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Exposure of the surgeon to radiation during surgery

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Summary. *Exposure to radiation over many years increases the incidence of cataracts and promotes the development of carcinoma of the thyroid gland. A prospective study of 24 operative procedures involving minimal invasive techniques and fluoroscopic guidance was undertaken in order to measure the radiation exposure to the primary surgeon. The study was conducted during 8 K-wire osteosyntheses in fractures of the distal radius, 8 closed interlocking intramedullary nailings in fractures of the femur and 8 internal fixator procedures, with or without posterior autogenic transpedicular bone grafting, in fractures of the lumbar spine. Radiation was monitored with the use of high sensitive thermoluminescent dosimeters. Fluoroscopy was necessary during the procedures, with exposure times ranging from 55 s to 12 min 35 s. The radiation dose received per procedure ranged from 0.6–259.3 μSv and was well within the dose limits set by German law.*

Résumé. *Une étude prospective de 24 interventions chirurgicales utilisant une technique invasive "à minima" avec l'assistance de la radioscopie a été realisée pour mesurer l'exposition aux radiations de l'opérateur principal. L'étude e été realisée durant 8 ostéosynthèses avec des broches de Kirschner pour les fractures du radius distal, 8 enclouages intramedullaires verrouillés de fractures du femur et 8 fixation internes avec ou sans greffe de fractures de vertébres lombaires. L'irradiation était enregistrée avec des dosimètres thermoluminiscents très sensibles. Durant les interventions la radioscopie était necessaire entre 55 secondes et 12 minutes 35 secondes. La dose de radiation enregistrée par intervention était entre 0,6–259.3 μSv. Ces valeurs etaient bien conforme à la réglementation allemande sur la protection contre les radiations. L'exposition aux radiations pendant des années peut prèdisposer à l'apparation d'une cataracte et peut produire le development d'une carcinome de la grande thyroide.*

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Introduction

Although the hands of the primary surgeon are very close to the radiation beam, the amount of radiation received during a specific operative procedure is almost unknown [8, 11]. Little information is available as to the extent which tissues with a high sensitivity to radiation, such as the eyes or the thyroid gland, are loaded with scattered rays. Equally, the precise risk to these tissues is unknown. As the 'safe' dose of radiation is uncertain, it is reasonable to keep radiation exposure as low as possible, regardless of safety regulations.

In the studies presented in this article, we measured the radiation exposure to the primary surgeon by scattered rays at four different points during three operative procedures.

Materials and methods

In order to measure the radiation exposure to the surgeon, thin-layer lithium fluoride thermoluminescence dosimetry chips (TLD 100 H, Harshaw Chemicals, Solon, Ohio, USA) were used. These chips function on the basis of thermoluminescence and they store the energy of the scattered X-rays as a change in their crystalline structure. After heating the chips for subsequent evaluation, the absorbed energy is set free as light. The amount of scattered rays can then be calculated from the quantity of light which is emitted.

The anatomical sites selected for dosimetry measurements in the primary surgeon were the eyes and the thyroid gland, as these tissues have a high sensitivity to radiation. During measurements, the chips were fixed with a plaster on the forehead near the eyelid and on the skin directly above the thyroid gland. The dominant hand of the surgeon that is very exposed to the beam of the X-ray image amplifier was also used. In addition, we placed chips under the lead apron close to the genitals. In order to improve the precision of the investigation we undertook three measurements in each instance.

Three surgical procedures were selected for study. We performed 8 K-wire osteosyntheses after closed reduction of fractures of the distal radius and 8 reamed intramedullary interlocking nailings in fractures of the femur after closed reduction. Additionally, we carried out 8 internal fixator procedures with or without "anterior repair" (posterior autogenic transpedicular bone grafting) in fractures of the lumbar spine. During the procedures we used a mobile c-arm fluoroscope (Exposcop CB 7-D, Ziehm, Kraus GmbH, Germany). The standard image memory mode was employed.

After each surgical procedure the lithium fluoride dosimetry chips were evaluated for radiation exposure using a TLD reader (TLD 4000, Harshaw Chemicals, Solon, Ohio, USA). The protocol included the recording of the duration of each operation and the X-ray energy used for fluoroscopy at the different anatomical sites.

Results

The duration of the operative procedures and the characteristics of fluoroscopy during surgery (radiation quality, duration) are shown in Table 1. Fluoroscopic guidance was necessary during the procedures, ranging from 55 s to 12 min 35 s. The average time that fluoroscopy was used during the K-wire osteosyntheses was 131 s, during interlocking nailing of the femur 450 s and during osteosyntheses of the lumbar spine with internal fixator with or without "anterior repair" 555 s (Table 1).

In Table 2 the data that were derived from the thermoluminescent dosimeters at the various anatomical sites are reviewed. No evident radiation exposure was measured under the lead apron close to the genitals.

The highest averages of radiation exposure at all points of measurement were found during the internal fixator osteosyntheses of the lumbar spine (range 49.8 μSv to 117.0 μSv). The maximum amount at the site on the dominant hand during surgery of the lumbar spine ranged from 24.9 μSv to 259.3 μSv.

