Can fluoroscopy radiation exposure be measured in minimally invasive trauma surgery?

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\textbf{KEYWORDS}
Radiation; Osteosynthesis; Orthopedic; Radiation safety; Radiation exposure

\textbf{Summary} Repeated use of X-rays in orthopedic surgery poses the problem of irradiation of patient and caregivers. Seven common minimally invasive bone trauma surgical procedures requiring image intensifier use were investigated: percutaneous K-wire fixation of the wrist, minimally invasive fixation plating of the wrist, percutaneous intramedullary nailing of the tibia and of the femur, short and long trochanteric nail fixation of trochanteric and sub-trochanteric fracture, and percutaneous fixation of thoracolumbar fracture. The study analyzed three parameters: dose area product (DAP), radiation duration, and skin entrance dose (SED). Data were collected from 15 successive implementations of each procedure. The aim of the study was to establish a database for this kind of bone trauma surgery and a hierarchy of the X-ray doses delivered. Percutaneous spinal osteosynthesis involved the highest dose, followed in decreasing order by long trochanteric nailing, femoral nailing, short trochanteric nailing, tibial nailing, wrist K-wire fixation and frontal wrist plate osteosynthesis. One short trochanteric nail procedure delivered the same DAP as 13 wrist K-wire fixation procedures, and one spinal osteosynthesis was equivalent to 13 short trochanteric nail or 174 wrist K-wire procedures. The anatomic area X-rayed appeared to be the main radiation dose factor. A database was established, but actual patient and staff radiation levels remained unknown.

\textbf{Level of evidence:} Level III, case-control study.
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\textbf{Introduction}

There is rising community awareness of the harmful nature of medical ionizing radiation and of the X-rays emitted during fluoroscopic image intensification.

Any ionizing radiation may harm the organism over the medium- and long-term, depending on the dose delivered and the receiving organ. Patients may be considered as running a slight extra risk from radiation involved in fracture osteosynthesis [1]. This is all the more true for medical and paramedical staff, faced by daily exposure.

In France, the 2006 Ministry of Health circular on the dosimetric information to be specified in ionizing radiation procedure reports [2] requires each radiologic procedure...
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establish a hierarchy for the doses delivered.

procedures standardly performed in our department, and to dosage in the minimally invasive traumatologic bone surgery.

pedic surgeons and staff is sparse [4—6].

received by both patients and caregivers during medical procedures.

Staffs are monitored by the Occupational Medicine service, using dosimeters or dosimetric film badges.

The international literature on the risk incurred by orthopedic surgeons and staff is sparse [4—6].

Paradoxically, minimally invasive techniques under fluoroscopy are increasingly used in both orthopedic and traumatologic surgery.

The present study sought to draw up a database for X-ray dosage in the minimally invasive traumatologic bone surgery procedures performed in our department, and to establish a hierarchy for the doses delivered.

Material

Seven minimally invasive traumatologic bone surgery procedures requiring peroperative fluoroscopy frequently performed in the Nice University Hospital Center (France) were selected:

- percutaneous wrist osteosynthesis using one or two dorsal K-wires following Kapandji and a stylloid K-wire following Castaing;
- minimally invasive wrist osteosynthesis using a DRP 2.4TM anterior plate (Synthes, Etupes, France);
- percutaneous tibia and femur nailing on fracture table with transosseous traction (transcalcaneal for the tibia and transproximal tibia for the femur) without distal locking ancillary, using an S2TM nail (Stryker, Pusignan, France);
- trochanteric fracture osteosynthesis using a short percutaneous trochanteric nail on fracture table with shoe traction, and subtrochanteric fracture osteosynthesis using a long percutaneous trochanteric nail on fracture table with shoe traction, without distal locking ancillary (standard and long GammaTM: Stryker, Pusignan, France);
- percutaneous thoracolumbar fracture osteosynthesis using a percutaneous targeting ancillary to position four to six screws, depending on the fracture, and two CD Horizon Sextant IIITM rods (Medronic, Boulogne-Billancourt, France).

Data were prospectively collected from November 1st, 2008 for 15 successive implementations of each of the above procedures, including 105 patients in all.

The 15 spinal osteosyntheses were performed by an experienced specialist, and all other procedures by a single surgeon.

