Real-time dosimetry reduces radiation exposure of orthopaedic surgeons

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1. Introduction

The C-arm fluoroscope as the most commonly used intraoperative imaging system in orthopaedic surgery provides real-time moving images of osseous structures. It enables the surgeon to reduce fractures and perform implant placement without extensive soft tissue devitalisation resulting in a trend of minimally invasive surgery in the past decades.

Adhering to these guiding principles can require numerous fluoroscopic examinations resulting in exposure to high levels of radiation, especially if the C-arms continuous mode is used extensively\textsuperscript{[1]}. The use of fluoroscopy is a major concern for the operating team that performs this type of operations on a regular basis. In the recent years, there is a rising alertness concerning the harmful effects of exposure to long-term low-dose irradiation. Mastrangelo et al. found a highly significant cumulative cancer incidence in orthopaedics, exposed to irradiation in contrast to unexposed workers\textsuperscript{[2]}. Zabel et al. reported an elevated risk of developing thyroid cancer in female radiologic technologist\textsuperscript{[3]}. Ronckers et al. assume that ionization radiation exposure is an established breast cancer risk factor\textsuperscript{[4]}. Chou et al. confirm that cancer prevalence of female orthopaedic surgeons is 1.9-fold increased, the prevalence of breast cancer even 2.9-fold increased than that of the general U.S. female population\textsuperscript{[5,6]}. They suppose that continuous ionizing radiation exposure is jointly responsible for the elevated risk of developing cancer. Therefore, the use of ionising radiation must follow the “ALARA” (as low as reasonable achievable)-principle to ensure the safety of the caregivers occupational exposed by irradiation. The International Commission on...
Radiological Protection recommends a limit for occupational irradiation exposure an effective dose of 20 milliSievert (mSv) per year, averaged over defined 5 year periods (100 mSv in 5 years) [7].

Although lead aprons, protective eyeglasses and even lead shields are mainly available in the operation rooms, consequent usage is questionable. Chou et al. report only 80.4% of the female orthopaedic surgeons use protective shielding > 75% of the time; moreover only 42.2% reported use of a thyroid shield [5].

Medical staff exposed to radiation is officially monitored by use of thermoluminescence dosimeter (TLD) badges worn below the lead apron. The issue data are analysed retrospectively at a later stage. Therefore, the staff members can hardly reflect the circumstances of increased exposure to irradiation and whether it might have been preventable. For this reason, a dosimeter which gives information about the actual radiation exposure is desirable. It might help to decrease irradiation in the operation room by creating a rising awareness for the acute radiation exposure.

A new dosimeter called DoseAware® which visualizes radiation exposure in real-time has been shown to reduce staff radiation doses in an angiography room and during pediatric interventional radiological procedures [8–10].

We hypothesized that using this new dosimeter during orthopaedic surgeries, radiation will be reduced in comparison to operations without using this tool.

Within a matched-pair analysis, we compared orthopaedic procedures, the surgeon and the C-arm operator used this new tool to a control group without using this device.

2. Materials and methods

Between July and October 2012, the surgeon and the C-arm operator were equipped with a novel dosimeter called DoseAware® (RaySafe™, Billdal, Sweden, distributed by Philips, Eindhoven, The Netherlands) while operative treatment of 104 patients in the orthopaedic and trauma surgery department of the University of Bonn Medical Center. For all 104 patients, a Philips mobile C-arm system (BV Pulsera®, Eindhoven, The Netherlands) was used for the fluoroscopic examinations in the conventional 2D mode.

DoseAware® is a dosimeter badge that was worn upon the lead apron (Fig. 1) (in addition to the official dosimeters, regularly worn below the lead apron). It measured the individual radiation exposure and sent the dose rates wireless and in real-time to a display placed in sight of the operating team. Surgeon and C-arm operator could watch their individual amount of exposure online and parallel on this display. Scatter dose rates were shown in a logarithmic scale with bars increasing in size and changing colour from green to yellow to red (green bar: 0.02–0.2 mSv/h; yellow bar: 0.2–2 mSv/h; red bar: 2–20 mSv/h; Fig. 2) with increasing dose rates in real-time. In this way, the staff members were warned of high scatter dose rates instantly and could react to decrease radiation exposure by limiting fluoroscopic time, use pulsed fluoroscopy, tight collimation or avoid suboptimal X-rays by use of the laser cross-hair.

