ORIGINAL PAPER

UROLITHIASIS

Effect of leaded gloves on patient and surgeon radiation exposure in percutaneous nephrolithotomy: A prospective pilot study

Luke A. Brawer, Johnny Wang, Matthew Skalak, Joel Vetter, Ethan Vargo

Washington University in St. Louis School of Medicine, St. Louis, Missouri, United States of America

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Corresponding author
Luke Brawer
660 S Euclid Ave,
St. Louis, MO,
US 63110-1010
BLuke@wustl.edu

Introduction Ionizing radiation exposure is a significant occupational hazard for urologists performing percutaneous nephrolithotomy (PCNL). Surgeon hands are particularly vulnerable during fluoroscopic access. Leaded gloves are a proposed mitigation strategy. This prospective pilot study evaluated surgeon hand and patient collar radiation exposure during PCNL with standard vs leaded gloves.

Material and methods Twenty patients were prospectively allocated to standard or leaded glove groups in sequential fashion. All cases were performed by a single high-volume endourologist with patients in the prone position. Clinical variables including BMI, operative time, stone size, and fluoroscopy dose were recorded. Surgeon hand exposure was measured using ring dosimeters. Patient exposure was measured with clip-on dosimeters at the collar, reported as deep dose equivalent (DDE), lens dose equivalent (LDE), and shallow dose equivalent (SDE).

Results At baseline, patient BMI ($p = 0.005$) and fluoroscopy radiation dose ($p <0.001$) were greater in the standard glove group. There was no significant difference in surgeon hand exposure at the right ($p = 0.143$) or left hand ($p = 0.608$). Leaded gloves were associated with a significant increase in patient collar radiation at DDE ($p = 0.002$), LDE ($p = 0.009$), and SDE ($p = 0.009$).

Conclusions In this pilot study, leaded glove use was associated with a significant and consistent increase in patient collar radiation across all measurement depths. The non-significant reduction in surgeon hand exposure should be interpreted cautiously given limited statistical power. These findings do not support routine leaded glove use during PCNL, and adequately powered studies are needed to confirm these findings and identify optimal radiation protection strategies.

Key Words: percutaneous nephrolithotomy ‹› calculi ‹› endourology ‹› radiology

INTRODUCTION

Percutaneous nephrolithotomy (PCNL) remains the gold standard for treatment of large or complex kidney stones. In much of North America and Europe, percutaneous access during PCNL is most commonly obtained under fluoroscopic guidance, employing one of two common needle-targeting approaches: the "bull's-eye" technique or the triangulation technique [1]. However, PCNL without fluoroscopy is commonly practiced in other regions, such as Asia, and mitigates ionizing radiation exposure to both patient and surgeon [1, 2]. Where fluoroscopy is used, reliance on it risks ionizing radiation exposure to patients and surgical staff. Chronic exposure to ionizing radiation presents both stochastic and deterministic risks. Stochastic effects include increased lifetime risk of malignancy, while deterministic effects include radiation-induced cataracts and skin injury [3]. Standard protections like lead aprons and thyroid shields are routinely used,

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but other strategies to ensure long-term safety of surgeons should be explored.

Among urologic procedures, PCNL has been associated with the highest radiation exposure per case [4, 5]. Some reports estimate that surgeon hand radiation exposure can exceed 4 mGy per procedure, with cumulative doses for high-volume surgeons potentially exceeding the 500 mGy annual safe limit for hand radiation exposure instated by the International Commission on Radiological Protection (ICRP) [4, 6, 7]. These findings emphasize the importance of hand protection strategies.

Leaded surgical gloves have been proposed as a potential method to mitigate surgeon hand exposure. However, the benefits and limitations of leaded gloves remain uncertain. As such, recent data demonstrate that only 20% of endourologists report using radiation-attenuating surgical gloves [8]. By quantifying both surgeon and patient radiation exposure during PCNL with and without the use of leaded gloves, this study seeks to provide a more comprehensive assessment of their risk-benefit profile and help inform future recommendations for radiation safety practices in endourology.

