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Radiation exposure during different percutaneous renal puncture techniques: A YAU endourology & urolithiasis study

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Purpose: Radiation exposure is affected by C-arm fluoroscopy device positioning during percutaneous renal puncture. Our aim was to compare the exposure of surgeon's lens, hand and chest with a fluoroscopy protocol replicated in different C-arm positions.

Materials and Methods: A standardized fluoroscopy protocol was created using water-equivalent solid phantoms to replicate a surgeon and patient. 111 mGy radiation (360 s) was applied in standard fluoroscopy mode (91 kVp, 2.7 mA/mAs). Dosimeters were placed on lens, chest and hand of surgeon and patient phantom models. 7 different C-arm positions were created: 0°, mediolateral (ML) +90°, ML -90°, ML +30°, ML -15°, craniocaudal (CC) +30°, CC +15°. Measurements were evaluated separately for different positions.

Results: The highest radiation exposure was measured on patient dosimeter (2.97 mSv). The highest exposure on surgeon was recorded on finger dosimeter in all C-arm positions; highest dose was recorded in ML +90° position (2.88 mSv). In finger dosimeters, lowest exposure was recorded in 0° position (0.51 mSv). The lowest exposure of all positions was measured in chest dosimeter in ML -90° position (0.24 mSv).

Conclusions: In positions where X-ray generator of the C-arm was facing towards the surgeon, radiation exposure measured in all dosimeters was higher compared to positions where the generator was facing away. The hand radiation exposure in all positions was higher than chest and lens. Special care must be taken to avoid facing the X-ray generator tube and hands should be as well-protected as chest and eyes with special protective gear.

Keywords: Percutaneous nephrolithotomy; Radiation exposure

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INTRODUCTION

Percutaneous nephrolithotomy (PCNL) is the 1st choice for stones larger than 2 cm, however with miniaturization of endoscopes, and popularization of miniaturized PCNL it is widely performed for any sized stone in the collecting system [1]. Radiation exposure is one of the major concerns for PCNL as professional exposure is higher compared to other endourological procedures [2].

The main source of radiation to the operating room (OR) personnel is the scattered radiation from the patient. With the "ALARA" (As Low As Reasonably Achievable) principle, on-going efforts are being made to decrease the exposure to both patients, surgeons and also to the OR personnel. The most important step towards reducing radiation exposure during PCNL is the use of ultrasound for kidney puncture [3,4]. However, fluoroscopic percutaneous renal access, whether alone or combined with the ultrasound, is still widely used in many centers.

The distribution of radiation exposure during PCNL is not uniform. Supine and prone PCNL have different radiation exposure profiles [4] and even left and right sided procedures may have different amounts of radiation exposure [5]. During different fluoroscopic puncture techniques, there are variable radiation exposure doses based on different C-arm positions. The positioning of the X-ray tube and the image intensifier of the C-arm device and along with the patient positioning are the main factors for the difference in radiation exposure.

In this study, our aim was to compare the radiation exposure of the surgeon's lens, hand and chest by creating a standard fluoroscopy protocol that had been replicated in different C-arm positions. After standardized fluoroscopy exposure, dosimeter measurements were evaluated separately for different positions.

MATERIALS AND METHODS

In order to compare the radiation exposure during different percutaneous renal puncture techniques, a standardized fluoroscopy protocol was created using phantom models to replicate a surgeon and a patient. Optically stimulated luminescence (OSL) dosimeters were placed on the lens, chest and hand positions of the surgeon and patient phantoms (Fig. 1). The OSL dosimeters that were used in different areas and positions of the protocol were individually labeled and each measurement had a single dedicated dosimeter and none of the dosimeters was used twice. The use of phantoms offers the advantage of exposing the dosimeter to longer radiation duration and higher cumulative radiation than what the surgeon is usually exposed to in real-life situations. This, in turn provides the advantage of a more profound analysis of radiation exposure differences in different positions.