Dose information, stored at the individual dosimeter, could be transferred to a computer after each operative procedure and a database might be created with the help of special software (Dose Manager®, RaySafe™) as a further tool. In this way, the history of the individual dose rate profiles (date, time, personal dose rates and accumulated personal dose rates of the yearly maximum [20 mSv]) achieved by different operations and different staff members could be stored. As the personal irradiation history of each operative procedure was not the focus of this study, the individual databases were not evaluated.

Fig. 1. Dose Aware® badge worn upon the lead apron (red circle).

Fig. 2. A logarithmic scale with bars increasing in size and changing colour from green to yellow to red (green bar: 0.02–0.2 mSv/h; yellow bar: 0.2–2 mSv/h; red bar: 2–20 mSv/h) shows the individual scatter dose rates.

The fluoroscopic time (FT in sec) and the radiation dose (RD in mGy; for X-rays equals mSv) were provided by the C-arm. Within a matched-pair analysis, data (FT and RD) recorded during usage of DoseAware® (DA group) were compared retrospectively to data without using this tool (control group) archived before July 2012. The two groups were matched for the following factors: surgeon, C-arm operator, age, gender, type of fracture and operation technique. For the surgeon and the C-arm operator (both serve as one operation team), genre, type of fracture and operative technique, 100% agreement were mandatory. Fractures were classified according to the AO/ASIF-classification. Concerning spine injury, accordance for level and number of injured vertebræ was claimed. For each surgical procedure, unity of the operative technique and the implant used was required. In case of differing age, a patient with the lowest age difference was chosen for comparison.

3. Statistical methods

The paired Student t-test was used. Values were presented as mean ± standard deviation (SD). P values < 0.05 were considered to be statistically significant. Evaluation was carried out using the statistics program Instat 3 for Windows XP.

4. Results

Thirty-six of the 104 patients the surgeon and the C-arm operator were equipped with the DoseAware® badge had to be excluded from matched-pair analysis as no match in surgeon and C-arm operator could be found. For example, despite of idem surgeon, diagnosis and operative treatment, a different C-arm operator made the case not suitable for statistical comparison.

Sixty-eight patients of the DA group were included in the matched-pair analysis and compared to 68 controls. All procedures were performed without navigation (Table 1). All osteosynthesis of the extremities were performed by two surgeons (M.M. and C.B.), the kyphoplasties and the percutaneous dorsolumbar spinal osteosynthesis were performed by an experienced spine surgeon.

Concerning the FT, use of DoseAware® led to a significant reduction for all evaluated operation types except for internal fixation of distal radius fractures (P = 0.0511) compared to the control group (Table 2). Most decrease of FT (−42%) was observed for fixation of clavicular, distal radius and trochanteric fractures. Regarding RD, use of DoseAware® led to a significant reduction for all evaluated operation types except for stabilisation of pterochanteric femoral fractures with a PFNA® (P = 0.0841). Most decrease of RD (−45%) was observed for fixation of clavicular fractures.

5. Discussion

In orthopaedic surgery, the radiation dose the surgeon receives is directly proportional to fluoroscopic time and inversely proportional to the surgeons experience [12]. For fixation of femoral neck fractures, Giannoudis et al. demonstrated that the fluoroscopic screening time and the radiation dose are proportional to the complexity of the fracture [13]. Riley [14] and Khan et al. [12] showed that the surgeons’ dominant hand receives the highest dose of radiation during dynamic hip screw insertion. Hafez et al. even describe higher radiation doses for the fingertip than the finger base caused by accidentally caught in the fluoroscopy beam [15]. Although only 65 mSv direct radiation to the thyroid gland lead to a statistical increased incidence of thyroid cancer and a radiation-induced cataract will appear after a radiation exposure of 2–4 Sv, leaded glasses and thyroid shielding are often ignored by the operation team [cited in 12]. There is no threshold dose above which hazardous radiation effects could occur [7]. Nevertheless, as long term effects of low-dose radiation are uncertain, majorities of the studies focusing on radiation exposure in orthopaedic operation theatres emphasize alertness [12–17].

Due to the fact that X-rays are invisible, how sure can the staff be to follow the ALARA principle? Therefore, Richter et al. recently demanded for new technologies that will help to reduce the emission of radiation [16].

