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ORIGINAL ARTICLE

Radiation exposure of urologists during endourological procedures: a systematic review

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Abstract

Introduction Ionizing radiation is used daily during endourological procedures. Despite the dangers of both deterministic and stochastic effects of radiation, there is a lack of knowledge and awareness among urologists. This study reviewed the literature to identify the radiation exposure (RE) of urologists during endourological procedures.

Methods A literature search of the Medline, Web of Science, and Google Scholar databases was conducted to collect articles related to the radiation dose to urologists during endourological procedures. A total of 1966 articles were screened. 21 publications met the inclusion criteria using the PRIMA standards.

Results Twenty-one studies were included, of which 14 were prospective. There was a large variation in the mean RE to the urologist between studies. PCNL had the highest RE to the urologist, especially in the prone position. RE to the eyes and hands was highest in prone PCNL, compared to supine PCNL. Wearing a thyroid shield and lead apron resulted in a reduction of RE ranging between 94.1 and 100%. Educational courses about the possible dangers of radiation decreased RE and increased awareness among endourologists.

Conclusions This is the first systematic review in the literature analyzing RE to urologists over a time period of more than four decades. Wearing protective garments such as lead glasses, a thyroid shield, and a lead apron are essential to protect the urologist from radiation. Educational courses on radiation should be encouraged to further reduce RE and increase awareness on the harmful effects of radiation, as the awareness of endourologists is currently very low.

Keywords Endourology · Fluoroscopy · Lead shielding · PCNL · Radiation · RIRS · SWL · Systematic review · Ureteroscopy · Urolithiasis

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Introduction

Ionizing radiation is used in daily practice during endourological procedures. It is well known that radiation has side effects on the human body, including deterministic and stochastic effects. Deterministic effects of radiation manifest after exposure to ionizing radiation surpasses a specific threshold. Examples of such effects include hair loss and dermal burns. [1]. Fortunately, these radiation thresholds are not reached during endourological procedures under normal conditions. Stochastic effects, conversely, occur in a linear manner, without a lower threshold for their manifestation. This suggests that higher levels of exposure elevate the likelihood of an effect rather than the type or severity of the radiation's impact. Examples include leukemia, multiple myeloma, and various types of cancers, such as thyroid, bladder, breast, lung, ovarian, and colon cancers. Stochastic effects do occur in endourological procedures where ionizing rays are used [2]. The development of cataracts is considered to be a consequence of both deterministic and stochastic effects of radiation [1]. Minor opacities of the eye lens result from stochastic effects of radiation and occur in a linear fashion. Visually impairing cataracts, however, result from exceeding a certain threshold of radiation, which is a deterministic effect [1].

Generally, there is lack of knowledge and awareness about the dangers of ionizing radiation among urologists. After conducting a survey among urology residents in 2012, it was found that half of the residents were unaware of the potential fatal cancer risk associated with ionizing radiation [3]. Urology residents exhibited notably low compliance with protective equipment during various procedures. Merely 30.6% consistently wore a thyroid shield, and a mere 4% consistently wore protective eyeglasses during endourological procedures [3]. In contrast, 52% of high-volume endourologists used protective lead eyewear with every procedure [4]. These results highlighted the large gap between residents and high-volume urologists. In a recent study, urologists with 15–20 years of experience wore a thyroid shield in 90% of cases and protective glasses in 16% of cases. Conversely, residents utilized these protective items in 93.5% and 8.7% of cases, respectively [5]. Only 15–35% of urologists always wore their dosimeter [3, 4, 6, 7]. Urologists who took an educational course on ionizing radiation, wore protective equipment significantly more frequently than those who never took a course on radiation safety [3].

Considering the knowledge gaps mentioned above, we aimed to identify the radiation exposure (RE) of urologists during endourological procedures, as reported in published literature, to further increase the awareness about the risks related to ionizing radiation for urologists.