MATERIAL AND METHODS

This was a prospective pilot study conducted at a single academic tertiary referral center. After Institutional Review Board approval (IRB #202203108) was obtained, patients were recruited between September 12, 2023 and July 5, 2024. Eligible participants were patients who were over the age of 18 undergoing PCNL as definitive surgical management of large kidney stones. Though this study was originally intended for sequential 1 : 1 randomization, limitations with the availability of dosimeter equipment prompted a change in approach. Patients were instead assigned to one of two arms: the first ten consecutive patients to the standard sterile glove group and the subsequent ten consecutive patients to the leaded glove group. All procedures were performed by a single high-volume endourologist with the patient in the prone position. During each procedure, the surgeon wore radiation dosimeter rings on the 4th and 5th fingers of each hand, and an additional clip-on dosimeter was placed under the sterile drape near the patient's back at the collar. Surgeon hand exposure was measured using Landauer Saturn Ring dosimeters (Landauer, Inc., Glenwood, IL), which utilize thermoluminescent dosimetry (TLD) technology with a lithium fluoride (LiF) detector and a minimum reportable dose of 0.1 mSv. Patient collar exposure was measured using Landauer Luxel+ dosimeters (Landauer, Inc., Glenwood, IL), which utilize optically stimulated luminescence (OSL) technology with an Al_2O_3:C detector and a minimum reportable dose of 0.01 mGy. Both dosimeter types are processed by Landauer's NVLAP-accredited laboratory (NVLAP Lab Code: 100518-0). The primary outcome of radiation dose exposure was measured in terms of deep dose equivalent (DDE) (1 cm depth), lens dose equivalent (LDE) (0.3 cm depth), and skin dose equivalent (SDE) (0.007 cm depth). Demographic and operative variables, including patient age, sex, body mass index (BMI), stone burden, access technique, number of access attempts, total fluoroscopy time, and C-arm fluoroscopy radiation dose were collected during surgery or from the medical record. All dosimeters were replaced and logged after each case.

Continuous variables were reported as median [IQR] and compared using Wilcoxon rank-sum tests. Categorical variables were compared using the Chi-square test or Fisher's exact test. Given the exploratory pilot nature of the study and small sample size, no formal adjustment for baseline imbalances was performed. No a priori power calculation was performed, as prospective dosimeter data in this surgical environment were not available at the start of the study. The study was registered with the IRB as an exploratory pilot, and all nonsignificant findings should be interpreted accordingly. Statistical significance was defined as $p < 0.05$.

Bioethical standards

The study was approved by the Washington University in St. Louis Institutional Review Board (IRB #202203108).

RESULTS

Demographic and operative variables

A total of 20 patients undergoing PCNL were allocated to standard glove (n = 10) or leaded glove (n = 10) groups (Table 1). Median patient BMI was significantly higher in the standard glove group compared to the leaded glove group (38.0 [35.4–43.3] kg/m^2 vs 27.0 [25.7–30.9] kg/m^2; p = 0.005). Operative time (150 [107–183] min vs 125 [107–132] min; p = 0.487) and stone size (28.5 [24.5–32.8] mm vs 25.5 [21.3–29.3] mm; p = 0.57) were similar between groups. C-arm fluoroscopy radiation dose was significantly higher in the standard glove cohort (14.5 [12.7–20.3] mGy vs 5.83 [5.36–6.82] mGy; $p < 0.001$). There were no significant differences in stone laterality, access location, number of access attempts, or number of access sites between groups.

Radiation exposure at surgeon hand

A comparison of radiation dose exposure between standard and leaded gloves measured by ring dosimeter on the surgeons' hands is shown in Figure 1. Median surgeon hand exposure at the right hand was 5.0 [0–23.0] mGy and 0 [0–0] mGy for standard and leaded glove groups, respectively. There was no significant difference in right hand radiation exposure with standard vs leaded gloves ($p = 0.143$). Median surgeon hand exposure at the left hand was 0 [0–0] mGy and 0 [0–10.8] mGy for standard and leaded glove usage, respectively. There was no significant difference in left hand radiation exposure with standard vs leaded gloves ($p = 0.608$).