The aim of this study was to test the utility of the novel radiation dose monitoring system DoseAware® providing real-time feedback in an orthopaedic operation room. Use of the novel system resulted in a significant reduction of fluoroscopic time and radiation dose in six of seven evaluated operation techniques compared to the use of the fluoroscope without DA.

| Table 1 |

<table>
<thead>
<tr>
<th>Fracture type</th>
<th>Operation technique</th>
<th>Implant</th>
<th>n</th>
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<tbody>
<tr>
<td>Subcapital humerus fracture</td>
<td>Plate osteosynthesis</td>
<td>Philos® Plate, Synthes Germany</td>
<td>6</td>
</tr>
<tr>
<td>Midshaft clavicular fracture</td>
<td>Elastic stable intramedullary nailing (ESIN)</td>
<td>TEN®, Synthes Germany</td>
<td>9</td>
</tr>
<tr>
<td>Distal radial fracture</td>
<td>Palmar plate osteosynthesis</td>
<td>LCP® Volar Distal Radius Plate, Synthes Germany</td>
<td>6</td>
</tr>
<tr>
<td>Pterochanteric femoral fracture</td>
<td>Standard trochanteric nailing</td>
<td>PFNA®, Synthes Germany</td>
<td>10</td>
</tr>
<tr>
<td>Ankle fracture</td>
<td>Plate osteosynthesis</td>
<td>Small Fragment Plate, Synthes Germany</td>
<td>15</td>
</tr>
<tr>
<td>Traumatic vertebral fracture</td>
<td>Percutaneous dorsolumbar spinal osteosynthesis of two levels</td>
<td>Revolve®, Globus Medical Germany</td>
<td>7</td>
</tr>
<tr>
<td>Osteoporotic vertebral fracture</td>
<td>Bilateral radiofrequency kyphoplasty</td>
<td>StabiliT® Vertebral Augmentation System, DFine Europe</td>
<td>15</td>
</tr>
</tbody>
</table>

* The 15 patients with osteoporotic vertebral fractures included seven patients with two vertebral fractures, seven patients with three vertebral fractures and one patient with four vertebral fractures.

| Table 2 |

<table>
<thead>
<tr>
<th>Fracture type</th>
<th>FT (sec)</th>
<th>DA</th>
<th>controls</th>
<th>P</th>
<th>RD (mGy)</th>
<th>DA</th>
<th>controls</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcapital humerus fracture</td>
<td>58 ± 16.8</td>
<td>83.7 ± 16.3</td>
<td>0.023</td>
<td>4.7 ± 2.1</td>
<td>7.5 ± 2.2</td>
<td>0.049</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midshaft clavicular fracture</td>
<td>45.3 ± 31.4</td>
<td>78 ± 32.5</td>
<td>0.046</td>
<td>3.2 ± 1.8</td>
<td>5.8 ± 2.8</td>
<td>0.016</td>
<td></td>
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<tr>
<td>Distal radial fracture</td>
<td>41.6 ± 14.7</td>
<td>71.2 ± 29.2</td>
<td>0.051</td>
<td>0.77 ± 0.34</td>
<td>1.18 ± 0.6</td>
<td>0.043</td>
<td></td>
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</tr>
<tr>
<td>Pterochanteric femoral fracture</td>
<td>54.2 ± 45.7</td>
<td>93.5 ± 37.3</td>
<td>0.049</td>
<td>6.85 ± 3.8</td>
<td>10.5 ± 6.6</td>
<td>0.084</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle fracture</td>
<td>37.2 ± 18.1</td>
<td>53.7 ± 24.8</td>
<td>0.041</td>
<td>1.22 ± 0.6</td>
<td>1.79 ± 0.78</td>
<td>0.035</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traumatic vertebral fracture</td>
<td>216 ± 77.7</td>
<td>303.9 ± 69.2</td>
<td>0.045</td>
<td>58.2 ± 19</td>
<td>83.9 ± 21.9</td>
<td>0.038</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osteoporotic vertebral fracture</td>
<td>220.1 ± 109.7</td>
<td>293.1 ± 80.4</td>
<td>0.047</td>
<td>49.6 ± 25.7</td>
<td>70.8 ± 27.3</td>
<td>0.037</td>
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</table>

Precondition for implementation of this new system in this study was a close cooperation of the surgeon and the C-arm operator in order to reduce avoidable irradiation. In addition to the individual safety precautions like keeping distance from the C-arm X-ray tube to reduce scatter irradiation or wearing lead glasses and lead aprons (ideally torso surrounding, thyroid protecting and leaded gloves for operations, the finger tips might be compromised by direct radiation), the following general measures might reduce irradiation in the operation room [10,17,18]:

- use of pulsed fluoroscopy;
- tight collimation;
- manually reduction of the dose rate;
- use of saved images;
- use of the laser cross-hair to avoid suboptimal image-projections;
- less use of electronic magnification;
- optimised source-to-detector distance.

