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FULL PAPER

Radiation exposure of the interventional radiologist during percutaneous biopsy using a multiaxis interventional C-arm CT system with 3D laser guidance: a phantom study

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Objective: Evaluation of absolute radiation exposure values for interventional radiologists (IRs) using a multi-axis interventional flat-panel C-arm cone beam CT (CBCT) system with three-dimensional laser guidance for biopsy in a triple-modality, abdominal phantom.

Methods: In the phantom, eight lesions were punctured in two different angles (in- and out-of-plane) using CBCT. One C-arm CT scan was performed to plan the intervention and one for post-procedural evaluation. Thermoluminescent dosimeters (TLDs) were used for dose measurement at the level of the eye lens, umbilicus and ankles on a pole representing the IRs. All measurements were performed without any lead protection. In addition, the dose-area product (DAP) and air kerma at the skin entrance point was documented.

Results: Mean radiation values of all TLDs were 190 μ Sv for CBCT (eye lens: 180 μ S, umbilicus: 230 μ Sv, ankle:

150 μ Sv) without a significant difference ($p > 0.005$) between in- and out-of-plane biopsies. In terms of radiation exposure of the phantom, the mean DAP was not statistically significantly different ($p > 0.05$) for in- and out-of-plane biopsies. Fluoroscopy showed a mean DAP of 7 or 6 μ Gym², respectively. C-arm CT showed a mean DAP of 5150 or 5130 μ Gym², respectively.

Conclusion: In our setting, the radiation dose to the IR was distinctly high using CBCT. For dose reduction, it is advisable to pay attention to lead shielding, to increase the distance to the X-ray source and to leave the intervention suite for C-arm CT scans.

Advances in knowledge: The results indicate that using modern navigation tools and CBCT can be accompanied with a relative high radiation dose for the IRs since detector angulation can make the use of proper lead shielding difficult.

INTRODUCTION

Today's multidisciplinary, personalized therapies require tissue samples for histological specification and molecular profiling for targeted therapy; for example, CD20 expression in non-Hodgkin lymphoma. For this purpose, CT-guided interventions (CTGIs) are being used with increasing frequency.^{1,2} A closed gantry-based setting for biopsies might be limiting because of a small gantry opening or the gantry angulations that are needed.³ As flat-panel (FP) C-arm cone beam CT (CBCT) systems have a different X-ray beam geometry, spatial resolution, image quality, signal-to-noise ratio and scatter radiation than multidetector CT (MDCT), most studies have focused on increased radiation doses to the patient using FP CBCT and not on the radiation exposure of the interventional radiologist (IR) in the intervention suite.⁴⁻⁷

With the different angulations that are possible when using the CBCT system, the radiation dose might be higher for the IR than when using MDCT. To avoid unnecessary radiation exposure, recent developments in image guidance and navigation tools have been tested, such as remote robotic steering systems or real-time three-dimensional (3D) imaging, for visualizing the sensitive target organs and placing the needle more effective and faster.⁸ Therefore, it also seems important to evaluate radiation exposure of the IR to raise awareness concerning radiation and to encourage appropriate use of radiation protection.

The aim of this phantom study was to evaluate radiation exposure of the IR using a multiaxis interventional C-arm CT system with 3D laser guidance.

METHODS AND MATERIALS

For needle guidance during percutaneous biopsy, the multiaxis interventional FP C-arm cone beam CT (Artis zeego®; Siemens Healthcare, Erlangen, Germany) was used for biopsy with 3D laser support (syngo® iGuide, syngo X-Workplace; Siemens Healthcare). A triple-modality 3D abdominal phantom (model 057A; CIRS, Norfolk, VA; width × height × depth: 26 × 19 × 12.5 cm) was punctured with a 20-G biopsy needle (Figure 1). This study was conducted as part of a larger research initiative comparing CBCT and MDCT.

In the abdominal phantom, eight lesions were identified (six liver, one right/ one left renal pelvis). Each lesion was biopsied twice at different angles (eight in plane, eight out of plane) using the CBCT. Two 20-l water containers (width × height × depth: 28 × 35 × 20.5 cm) were placed adjacent to the phantom to increase its volume, so as to cover the full field of view (FoV) of the scanner and to realize a realistic scatter scenario (Figure 2). Fluoroscopy and procedural times (from planning CT to control CT) were also measured.

