Radiation Dose in OR –
A Comparison of Computer Assisted Procedures

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Since the 1990s, computer-assisted methods have become well established in the fields of orthopedics and traumatology. In addition to the proven improvement in the field of surgical precision compared with conventional techniques, the decrease in the amount of emitted ionizing radiation inside the operating room was cited to constitute an additional major advantage of computer-based navigation. The goal of this study was to quantify X-ray dose values exposed during both conventional methods and computer-assisted procedures, the latter being performed using a C-arm device SIREMOBIL Iso-C³ (Siemens Medical Solutions). The clinical measurements were supplemented by laboratory experiments using a pinpoint ionization chamber placed inside a standard lucite phantom. The clinical part of the study investigated the application of new, i.e. computer assisted, techniques in comparison with conventional procedures on in total 42 patients experiencing surgery either on their lower extremities (n = 14) or on the spine (n = 28). The techniques applied were: (1) conventional surgical procedure, (2) CT-based navigation, (3) C-arm navigation, and (4) Iso-C³-navigation. The main focus of the clinical evaluation was the determination of radiation dose values by means of thermo-luminescence dose meters, accompanied by the registration of the operation times of the X-ray tube during a surgical intervention. The conclusions from the clinical studies are in agreement with the results from the laboratory measurements. Computer-assisted techniques led to a significant reduction in X-ray dose exposure and drastically shortened irradiation times. The most pronounced decrease in the emission of ionizing radiation was achieved in case of the Iso-C³-navigation, which has only recently been introduced into clinical practice, i.e. during runtime of this study.

Keywords
CAOS · Navigation · C-arm · X-ray image intensifier · X-ray dose

Since the 1990s, computer-assisted methods have become well established in the fields of orthopedics and traumatology [4]. In addition to the increase in surgical precision compared with conventional techniques proclaimed since that time, one of the major advantages gained from computer navigation has been the decrease in the amount of ionizing radiation during trauma surgery. A number of studies have confirmed the first assertion. The new operating methods are superior to conventional methods in the accuracy of hardware placement [7, 8, 11, 12].

Moreover, particularly due to the increased use of minimally invasive procedures, a further increase must be expected in the use of x-radiation. A study was therefore carried out in the Trauma Department of the University of Ulm Hospital in order to quantify and, for the first time, prove which methods are superior with regard to minimizing the emitted X-ray dose, using a SIREMOBIL Iso-C³ (Siemens Medical Solutions).

The clinical measurements were supplemented with laboratory measurements on a standard lucite phantom.

Material and methods
Clinical measurements

Between July 2000 and September 2001, a total of 42 patients were operated on in the Trauma Department of the University of Ulm Hospital who, with respect to their injuries, could be treated both conventionally and with navigation support. Both interventions on the lower extremities and operations on the spine were studied. All operations were performed by two experienced surgeons in order to obtain a comparison of the fluoroscopy times in particular for the conventional procedure. The Iso-C arm was used in all cases as
the C-arm, which was operated in either 2D (conventional) or 3D mode.

A total of 14 patients underwent operations of the lower extremities, while 28 patients underwent spinal operations.

Of the 14 patients subjected to operations in the area of the proximal femur, two underwent operations by C-arm navigation, six by Iso-C3D navigation [2, 3, 6, 9, 10] and also six patients by conventional technique, that is without any computer navigation. Of the 28 patients subjected to spinal operations, ten underwent CT-based operations, nine operations were by C-arm navigation, one by Iso-C3D navigation and eight by conventional technique.

Figure 1 summarizes this.

The measurement of X-ray doses was performed using thermoluminescence dosimetry (TLD). The principle of this procedure is based on the ability of certain crystals to store energy (here in the form of ionizing radiation). During irradiation, electrons are freed from their bonds and can be captured by so-called ion traps in states of higher energy. These ion traps can be emptied by heating. The energy previously absorbed by X-radiation is then radiated away as visible light. The amount of light emitted can be measured in analyzing units. From this it is possible to calculate back to the X-ray dose originally incident on the detector crystal.

The dosimeters used in the clinical study were TLD 100 units from Harshaw® (Figure 2). The detector element is made of lithium fluoride. To increase their storage capacity, they are treated with magnesium and titanium. These materials function as ion traps [1, 5].