Table 1. Characteristics of procedures and fluoroscopy

Procedure	No. of procedures	Duration of procedure Average (min)	Duration of fluoroscopy (s)			Radiation quality	
			Range	Average	Mean	kV	mA
K-wire osteosynthesis – distal radius	8	20	55–198	131	135	43–50	0.5–1.0
Interlocking intramedullary nailing – femur	8	135	255–708	450	388	59–75	1.3–2.6
Internal fixator (with or without anterior repair) – lumbar spine	8	175	175–755	555	523	78–99	2.5–3.1

Table 2. Exposure to radiation that was derived from the thermoluminescent dosimeters

Procedure and spot of measurement	Dose of radiation (μSv)		
	Range	Mean	Average (±SD)
K-wire osteosynthesis			
distal radius			
eyes	0.6–1.7	1.1	1.1 (±0.36)
thyroid gland	0.6–1.7	1.1	1.1 (±0.35)
hand	1.5–4.1	3.3	3.1 (±0.89)
genitals	–	–	–
Interlocking nailing			
– femur			
eyes	11.2–45.5	13.9	19.0 (±11.1)
thyroid gland	16.7–67.9	30.5	35.4 (±15.5)
hand	28.9–69.1	39.4	41.7 (±12.4)
genitals	–	–	–
Internal fixator			
– lumbar spine			
eyes	19.9–93.1	39.3	49.8 (±26.1)
thyroid gland	23.3–93.0	65.6	55.5 (±26.2)
hand	24.9–259.3	92.4	117.0 (±73.2)
genitals	–	–	–

The averages of radiation exposure by scattered rays were low during the K-wire osteosyntheses at all points. Similarly, in the other surgical procedures, the highest amounts of radiation were measured on the dominant hand of the surgeon, which is close to the radiation beam (average 3.1 μSv).

Our findings indicate that the amount of radiation to the surgeon at the different points is proportional to its duration and that the exposure to scattered rays decreases with an increase of the distance to the radiation beam.

Discussion

In this study, the radiation dose measured at four different sites on the surgeon's body during three operative procedures which required fluoroscopic guidance, was found to be uniformly low. In particular, the maximum average amounts of 117.0 μSv on the dominant hand and 55.5 μSv at the thyroid gland, per procedure are not serious (Table 2). The German government guidelines [2] allow a total body dose per year of 500 mSv at the hands and 300 mSv at the thyroid gland, corresponding to an average of more than 4000 respectively 5000 procedures on the lumbar spine per year. On the basis of our findings there is no likelihood of exceeding the limits even in a very busy operative environment.

Barry [1] measured the amount of radiation that he received in the operating room over the course of a year by wearing a universal film badge at the collar and a second badge under the lead apron at his waist. Beneath the lead apron he received a total dose of five millirems (100 mrem=1 μSv) while the dose to the head and neck totalled 227 millirem for the entire year.

Giachino and Cheng [5] measured radiation scatter during pinning of the neck of the femur and found that the dose could be greatly reduced by an increase of the distance to the radiation source. After 7 min of fluoroscopy during interlocking intramedullary nailing the dose at 40 cm was seventeen millirems (100 mrem=1 μSv) and at 80 cm it was two millirem [3]. No dosage was measurable behind an apron.

As the hands of the surgeon are close to the operating field Goldstone et al. [6] investigated radiation exposure with TLD dosimeters on the middle phalanx of the operating surgeon's dominant hand. Over a period of one month 44 procedures were carried out by nine different surgeons. The total radiation dose received per surgeon for the whole month ranged from 48-2329 μSv with a mean of 511 μSv. In this study the most junior and inexperienced surgeon had the highest radiation exposure [6]. In our study we also found that the range of exposure to radiation was very wide and that it was dependent upon the experience of the surgeon, the duration of fluoroscopy and the nature of the operative procedure. The individual location and distance to the radiation source was also relevant, as was the frequency of the surgeon's use of fluoroscopy to determine the amount of scatter.

The limit for the appearance of radiation-induced glaucoma is a dose of 2–4 Sv per life as a total load. It seems impossible to exceed this dose even in a very busy operative environment; nevertheless, the radiation exposure during professional activities has to be added to the individual exposure during private life. There is evidence that carcinogenic potential exists from low-dose, low-energy electromagnetic radiation [9] especially for the formation of malignant nodules of the thyroid gland [7]. It has shown that as little as 6.5 rad (65 μSv) of external irradiation to the thyroid bed leads to a statistically increased incidence of thyroid cancer, many years later. The German Ministry of the Environment [2] pointed out that a dose of 10 mSv per year causes an increased incidence of this malignant tumour by a factor of 2.2 per million. In this context, from our results, it seems possible to exceed this dose.

In order to reduce the radiation exposure both to the surgeon and the patient the AO has produced a radiolucent drive for distal interlocking during intramedullary nailing [10]. Friedl [4] modified the operative technique for the stabilisation of lumbar spine fractures using a central cannulated drill which is placed over a K-wire.

It is recommended [8] that the following precautions be taken to reduce the duration of fluoroscopy and the dose:

- The surgeon should be familiar with the technique of closed reduction and instrumentation.
- Whenever possible the image memory mode should be used.
- Since the radiation exposure decreases as the distance from the source increases, all personnel should stand back as far from the patient as feasible during any operative step that requires imaging.
- Appropriate lead aprons should be worn.
- During the op. projection the X-ray tube should be at the maximum distance from the patient with the image intensifier close to the patient. This position decreases the level of scatter which is reflected back to the surgeon.

Other factors which indirectly reduce the amount of radiation exposure include automatic brightness-control mechanism, automatic gain-control mechanism, the size of the focal spot and the lens and television systems together with the memory mode. The risks of radiation which are low at the present time will be further reduced in the near future by new technology such as computer assisted surgery or robotic surgery.

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