Guidance protocol

Using the CBCT, one C-arm CT (syngo DynaCT; Siemens Healthcare) was performed to plan the intervention, and one for post-procedural evaluation to properly identify the needle point within the lesion. C-arm CT uses a 200° rotation from 170° right anterior oblique to 30° left anterior oblique. Image acquisition was triggered for every 0.5° during a 6-s rotation. No collimation was used throughout the whole procedure. A cylinder of 24.72 cm in diameter and 19.5 cm in height (FoV) was reconstructed in 391 CT slices with a thickness of 0.5 mm and an image matrix of 512 × 512. Tube voltage was 90 kV, and the pulse time was 3.5 ms. Measurements were performed with automatic tube current modulation (median: 260 mA; quartile: 225–265 mA). The stated preferences were the same as used in a clinical setting.

The skin entry point and target point were defined on the acquired image data set. Based on these markings, three projections were computed using the 3D laser support system (iGuide

Figure 1. Triple modality three-dimensional abdominal phantom with needle placed in lesion.

Figure 2. Study setting in the intervention suite using the multiaxis interventional flat-panel C-arm cone beam CT in “progression view” angulation.

software): one “bull’s-eye view” in which the needle is adjusted (Figure 3) and two “progression views” that show the needle path overlaid on live fluoroscopy. The two perpendicularly oriented laser fans of the laser cross-hair in the bull’s-eye view show the entry point on the skin and the required orientation of the needle in space.

Alternating between the progression views, the needle was advanced into the lesion using the overlaid needle path on live fluoroscopy as guidance. Fluoroscopy was triggered only as long as needed for image acquisition with last image hold technique.

Documentation of radiation exposure

Thermoluminescent dosimeters (TLDs) were positioned without any lead apron or any additional lead shielding available in the CBCT environment (lead protection glass and lead curtains) to measure partial body doses (PBDs). For each intervention, three TLDs were placed at the level of the eyes, umbilicus and ankles on a pole facing the phantom to collect representative radiation exposure values. The pole was placed at a distance of 60 cm from the phantom on a possible position of the IR during interventions without lead shielding and was not moved for the entire duration of the intervention.

The TLDs were read according to a study by Häusler *et al.*⁹ Each TLD was calibrated for the personal surface-dose-equivalent H_p (0.07) on a plastic rod. Irradiation conditions similar to those at

Figure 3. Needle placement using “bull’s-eye view”.

interventional workplaces were used with spectra of the type N-40, N-60, W-110 and W-150 according to ISO 4037-1. The TLDs were read with a Harshaw TLD™ Model 3500 (Thermo Electron GmbH, Erlangen, Germany) reader. Annealing and heating conditions were performed according to the manufacturer's recommendation.

In addition, the system dose report of Artis zeego was analysed in order to assess how much of the total patient dose was produced by C-arm CT and fluoroscopy.

Statistical analyses

Absolute and relative frequencies are presented with standard deviation and range. Kolmogorow–Smirnow test was performed to test for normal-value distribution. As normal-value distribution was proven, independent sample *t*-test was used to compare different groups. All statistical analyses were performed with SPSS® v. 21 (IBM Corporation, Armonk, NY; formerly SPSS Inc., Chicago, IL). A *p*-value <0.05 was considered statistically significant.

RESULTS

Cone beam CT

For all 16 biopsies taken with CBCT guidance, median fluoroscopy time was 4.0 s (range: 2–6 s) and median overall

procedural duration was 827 s (range: 609–11,487 s) to properly position the needle within each target lesion (Table 1). For in-plane needle placement, median fluoroscopy time was 4.0 s (range: 3–5 s) and median overall procedural duration was 843 s (range: 771–1121 s); for out-of-plane mode median fluoroscopy time was 4.0 s (range: 2–6 s) and median overall procedural duration was 827 s (range: 609–11,487 s).

Mean radiation value of all 48 TLDs was 190 μ Sv (± 60 , range: 100–420 μ Sv; Table 1). Whereas 71% (*n* = 34) of TLD dose values were between 100 and 200 μ Sv, 25% (*n* = 12) were between 200 and 300 μ Sv; 2% (*n* = 1) were between 300 and 400 μ Sv; and 2% (*n* = 1) were between 400 and 500 μ Sv. No TLD value was >500 or <100 μ Sv.