Materials and methods

Two authors (LH and XM) conducted a systematic review of literature using the Medline, Web of Science and Google Scholar databases in August 2023. The search terms “fluoroscopy AND (urology OR ureteroscopy OR urs OR (retrograde intrarenal surgery) OR rirs OR (percutaneous nephrolithotomy) OR pcnl OR (extracorporeal shock wave lithotripsy) OR eswl OR lithotripsy)” were used and the filters “english” and “humans” were applied. Articles published since 1980 were considered. All articles related to the radiation dose to urologists during endourological procedures, were included. After full text assessment of these articles (L.H. and X.M.) and using the population, intervention, comparator, outcome (PICO) study design approach and Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) standards, publications that met the inclusion criteria for this review were chosen (Fig. 1). Case reports, editorials and letters were excluded. Additional articles, identified through references lists, were also included. A narrative synthesis for analysis of the studies was used.

Data was summarized in tables, which were classified according to the body location of the dosimeter and according to the procedure type. Only the studies that reported the effective dose to the urologist in mSv were further discussed and analyzed, to be able to compare their results to the recommendations of ICRP, which also report RE in mSv [8, 9]. The studies that reported effective dose in other units were still included, but not further discussed, nor were they compared to the studies that reported effective radiation dose in mSv. The positions of the patient during percutaneous nephrolithotomy (PCNL) were divided into prone, supine, or not specified. When the RE of a limb of the urologist was measured, they were divided into right side, left side, dominant side or not specified.

Results

The literature search included 2036 records. After exclusion of the duplicates, 1966 records remained. Then, 1815 records were excluded based on title and abstract. Next, 151 full articles were assessed. 130 articles that only investigated radiation time or radiation dose to the patient and not to the urologist, were excluded. Finally, 21 articles were included in the review to examine the radiation dose to urologists during endourological procedures (Supplementary Fig. 1) [10].

Characteristics of the included studies are shown in Table 1 [6, 11–30]. A summary of the reported RE is shown in Table 2, categorized per body location and procedure [6, 11–30].

