

Uncovering the real outcomes of active renal stone treatment by utilizing non-contrast computer tomography: a systematic review of the current literature

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Abstract

Purpose To evaluate the stone-free rates (SFRs) and stone clearance rates (SCRs) of extracorporeal shock-wave lithotripsy (SWL), retrograde intrarenal surgery (RIRS), and percutaneous nephrolitholapaxy (PCNL) according to non-contrast computer tomography (NCCT) findings.

Methods Original articles were identified from PubMed. After exclusion of ineligible papers, twenty-three studies with 2494 cases were included in the review.

Results Six SWL, five RIRS and eight PCNL studies were selected. Additionally, four comparative articles were identified. SWL presents SFRs ranging 35–61.3 % and SCRs for residuals <4 mm being 43.2–92.9 %. RIRS studies report SFRs of 34.8–59.7 % and SCRs for residuals <4 mm ranging 48–96.7 %. Finally, PCNL presents SFRs of 20.8–100 % and SCRs for residuals <4 mm being 41.5–91.4 %. According to the comparative studies, SFRs are 17–61.3 % for SWL, 50 % for RIRS, and 95–100 % for PCNL.

Conclusions According to NCCT findings, it seems that PCNL provides better SFRs than ESWL and RIRS. However, further research with comparable and complete preoperative parameters and outcomes could reduce the heterogeneity of current data.

Keywords Computer tomography · CT · Non-contrast CT · Extracorporeal shock-wave lithotripsy · SWL · Retrograde intrarenal surgery · RIRS · Flexible ureteroscopy · Percutaneous nephrolithotomy · Mini PCNL · MIP · Micro PCNL · T.R.U.S.T

Introduction

SWL, RIRS, and PCNL are the standard options for active treatment of nephrolithiasis. According to the European Association of Urology guidelines, all three modalities can be used selectively depending on stone size and location [1].

Successful active stone treatment is mainly defined either by the complete absence of residual stones or by the presence of clinically insignificant residual fragments. SFRs and SCRs quantify the above states, respectively. At the same time, the treatment should be characterized by minimal hospitalization and complication rates (CRs). By definition, SWL offers an outpatient, noninvasive, treatment with the drawback of limited SFRs, often requiring further treatment [2]. A recent meta-analysis by De et al. [3] corroborates the high SFRs but also the higher CRs and longer hospital stay reported for PCNL. Finally, RIRS has been also greatly evolving, being utilized in the management of even larger or multiple renal stones throughout the entire pelvicalyceal system [4, 5]. The main drawbacks of retrograde access include a potential violation of the ureter [6], as well as the limited visualization [7].

There has been a great scientific effort to elucidate the SFRs and SCRs of the different techniques and implement the correct indications for treating different types of stones according to stone size and localization. Undeniably, NCCT is the most sensitive diagnostic tool, for detecting

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residual fragments as it offers higher sensitivity regardless of stone size, compared to plain kidney–ureter–bladder X-ray and ultrasonography [8–14]. Additionally, NCCT has a higher capability of predicting occurrence of stone-related events [15]. Different NCCT modalities include regular-dose NCCT and low-dose NCCT, which reduces the radiation risk by offering a sensitivity of 96.6 % and specificity of 94.9 % [16, 17]. At the same time, accuracy of stone detection increases by decreasing the NCCT slice thickness, which nowadays can be as low as 0.625 mm [18, 19]. Yet, most of the studies have not utilized NCCT during in their postoperative follow-up. The aim of this review is to compare the SFRs and SCRs of the three modalities according to NCCT findings.

Materials and methods

Literature search and article selection (fig)

A systematic literature review was performed up to November 2015 using PubMed in order to identify relevant original studies (“Appendix 1, 2”). Different keywords included “extracorporeal shock wave lithotripsy,” “retrograde intrarenal surgery,” “RIRS,” “flexible ureteroscopy,” “percutaneous nephrolithotomy,” “mini PCNL,” “micro PCNL.” Six hundred and twenty six records were identified through database searching. After duplicates were removed, 465 records remained. After record screening, 136 records, which were not written in English or were in vitro and pediatric studies, were excluded. From the 330 full-text articles assessed, complex lithiasis studies, papers not reporting SCRs and SFRs and studies that did not use NCCT in their follow-up, or did not define the method used, were also excluded. Cited references from the selected articles retrieved in the search were also assessed for significant papers. Two independent reviewers (TT, MH) performed the literature search, and twenty-three studies were judged as eligible by their consensus. The quality of the studies was graded according to the Grading of Recommendations, Assessment, Development, and Evaluation system [20]. Levels of evidence (LEs) and grade of guideline recommendations were rated in accordance with the European Association of Urology guidelines [1].