Radiation exposure at patient collar

A comparison of radiation dose exposure between standard and leaded gloves measured by clip-on dosimeter at the patient collar is shown in Figure 2. Exposure at DDE depth was 0 [0–1.5] mGy and 8.0 [7.3–9.8] mGy for standard and leaded glove groups, respectively. Exposure at LDE depth was 0 [0–1.5] mGy and 7.0 [7.0–8.8] mGy for standard and leaded glove groups, respectively. Exposure at SDE depth was 0 [0–1.0] mGy and 7.0 [7.0–8.8] mGy for standard and leaded glove groups, respectively. There was significantly more radiation exposure at all collar measurement depths when leaded gloves

Table 1. *Baseline patient and operative variables*

Variable	Standard (n = 10)	Leaded (n = 10)	p-value
Patient BMI	38.0 (35.4–43.3)	27.0 (25.7–30.9)	**0.005**
Operative time (min)	150 (107–183)	125 (107–132)	0.487
Stone size (mm)	28.5 (24.5–32.8)	25.5 (21.3–29.3)	0.570
C-arm fluoroscopy radiation dose (mGy)	14.5 (12.7–20.3)	5.83 (5.36–6.82)	**<0.001**
Stone laterality			
Left	8	6	0.628
Right	2	4	
Access location			
Lower	6	7	1.000
Upper	4	3	
Access attempts			
1	5	7	0.650
2	5	3	
Access sites			
1	9	10	1.000
3	1	0	

* Values are presented as median (IQR). Significant p-values (<0.05) are shown in bold
BMI – body mass index

Table 2. *Proportion of cases with <1 mGy of radiation*

Measurement site	Standard gloves (%)	Leaded gloves (%)	p-value
Right hand	50.0	80.0	0.350
Left hand	80.0	60.0	0.628
Collar DDE	70.0	0.0	**0.003**
Collar LDE	70.0	0.0	**0.003**
Collar SDE	60.0	0.0	**0.011**

* Significant p-values (<0.05) are shown in bold
DDE – deep dose equivalent; LDE – lens dose equivalent; SDE – shallow dose equivalent

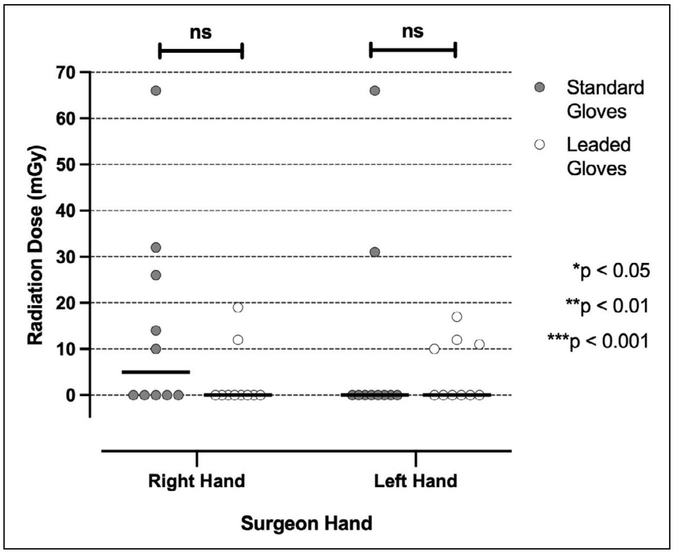

Figure 1. *Radiation dose measured by ring dosimeter by surgeon hand for standard and leaded gloves from twenty percutaneous nephrolithotomies. Horizontal bars denote medians.*

