Emission of radiation in the orthopaedic operation room: a comprehensive review

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Abstract

Introduction

Ionising radiation is a constant risk to exposed workers. Recently, it was shown that the incidence of malignant diseases was increased in an orthopaedic hospital among exposed personnel. However, the surgeons are often ill-informed about the utilisation of the fluoroscopic units, which leads to unnecessary exposure to radiation, for both the operating team as well as the patients. This review article aims to give a comprehensive review on the exposure of staff in the orthopaedic operation room and to develop advises to reduce the risk deriving from ionising radiation.

Material and methods

A comprehensive review of the published literature associated to intra-operative radiation in orthopaedics was performed. The electronic platform, PubMed was used to search for relevant studies. The keywords used included ‘intra-operative radiation’, ‘radiation orthopaedics’ and ‘radiation’. The search was performed in English and German. The reference list of identified articles was crosschecked to identify further articles that contributed to the topic.

Results

Using the above mentioned inclusion criteria, 30 articles were identified that contributed to the topic. Intra-operative fluoroscopy increases the radiation dose distinctly. Especially, the scatter radiation leads to increasing doses for the surgical team. Scatter radiation occurs while passing through the patient’s body. Only 2% of the emitted photons actually reach the image intensifier. On the contrary, 10%–20% of the photons are scattered.

Conclusion

Intra-operative fluoroscopy is a precious and essential tool for orthopaedic operations. If the surgical staff follow the principles (shielding, ALARA, etc.), the radiation exposure in the operating room can be reduced significantly. New technologies will hopefully help in the future to further reduce the emission of radiation.

Introduction

Ionising radiation is a constant risk to exposed workers. In medicine, the most exposed professionals are among cardiologists, radiologists and orthopaedic surgeons. Recently, it was shown that the incidence of malignant diseases increased in an orthopaedic hospital among the exposed personnel. In the last decades, orthopaedic surgeries became less invasive, because of the development of minimal-invasive techniques and implants. Therefore, the use of intra-operative fluoroscopy is indispensable in orthopaedic procedures nowadays. For instance, it is commonly used for closed reductions, intramedullary nails, open reduction and internal fixations (ORIF), as well as dorsal vertebral stabilisations. Furthermore, three-dimensional (3D)-C-arms, which produce a computed tomography (CT)-like image of the region of interest, are widely used in operating theatres. The patients and especially, the surgical staff are exposed to ionising radiation in the daily routine. However, the surgeons are often ill-informed about the utilisation of the fluoroscopic units, which leads to unnecessary exposure to radiation for both the operating team as well as the patients. This review article aims to give a comprehensive review on the exposure of staff in the orthopaedic operation room (OR) and to develop advises to reduce the risk deriving from ionising radiation. Our aim was to work out to determine the amount of radiation, both the patients and the surgical staff, are exposed. Furthermore, we wanted to generate some guidelines for the use of intra-operative fluoroscopy.

Material and methods

A comprehensive review of the published literature associated to intra-operative radiation in orthopaedics was performed. The electronic platform PubMed was used to search for relevant studies. The keywords used included ‘intra-operative radiation’, ‘radiation orthopaedics’ and ‘radiation’. The search was performed in English and German. The reference list of identified articles was crosschecked to identify further articles that contributed to this topic.