Water equivalent solid phantoms (solid plate phantom SP 34, made of white polystyrene, type RW3, IBA Dosimetry GmbH) which have similar density characteristics with human tissue were used. Their physical density is 1.045 g/cm^3, electron density is 3.43×1,023 e/cm^3 and they consist of white polystyrene containing 2% TiO_2 and their density difference between human soft tissue and muscle tissue is negligible. Due to these properties, the solid phantoms would reflect similar effects and scatter similar amount of radiation compared to a real patient when adjusted to a similar human torso width. A solid phantom model of 30×30×20 cm was used as the patient torso. As a surgeon, 1 standard size movable human dummy model of 170 cm height was placed by imitating the puncture position of the PCNL surgeon in real life.

Seven different C-arm positions according to different renal puncture techniques described in the literature were created. These positions were; Neutral 0 degrees, mediolateral (ML) +90°, ML -90°, ML +30°, ML -15°, craniocaudal (CC) +30°, CC +15° according to the standing position of the C-arm fluoroscopy device (Fig. 2).

A standardized fluoroscopy exposure was performed in pre-defined positioning of the C-arm, patient and surgeon phantoms. C-arm fluoroscopy device from GE Healthcare, GE Essential Brivo OEC 785 C-arm was used in standard fluoroscopy mode (91 kVp and 2.7 mA/mAs). The applied radiation dose was calculated in gray (Gy). Measurements were made by giving a total dose of 111 mGy radiation in

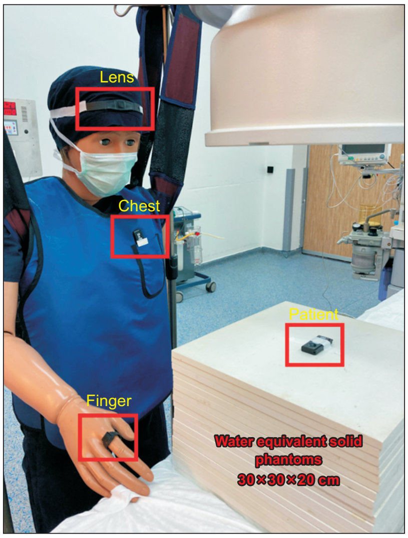

Fig. 1. Optically stimulated luminescence dosimeter placements.

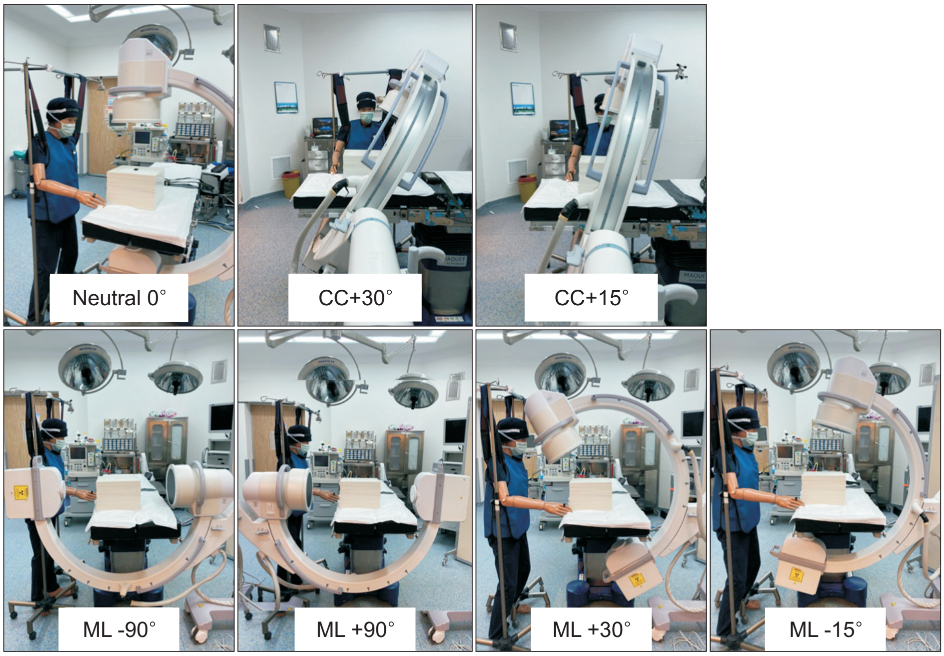

Fig. 2. Images showing the surgeon model, the phantom models used as the patient at different C-arm positions used in the study.

