose under the apron of the orthopaedic surgeon was 17 times less than above the apron. Full-body lead protection of 0.35 mm lead equivalent is mandatory for the surgeon close to the patient. Assisting permanent personnel in the theatre must be positioned at the furthest distance possible from the X-ray source and must wear a full-body protective apron of 0.25 mm lead equivalent. Radiation must be monitored monthly with a dosimeter badge.

A limitation of the study is the varying sample sizes: 39 patients for back pain, 7 for endoscopic retrograde cholangiopancreatography procedures, and 48 orthopaedic cases.

Conclusions

Tableside fluoroscopy receives among the highest occupational radiation exposures within the health system. The main culprit is scatter.[11] Surgeons exposed to low doses during fluoroscopy are vulnerable to the stochastic effect of radiation. The purpose of the study on which this article is based was to determine whether radiation doses fall within the ICRP limits and to revisit current protocols.

Radiation dose levels with the X-ray tube above the table during back pain procedures in the current theatre exceeded the occupational annual recommendation of 500 mSv to the neurosurgeon's hands. The converse is true with the II above the table. Measurements taken in the neurological theatre indicated that the dose to the neurosurgeon was lower at the chest, pelvis and finger with the X-ray tube under the table. This resulted in the protocol regarding the orientation of the C-arm being changed so that the II is placed above the table at all times during back pain management procedures. Orientation of the C-arm needs meticulous thought in every unique situation. The ideal is that the surgeon be placed closer to the II than to the X-ray tube, i.e. must maximise his/her distance from the X-ray source.

Deterministic biological effects will always occur above a certain threshold, therefore radiation limits are set to avoid the effect. Stochastic effects that may occur with exposure to ionising radiation are limited by applying the ALARA principle. The source of radiation is mainly scatter from the patient. Radiation workers are therefore obliged to follow the recommendations set by the Department of Health to wear a 0.35 mm lead apron when within 1 m of the X-ray source. The level of ionising radiation exposure to the orthopaedic surgeon was shown to be the highest at the umbilical area on the outside of the lead apron, therefore shielding against radiation is not negotiable.

X-rays are invisible, therefore monitoring by means of a dosimeter badge will indicate monthly levels of exposure. This awareness of monthly radiation values contributes to protection awareness.

It is impossible to avoid ionising radiation during fluoroscopy in theatre, especially in the case of a surgeon in close proximity to the X-ray source. The lead apron does not protect every part of the body. Sufficient protection for the lens of the eye can be achieved by using a lead screen or wearing lead glass eyewear to reduce the probability of cataract to a negligible level. A dosimeter placed outside the lead apron at neck level should be effective in estimating dosage to the eyes until such time as advanced eye dosimeters are available.[12]

All radiation workers should, however, focus on reducing the absorption by biological tissues because long-term adverse biological effects of long-term low-dose radiation exposure remain unclear at the moment. Malignant as well as genetic changes are a possibility.[2]

With acknowledgement to the role models in terms of protection: Drs S P Grobler, W van Jaarsveld and F P du Plessis.

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