Method

Three X-ray dose parameters were studied:

- dose area product (DAP) in mGy/cm², calculated from the acquisition parameters by a dose calculator built into the image intensifier X-ray generator and providing DAP graphs according to kilovolts (voltage), milliamperes (current) and collimator opening (field) with filtration correction. Thus the total DAP per procedure was provided directly by the fluoroscope apparatus;
- skin entrance dose (SED) in mGy, obtained by dividing the DAP by the area of the beam on the patient’s skin multiplied by a backscatter factor of 1.35 (SED = [DAP/beam area]×1.35). The backscatter factor was 1.35 because the fluoroscope used had an X-ray tube of 125 kV max and a focus of 0.3. SED represents the radiation quantity on the patient’s skin and thus, by subtraction from DAP, the quantity scattered in the surgery room. Beam area was estimated for each type of procedure, given that the fluoroscopic beam diameter was 23 cm with the generator at 1 m from the patient’s skin. Assessment was straightforward for large operative areas such as spine, buttock or thigh, where the radiation region corresponded to the beam diameter. For wrist and leg, on the other hand, mean thickness was measured frontally and sagittally on each operative site in the 15 patients; for the wrist, measurement was 10 cm up from the joint line on the forearm to 5 cm down on the metacarpal mid-shaft; for the leg, the landmarks were the proximal/mid-third and distal/mid-third junctions. Total SED per procedure was calculated from total DAP and estimated mean beam area;
- radiation duration, in seconds, was provided by the fluoroscopic apparatus for each procedure.

All procedures used the same OEC 9800 plusTM image intensifier (General Electric, Puteaux Nanterre, France).

Results

Results on the three parameters (total DAP, total SED and radiation duration) are shown in Tables 1—3.

In decreasing order of radiation dose, were:

- percutaneous dorsolumbar spine osteosynthesis, with a mean total DAP of 10,347 mGy/cm² (range: 1,916 to 28,816), mean total SED of 51.5 mGy (range: 13.2 to 135) and mean radiation duration of 158 sec (range: 46 to 388);
- long trochanteric nailing;
- femoral nailing;
- standard (short) trochanteric nailing;
- tibial nailing;
- wrist K-wire fixation;
- anterior wrist osteosynthesis.

The various procedures were compared on the three radiation parameters (Tables 4—6).

Thus, in terms of SED, with wrist K-wire fixation as reference, percutaneous dorsolumbar spine osteosynthesis equalled 102 wrist K-wire fixations, long trochanteric nailing: 17, femoral nailing: 11, standard trochanteric nailing: seven, and tibial nailing: three.
Table 1  Mean total DAP (mGy/cm²).

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Anterior wrist osteosynthesis</th>
<th>Wrist K-wire fixation</th>
<th>Tibial nailing</th>
<th>Standard trochanteric nailing</th>
<th>Femoral nailing</th>
<th>Long trochanteric nailing</th>
<th>Percutaneous dorsolumbar spinal osteosynthesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean total DAP</td>
<td>38.4</td>
<td>59.6</td>
<td>238</td>
<td>794</td>
<td>1197</td>
<td>1843</td>
<td>10,347</td>
</tr>
<tr>
<td>Range</td>
<td>8—74</td>
<td>8—104</td>
<td>114—574</td>
<td>306—1754</td>
<td>397—2215</td>
<td>378—3517</td>
<td>1916—28,816</td>
</tr>
</tbody>
</table>

Table 2  Mean total SED (mGy).

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Anterior wrist osteosynthesis</th>
<th>Wrist K-wire fixation</th>
<th>Tibial nailing</th>
<th>Standard trochanteric nailing</th>
<th>Femoral nailing</th>
<th>Long trochanteric nailing</th>
<th>Percutaneous dorsolumbar spinal osteosynthesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean total SED</td>
<td>0.35</td>
<td>0.49</td>
<td>1.4</td>
<td>3.5</td>
<td>5.6</td>
<td>8.35</td>
<td>51.5</td>
</tr>
<tr>
<td>Range</td>
<td>0.12—0.6</td>
<td>0.1—0.9</td>
<td>0.7—3.5</td>
<td>1.4—8.4</td>
<td>2—10.4</td>
<td>4.2—19.5</td>
<td>13.2—135</td>
</tr>
</tbody>
</table>

Table 3  Mean radiation duration (sec).

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Anterior wrist osteosynthesis</th>
<th>Wrist K-wire fixation</th>
<th>Standard trochanteric nailing</th>
<th>Tibial nailing</th>
<th>Long trochanteric nailing</th>
<th>Femoral nailing</th>
<th>Long trochanteric nailing</th>
<th>Percutaneous dorsolumbar spinal osteosynthesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation duration</td>
<td>15</td>
<td>26</td>
<td>32</td>
<td>56</td>
<td>65</td>
<td>89</td>
<td>158</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>6—27</td>
<td>38—6</td>
<td>20—52</td>
<td>34—95</td>
<td>34—104</td>
<td>35—133</td>
<td>46—388</td>
<td></td>
</tr>
</tbody>
</table>