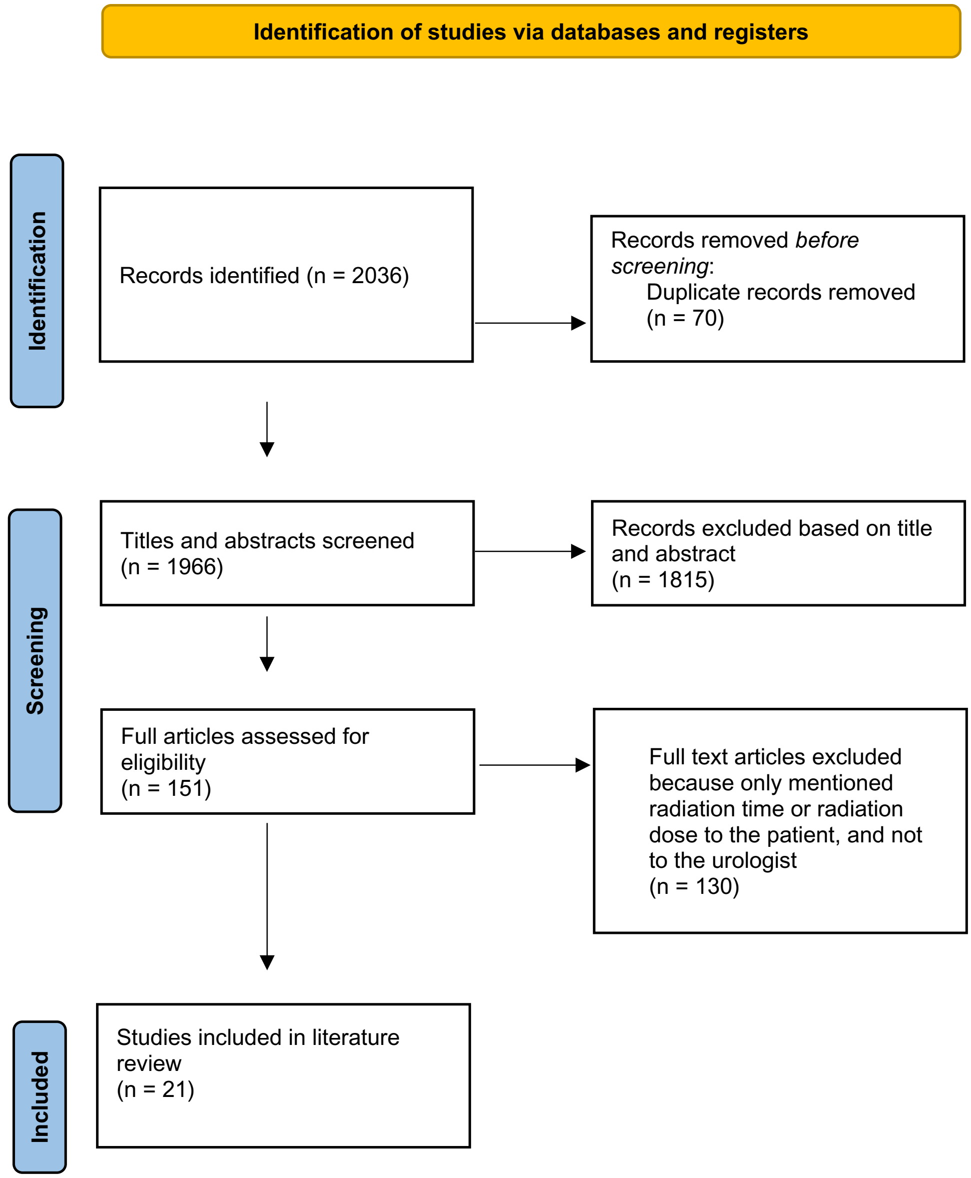

Fig. 1 Prisma flow diagram

Considering the studies that reported effective dose (unit: mSv), the average radiation exposure (RE) to the eyes ranged from 0.02 mSv to 0.8 mSv per procedure, as outlined in Table 2. Similarly, the mean RE to the forehead varied between 0.03 mSv and 0.18 mSv per procedure (Table 2). Notably, there existed a distinction between the RE to the neck above the thyroid shield (ranging from 0.00222 mSv to 0.33 mSv per procedure) and the RE to the neck under the thyroid shield (ranging from 0.00084 mSv to 0.099 mSv) (Table 2). Regarding the chest, the mean RE over the lead apron varied from 0.0001 mSv to 1.12 mSv per procedure, while the mean RE under the lead apron ranged from 0 mSv to 0.02 mSv per procedure (Table 2). Moreover, the mean RE to the urologist's arm ranged from 0.31 mSv to 0.55 mSv (Table 2), whereas the mean RE to the urologist's hands varied between 0.008 mSv and 4.36 mSv per procedure (Table 2). Additionally, the mean RE to the urologist's foot ranged from 0.05 mSv to 0.1 mSv per procedure (Table 2). Lastly, the mean RE to the urologist's leg ranged from 4.1 µGy to 167 µGy (Table 2).

Five studies evaluated the reduction of RE when wearing a thyroid shield and a lead apron (Supplementary table) [17, 22, 26–28]. Wearing this protective equipment resulted in a 94.1 to 100% reduction of RE. Inoue et al. evaluated the influence of a lead curtain on RE [28]. They noticed a reduction of RE from 62.2% to 86.1% when wearing a thyroid and lead apron, respectively. When the lead apron was combined with the use of a lead curtain, this resulted in absolutely no measurable RE (0 mSv) under the lead apron [28].

