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Reducing Radiation Risk in Orthopaedic Trauma Surgery

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Summary

Fluoroscopy is considered indispensable during contemporary orthopaedic trauma surgery. However, there is increasing concern regarding occupational safety in the operating room (OR). During the course of a career, the orthopaedic surgeon and OR staff could be exposed to potentially dangerous levels of radiation. This exposure can cause substantial cytogenetic and chromosomal damage, potentially increasing cancer risk. The literature does not clearly identify a safe threshold for radiation exposure. Even relatively small doses

should be considered dangerous over the long-term. Therefore, it is accepted that annual exposure should be kept to an absolute minimum. Established protective measures include observance of safe working distance from the radiation source and the routine use of protective garments. In addition, promising computerized technologies may support improved surgical precision while significantly reducing dependence on intraoperative fluoroscopy.

Introduction

Radiography has greatly improved the physician's ability to diagnose and treat musculoskeletal disease and injury [1]. In orthopaedic trauma surgery, intraoperative fluoroscopy is particularly indispensable [2]. However, as fluoroscopic imaging becomes more and more common, there is increasing concern regarding occupational safety in the operating room (OR) [3, 4]. Specifically, frequent use of fluoroscopy may expose the trauma surgeon and OR staff to dangerous doses of radiation [1, 4-9].

The amount of health risk from radiation is primarily dependent upon intraoperative exposure time, cumulative career exposure, and the effectiveness of utilized protective measures [4, 9]. Moreover, the surgeon dose can vary 10 to 12-fold according to orthopaedic procedure [4, 9, 10]. Unfortunately, the majority of surgeons and OR staff remain relatively unknowledgeable regarding the specific risks and effects of radiation, resulting in varying compliance with protection proce-

dures [1, 2, 9, 11, 12]. This may be due to the perceived insignificance of exposure in the OR, as compared to sources of higher radiation dose, including nuclear weaponry and industrial equipment [14, 15]. However, it is important to understand that even relatively small amounts of radiation dose can result in cumulative tissue damage [1]. Therefore, it is generally accepted that exposure should be minimized whenever possible [1, 16, 17]. Surgeons and OR staff should work to increase their understanding of exposure risks, and improve adherence to protection procedures. Further, surgical techniques and technologies capable of reducing dependence on repeated intraoperative fluoroscopy should be utilized where available.

Biological Effects of Ionizing Radiation

Radiation can be defined simply as energetic particles or waves traveling through space. Natural radiation sources, including cosmic rays and terrestrial radon gas, account for approximately 85% of the exposure to humans [11]. The remaining exposure comes primarily from diagnostic radiography [18]. Natural sources account for an average annual exposure of approximately 0.125 radiation absorbed doses (rad) [1, 19, 20]. As a relative comparison, a single anterior-posterior chest radiograph carries an exposure of 0.025 rad [1, 2, 19, 20]. Fluoroscopy is of greater concern, as the average direct exposure dose per minute can range between 0.4-4.0 rad (Table 1) [2, 21].

Table 1: Radiation exposure estimates for common radiographic procedures [2].

Radiographic Procedure	Exposure (rad)
Chest Radiograph	0.025 rad
Dental Radiograph	0.45 rad
Hip Radiograph	0.5-0.6 rad
Mammogram	0.51 rad
Computerized Tomography, Hip	1.0 rad
Pelvic Fluoroscopy, regular C-arm	4.0 rad/min
Fluoroscopy, mini C-arm	0.12-0.4 rad/min

In contrast, ionizing radiation specifically refers to radiation waves carrying enough energy to remove electrons from atoms or molecules, thereby generating excessive free radicals capable of inducing cellular damage [1]. This damage increases with the energy of the radiation wave and with higher frequency of exposure, limiting the potential for cell recovery [1]. However, ionizing radiation remains harmful even at relatively low levels [22]. Morphological and functional damage has been observed in some cells dosed with as little as 0.001 rad [22]. Cellular damage from ionizing radiation has been reported for the skin, eyes, gonads, and blood, with the most important long-term concern being cytogenetic and chromosomal damage resulting in increased risk of carcinogenesis [9, 23, 24].

Diagnostic Radiation and Cancer Risk

Anecdotal reports relating cancer in orthopaedic surgeons and patients to radiation exposure are relatively common [25]. However, there is evidence in the literature supporting increased cancer risk in this population. Ronckers et al [26] assessed cancer mortality in 5,573 women diagnosed with spine disorders between 1912 and 1965. Due to repeated spine radiographs, the estimated cumulative radiation dose to the breast, lung, thyroid and bone marrow were 1,090, 410, 740 and 1,000 rad, respectively. Cancer mortality in these patients was 8% higher than in the control population, with a significant increase in deaths associated with breast cancer. This patient group was repeatedly exposed to ionizing radiation over a relatively long-period of time. Physicians who perform frequent radiography over the course of a career may be at similar risk. The results of Ronckers et al [26] are corroborated by Chou et al [25] and Jartti et al [27], who respectively observed 2.9 and 2.3 times increased breast cancer risk in female physicians, as compared to population controls. The available evidence clearly demonstrates a dose-response relationship between diagnostic radiation exposure and increased breast cancer risk in patients and physicians alike [25-30].