Table 4  Total DAP ratio per procedure.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Anterior wrist osteosynthesis</th>
<th>Wrist K-wire fixation</th>
<th>Tibial nailing</th>
<th>Standard trochanteric nailing</th>
<th>Femoral nailing</th>
<th>Long trochanteric nailing</th>
<th>Percutaneous dorsolumbar spinal osteosynthesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAP (mGy/cm²)</td>
<td>1</td>
<td>1.6</td>
<td>1</td>
<td>6</td>
<td>21</td>
<td>31</td>
<td>48</td>
</tr>
<tr>
<td>Anterior wrist osteosynthesis</td>
<td>1</td>
<td>1.6</td>
<td>1</td>
<td>6</td>
<td>21</td>
<td>31</td>
<td>48</td>
</tr>
<tr>
<td>Wrist K-wire fixation</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>21</td>
<td>31</td>
<td>48</td>
<td>270</td>
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<tr>
<td>Tibial nailing</td>
<td>21</td>
<td>13</td>
<td>3</td>
<td>31</td>
<td>48</td>
<td>270</td>
<td>174</td>
</tr>
<tr>
<td>Standard trochanteric nailing</td>
<td>31</td>
<td>20</td>
<td>5</td>
<td>31</td>
<td>48</td>
<td>270</td>
<td>174</td>
</tr>
<tr>
<td>Femoral nailing</td>
<td>48</td>
<td>31</td>
<td>8</td>
<td>2.3</td>
<td>31</td>
<td>48</td>
<td>270</td>
</tr>
<tr>
<td>Long trochanteric nailing</td>
<td></td>
<td></td>
<td></td>
<td>2.3</td>
<td>31</td>
<td>48</td>
<td>270</td>
</tr>
<tr>
<td>Percutaneous dorsolumbar spinal osteosynthesis</td>
<td>270</td>
<td>174</td>
<td>44</td>
<td>13</td>
<td>9</td>
<td>5.6</td>
<td>1</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Table 5  Total SED ratio per procedure.</th>
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<tr>
<td>SED (mGy)</td>
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<td>-----------</td>
</tr>
<tr>
<td>Anterior wrist osteosynthesis</td>
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<tr>
<td>Wrist K-wire fixation</td>
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<tr>
<td>Long trochanteric nailing</td>
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<table>
<thead>
<tr>
<th>Table 6  Radiation duration ratio per procedure.</th>
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<tbody>
<tr>
<td>Time (sec)</td>
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<tr>
<td>-----------</td>
</tr>
<tr>
<td>Anterior wrist osteosynthesis</td>
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</tr>
</tbody>
</table>

Discussion

Study limitations

The study involved two limitations. Firstly, the small number of patients per procedure precluded statistical analysis. Secondly, the method of calculating total SED: to have a rigorous measurement, the DAP should be taken for each incidence and X-ray emission, rather than using the total procedure DAP and mean estimated beam area; the DAP as calculated here is merely an approximation of the received dose.

In terms of radiation protection, what is important is the effective dose. In practice, however, it is difficult to assess, as the thicknesses of the various tissues that are crossed would need to be known so as to be able to apply appropriate weightings to the energy transmitted to each.

DAP nevertheless represents the quantity of X-rays emitted by the fluoroscope, irradiating both patient and operator, and thus reflects overall radiation. It is an objective value, provided directly by the image intensifier, which is why the regulations require it to be traceable.

In the present study, short trochanteric nailing was found to deliver the same DAP as 13 wrist K-wire procedures, and spinal osteosynthesis was equivalent to 13 short trochanteric nailing procedures, or 174 wrist K-wire procedures.

Thus, certain procedures involve more ionizing radiation than others. But what factors determine these radiation levels? Anterior plate wrist osteosynthesis was found to involve less radiation than percutaneous K-wire fixation of the wrist; but no conclusion could be drawn, due to lack of statistical power. Thus, not only fracture severity but also operator experience impact peroperative radiation levels: the learning curve is an essential factor, as inexperienced operators inevitably multiply incidences for their own reassurance. The present study, however, avoided this source of bias, using a single operator experienced in these various bone trauma procedures; some other factor must be
involved. Looking again at the differences between percutaneous K-wire fixation of the wrist and percutaneous spinal osteosynthesis, it emerges that, while the DAP ratio was 174:1, forSED it was only 102:1 and for radiation duration 6:1: the anatomic factor thus appears to be determining [7].

This is illustrated by the difference between standard trochanteric and tibial nailing: total DAP and total SED were two times as great in the former as the latter, while radiation duration was 1.8-fold greater in the latter than the former. This can be explained by the need to increase the X-ray rate due to the greater thickness to be crossed in the pelvis than the leg.