The different dose values for all three TLD positions are listed in Table 2 and presented in Figure 4. The mean TLD dose value at the level of the eye lens was 180 μ Sv (± 40 μ Sv, range: 120–290 μ Sv; *n* = 16), of the umbilicus was 230 μ Sv (± 70 μ Sv, range: 140–420 μ Sv; *n* = 16) and of the ankle 150 μ Sv (± 30 μ Sv, range: 100–190 μ Sv; *n* = 16). The mean absolute values of radiation exposure of the eight out-of-plane biopsies were higher for all three TLD positions compared with the eight in-plane biopsies (eye lens: 200 vs 160 μ Sv, umbilicus: 260 vs 200 μ Sv and ankle: 160 vs 140 μ Sv; Table 2, Figure 5). But the difference between in- and out-of-plane biopsies was not statistically significant (eye lens: *p* = 0.075, umbilicus: *p* = 0.079 and ankle: *p* = 0.065).

System dose report of cone beam CT system

Table 3 shows the mean dose–area product (DAP) as documented in the dose report of the CBCT. The mean DAP for in- and out-of-plane biopsies did not differ statistically significantly (*p* > 0.05). For in-plane and out-of-plane biopsies, fluoroscopy showed a mean DAP of 7 or 6 μ Gym², while C-arm CT showed 5150 or 5130 μ Gym², respectively. In conclusion, C-arm CT accounted for 99.9% of the radiation exposure and fluoroscopy only for 0.1%. The mean air kerma throughout all interventions was 61 mGy $\pm$ 3 (median: 61 mGy, quartile: 60–63 mGy and range: 54–64 mGy).

Table 1. Baseline characteristics of the performed biopsies using the multiaxis interventional flat-panel C-arm cone beam CT (CBCT)

Baseline characteristics	Value
Dose measurements	<i>n</i> = 48
Mean dose CBCT (SD; range) (μ Sv)	190 (± 60 ; 100–420)
Mean patient dose CBCT (SD; range) (μ Gym ²)	5140 (± 560 ; 3760–5740)
Median fluoroscopy time CBCT (range) (s)	4 (2–6)
Median procedural duration CBCT (range) (s)	827 (609–11,487)

SD, standard deviation.

Table 2. Radiation value of all three thermoluminescent dosimeter (TLD) positions using the multiaxis interventional flat-panel C-arm cone beam CT

TLD position	Mean dose (μSv) $\pm$ SD (range)	Mean dose (μSv) $\pm$ SD (range)		
	Overall	In-plane	Out-of-plane	<i>p</i> -value
Eye lens	180 $\pm$ 40 (120–290)	160 $\pm$ 30 (120–190)	200 $\pm$ 50 (120–290)	0.075
Umbilicus	230 $\pm$ 70 (140–420)	200 $\pm$ 40 (140–260)	260 $\pm$ 80 (160–420)	0.079
Ankle	150 $\pm$ 30 (100–190)	140 $\pm$ 20 (100–160)	160 $\pm$ 30 (110–190)	0.065

SD, standard deviation.

DISCUSSION

Owing to limitations in closed-gantry CT systems, C-arm-guided biopsies are becoming more and more attractive; several studies reported promising results for renal, bone, hepatic and thoracic interventions in terms of practicability, interventional success and complication rate.^{10–13} In this context, radiation exposure is an important issue not only for the patient but also for the IR.

With today's FP C-arm CBCT systems, it might become time consuming to effectively position the lead shielding, as any possible lead glass or lead curtains might impair the mobility of CBCT; for the laser-assisted 3D navigation tool, the C-arm requires high mobility to be able to move into the bull's-eye and progression views.

Published results of a study comparing exposure of the IR in 33 bone biopsies by Tselikas *et al*¹⁴ in 2013 suggest that the radiation dose is lower with CBCT than with MDCT. They reported a dose below detection limits for CBCT in 41% of the cases and for MDCT in 73% of the cases ($p = 0.01$). Doses were measured with electronic dosimeters, which were positioned under a lead apron (0.25 mm). It is not known, however, whether additional lead shielding was used or whether the IR remained within the intervention suite throughout each control scan. For initial measurements, we used additional lead shielding (lead protection glass and lead curtains) without lead apron. On the one hand, irradiation values were below detection limits, and on the other hand, certain projections to perform biopsy were

Figure 4. Radiation value of all three thermoluminescent dosimeter positions using the multiaxis interventional flat-panel C-arm cone beam CT.