A few studies did not differentiate RE by type of procedure [12, 15, 21]. For PCNL, most studies did not mention whether the procedure was performed with the patient in

Table 1 Characteristics of included studies

Author (publication year)	Pro/Retrospective	Single-/multi-center	Time period	Nr. of procedures	Procedure type	Exposure detection method
Lowe et al. (1986) [29]	Retrospective	Single-center	Not specified	7	PCNL (prone)	Thermo-luminescent dosimeters
Rao et al. (1987) [11]	Retrospective	Single-center	Not specified	18	PCNL (not specified)	Film badges Thermo-luminescent dosimeters
Bagley et al. (1990) [27]	Prospective	Single-center	Not specified	116	URS	Film badges
Bowsher et al. (1992) [23]	Retrospective	Multi-center	Not specified	Not specified	PCNL (not specified)	Thermo-luminescent dosimeters
Hellawell et al. (2005) [18]	Prospective Retrospective	Multi-center	4 months	18 6	General ureteral procedures PCNL (not specified)	Thermo-luminescent dosimeters
Kumari et al. (2006) [30]	Prospective	Single-center	Not specified	50	PCNL (prone)	Thermo-luminescent dosimeters
Safak et al. (2009) [19]	Prospective	Single-center	Not specified	20	PCNL (prone)	Thermo-luminescent dosimeters
Majidpour et al. (2010) [20]	Retrospective	Single-center	Not specified	100	PCNL (prone)	Thermo-luminescent dosimeters
Ritter et al. (2012) [24]	Prospective	Single-center	6 months	235	PCNL (not specified) Percutaneous stent change Ureteral stent change Ureteral stent placement URS	Thermo-luminescent dosimeters
Taylor et al. (2013) [12]	Prospective	Single-center	9 months	13 7 8	URS Cystoscopy PCNL (not specified)	Thermo-luminescent dosimeters
Hristova-Popova et al. (2015) [13]	Prospective	Single-center	6 months	16 15	PCNL (not specified) URS	Educational Direct *Dosimeter*
Galonnier et al. (2016) [6]	Prospective	Multi-center	1 month	35	PCNL (supine) PCNL (prone)	Thermo-luminescent dosimeters Radio-photo-luminescent dosimeters
Kim et al. (2016) [26]	Prospective	Single-center	7 months	49	URS	Optically stimulated luminescence dosimeters
Vano et al. (2016) [14]	Prospective	Single-center	Not specified	23	PCNL (not specified)	Optically stimulated luminescence dosimeters Electric pocket dosimeters
Yecies et al. (2017) [22]	Retrospective	Single-center	12 months	154	URS	Not specified
Inoue et al. (2017) [28]	Prospective	Single-center	13 months	62 61 (protective lead curtain)	URS	Electric pocket dosimeters
Patel et al. (2017) [21]	Retrospective	Single-center	14 months	182	PCNL (not specified) Stent insertion URS	Not specified

Table 1 (continued)

Author (publication year)	Pro/Retrospective	Single-/multi-center	Time period	Nr. of procedures	Procedure type	Exposure detection method
Medici et al. (2017) [15]	Prospective	Multi-center	Not specified	33	Cystograms RPG URS	Thermo-luminescent dosimeters
Hartmann et al. (2018) [16]	Prospective	Single-center	2 months	95	Not specified	Thermo-luminescent dosimeters
Park et al. (2021) [17]	Prospective	Single-center	11 months	227	RIRS	Optically stimulated luminescence dosimeters
Amirhasani et al. (2021) [25]	Retrospective	Single-center	7 months	30	PCNL (prone)	Thermo-luminescent dosimeters

supine or prone position [11–14, 18, 21, 23, 24]. Finally, no study reported RE per urologist per year.

Discussion

This is the first systematic review in literature analyzing the RE to the urologist over a period of more than four decades. While RE generally remained very low during most endourological procedures, a few studies have reported rather high mean RE per procedure and deserve detailed analysis.

