Measurement of the dose of radiation to the surgeon during surgery to the foot and ankle

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We carried out a prospective study over a period of 12 months to measure the exposure to radiation of the hands of a dedicated foot and ankle surgeon. A thermoluminescent dosimeter ring (TLD) was used to measure the cumulative dose of radiation. Fluoroscopy was used in operations on the foot and ankle. The total screening time was 3028 s, with a mean time per procedure of 37.4 s (0.6 to 197). This correlated positively with the number of procedures performed ($r = 0.92, p < 0.001$), and with the dose of radiation in both the left ($r = 0.85, p = 0.0005$) and right TLDs ($r = 0.59, p = 0.419$). There was no significant difference in the dose of radiation between the two hands ($t$-test, $p = 0.62$). The total dose to the right TLD over the 12 months was 2.4 millisieverts.

This is a simple and convenient method for evaluating the exposure of a single surgeon to radiation. The radiation detected was well below the annual dose limit set by the International Commission on Radiological Protection.

Radiographs are a form of ionising radiation and produce a large amount of energy which causes the ejection of an orbital electron, resulting in a molecule becoming positively charged or ionised. In tissues, ionised atoms can cause complex molecules to split or can form highly reactive free radicals, which may then produce chemical damage within the cells which is proportional to the energy absorbed by the tissue from the radiographs.

The standard international (SI) unit of radiation is the gray (Gy) and is the energy absorbed in joules per unit mass of material expressed in kilograms. The Gy does not give the complete picture of the damage caused by radiation. Heavily ionising radiation or highly charged particles cause much greater local ionisation and hence greater local biological damage. The unit that takes account of this is the sievert (Sv). The millisievert (mSv) is a unit of measure of absorbed radiation in human tissue.

Use of an image intensifier has become an essential part of orthopaedic practice and there has been concern regarding the exposure to radiation of the surgeon and the patient during fluoroscopically-guided procedures. Fluoroscopy may produce a high dose of radiation (as much as 0.004 Gy/min). Doses can differ significantly between fluoroscopic machines because of differences in design or calibration, beam collimation and the output of radiation. Interest in protection from radiation has recently increased in the medical profession. The responsibility of the orthopaedic surgeon to minimise the exposure of patients to radiation has been previously emphasised. Such responsibility also extends to the protection of themselves and other staff. Individuals performing or assisting in fluoroscopically-guided procedures may well be exposed to high doses of radiation. The dose of radiation received by a surgeon depends on that given to the
patient, its duration, the distance from the source of radiation, coning, and the degree of shielding of the surgeon. The hands of the surgeon are most likely to be directly exposed during fluoroscopic screening and the potential effect of radiation to the skin of the hands is a limiting factor.

There is little information available on the level of exposure to radiation during the normal working pattern of individual foot and ankle surgeons using fluoroscopy. We wished to obtain accurate measurements of the effective dose to the skin of the hands during fluoroscopically-guided procedures on the foot and ankle, and to estimate the maximum permissible workload of surgery of the foot and ankle that was compliant with the current guidelines concerning radiation.

**Materials and Methods**

Over a period of 12 months the fluoroscopic screening time was recorded prospectively during consecutive procedures of the foot and ankle. The senior author (RD) is right-hand dominant and performed all the surgery in a standard hospital operating theatre. All the procedures used the same image intensifiers (Philips BV29; Stenoscop Image Intensifier (IGE, GE Healthcare, Slough, United Kingdom)).

In all cases a standard 0.35 mm lead apron was worn by the surgeon (RD) over the thorax and abdomen. Fluoroscopic screening was undertaken by different radiographers. The C-arm was used with the radiograph tube below and the image intensifier above, with the surgeon standing on the side of the patient opposite the C-arm.

The exposure to radiation of the primary surgeon (RD) was monitored using thermoluminescent dosimetry (TLD) devices (Landauer UK, Kidlington, United Kingdom) worn on each little finger under double gloves (Figs 1 and 2). The TLD is a ring that contains a chip of lithium fluoride and measures the accumulated exposure. The rings are tissue equivalent and are designed to measure shallow (skin) and deep (whole body) radiation exposure in mSv. We measured radiation to the skin of the hands to a depth of 0.07 mm. The TLD rings had a sensitivity threshold of 0.3 mSv.

For each case the radiographer recorded the time and range of exposure used during the procedure from the control panel of the image intensifier. A calibrated dose area product meter recorded the exposure of the patients to radiation in units of mGy/cm².

At the end of each month, the thermoluminescent rings were changed and the exposed devices sent to a recognised monitoring laboratory for reading. The dose of radiation absorbed by the rings was recorded in the form of a report, detailing the radiation exposure to the rings and the cumulative amount of radiation.

Statistical analysis was performed using Pearson’s coefficient and the paired t-test. Statistical significance was set at a p-value of < 0.05.

**Results**

During the period of study 80 procedures required the use of fluoroscopy (mean 6.8 cases/month). There were 51 elective and 29 trauma procedures. There were 18 fractures of the ankle, calcaneum and tibial pilon, 24 midfoot and hindfoot fusions, and 38 miscellaneous procedures.