DA visualizes “invisible” scattered irradiation for the first time and therefore demonstrates the effect of those individual and general irradiation reduction techniques immediately supporting the staff to follow the ALARA principles. This protects the whole operating team who uses the fluoroscope in the daily routine. It might be recommended, that DA should be worn by all staff members (including assisting surgeons, nurses and anaesthesiologists) and ideally be personalized. In contrast to the TLDs, DA would enable the whole staff to react on increased personal scattered irradiation instantly. Awareness concerning irradiation in the operative room might be increased and team spirit for avoiding radiation exposure gained.

Nevertheless, reduction of fluoroscopic time and radiation dose may also have a vital impact on the patient, especially in operations performed close to radiosensitive organs like the thyroid (ESIN of the clavicle or subcapital humerus fracture fixation) or the reproductive organs (fracture fixation of the proximal femur or the lumbar spine). In our study, spine surgery achieved the longest fluoroscopic time and highest radiation dose. DA achieved a significant reduction of both criteria.

In this study, all operations were performed by experienced surgeons (senior physician, head of the department and spine specialist). As surgeons experience influences screening time and radiation dose, future studies should prove the effect of DA on unexperienced surgeons [12]. Will repeated use of DA train experienced and unexperienced surgeons adequately and what kind of learning curve will be observed?

Nevertheless, the ideal osteosynthesis must be the ultimate ambition for the surgeon. Additional studies should also consider whether the quality of the osteosynthesis in the long run is equal using less irradiation that means with and without using DA.

All operation techniques were performed using the C-arm fluoroscope in conventional 2D mode. Further approaches should show whether intraoperative CT-scanning (fluoroscopes 3D mode) including navigated implant placement can further reduce radiation compared to the conventional method. The navigation system allows the staff to keep a distance from the C-arm during image acquisition. Using the navigation system, confirmatory fluoroscopic images not necessarily are needed until the final implant position has been achieved [19,20].

This study revealed some limitations. One weakness is the absence of intramedullary nailing involving distal locking as this procedure results in a great level of radiation [17]. Distal interlocking is a procedure usually performed with a radiolucent angular gear and the surgeon focusing the fluoroscope screen while using the continuous radiation mode. It would be interesting whether DA might help to reduce irradiation in terms of the surgeon being warned by colleagues watching the bars on the display screen while he is concentrated on the fluoroscope screen.

In addition, the number of patients in each group was small. Therefore, statistically significant differences have to be proven by a larger number of patients per group. Also, significant differences might be hidden, due to lack of statistical power.

A further weakness of this study is the fact that we only compared the RD provided by the C-arm. We did not measure the individual reduction of the ionizing radiation exposure to the operation staff. Analysis of individual dose rate profiles should be taken into account for future studies.

Another potential criticism is the fact that the DA badge is worn upon the lead apron. Therefore, the equivalent dose is not measured adequately. Nevertheless, multiple badges worn on protected and unprotected parts of the body would approximately give sufficient information about the real radiation exposure. Yet, the surgeon has to be aware of the final consequence of being prohibited from using the C-arm fluoroscope if an effective dose of 20 mSv per year is reached.

6. Conclusion

Use of the radiation dose monitoring system DoseAware® providing real-time feedback of the radiation exposure reduces fluoroscopic time and radiation dose in the hand of experienced orthopaedic surgeons. Although these results are promising, additional studies involving further operative procedures including intramedullary nailing involving distal interlocking with an increased number of patients to enhance statistical power should be undertaken. The systems option of evaluating the personal radiation exposure history should be used in order to see which individual protection practises are most effective.

The authors believe that real-time visual feedback of radiation exposure with DA constantly reminds the staff of the need for irradiation reduction and instantly demonstrates the effect of dose-reduction techniques.

Disclosure of interest

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

References


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