Generally, there was a large variation in mean RE to the urologist between studies. In studies that compared different procedure types, RE was highest during PCNL [6, 16, 20, 26]. The studies reporting the highest mean RE to the urologist ranged up to 0.8 mSv to the eyes, 0.18 mSv to the forehead, 4.36 mSv to hands and 0.1 mSv to feet, respectively [11, 24, 25]. In prone PCNL, highest RE was documented to the eyes and hands [6, 11]. Considering the latter, RE to the hands and eyes was higher during prone PCNL compared to supine PCNL [6]. For supine PCNL, highest RE was documented to the neck and chest [6]. Concerning comparisons between operating staff, highest RE in PCNL was measured to the person standing closest to the patient [14, 30]. As for URS, the RE was generally lower compared to PCNL, with the highest mean RE reaching 0.0427 mSv to the eyes, 0.10 mSv to the forehead, and 0.81 mSv to the hand, respectively [13, 24, 26]. During URS, highest RE under the thyroid shield and lead apron was reported to be 0.01 mSv and 0.02 mSv, respectively [26].

A markable reduction of RE ranging from 94.1 to 100% was seen when wearing a thyroid shield and lead apron (Supplementary table) [6, 17, 22, 26–28]. This corresponds with reports on transmitted exposure through lead equivalent aprons: lead aprons of 0.25 mm and 0.5 mm thickness were shown to attenuate at least 90% and 98% of RE, respectively [31–33]. Also, lead glasses, including their lateral protection, have been proven useful. Without lateral protection, the eyes are still exposed to 50% of the radiation load [2, 34]. One study stated that the registered eye lens RE to the urologist does not seem to be related to the number of procedures, but rather to the use of lead glasses and the ALARA protocol, which will be further discussed below [35].

The maximum effective dose per year, determined by the ICRP, is 20 mSv to the lens of the eye and 500 mSv to the skin, hands and feet [8, 9]. On a hypothetical basis and considering studies with higher RE range, some urologists could only perform 25 PCNL procedures or 69 URS procedures per year before exceeding the ICRP maximum effective dose to the eyes [11, 14, 17]. Vano et al. compared their high RE to the eyes (0.296 mSv) and long mean fluoroscopy time (11.5 min) during PCNL with other disciplines in their hospital [14]. The radiation exposure (RE) to urologists was found to be 18.7 times higher than that experienced by radiologists and cardiologists, and 4.2 times higher than the values recorded for vascular surgeons [14]. Urologists seem to be more exposed to radiation when sitting down, due to the closer distance to the radiation source [36]. Therefore, some studies advised to perform endourological procedures in a standing position [36]. Other factors that increased RE during PCNL include standing closely to the patient, larger stone burden, increased number of accesses, larger sheath size, higher kV on fluoroscopy settings and lower stone Hounsfield units [14, 30, 34, 37].

To avoid exceeding dose limits and the associated negative long-term effects of ionizing radiation, it is recommended to act in accordance with the "as low as reasonably achievable (ALARA)" principle [38–40]. This can be achieved by reducing fluoroscopy time, using pulsed fluoroscopy, low-dose radiation, collimation to the zone of interest, increasing the distance between the radiation source and the urologist, and keeping hands out of the radiation beam [7, 38, 41]. Also, synchronizing the patient's respiration with the use of fluoroscopy can reduce RE [42]. Unfortunately, following a recent survey, 10% of urologists did not know this ALARA principle and 6% of urologists never took any additional radiation protection course [7]. Educational courses