The evaluation took place in the TLD system model 5500 of Harshaw/Bicron®, and the heating in the microprocessor-controlled Temperofen oven of PTW, Freiburg, Germany (model PTW-TLDO type 1231) for the reproducible tempering and pre-heating of TLD crystals. The dosimeters have a cylindrical form, with a diameter of 1 mm and a length of 6 mm.

Before the beginning of each operation, the dosimeters were arranged in pairs at three measurement positions: two at the radiation source, two at the patient in the radiation beam on the side of the patient turned to the operating table, and two on the radiation detector (see Figure 3). The mean value of the two measurements for each position was calculated in order to improve accuracy and minimize the probability of faulty measurements.

Certainly, the most meaningful values measured are those from the dose meters located directly in the beam path near the radiation source, since these do not depend on the changes in the parameters between different measurements, particularly the size of the patient’s body.

For each clinical intervention, the time during which the X-ray tube was operated was also measured. This time was read directly from the tube.

### Laboratory measurements

The everyday clinical use of C-arm systems does not allow for sufficiently meaningful comparisons of X-ray tube operating times after calculating the mean value over several patients. The reason is the occurrence of variable radiation qualities resulting from changing the direction of radiation, and even more from the different patient body sizes encountered from case to case.

Due to the nature of clinical applications, the ideally required comparison of the dose exposure with different methods of navigation on one and the same patient is not possible. Measurements on phantoms are, however, not subject to this limitation. Thus, in January 2002 supplementary laboratory investigations were performed at Siemens Medical Solutions, using a SIREMOBIL Iso-C3D C-arm system identical with the system used for the clinical measurements.

The goal of the laboratory investigations was to quantify how much irradiation time in continuous fluoroscopy mode is required to yield the equivalent dose to a standard Iso-C3D acquisition on the same object.

Figure 4 illustrates the phantom used for the laboratory measurements, consisting of lucite in cylindrical form with a height of 16 cm and 16 cm diameter (“CTDI head phantom”). A cylinder-shaped ionization measuring chamber (Capintec, Ramsey, NJ, USA) was placed in the central axial bore for the measurement of the dose-length product and coupled to a Unidos dose meter (PTW, Freiburg, Germany).

The phantom was then placed onto a standard composite carbon fiber patient table in the scanning plane of the C-arm and furthermore positioned within the isocenter of the C-arm. The central phantom bore was oriented so as to coincide with the axis of rotation of the C-arm.

The dose-length product values measured in the ionization chamber were documented. The respective values for the mean dose within the central phantom bore were derived by dividing by the length of the measuring chamber of 96 mm. The local dose at any arbitrary reference point on the axis of the phantom deviated only insignificantly from this, since the increase in the irradiated path in the lucite is well below 1 cm compared with that of the central plane of the phantom to the bottom or top surface.

![Fig. 1 ▲ Distribution of patients for the procedures investigated.](image-url)
Two different series of measurements were performed:

- A standard Iso-C™ scan with radiation quality varying over time, comprising 100 projections equidistantly distributed over an arc length of 190 degrees: The directions of radiation for the start and end orientation were approximately horizontal (as in the arrangement of Figure 4). The center point of the rotating arc for the image intensifier was positioned vertically beneath the patient table. In the interest of improving the statistical accuracy, the Iso-C™ measurement was carried out over a total of five times and the mean value of the five separate results calculated.

- A continuous 2D fluoroscopy with fixed orientation of the radiation source and image intensifier: For this measurement, the X-ray source was positioned vertically beneath the patient table. In the interest of improving the statistical accuracy, the Iso-C™ measurement was carried out over a total of five times and the mean value of the five separate results calculated.

The investigation of the application of this method for the example of the proximal femur (screw fixation for femoral neck fractures) showed that greater effort is required to perform the examination, without significantly better results following the operation. In addition, a comparison of the medians of the measurements at the X-ray source indicated that for conventional techniques only 1.2 times greater X-ray dose is emitted than with the C-arm navigation (see Figure 5a). For these two reasons, C-arm navigation was discontinued for the purposes of this study.