Results

Using the above-mentioned inclusion criteria, 30 articles were identified that contributed to the topic of intra-operative radiation in orthopaedics. Every person is exposed to natural radiation. This consists of internal (e.g., water, food and radon gas) and external (cosmic rays) radiations.
The yearly average exposure to natural radiation accounts for 300 mrem. Another 60 mrem is added by diagnostic radiographs. The limit of the effective dose of a non-exposed person is 1 millisievert (mSv) per year. On the other hand, the limit of the effective occupational dose is 20 mSv (2000 mrem), which is averaged over 5 years. Yet there are separate equivalent dose limits for the different organs. The yearly organ dose limit for the hand is 500 mSv, and for the eye it is 150 mSv. These limits were defined to prevent damages caused by the radiation. These damages are divided into deterministic and stochastic effects. The deterministic effects can be avoided, if the dose limits are not exceeded. In addition, radiation can harm the DNA directly or by development of radicals. This is called the stochastic effect. There seems to be no radiation limit for stochastic damage, which means it can occur even below the limits for stochastic damage, which are divided into deterministic and stochastic effects. The deterministic effects can be avoided, if the dose limits are not exceeded. In addition, radiation can harm the DNA directly or by development of radicals. This is called the stochastic effect. There seems to be no radiation limit for stochastic damage, which means it can occur even below the organ doses. In 2005, Mastrangelo et al. described that in a retrospective study, the cancer incidence in orthopaedic surgeons was significantly higher than in the control group.

Intra-operative fluoroscopy increased the radiation dose distinctly. Especially, the scatter radiation led to increased doses for the surgical team. Scatter radiation occurs while passing through the patient’s body. Only 2% of the emitted photons actually reach the image intensifier. On the contrary 10%–20% of the photons are scattered. The rest is absorbed by the patient. The scatter radiation is usually measured in ionisation chambers. This is very difficult to implement in an in vivo study. For this reason, the radiation doses are typically measured with thermoluminescent dosimeters (TLDs). Hereby, the radiation is converted to light and consecutively measured. The scatter radiation differs from procedure to procedure and from patient to patient. There have been several studies to investigate the radiation for the surgeon and the operating staff. Müller et al. performed 41 intramedullary nailings of the femur and the tibia. The surgeons as well as the first assistant wore ring dosimeters on the dominant index finger during the operations. The mean radiation time was 4.6 minutes (min). The mean radiation dose for one intervention was 1.27 mSv for the surgeon and 1.19 mSv for his first assistant. In 1983, Barry also measured the radiation dose with a ring dosimeter. He reported that the measured dose was 0 mrem of his left ring finger, wearing a lead glove when appropriate. Sanders et al. could show no statistical significant difference between positive reading of the ring TLD and the hand dominance in 65 mixed orthopaedic interventions. He found out that the radiation time seems to be a relevant factor for the positive reading of the ring TLD. For rings, without a positive reading, the mean fluoroscopy time was 2.3 minutes. On the other hand, in the positive group, the mean fluoroscopy time was found to be 4.7 minutes. There was no positive reading when the C-arm was used for less than 1.7 minutes. Kraus et al. showed in 2012, that duration of the radiation was significantly elevated comparing complicated fractures to simple fractures of the humeral head. In addition, an experienced team required less intra-operative fluoroscopy and could significantly reduce intra-operative emission of radiation.

In spine surgery, different studies showed a high exposure to radiation performing dorsal stabilisations on the spine. The position of the radiation source is really important to reduce the scatter radiation as much as possible. Rampersaud et al. performed pedicle screw placement in six cadavers. He showed that the dose rate at the torso of the surgeon was alarmingly high, while standing on the ipsilateral side of the beam source (53.3 mrem/min). This could be significantly reduced by standing on the side of the image intensifier (2.2 mrem/min). Furthermore, he wore a ring TLD on the dominant hand, which also showed a high radiation dose (58.2 mrem/min). It could also be reduced by standing on the side of the image intensifier. In addition, the radiation dose for the thyroid gland was measured using an ion chamber. On the beam source side, the levels of the radiation dose were elevated three to four times.

Most authors recommend the source in down position for an antero-posterior (AP) image of the spine (Figure 1). Again, the positioning of the C-arm can reduce the levels of scatter radiation compared to the contrariwise position. Some surgeons prefer the radiation source in up position, because of a larger working space and a lower patient exposure, yet the dose seems to be higher for the surgeon. Furthermore, the surgeon should stand on the detector side for the lateral images in our opinion.