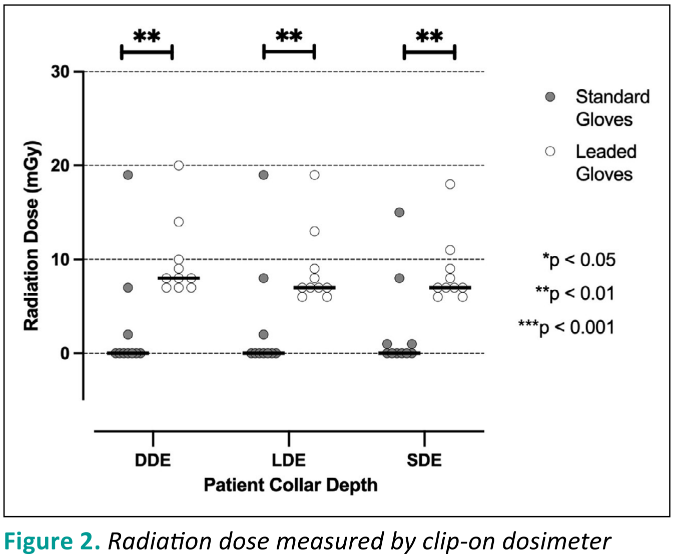

Figure 2. *Radiation dose measured by clip-on dosimeter at patient collar for standard and leaded gloves from twenty percutaneous nephrolithotomies. Horizontal bars denote medians.*

were used (p = 0.002, 0.009, 0.009, for DDE, LDE, and SDE, respectively).

Proportion of cases with <1 mGy of radiation exposure at surgeon hand

The proportion of cases with <1 mGy of radiation exposure at each measurement site is shown in Table 2. For cases where standard gloves were used, 50% and 80% of cases had <1 mGy of radiation exposure at the right and left hands, respectively. For cases where leaded gloves were used, 80% and 60% of cases had <1 mGy of radiation exposure at the right and left hands, respectively. Neither of these were significant (p = 0.35, 0.628).

Proportion of cases with < 1 mGy of radiation exposure at patient collar

Shown in Table 2, in cases where standard gloves were used, 70%, 70%, and 60% of cases had <1 mGy radiation exposure at the patient collar at DDE, LDE, and SDE, respectively. For cases where leaded gloves were used, all cases had >1 mGy of radiation exposure at DDE, LDE, and SDE. There was a significant difference at every collar depth (p = 0.003, 0.003, 0.011, at DDE, LDE, and SDE, respectively).

DISCUSSION

In this prospective pilot study, leaded surgical gloves were associated with an increase in patient radiation exposure measured at the patient collar, while producing no statistically significant change in surgeon hand exposure. The majority of cases performed with standard gloves resulted in a minor radiation dose (<1 mGy) measured at the patient collar, whereas cases performed with leaded gloves exceeded 1 mGy at the same measurement site (p = 0.002 to 0.011 across DDE, LDE, and SDE depths). These findings may challenge the presumption that leaded gloves confer operator protection without risk to the patient and is consistent with the International Atomic Energy Agency's guidance against their use during fluoroscopy, as leaded gloves may paradoxically increase radiation burden to the patient [9].

Prior studies of leaded gloves during PCNL have demonstrated mixed results. A prospective study by Emiliani et al. reported a 5-fold reduction in annual surgeon hand dose when leaded gloves were used (2.9 mGy/year vs 14.9 mGy/year), without measurable increase in whole body radiation dose [10]. Chen et al. [4], using a cadaver model, demonstrated a 37% reduction in hand dose accompanied by a 3% rise in patient dorsal radiation exposure. In contrast, our study found no significant difference in hand exposure with leaded gloves and found that patient collar radiation increased markedly with leaded glove use. However, unlike Emiliani et al. who evaluated 1,092 cases, our analysis is limited by a smaller sample size, which may reduce power to detect modest differences in outcomes.