Data extraction

Two independent reviewers (TT, MH) extracted the data of the selected studies. More specifically, six SWL studies (Table 1), five RIRS studies (Table 2), eight PCNL studies (Table 3), and four comparative studies (Tables 1–3) were reviewed. The data reviewed from the different studies included the number of procedures, number of stones

(mean, range), the stone size and location (mean, range), the duration of the procedures (mean, range), the slice thickness of CT images (collimation), the CT quality parameters (in mA and kV), the timing of post-treatment CT performance, and the stone size thresholds used to name residuals as clinically insignificant. The CRs, duration of hospitalization, and need for ancillary procedures were also recorded. The primary endpoint of the review is the SFRs and SCRs of the different procedures (Fig. 1).

Outcomes

SWL outcomes (Table 1)

A total of 10 studies with 933 cases were identified [2, 21–29]. Six of them were descriptive non-comparative studies (LE 4) [21–26], one was a cohort study (LE 3) [2], and three were randomized controlled trials (LE 2) [27–29]. The range of maximal stone diameter was 5–25 mm. The NCCTs were mainly performed at 3 months [2, 21, 22, 24–29]. The SFRs reported were 35–61.3 % [21, 23, 24, 27–29] and the SCRs with residual stone size ≤ 4 mm 43.2–92.9 % [2, 22–26, 28]. The rates for further treatment need ranged 16–67.7 % [2, 21, 23, 27–29].

RIRS outcomes (Table 2)

Overall, a total of seven RIRS studies with 563 cases were selected as eligible [2, 28, 30–34]. Five of them were descriptive non-comparative studies (LE 4) [30–34], one was a cohort study (LE 3) [2], and one was a randomized controlled trial (LE 2) [28]. The stone size range was 5–50 mm. The NCCTs were mainly performed 1–3 months postoperatively [2, 28, 30–32, 34], except in the study by Takazawa in which they were performed earlier than 2 weeks after the procedures [33]. The SFRs reported were 34.8–59.7 % [28, 30, 31, 34]. In particular, for stones with diameter greater than 2 cm, the SFRs were 59.7 % [34]. The SCRs for residual stone size ≤ 4 mm were 48–96.7 % [2, 28, 30–33]. The need for further active treatment was presented in four studies and was 3.7–35 % [2, 28, 30, 33].

PCNL outcomes (Table 3)

Eight PCNL single-arm (LE: 4) studies [9, 11, 12, 14, 35–38], one cohort study (LE 3) [2], and two randomized controlled trials (LE 2) with a total of 998 cases were selected in this review. The stone size could not be clearly assessed. In all studies, procedures were performed with standard PCNL instruments. Interestingly, most NCCTs were performed mainly either direct postoperatively [35] or during the first two postoperative weeks [9, 12, 14, 36–38]. Nevertheless, the three comparative [2, 27, 29] and

Table 1 SWL studies

Study	Number of cases	Stone size	Stone location	Number of sessions	Collimation (mm)/Quality/Window	Follow-up	SFRs no residuals (%)	SCRs residual stone size ≤ 2 mm (%)	SCRs residual stone size ≤ 4 mm (%)
Madbouly et al. [21]	108	14.42 \pm 5.11 mm (>20 mm in 13 %)	Lower pole	1–3	NA/NA/NA	3 months	50	NA	NA
Wang et al. [25]	80	<25 mm	Non-lower pole Lower pole Renal pelvis	1	3.75/200–280 mA, 120 kV/NA	3 months	NA	NA	52.5
Peartle et al. [28]	25	7.9 \times 5.1 mm	Lower pole	1	5/NA/NA	3 months	35	NA	65
El-Nahas et al. [26]	70	5–25 mm	Non-lower pole Lower pole Renal pelvis	1–more	NA/NA/NA	3 months	NA	NA	92.9
Yuruk et al. [29]	31	139.4 65.1 mm ²	Lower pole	1–3	NA/NA/NA	3 months 12 months	54.8 61.3	NA	NA
Deem et al. [27]	12	10–20 mm	Non-lower pole Renal pelvis	1–more	NA/NA/NA	1 week 3 months	17 33	NA NA	NA NA
Ouzaid et al. [23]	50	5–22 mm	Non-lower pole Lower pole Renal pelvis	1	NA/NA/NA	1 month	52	NA	76
Resorlu et al. [2]	251	14.9 \pm 2.9 mm	Lower pole Non-lower pole Renal pelvis	1–3	NA/NA/NA	3 months	NA	NA	66.5
Ng et al. [22]	206	5–20 mm	Upper pole Middle pole Lower pole	1	5/NA/NA	3 months	NA	NA	43.2
Torricelli et al. [24]	100	5–20 mm (mean 9.1 mm)	Lower pole	1	1/200–300 mA, 120 kV/bone window	3 months	37	NA	54