The screening time per procedure was a mean of 37.4 seconds (0.6 to 197). The longest screening times were with open reduction and internal fixation of hindfoot fractures and elective fusions of the foot and ankle that was compliant with the current guidelines concerning radiation.

The cumulative exposure to the TLD rings of the surgeon from the 80 procedures was 2.4 mSv. The mean monthly exposure was 0.2 mSv (0.01 to 0.8) and mean radiation dose per operation was 0.03 mSv. The monthly dose of radiation received by the surgeon and the cumulative total are tabulated for each month of the study in Table I and Figure 3. The relationship between the number of procedures performed and the screening time is shown in Figure 4 (Pearson’s correlation r = 0.92 (0.72 to 0.98), t-test p < 0.0001).

The relationship between the duration of screening time and the dose of radiation was calculated for each hand using Pearson’s correlation coefficient. For the TLD ring on the left hand Pearson’s correlation r = 0.85 (0.54 to
0.96) \(t\)-test \(p = 0.0005\) and for the right hand ring it was \(r = 0.59\) (0.03 to 0.87) \(t\)-test \(p = 0.0419\).

The relationship between the number of procedures performed and the exposure to radiation to the left TLD ring had a Pearson’s correlation coefficient \(r = 0.68\) (0.18 to 0.90) \(t\)-test \(p = 0.0143\) and for the right hand it was \(r = 0.56\) (-0.02 to 0.86) \(t\)-test \(p = 0.059\).

The difference between the mean exposure to the left hand of 0.165 mSv and to the right hand of 0.208 mSv was not significantly different when examined with the paired \(t\)-test \(p = 0.62\).

Discussion
Over the 12-month period the total radiation dose to the operator’s hands was 2.4 mSv. This result is well within recommendations and well below the dose limits set by the International Commission for Radiological Protection (ICRP).18

Smith, Wakeman and Briggs19 suggested that the limiting radiation dose is that to the hands, because of their proximity to the radiograph beam in many procedures. In our study, the skin dose was below the recommended upper limit for non-classified radiation workers, which is 1.50 mSv per annum, corresponding to a monthly dose of 12.5 mSv.16 The mean monthly dose in our study was 0.2 mSv (0.01 to 0.8), which is below the threshold by a factor of 62.5.

To decrease all risks, radiological units should undergo periodic calibration checks, and surgeons should wear protective devices, increase their working distance from the X-ray beam, and limit their duration of exposure to radiation.18

The most notable concern with long-term exposure to low-level radiation is the induction of malignancy.20 The average environmental radiation dose equivalent from cosmic rays, external sources, and ingested radioactive materials is approximately 3 mSv per year.21 Our study shows an 80% additional dose of radiation. The relative risk of death resulting from exposure to 1 microSievert (\(\mu\)Sv) of radiation is equivalent to a one-in-eight-million risk of dying of cancer, or a loss in life expectancy of 72 seconds, the same as is associated with crossing the street three times.22-24

Table I. Summary of data

<table>
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<th>Months</th>
<th>Number of procedures</th>
<th>Screening time (s)</th>
<th>Exposure to left TLD* (mSv)†</th>
<th>Cumulative total to left TLD (mSv)</th>
<th>Exposure to right TLD (mSv)</th>
<th>Cumulative total to right TLD (mSv)</th>
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<td>2.990.70</td>
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* TLD, thermoluminescent dosimeter
† mSv, millisievert

Fig. 3
Graph to show the cumulative dose to each thermoluminescent dosimeter (TLD).

Fig. 4
Graph to show the relationship between the number of procedures performed and the screening time.
ation, exposure to a low dose has not shown any long-term effects.\textsuperscript{25,26}

The cumulative and total dose of radiation is taken as the higher value of the right TLD, as the surgeon is right-handed-dominant. The screening time was shown to be proportional to the number of procedures performed and also the radiation dose in both TLDs. Longer screening times were associated with more complex procedures, such as triple fusion and open reduction and internal fixation of pilon fractures. The exposure to radiation would have been significantly greater during these observations and we observed that the more complex operative procedures, such as triple fusions, were associated with higher doses of radiation.

Four methods are available to reduce exposure from scatter, namely reduced exposure time, increased distance, shielding, and control of contamination.\textsuperscript{27,28} In order to reduce the amount of radiation being delivered, all fluoroscopic units are now routinely calibrated to allow delivery of the smallest possible beam collimation.\textsuperscript{29} By controlling the direction of the beam and frequent calibration of the unit, the amount of radiation can be reduced to all operating staff. Adequate experience on the part of both the surgeon and radiographer operating the image intensifier is important in minimising screening time and hence the dose received. Giannoudis, McGuigan and Shaw\textsuperscript{30} noted that experienced radiographers and surgeons administer lower radiation doses. Therefore, experience and training are key issues for the reduction in exposure to patients and staff in orthopaedics.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References