Figure 5. Comparison of radiation values for in-plane to out-of-plane biopsy of all three thermoluminescent dosimeter positions using the multiaxis interventional flat-panel C-arm cone beam CT.

not possible without repositioning or removing the lead protection. Our clinical experience with the CBCT for interventional guidance showed that in certain cases, lead protection cannot be applied throughout the whole procedure. In order to show a possible maximum radiation exposure and not be impaired by needle guidance, we changed our setting. The higher radiation doses found in our study compared to those reported by Tselikas et al¹⁴ can be explained by the absence of lead protection and also by the fact that the TLDs positioned next to the phantom remained there even during the C-arm CT scans. This would support the hypothesis that the position of the IR with regard to the position and angulations of the C-arm is important to reduce radiation exposure.

Published data on radiation exposure of the IR without lead protection during percutaneous biopsy using MDCT suggest

a fairly low radiation dose with a mean value of 12 μSv . 99.7% of all measured values were $<100 \mu\text{Sv}$.¹⁵ They also collected radiation dose of possible unprotected body parts such as the eye lens and the extremities. In our study setting, needle guidance with CBCT results in distinct higher radiation doses to the IR (mean dose: 190 μSv ; 100% $>100 \mu\text{Sv}$) than in the mentioned data (96.7% $<100 \mu\text{Sv}$).¹⁵ In daily routine, this demonstrates that the IR should pay special attention to radiation exposure and should take great care to make use of any radiation protection available.

It is important to keep in mind that the by comparison high radiation exposure during CBCT interventions might also be due to improved X-ray shielding of the latest CT gantry generations.¹⁵ This innate X-ray protection of a CT gantry is for

Table 3. Patient dose using the multiaxis interventional flat-panel C-arm cone beam CT (CBCT)

Patient dose	In-plane (μGym^2)	Out-of-plane (μGym^2)	<i>p</i> -value
Mean dose CBCT $\pm$ SD (range)	5160 $\pm$ 530 (3990–5740)	5130 $\pm$ 620 (3760–5620)	0.931
Mean dose fluoroscopy $\pm$ SD (range)	7 $\pm$ 2 (4–9)	6 $\pm$ 3 (3–10)	0.528
Mean dose C-arm CT $\pm$ SD (range)	5150 $\pm$ 530 (3980–5730)	5130 $\pm$ 610 (3750–5620)	0.933

SD, standard deviation.

architectural reasons, not realizable in a comparable fashion in CBCT-guided interventions, making a direct comparison difficult. In addition, a comparison of data acquired in a phantom study might differ from data acquired during clinical work.

Another option to reduce radiation exposure is to reduce scatter radiation. Here, Orth et al¹⁶ reported that one of the most effective strategies to reduce scatter radiation is *via* the FoV, which can be influenced by the operator. Reducing the FoV to the region of interest not only decreases scatter radiation and, at the same time, the radiation exposure of the patient and medical staff but also improves image contrast. For our experiment, we used the full FoV. With a mean dose value of 230 μ Sv at the level of the umbilicus, the radiation dose for the IR was already fairly low, but there are still many options to reduce it, such as reducing the FoV, lead protection and leaving the intervention suite during control scans. Kuon et al¹⁷ described a dose reduction of the operator to 0.8% with improved lead protection in coronary angiography.

Strocchi et al¹⁸ compared CBCT with MDCT in transthoracic biopsy: 74% of the effective dose in CBCT and 91% of the effective dose in MDCT for the patient are obtained by the CT-scan mode when planning the procedure or for generating images for 3D reconstructions. C-arm CT also caused the majority (99.9%) of radiation to the possible patient in our study setting. Although other studies^{9,19} revealed that irradiation in patients does not necessarily correlate with the irradiation of the medical staff, the results of Strocchi et al¹⁸ and ours suggest that for IRs, most of the radiation is produced by C-arm CT scans.

In our opinion, it is not necessary for the IR to stay in the intervention suite for these scans. Indeed, the present results suggest that leaving the room for C-arm CT would distinctively reduce radiation exposure of the IR besides wearing lead protection. In addition, Daly et al²⁰ showed a dose reduction to the eye lens of the patient by a factor of 5 when performing a posterior scan instead of an anterior one. Posterior tube rotations might also reduce dose exposure of the IR according to the inverse square law.

CONCLUSION

In our setting, the radiation dose to the IR was distinctly high using CBCT for biopsy guidance. The usage of proper lead protection, keeping distance to the X-ray source and leaving the intervention suite for C-arm CT might reduce radiation exposure to a level similar to or even below that in MDCT.

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