Comparing the mean dose values of the measurements close to the radiation source for the conventional technique and the Iso-C™ navigation (see Figure 5b), a reduction in radiation exposure by a factor of more than 16 was found for the computer-assisted method. A comparison of the medians, for a limited number of cases the more significant statistical measure, still gives a reduction of more than a factor of 11 for the use of Iso-C™ navigation.

Even the maximum measured value (132 mGy) for the Iso-C™ navigation is still well below the minimum value with the conventional technique (232 mGy).

With regard to the large difference between the mean value and the median with the conventional procedure, it must be mentioned that here the 95% confidence interval ranges from 229 mGy to 2303 mGy. This wide variation could be reduced only through a greater number of measurements. The 95% confidence interval for the Iso-C™ navigation, by comparison, has a range of only ± 40 mGy around the mean value and is therefore very narrow.

Comparing the mean operating times of the X-ray tube demonstrates that, for conventional interventions of the lower extremities, on average irradiation was about five times as long and, for C-arm-based navigation around three times as long as for Iso-C™ navigated operations. This supports the dosimetric results measured and points the way to the real value of reduced radiation exposure during surgical interventions.

**Spinal operations**

For operations on the spine, four different procedures were used within the scope of this study:

- Conventional (non-computer-assisted) procedure (eight patients)
- CT-based navigation (10 patients)
- C-arm navigation (nine patients)
- Iso-C™ navigation (one patient)

In the area of spinal operations as well, the highest values at all measurement positions were found for the conventional procedure.

The median of the measured dose values for the conventional procedure was found to be 2.5 times the corresponding value for CT-based navigation, 1.6 times that for C-arm navigation, and as much as 3.5 times that for Iso-C™ navigation (Figure 6a).

Nevertheless, the values for the Iso-C™ navigation must be evaluated with caution, since only one patient has been measured to date in the area of spinal operations with this method. This is because the 3D method was only introduced in the Traumatology Department at the University of Ulm Hospital during the course of the study.

**Interventions of the lower extremities**

For operations of the lower extremities three procedures were investigated:

- Conventional (non-computer-assisted) procedure (six patients)
- C-arm navigation (two patients)
- Iso-C™ navigation (six patients)

In the area of C-arm navigation, measurements were made on only two patients.
exposure: On average, this was 180 seconds for the conventional procedure and therefore 2.3 times as long as for the CT-navigated operations (79 seconds), twice as long as for C-arm navigations (91 seconds) and even nine times as long as for the Iso-C3D measurement (20 seconds).

In spite of the fact that only a single measurement was made for the Iso-C3D-based navigation, this comparison of times is significant, since in this case the C-arm is always in operation for the same time for each spinal intervention. The reason is that it automatically acquires 100 pulsed images of the region of interest, with a fixed, preset radiation time of 20 seconds.

A dorsal bisegmental spondylosyn- desis of the spine always requires three scans: 1-2 scans for instrumentation and one scan for verification of the implantation. The results found for each single measurement can be summed over the scans. Even in the extreme case of performing three Iso-C3D scans, the total irradiation time is still well below the corresponding times for the other methods.

According to the estimates possible at the present time, the newest method – Iso-C3D imaging – represents the technique in which the lowest level of ionizing radiation is emitted, even for spinal interventions. This tendency must be verified in the future by performing additional measurements.

**Laboratory results**

Scanning the lucite phantom with the Iso-C3D method yields a mean dose of 1.57 mGy measured on the object axis per complete data acquisition (consisting of 100 projections). Furthermore, during the rotation around the lucite phantom, a mean tube voltage of 63 kV and a mean tube current of 3.3 mA were measured.

The dose value of 1.57 mGy measured here is, for physical reasons, considerably lower than the values determined close to the radiation source. This is explained on the one hand by the larger distance between the ionization chamber and the X-ray tube and, on the other hand, by the absorption in the lucite body of the phantom.

An examination of the mean values showed that the lowest emission of ionizing radiation was for navigation with the Iso-C3D method. By comparison, the emitted X-ray dose was a factor of 1.5 greater for CT navigation, 2.3 times for C-arm navigation, and even 4.7 times greater for the conventional method (Figure 6a). Since in the case of the Iso-C3D only a single value was measured, this result must be verified by carrying out additional measurements.