Additional evidence of increased occupational cancer risk is reported by De Gonzalez et al [31]. Radiograph frequency, estimated dosage, and population based disease data were used to estimate cancer risk across 14 countries. Results suggested that approximately 0.6%-3.0% of cumulative cancer risk could be attributed to diagnostic radiography. Similar results were reported by Ashmore et al [32], who assessed cancer risk in 206,620 individuals chronically exposed to occupational radiation. The authors report that a 3.0% excess risk of

cancer was found for every 1 rad of exposure. It is clear that chronic exposure to low-energy ionizing radiation is an established risk factor for cancer [32, 33]. While individual risk is relatively low, the high annual frequency of diagnostic radiography increases risk across the affected population. Because the literature does not clearly identify a safe exposure threshold, it is recommended that occupational radiation dose should be kept as low as possible [1, 34, 35].

Reducing Radiation Risk

Radiation risk to the orthopaedic trauma surgeon and OR staff originates from two sources. First, the primary radiation beam is the path between the radiograph generator and image intensifier. Any body part that lies directly in the primary path is exposed to the highest possible dose. For example, when the hands are placed directly in the radiation beam, recommended annual occupational safety limits can be exceeded in as little as 12.5 minutes of exposure [2, 16]. The second radiation source is scatter, which is the interaction between the primary beam and patient, surgical table, instruments and equipment [2]. This is the source that places OR staff at risk.

There are four primary protective measures which can limit primary and scatter radiation exposure. First, maintaining a safe distance from the primary beam can greatly reduce radiation dose. At a distance of 2 meters, exposure is 0.025% of the direct beam intensity [36]. Maintaining a safe distance is an excellent solution to protect OR staff. However, increased surgeon distance can compromise surgical technique and patient outcomes [37]. Second, protective garments can effectively reduce exposure to the surgeon and OR staff regardless of distance. Lead aprons of 0.5 mm thickness have been shown to shield approximately 99% of potential radiation dose [2, 36]. Specialized glasses, gloves, thyroid masks, and drapes can provide additional shielding and protection for sensitive tissues. However, garment availability, maintenance, and compliance with protection procedures can limit the effectiveness of such measures [13]. Further, the use of heavy lead garments may be precluded by cost and difficulty of manipulation during surgery [38]. A third protective measure is contamination control. Frequent calibration of the fluoroscope can ensure the smallest effective radiation dose during intraoperative imaging [39]. Automatic image quality adjustment and direct surgeon control of fluoroscopy can also significantly reduce exposure time [40, 41].

A final method for reducing radiation risk in the OR is utilization of computer-assisted surgery (CAS) technologies. CAS uses digitized images of patient anatomy to enable surgical navigation in an improved virtual environment [42]. CAS does not create additional sources of radiation. Rather, stored radiographic images are utilized during navigation, eliminating the need for additional radiographs and unnecessary exposure [42-45]. Grutzner and Suhm [46] assessed the effectiveness of CAS generated virtual fluoroscopy during distal locking of pertrochanteric and diaphyseal fractures, as compared to mechanical guidance. As expected, results of the study demonstrated significantly reduced fluoroscopy times in the CAS group. The authors note that with further development, this technique could enable improved accuracy and reduced invasiveness during fracture reduction and fixation. However, clinical efficacy of standard CAS is currently limited by surgeon learning curve, increased surgical time, and specialized equipment and training needs [42, 46].

Tornetta et al [47] assessed an alternative computerized technology that utilizes a non-ionizing electromagnetic field tracking technology during intramedullary nail distal locking. (TRIGEN[®] SURESHOT[®] Distal Targeting System, Smith & Nephew, Inc., Memphis, TN, USA; Figure 1). Use of this technology in the operative theatre is further illustrated in Figure 2. Following insertion of 24 tibial and femoral nails, first-time drilling accuracy for distal interlocking of 100% and 96% was observed, respectively. Moreover, respective distal locking time was reduced by 32% and 48% compared to standard fluoroscopic methods. Regarding radiation emission, fluoroscopy time was reduced by 36 seconds during tibial nailing, which is equivalent to approximately 0.785 rad [48]. Fluoroscopy time was reduced by 49 seconds during femoral fracture fixation, eliminating 2.362 rad of emission. This data suggests that for surgeons performing one distal locking procedure per week for 10 years, approximately 6.5 hours of radiation emission (1,133.76 rad) could be eliminated. This reduction may correlate with reduced radiation dose to the surgeon and OR staff. However, these data are not conclusive. Clinical research is ongoing to further assess dosage with this technology during orthopaedic trauma surgery (ClinicalTrials.gov Identifier: NCT01327508).