360 seconds and all the measurements were performed once in each position. The total radiation dose was decided upon a previously published study where this aforementioned fluoroscopy dose protocol was used [2].

After the simulation, the dosimeters are sent to a certified Dosimetry Measurement and Evaluation Laboratory and measurements were evaluated separately for different positions. The radiation exposure in each dosimeter was reported in millisievert (mSv).

This study was approved by the Institutional Review Board (IRB) of the Marmara University in which it was performed and also by Marmara University Ethical Committee (protocol number: 09.2021.693.).

RESULTS

After a total of 111 mGy radiation in 6 minutes (360 s) application on the solid phantoms in 7 different C-arm positions, the OSL dosimeters that were located on the patient model, and on the lens, chest and finger positions of the surgeon model were sent for measurements.

The highest radiation exposure was measured on the patient dosimeter that was placed on the solid phantoms and the dose was 2.97 mSv. Among the lens, chest and finger dosimeters, the highest exposure was recorded on the finger dosimeters in all C-arm positions. The highest radiation received by the finger dosimeter was recorded in the ML +90° position. Conversely, the lowest radiation dose received by the finger dosimeter was recorded in Neutral 0° position and was 0.51 mSv.

Table 1. Dose measurement results according to positions

C-arm position	Lens dose (mSv)	Chest dose (mSv)	Finger dose (mSv)	Patient dose (mSv)
Neutral 0°	0.33	0.34	0.51	2.97
ML +90°	0.67	1.05	2.88	
ML -90°	0.50	0.24	0.59	
CC +30°	0.34	0.37	0.68	
ML -15°	0.41	0.47	0.82	
ML +30°	0.34	0.45	1.72	
CC +15°	0.34	0.33	0.61	

mSV, millisievert; CC, craniocaudal; ML, mediolateral.

At different C-arm fluoroscopy positions, the highest dose recorded was 2.88 mSv in the ML +90° position, followed by 1.72 mSv at ML +30° position, both of which were recorded on the finger dosimeters. Among the chest dosimeters, the highest recording was measured in the ML +90° position with 1.05 mSv. Similarly among the lens dosimeters, the highest recording was 0.67 mSv also in the ML +90° position.

The lowest dose of radiation exposure among all positions was measured in the chest dosimeter in the ML -90° position with a reading of 0.24 mSv.

The total radiation doses recorded by the dosimeters are given in Table 1.

DISCUSSION

The risks of radiation exposure during urological practice comes from cumulative exposure to X-rays throughout the diagnostic and therapeutic steps in patients with urolithiasis. However, these patients are only exposed to radiation when the clinical benefits outweigh any risks from the radiation that may arise at any point of the evaluation and treatment process.

Patients are at lower risk groups compared to urologists who are actively participating in treatment of urolithiasis [6]. It has been demonstrated that the increase in the use of fluoroscopic interventions during surgeries have increased the risks of certain skin diseases as well as certain cancers, such as skin cancer, leukemias and lymphomas, among healthcare workers especially among surgeons who actively participate in fluoroscopic-guided operations [7].

Therefore, radiological protection during surgical interventions is of utmost importance. This is why the "ALARA" principle has been developed. The idea is to use as low radiation as possible to achieve the maximum benefit from a surgical or diagnostic intervention.

There are strategies such as teaching programmes, fluoroscopy checklists and judicious use of radiation protection devices to decrease X-ray exposure during surgeries but when PCNL is discussed, perhaps the most important step to minimize exposure is the use of ultrasound for percutaneous access [8,9].