The measurements performed on the patient confirm the results of the dose meter at the X-ray source. Thus, the dose with the conventional procedure was found to be 2.7 times the dose emitted in CT-navigated operations and 1.4 times that of the C-arm-navigated method. For the Iso-C3D method, as for the interventions of the lower extremities, no measurement was performed in the vicinity of the patient.

For the measurements at the radiation detector, the ratio is shifted in favor of C-arm navigation, which gives the lowest value here. By comparison, the dose for conventional operations is 1.8 times greater. The dose meters used with the conventional procedures registered 1.4 times the X-ray dose of the TLD used with the CT navigation and 1.3 times that of the TLD used with the Iso-C3D navigation.

Similarly, the operating times of the X-ray tube for the different procedures allow conclusions concerning the radiation
The irradiation of the same phantom in continuous fluoroscopy mode with the C-arm at rest gave a mean measured dose rate of 0.040 mGy/s. The tube voltage for this measurement was constant at 62 kV, and the tube current was also constant at 1.7 mA.

The comparison of these two measured results shows that, with regard to the dose exposure, a standard Iso-C3D data acquisition is the equivalent of 39.3 seconds continuous fluoroscopy. In other words, for the cylindrical lucite phantom every continuous fluoroscopy lasting more than 39.3 seconds results in a higher dose than an Iso-C3D scan, with 100 projections.

The time of 39.3 seconds will now be compared with typical irradiation times during operational interventions not supported by Iso-C3D. The corresponding values for clinical interventions on the spine, of the order of magnitude of three minutes for conventional procedures, and 90 seconds for C-arm-based navigation, show without a doubt that the advantage of reduced dose is clearly in favor of the Iso-C3D method.

To a very good approximation, this result also holds up to the possible objection that a different geometry of the irradiated object automatically results in different dose values. Thus, for example, a thicker phantom always requires a greater tube current and therefore an increase in the dose emitted by the X-ray tube. However, this applies in equal measure for the two isocentric C-arm operating modes discussed here, so that the result is ultimately the same, in the form of an equivalent irradiation time for fluoroscopy mode.

**Discussion**

In all clinically investigated areas, with regard to the level of X-radiation emitted and the operating time of the X-ray tube, computer navigation was clearly superior to the conventional procedures. This is especially clear for the values determined at the radiation source; of all measuring positions investigated, this measurement holds the greatest meaning since it is measured under the same conditions for each patient and does not depend on variable factors (as is the case at the other positions measured).

The measurements on the patient and at the radiation detector always depend on the size of the patient’s body, which the radiation must first penetrate before it can be registered. Moreover, for a measuring point on the patient, it is not always certain that the patient is positioned in the center of the beam path, since in addition to images with a sagittal beam path others can also be acquired with a transverse beam path.

The results of dosimetry agree with the registered operating times for the X-ray tube. The consideration of shorter operating times, but above all the vastly lower doses, clearly indicate that the use of computer-assisted methods in the area of spinal surgery and for interventions of the lower extremities leads to a significant reduction in exposure to ionizing radiation, both for patients and particularly for the operating room staff.

The results of the laboratory measurements are in close agreement with these results: They show that, for a given irradiated object, a dose exposure lower than that for a standard Iso-C3D data acquisition is possible only under the conditions of extremely short, and thus for the operative area atypical, irradiation times with conventional fluoroscopy or C-arm navigation.

In summary, a comparison of the various computer-assisted methods demonstrates that Iso-C3D imaging is the technique that subjects the patient and the operating room staff to the least amount of ionizing radiation. Further studies should be conducted in the future with the aim of verifying this tendency.

Additionally, in a comparison of CT navigation vs. C-arm navigation, as expected less radiation was emitted for CT navigation than for C-arm navigation.

**Conclusion for practical applications**

The results presented here show that the use of computer-assisted methods in all areas investigated leads to a considerable reduction in radiation exposure and shorter fluoroscopy times along with the known improvement in diagnostic accuracy.

The greatest reduction in the level of ionizing radiation emitted was found for Iso-C3D navigation, which was only recently introduced into clinical operation, at the time of this study.
Literature