A potential explanation for the increase in patient radiation exposure is the use of automatic exposure control (AEC) systems in fluoroscopy units. These systems trigger a compensatory increase in X-ray output to account for the presence of radio-dense materials, such as leaded gloves, in the field [9]. The radio-opaque lead within the leaded gloves attenuates the beam, prompting the fluoroscope to increase output, which may raise radiation exposure to both the patient and operator rather than reduce it. This consequence of increased patient radiation dose has been observed in other studies and has led to international guidance discouraging the use of leaded gloves during fluoroscopic procedures [9, 11]. This is particularly relevant for a procedure such as a PCNL where the surgeons' hands are often within the field of exposure. The observed lack of benefit in surgeon radiation exposure with leaded gloves may also be attributed to a false sense of security when used. This sense of security can lead to increased duration of exposure and poorer adherence to best practices for radiation avoidance [9].

The International Commission on Radiological Protection (ICRP) recommends an occupational dose limit of 500 mGy per year to the extremities [6]. Although average hand exposure per procedure remains well below this threshold, cumulative dose becomes a concern for high volume endourologists [12]. While individual case radiation dose alone is unlikely to cause deterministic harm, its accumulation over time can become clinically relevant. Radiation safety protocols in endourology already emphasize the "as low as reasonably achievable" (ALARA) concept, encouraging the use of lead aprons, thyroid shields, pulsed and low-dose fluoroscopy modes, and proper C-arm positioning [8].

Though not included in this study, the use of ultrasound (US) guidance during PCNL may represent a more effective strategy for radiation attenuation than use of leaded gloves. Hosier et al. compared US-only PCNL to fluoroscopy-directed PCNL and found no significant increase in complications or stone-free rate, with US providing the added benefit of a shorter operative time [2]. Perez et al. [13] examined the effect of increased BMI on US-only PCNL success and found that while US-only PCNL procedures are more difficult in obese patients, there was no significant difference in outcomes or procedural morbidity following the procedure. In addition to using US guidance over fluoroscopy, devices that keep the hand away of the beam, such as a needle holder proposed by Chen et al. [4], may offer safer, more reliable protection than leaded gloves.

This study has several limitations. Firstly, the sample size of twenty patients is small and limits the statistical power to detect modest differences between groups in radiation exposure. No a priori power calculation was performed, as prospective dosimeter data in this surgical environment were unavailable at the beginning of the study, and the study was registered as an exploratory pilot. As such, the nonsignificant hand dose comparisons should be interpreted as hypothesis generating rather than definitive. Second, patient allocation was sequential with the first ten consecutive patients being assigned to the standard glove arm and the subsequent ten to the leaded glove arm. This design was adopted to simplify coordination of dosimeter equipment but introduces the possibility of temporal confounding and likely contributes to differences in baseline characteristics, most notably in BMI (38.0 vs 27.0 kg/m^2; p = 0.005). Because increased BMI degrades fluoroscopic image quality and complicates renal access due to increased tissue to traverse, a higher-BMI cohort would be expected to receive more collar radiation [14, 15]. The observation that the leaded glove group received significantly more patient collar radiation despite a lower BMI and a lower total C-arm dose therefore strengthens, the argument that leaded gloves increase radiation exposure at patient collar. Third, all procedures were performed at a single academic center with the patient positioned prone, limiting generalizability to supine PCNL and other practice settings. Nonetheless, this pilot study provides an exploratory assessment of both surgeon hand and patient collar radiation exposure within the same PCNL procedure, and the consistency of the increased patient radiation dose across all three measurement depths warrants further investigation in a larger trial.

CONCLUSIONS

In this pilot study, leaded glove use during PCNL was associated with a significant and consistent increase in patient radiation exposure measured at the collar with no statistically significant reduction in surgeon hand exposure. Because the study was not powered to detect modest differences in hand dose, the absence of a significant reduction in hand dose should be interpreted cautiously. However, the increased patient dose finding is both statistically significant and mechanistically plausible via automatic exposure compensation. Adequately powered trials are needed to confirm these findings and to compare leaded gloves against alternative radiation reduction strategies, including ultrasound-guided access, beam-avoidance instruments, and surgeon behavioral modification.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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ETHICS APPROVAL STATEMENT

The study was approved by the Washington University in St. Louis Institutional Review Board (IRB #202203108).

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