Conclusion

Following review of the available evidence, there appears to be considerable risk associated with long-term exposure to low level ionizing radiation. As such, every effort must be made to reduce dependence on intraoperative fluoroscopy during orthopaedic trauma surgery. Surgeons and OR staff should work to ensure compliance with protective procedure. Moreover, precise computerized technologies capable of reducing radiation exposure should be evaluated and utilized where available.

Figure 1: TRIGEN® SURESHOT® Distal Targeting System (Smith & Nephew, Inc., Memphis, TN, USA).

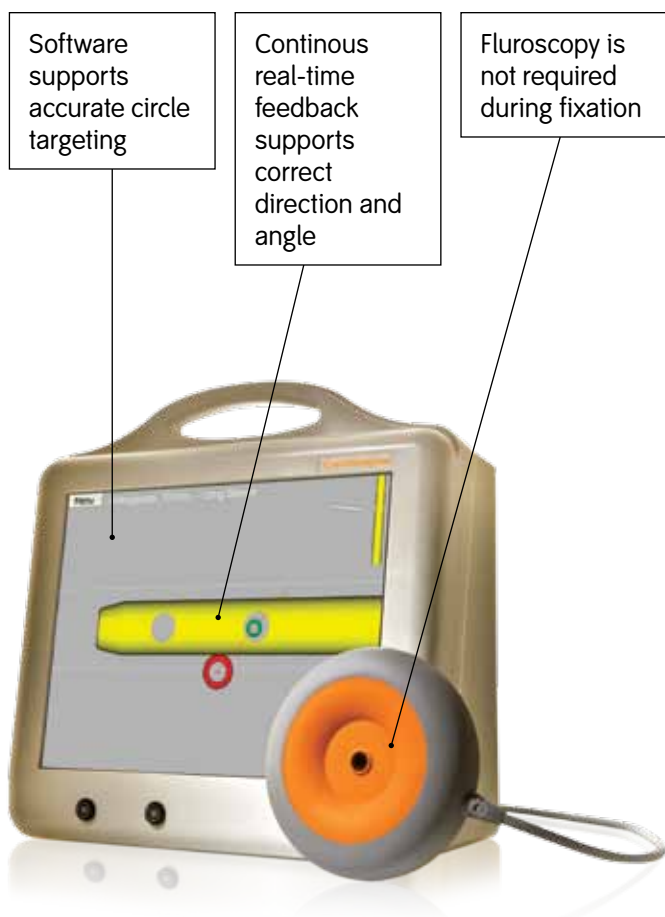
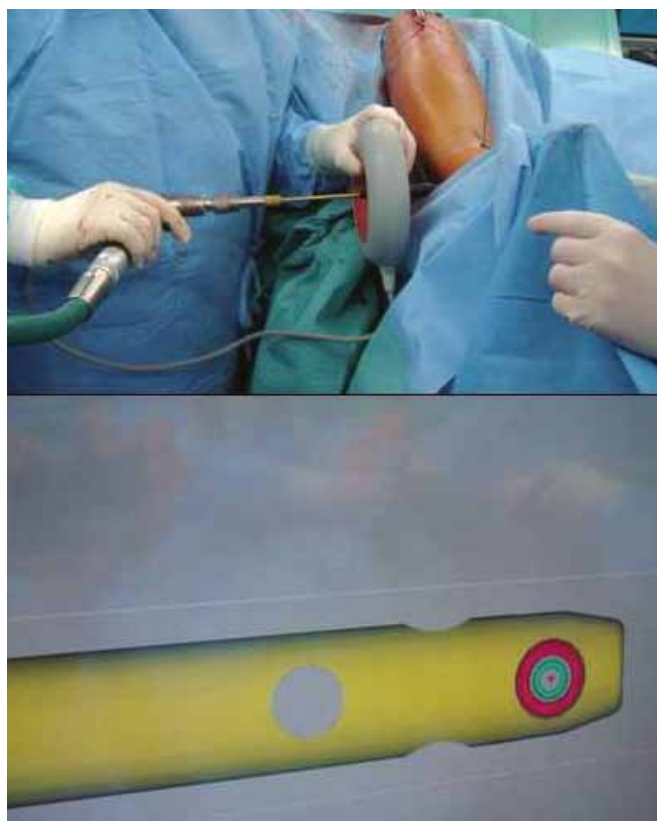


Figure 2: Intraoperative image of surgeon verifying screw alignment prior distal locking (Image provided by Prof. Johannes M. Rueger, University Medical Center Hamburg-Eppendorf).



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