Fluoroless PCNL, which may eliminate the radiation exposure entirely, requires great expertise as it is hard to master. That is why, flexible ureteroscopy can be used as an addition adjunct to fluoroless PCNL technique [10]. However, this may increase the financial burden of the procedure as 2 urologists and additional equipment are required. Due to these issues, fluoroscopy is still widely used during PCNL either solely or as an adjunct to ultrasound with similar success rates in surgical outcomes [11].

During percutaneous access to kidney, different techniques of puncture have been described [12-15]. In literature there are modifications of fluoroscopic C-arm position during the puncture such as monoplanar access, biplanar access using a triangulation technique, "Eye-of-the-needle" technique of a 0°–90° angulation technique, etc [13,15]. The differences between the radiation exposure potentials of these individual techniques have not been studied as a whole, but instead comparisons of some of them have been reported in clinical studies. Dede et al. [15] reported in their study that the monoplanar technique has a significantly lower fluoroscopy screening time (4.4±1.7 min vs 5.7±1.6 min) compared to biplanar technique which is described as a "Eye-of-the-needle/Bull's Eye" maneuver. The authors didn't report the radiation exposure doses in mSv or Gy units. In a different study, Abdallah et al. [14] compared the triangulation and "Eye-of-the-needle" techniques on a biological model and reported that the fluoroscopy time was shorter in "Eye-of-the-needle" technique. In a similar clinical study, Budak et al. [16] compared the fluoroscopic time in minutes while performing either the triangulation and "Eye-of-the-needle" techniques on 104 and 91 patients respectively and they found out that the fluoroscopic times were similar in-between these techniques. Although the fluoroscopic time and radiation doses are generally reported in most of the studies including PCNL, comparisons between different techniques are rarely encountered in literature. It is also ethically and practically hard to compare these techniques in clinical studies due to the high need for radiation exposure to compare the differences. That is why we conducted a bench-model study where we could apply high doses of radiation without the concern for radiation-related health problems to either the surgical team or the patients, as the subjects that faced the high radiation exposure were the phantoms. Water-equivalent phantoms are widely used in experimental settings where radiation exposure is studied [2]. Also, we had the chance to replicate as many C-arm positions as we could, which were either described in literature as validated studies or as expert opinions.

In most of the clinical studies evaluating radiation during PCNL, the fluoroscopy devices are used in pulsed-fluoroscopy mode. Pulsed fluoroscopy provides lower radiation exposure compared to continuous mode [17]. In our study, we created a standardized fluoroscopy protocol using continuous mode fluoroscopy to increase the exposure in different dosimeters placed on the surgeon and patient models. As we didn't have any real patient and urologist involved in the experimental process, the high radiation exposure wasn't a concern but rather a useful situation to better understand and analyze even the small differences in measurements and potentially eliminate the bias from individual practices.

During emission of radiation from a C-arm device, X-rays are generated inside the X-ray generator tube, these rays travel towards the image intensifier of the device. The patient and the operating table shield some of the X-rays travelling towards the image intensifier and these shielded X-rays are scattered to the surrounding environment. These scattered X-rays and the X-rays that are travelling towards the image intensifier are the main sources of radiation hazard to the operating personnel [2]. St-Laurent et al. [2] compared the radiation exposure differences between supine and prone PCNL positions on a bench-model, and found that the effective dose is 1.5- and 1.3-fold higher for lens and extremity dosimeters, respectively, in prone PCNL position compared to supine PCNL position. In our study, we used a similar fluoroscopy protocol where we also used 360 seconds continuous fluoroscopy exposure at a constant setting (91 kVp and 2.7 mA/mAs). However, unlike this aforementioned study, we didn't compare different PCNL positions but instead we compared different C-arm puncture positions. This point is important because percutaneous renal puncture generally requires a combination of different C-arm positioning and surgeons must be aware of the radiation risk they are facing while performing the procedure at different C-arm settings.