Table 2 RE categorized per body location and procedure

Authors and publication year	Organ	Procedure type (position*)	Nr. of procedures	Mean exposure per procedure	Mean radiation time per procedure
Eyes and forehead					
Rao et al. (1987) [11]	Eyes	PCNL (not specified)	18	0.8 mSv	21.9 min
Taylor et al. (2013) [12]	Eyes	URS Cystoscopy PCNL (not specified)	13 7 8	0.208 mSv	3.4 min 3.4 min 8.27 min
Hristova-Popova et al. (2015) [13]	Eyes	PCNL (not specified) URS	16 15	0.2141 mSv 0.0427 mSv	4.5 min 0.9 min
Galonnier et al. (2016) [6]	Eyes	PCNL (supine) PCNL (prone) URS	35	0.062 mSv 0.092 mSv Below detection limit	Not specified
Vano et al. (2016) [14]	Eyes	PCNL (not specified)	23	0.296 mSv	11.5 min
Medici et al. (2017) [15]	Eyes	Cystograms RPG URS	33	0.078 mSv	0.86 min
Hartmann et al. (2018) [16]	Eyes	Not specified	95	0.020 mSv	1.27 min
Park et al. (2021) [17]	Eyes	RIRS	227	0.29 mSv	5.13 min
Hellawell et al. (2005) [18]	Eyes	General ureteral procedures PCNL (not specified)	18 6	1.9 µGy 40 µGy	1.3 min
Safak et al. (2009) [6]	Eyes	PCNL (prone)	20	26 µGy	12 min
Majidpour et al. (2010) [20]	Eyes	PCNL (prone)	100	0.04 µGy	4.5 min
Patel et al. (2017) [21]	Eyes	PCNL (not specified) Stent insertion URS	182	5.64 µGy	0.58 min
Yecies et al. (2017) [22]	Eyes	URS	154	120 mrad	1.4 min
Bowsher et al. (1992) [23]	Forehead	PCNL (not specified)	Not specified	0.12 mSv	2 min
Ritter et al. (2012) [24]	Forehead	PCNL (not specified) Percutaneous stent change Ureteral stent change Ureteral stent placement URS	235	0.18 mSv 0.03 mSv 0.06 mSv 0.04 mSv 0.10 mSv	7.3 min 0.6 min 0.7 min 1 min 1.1 min
Amirhasani et al. (2021) [25]	Forehead	PCNL (prone)	30 23 (new shielding method)	0.1 mSv 0.08 mSv	0.82 min 1.15 min
Majidpour et al. (2010) [20]	Forehead	PCNL (prone)	100	0.47 µGy	4.5 min
Neck and chest					
Kim et al. (2016) [26]	Neck over thyroid shield	URS	49	0.33 mSv	3.15 min
Inoue et al. (2017) [28]	Neck over thyroid shield	URS	62 (no lead curtain) 61 (lead curtain)	0.00222 mSv 0.00084 mSv	1.94 min 1.98 min
Park et al. (2021) [17]	Neck over thyroid shield	RIRS	227	0.31 mSv	5.13 min
Bagley et al. (1990) [27]	Neck without thyroid shield	URS	116	2 mrem	3.15 min

Table 2 (continued)