Computer-assisted image guidance is a very helpful tool, especially in spine and pelvic surgeries. It can be performed using a two-dimensional (2D) or 3D-C-arm. In 2010, Kraus et al. showed a significant reduction of the effective dose for the patient. Other authors found comparable results. Mehlmán and DiPasquale investigated the impact of the distance of the operating team to the C-arm. They confirmed that distance in the OR is an important factor. At first, they showed that direct beam contact resulted in 4,000 mrem/min. An unprotected surgeon, who was 30.5 cm away from the C-arm, which was placed in a source-up position, would be able to perform 345 cases/year until reaching the hand limits and only 50 cases before reaching the whole body limits. If he moved to 70 cm away from the beam, he would be able to perform 1,000 cases per year until reaching the hand and 167 cases before reaching the whole body dose limit. Another phantom,
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Most studies did not record the distance of surgeons from the C-arm. The distance is one of the most important factors for working with an X-ray device following the inverse square law. Especially, the hands of the surgeon seem to be the part of the body with the highest level of exposure\(^1\). All authors investigating the distance could show a distinct reduction by just increasing the distance of the surgeon or the scrub nurse to the C-arm\(^12,21,22\). Increasing the distance between the X-ray source and the patient can reduce radiation for both the patient and the surgeon\(^23\).

Shielding of the surgical staff is crucial in the orthopaedic OR. Lead aprons and thyroid shields should always be used. Different studies showed a distinct reduction in using shielding. In addition, it was recommended to wear leaded glasses and, if possible, leaded-protection gloves\(^1,10,21,24\). The simple use of collimators can reduce radiation drastically\(^25\). New technologies have become more important nowadays. In an orthopaedic theatre intra-operative navigation can help to reduce radiation, especially in spine and pelvic surgeries. The accuracy and safety of screw placement in 3D-navigated pedicle and iliac screws is higher compared to the standard procedure\(^26,27\). In addition, the intra-operative radiation can be reduced\(^16,19\). The reduction of radiation using a 3D-C-arm in combination with image-guidance caused the introduction of a new generation of intra-operative C-arms (Figure 3). These imaging devices are either intra-operative CT’s or flat-panel C-arms, which are mounted on a robotic arm (ArtisZeego\(^\circ\), Siemens, Erlangen, Germany).\(^\text{28}\) The flat-panel C-arms create better and larger images compared to a conventional C-arm. Moreover, the machine can be controlled entirely by the surgeon right at the operating table. The C-arm is electronically linked to the operating table. This enables the surgeon to store exact positions of the C-arm. All stored positions can be automatically approached by the C-arm during the surgery without further radiation. Hopefully, this will further reduce radiation exposure to the patient and the surgeon in the future\(^28\).

### Conclusion

Intra-operative fluoroscopy is a precious and essential tool for orthopaedic operations. If the surgical staff follows the principles (shielding, ALARA, etc.) mentioned above, the radiation exposure in the OR can be reduced significantly. New technologies will hopefully help in the future to further reduce the emission of radiation.

### Abbreviations list

| 2D | two-dimensional |
| 3D | three-dimensional |
| AP | antero-posterior |
| CT | computed tomography |
| OR | operation room |
| TLD | thermoluminescence dosimeters |

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[Figure 3: Different C-arm-types are available for orthopaedic procedures, among these 2D-C-arms (A: Ziehm Imaging GmbH\(^\circ\), Nuremberg, Germany) and machines capable of creating CT-like images by performing orbital rotations with multiple image acquisition (B: Siemens\(^\circ\), Erlangen, Germany). The most recent machines are mounted on robot devices and can be controlled by the operating surgeon (C (position 2): ArtisZeego Siemens\(^\circ\), Erlangen, Germany). Further reduction of the emission of radiation is expected in combination with intra-operative navigation ([position 1]: Brainlab Curve, BrainlabAG\(^\circ\), Feldkirchen, Germany) in a hybrid-OR setting.]
Review

References


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