The study has shown that the surgeon's hands receive the highest radiation among the positioned dosimeters. During the real-life setting, the hands of the surgeon are always mobile for different steps of the procedure. However, having a fixed hand position during experiments allowed us to make comparisons solely among the different C-arm positions without the bias of hand distance to the fixed radiation exposure area.

Given that the radiation is travelling from the generator to the image intensifier, we hypothesized that the surgeon would receive more radiation in C-arm positions where they face the X-rays that are travelling towards them directly. A hypothetical counter-argument was the shielding effect of the patient, that would diminish most of the radiation exposure measurements travelling towards the surgeon. However, the results of our study showed us in a numerical fashion that in this bench model of PCNL, the surgeon dosimeters would receive more radiation while the X-ray generator is in front, and the image intensifier is near the dosimeters placed on the surgeon model.

The findings of this study should guide the surgeons to have an overall understanding of the radiation exposure mechanisms of different C-arm positions and provide them a chance to master maneuvers to reduce their radiation exposure by changing their practice patterns.

1. Limitations

This is an *in-vitro* bench study that is trying to replicate the real-life situations.

Dose measurement in each position was performed only once due to the need for a high number of dosimeters for multiple measurements. This situation prevented a statistical analysis to be performed, however a numerical data was provided for all measurements. Additional measurements in the same experimental settings would add more value to the statistical results of the study and will be performed and integrated to future studies to better understand the radiation exposure mechanisms.

2. Strong points

This is the first study in the literature that provides a thorough understanding of the surgeon exposed to radiation by different C-arm fluoroscopy positions during percutaneous renal puncture.

A high cumulative radiation exposure on a bench protocol model without real patients and surgeons can provide a greater difference between different measurements. This situation is rather useful to better understand and analyse even the small differences in measurements and potentially eliminate the bias from individual practices. In *in-vivo* settings, this amount of radiation fortunately isn't produced due to harmful effects on patients and OR staff.

CONCLUSIONS

Percutaneous renal puncture generally requires a combination of different C-arm positionings and surgeons must be aware the radiation risk they are facing while performing these procedures at different settings.

In this bench model study of standardized radiation exposure, the latter was higher in positions where the X-ray generator of the C-arm fluoroscopy device faced towards surgeon. The amount of radiation received on the surgeon's hand dosimeters in all C-arm positions was higher than the radiation doses recorded on the chest and lens dosimeters.

Special care must therefore be taken to avoid facing the X-ray generator tube during percutaneous renal puncture to decrease radiation exposure of surgeons. Additionally, hands should be as well-protected as chest and eyes by wearing special lead gloves in addition to lead aprons and lead glasses.

CONFLICTS OF INTEREST

The authors have nothing to disclose.

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AUTHORS' CONTRIBUTIONS

Research conception and design: Tarik Emre Sener, Yiloren Tanidir, Amelia Pietropaolo, and Esteban Emiliani. Data acquisition: Tarik Emre Sener, Serap Ketenci, Umut Kutukoglu, Dogancan Dorucu, and Huseyin Cayir. Statistical analysis: Tarik Emre Sener, Yiloren Tanidir, Umut Kutukoglu, Dogancan Dorucu, and Bhaskar Somani. Data analysis and interpretation: Tarik Emre Sener, Yiloren Tanidir, Esteban Emiliani, and Bhaskar Somani. Drafting of the manuscript: Tarik Emre Sener, Umut Kutukoglu, Dogancan Dorucu, and Bhaskar Somani. Critical revision of the manuscript: Tarik Emre Sener, Yiloren Tanidir, Amelia Pietropaolo, and Bhaskar Somani. Obtaining funding: Serap Ketenci, Huseyin Cayir, and Dogancan Dorucu. Administrative, technical, or material support: Tarik Emre Sener, Serap Ketenci, Huseyin Cayir, Dogancan Dorucu, and Umut Kutukoglu. Supervision: Yiloren Tanidir, Amelia Pietropaolo, and Bhaskar Somani. Approval of the final manuscript: all authors.

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