Authors and publication year	Organ	Procedure type (position*)	Nr. of procedures	Mean exposure per procedure	Mean radiation time per procedure
Galonnier et al. (2016) [6]	Neck under thyroid shield	PCNL (supine) PCNL (prone) URS	35	0.099 mSv 0.085 mSv 0.033 mSv	Not specified
Kim et al. (2016) [26]	Neck under thyroid shield	URS	49	0.01 mSv	3.15 min
Park et al. (2021) [17]	Neck under thyroid shield	RIRS	227	0.01 mSv	5.13 min
Amirhasani et al. (2021) [25]	Neck under thyroid shield	PCNL (prone)	30 23 (new shielding method)	0.073 mSv 0.072 mSv	0.82 min 1.15 min
Safak et al. (2009) [19]	Neck under thyroid shield	PCNL (prone)	20	48 µGy	12 min
Lowe et al. (1986) [29]	Neck under thyroid shield	PCNL (prone)	7	2.5 mrad	27.8 min
Kim et al. (2016) [26]	Chest over lead apron	URS	49	1.12 mSv	3.15 min
Vano et al. (2016) [14]	Chest over lead apron	PCNL (not specified)	23	0.576 mSv	11.5 min
Inoue et al. (2017) [28]	Chest over lead apron	URS	62 (no lead curtain) 61 (lead curtain)	0.00548 mSv 0.00076 mSv	1.94 min 1.98 min
Park et al. (2021) [17]	Chest over lead apron	RIRS	227	0.58 mSv	5.13 min
Amirhasani et al. (2021) [25]	Chest over lead apron	PCNL (prone)	30 23 (new shielding method)	0.07 mSv 0.04 mSv	0.82 min 1.15 min
Safak et al. (2009) [19]	Chest over lead apron	PCNL (prone)	20	12 µGy	12 min
Yecies et al. (2017) [22]	Chest over lead apron	URS	154	116 mrad	1.4 min
Bagley et al. (1990) [27]	Chest over lead apron	URS	116	8 mrem	3.15 min
Galonnier et al. (2016) [6]	Chest under lead apron	PCNL (supine and prone) URS	35	0 mSv	Not specified
Kim et al. (2016) [26]	Chest under lead apron	URS	49	0.02 mSv	3.15 min
Inoue et al. (2017) [28]	Chest under lead apron	URS	62 (no lead curtain) 61 (lead curtain)	0.00010 mSv 0 mSv	1.94 min 1.98 min
Park et al. (2021) [17]	Chest under lead apron	RIRS	227	0.01 mSv	5.13 min
Yecies et al. (2017) [22]	Chest under lead apron	URS	154	6.8 mrad	1.4 min
Bagley et al. (1990) [27]	Chest under lead apron	URS	116	0 mrem	3.15 min
Limbs					
Kim et al. (2016) [26]	Arm right	URS	49	0.31 mSv	3.15 min
Park et al. (2021) [17]	Arm right	RIRS	227	0.55 mSv	5.13 min
Rao et al. (1987) [11]	Hand not specified	PCNL (not specified)	18	1.5 mSv	21.9 min
Bowsher et al. (1992) [23]	Hand Left Right	PCNL (not specified)	Not specified	0.14 mSv 0.145 mSv	2 min
Kumari et al. (2006) [30]	Hand dominant	PCNL (prone)	50	0.28 mSv	6.04 min

Table 2 (continued)

Authors and publication year	Organ	Procedure type (position*)	Nr. of procedures	Mean exposure per procedure	Mean radiation time per procedure
Ritter et al. (2012) [24]	Hand not specified	PCNL (not specified) Percutaneous stent change Ureteral stent change Ureteral stent placement URS	235	4.36 mSv 0.22 mSv 0.22 mSv 0.13 mSv 0.15 mSv	7.3 min 0.6 min 0.7 min 1 min 1.1 min
Galonnier et al. (2016) [6]	Hand Left Right Left Right Left Right	PCNL (supine) PCNL (prone) URS	35	0.316 mSv 0.437 mSv 0.862 mSv 0.986 mSv 0.008 mSv 0.012 mSv	Not specified
Kim et al. (2016) [26]	Hand Left Right	URS	49	0.81 mSv 0.60 mSv	3.15 min
Park et al. (2021) [17]	Hand Left Right	RIRS	227	0.56 mSv 0.73 mSv	5.13 min
Amirhasani et al. (2021) [25]	Hand Left	PCNL (prone)	30 23 (new shielding method)	0.2 mSv 01 mSv	0.82 min 1.15 min
Hellawell et al. (2005) [18]	Hand not specified	General ureteral procedures PCNL (not specified)	18 6	2.7 µGy 48 µGy	1.3 min
Safak et al. (2009) [19]	Hand Left Right	PCNL (prone)	20	33 µGy 34 µGy	12 min
Majidpour et al. (2010) [20]	Hand not specified	PCNL (prone)	100	0.21 µGy	4.5 min
Lowe et al. (1986) [29]	Hand Left Right	PCNL (prone)	7	9.4 mrad 2.2 mrad	27.8 min
Bagley et al. (1990) [27]	Hand not specified	URS	116	98 mrem	3.15 min
Amirhasani et al. (2021) [25]	Foot left	PCNL (prone)	30 23 (new shielding method)	0.1 mSv 0.05 mSv	0.82 min 1.15 min
Hellawell et al. (2005) [18]	Foot not specified	General ureteral procedures PCNL (not specified)	18 6	6.4 µGy 93 µGy	1.3 min
Hellawell et al. (2005) [18]	Leg not specified	General ureteral procedures PCNL (not specified)	18 6	11.6 µGy 167 µGy	1.3 min
Safak et al. (2009) [19]	Leg Left Right	PCNL (prone)	20	137 µGy 126 µGy	12 min
Majidpour et al. (2010) [20]	Leg not specified	PCNL (prone)	100	4.1 µGy	4.5 min

*patient position is specified for PCNL

about the possible dangers of RE have been proven to raise awareness among urologists and to decrease RE [3, 43].