Another such illustration is the difference between long trochanteric nailing and femoral nailing: total DAP and total SED were 1.5 times as great in the former as the latter, while radiation duration was 1.4-fold greater in the latter than the former. Tissue thickness in the pelvis and particularly the buttocks requires an increased X-ray rate.

The present results simply determined the DAP delivered in certain traumatologic procedures; DAP is merely a reflection of radiation dose, and our findings in no way determined precisely the doses received by the patient or by regularly exposed team members.

Is there a risk?

There is no risk that could be called deterministic, but the same cannot be said of so-called stochastic risk.

The International Commission on Radiological Protection asserts that pathologic risk associated with low-dose radiation, and X-rays in particular, is linear to dose [7].

Likewise, the prevalence of low-dose X-ray related pathologies is linear to dose [8,9].

Certain authors claim a benefit for iterative low-dose radiography, but without scientific validation [9,10].

The International Commission on Radiological Protection, in its Publication 60 (CIPR 60) [11], cites a 5% lifetime increase in death from cancer per Sievert: five out of 100,000 persons exposed to 1 milliSievert (mSv) will during their lifetime contract a lethal cancer implicating this exposure.

Most authors and public authorities consider iterative radiation exposure to be a risk factor in healthcare personnel [12,13]. Proof is almost nonexistent, but the elevated mortality of radiologists before 1920 is an ever-present memory [14].

The maximum yearly iterative dose or dose-equivalent (cumulative dose absorbed by a tissue or organ over time) per hand, forearm, foot and ankle is 500 mSv (for X-rays, 1 mGy equals 1 mSv) and 150 mSv for the crystalline lens, according to the EU Council’s 1996 96/29/EURATOM directive [15] setting basic norms for ionizing radiation protection for the general population and workers.


Repeated performance of procedures thus exposes caregivers to increased risk. This seems clear in the case of certain procedures such as percutaneous spinal osteosynthesis [17,18]. Fortunately, this is not the most frequent procedure. The low radiation dose associated with K-wire fixation of the wrist or trochanteric nailing, however, does not justify complacency, as these procedures are performed on a daily basis.

It should nevertheless be borne in mind that natural background radiation in France corresponds to an effective dose of 2.5 mSv per year.

It should not be forgotten that the X-ray transmitter is the main source of variation in dose. Present generation image intensifiers emit lower doses than in the past, but still need regular checking to avoid an increased radiation level [9,11,13].

Our study of the literature failed to find evidence of risk for the patient [19,20]. The stakes for the patient are different: procedures involving radiation are occasional, with a measured risk/benefit ratio. Any radiological procedure is performed purely in the patient’s interest.

In principle, a single procedure during a given year should involve no risk for the patient. Nevertheless, the real risk run by the patient cannot be assessed without knowing the total dose received.

The X-ray views most commonly prescribed in community medicine are plain thoracic and abdominal, which deliver a DAP of 140 mGy/cm² and 4,500 mGy/cm² respectively when fluoroscopy is not used. In terms of effective dose, on the other hand, chest X-ray involves 0.02 mSv, equivalent to 3 days’ natural exposure, and plain abdominal X-ray 1 mSv or 6 months’ natural exposure. Thus, apart from certain difficult thoracolumbar spinal osteosyntheses, all the procedures examined here delivered DAPs lower than an everyday plain abdominal X-ray.

Personnel surveillance

In our center, the only monitoring device is the dosimetric film badge and, recently, an electronic dosimeter worn on the anterior trunk under the lead apron, but which does not measure radiation to the crystalline lens or hands.

The Occupational Medicine service performs annual monitoring of personnel exposed to ionizing radiation, as recommended in the 2003 circular n° 2003-296 (article R. 231-100) on workers’ ionizing radiation protection under the Employment Code [16]. Monitoring comprises systematic medical consultation, possible ophthalmologic screening for cataract, and standard biologic assessment (CBC abnormality screening).

All the data thus collected are recorded in the individual medical file and saved for use for 50 years.

This scheme applies only to hospital workers; university personnel are not followed up by the Occupational Medicine service.

Can better awareness of received doses be demanded by the personnel?

All caregivers working in a traumatology theatre should have three demands: training in the use of ionizing radiation, protection against ionizing radiation, and knowledge of the doses delivered. We have shown that the real radiation dose
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Conclusion

We established a database for traumatology theatre radiation and a hierarchy of procedures. The real radiation level received by patient and caregivers, however, remains unknown.

We would like traumatology teams, who are often very young, to have these facts available. We stress the importance of preventing personnel overdose and the need for control. Ionizing radiation is a recognized cause of occupational ill-health. Let us not follow in our elders’ footsteps but rather make use of the means of protection and control that exist, with, it is to be hoped, ever more effective surveillance.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References