The exposure detection methods have changed over the years. In the oldest studies, film badges were used, which directly measure radiation dose [11, 27]. Some studies used optically stimulated luminescence dosimeters [14, 17, 26]. These passive dosimeters measure the scattered dose [14]. Other studies used electronic pocket dosimeters [14, 28] that measure the scattered dose and the dose rate received by the urologist every second. When worn on the chest over the lead apron, they can estimate RE to the eyes, according to the ICRP [14]. In the more recent articles, thermoluminescent dosimeters were the standard method of detection of RE. These dosimeters are compact and lightweight, which make them easy to wear on different parts of the body [11]. Only one study used educational direct dosimeters, which are not as compact, but can detect the radiation dose very accurately [13].

This review has some limitations. Due to methodological variations between studies, evolution of RE cannot be identified over the years. Some studies documented RE in other units than mSv. This impedes the comparison between studies and the contextualization of these results in relation to the annual maximum radiation doses established by the ICRP. Also, different methods of radiation detection were used, which might have caused variations in reported RE.

Based on the results of this review, wearing lightweight thermoluminescent dosimeters during every procedure on different parts of the body, as well as wearing a lead apron, a thyroid shield and lead glasses with lateral protection, would provide adequate protection during endourological procedures. The recommendation of wearing gloves is contradicted by the high annual dose limit to the extremities, i.e. 500mSv, as well as the risk of increasing fluoroscopy time due to the lesser tactile function when gloves are worn [8, 44]. Also, it remains important to use pulsed fluoroscopy and to keep distance from the patient's body, as RE to the urologist is reduced approximately by 4 when the distance between urologist's and patient's bodies is doubled [44]. Furthermore, it would be of interest to gain knowledge of total RE to the urologist on an annual basis, as well as detailing the number of endourological interventions per operator. This would provide information between high and low volume centers. Also, recent studies found reduced RE when including ultrasound during endourological procedures without compromising outcomes [45–50]. Some studies have even shown that fluoroscopy is not needed at all to perform a successful endourological procedure [51–54]. The role of a radiation technologist has also been studied to a limited extent and could contribute to a lower RE [55, 56]. Together with the influence of lead gloves, the role of caseload and surgical experience, this should be evaluated in future prospective studies to further reduce RE.

Conclusions

There is a large variation in RE to the urologist during endourological procedures. Highest RE is observed during PCNL, especially in prone position. Considering studies with highest RE, urologists would be limited to 25 PCNL or 69 URS procedures per year before reaching the ICRP maximum effective dose of 20 mSv to the lens of the eye. Wearing a thyroid shield and lead apron resulted in a reduction of RE ranging between 94.1 and 100%. Educational courses on radiation have been proven to reduce RE and increase the awareness on the harmful effects of radiation.

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Data availability statement The data that support the findings of this study are available on request from the corresponding author.

Declarations

Conflict of interest Vincent De Coninck is a speaker and/or consultant for BD, Coloplast, and Karl Storz, and has no specific conflicts relevant to this study. Olivier Traxer is a consultant for Coloplast, Karl Storz, Rocamed, Quanta Systems, Ambu, Boston Scientific, and IPG Medical, and has no specific conflicts relevant to this study. Etienne Xavier Keller is a speaker and/or consultant for Coloplast, Olympus, Boston Scientific, Recordati, Debiopharm and Alnylam, and has no specific conflicts of interest relevant to this work. All other authors have no conflicts of interest.

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