SWL extracorporeal shock-wave lithotripsy, NA not available, SFRs stone-free rates, SCRs stone clearance rates

Table 2 RIRS Studies

Study	Number of cases	Stone size in	Stone location	Collimation (mm)/Quality/Window	Follow-up	SFRs No residuals (%)	SCRs Residual stone size ≤ 2 mm (%)	SCRs Residual stone size ≤ 4 mm (%)
Pearle et al. [28]	27	6.9 × 5.0 mm	Lower pole	5/NA/NA	3 months	50	NA	72
Portis et al. [30]	35	5–15	Non-lower pole Lower pole	5/NA/bone window	1 month	54.5	84.8	96.7
Macejko et al. [31]	47	Mean: 8	Non-lower pole Lower pole	3/NA/NA	3 months	34.8	48.5	80
Rippel et al. [32]	78	Mean: 7.6 mm (+ureter stones)	Non-lower pole Lower pole	3/NA/NA	1–3 months	NA	48	NA
Takazawa et al. [33]	20	20–50 mm (mean: 31 mm)	NA	NA/NA/NA	1–2 weeks	NA	NA	65
Resorlu et al. [2]	46	15.6 ± 3.4 mm	Lower pole Non-lower pole Renal pelvis	NA/NA/NA	1–2 months	NA	NA	87.0
Ito et al. [34]	310	Mean: 22.70 mm	Non-lower pole Lower pole	axial: 5 coronal: 3.5/NA/NA	3 months	59.7	NA	NA

RIRS retrograde intrarenal surgery, NA not available, SFRs stone-free rates, SCRs stone clearance rates

two single-arm studies [11, 37] reported outcomes after 1–12 months. The SFRs reported are 20.8–100 % [9, 11, 12, 14, 27, 29, 36, 37]. The SCRs for residual stone size ≤ 4 mm were 41.5–91.4 % [2, 9, 11, 14, 35, 37, 38]. The necessity for ancillary procedures reported was 0.00–30.18 % [2, 9, 11, 12, 14, 27, 29, 37].

Discussion

Selecting the optimal renal stone treatment can be challenging, as each technique is characterized by unique benefits and drawbacks. Furthermore, the absence of high-quality comparative trials or reviews and meta-analyses comparing the three modalities is more than apparent. Only recently, a meta-analysis by De et al. [3] compared RIRS with PCNL and minimally invasive PCNL (MIP). The authors concluded that PCNL offers higher SFRs than MIP and RIRS. They also purported that RIRS provides better SFRs than MIP and should be the standard of care for renal stones with diameter < 20 mm. However, most of the studies included did not utilize NCCT to detect stone residuals. We tried to assess the SFRs and SCRs of all treatment modalities according to postoperative CT follow-up.

By examining the single-arm studies, the outcomes presented are less favorable than the ones reported by using other means to estimate residual fragments [39–45].

Interestingly, by examining the results of the four comparative studies, the results are significantly different in favor of PCNL. More specifically, the SFRs reported were 17–61.3 % for SWL, 50 % for RIRS, and 95–100 % for PCNL [2, 27–29]. Pearle et al. [28] reported SFRs of 35 % and 50 % for SWL and RIRS, respectively ($p = 0.92$). The SFRs presented by Yuruk and associates [29] were 96.7 and 32.2 % for PCNL and SWL ($p < 0.001$). Deem et al. [27] presented SFRs at 3 months 85 and 33 % ($p = 0.006$) for PCNL and SWL, respectively. Finally, Resorlu et al. [2] presented SCRs at 1–2 months for stone residual diameter < 4 mm of 91.4, 87.0 and 66.5 % for PCNL, RIRS and SWL, respectively ($p < 0.001$). These outcomes remain less favorable than the already reported for SWL [39–41] and RIRS [42–45], but are comparable for PCNL [42–45].

Albeit our efforts to reduce heterogeneity of studies dealing with active stone treatment, we should be cognizant that a relative deficiency and heterogeneity of data still exists. First, the quality of the different studies varies, with most of them being descriptive, single-arm, retrospective cohorts (LE 4) and only three of them being randomized prospective trials [27–29]. Moreover, the sample size difference between the three different treatment modalities is undeniable as nine SWL studies with 863 cases, seven RIRS studies with 563 cases, and 11 PCNL studies with 998 patients were included.

Table 3 PCNL studies

Study	Number of cases	Stone size (%)	Stone location	Collimation (mm)/Quality/Window	Follow-up	SFRs No residuals (%)	SCRs Residual stone size ≤ 2 mm (%)	SCRs Residual stone size ≤ 4 mm (%)
Geterud et al. [35]	80	3–35 mm mean: 14.6 mm	NA	9/240 mA, 120 kV/NA	7 days	76	NA	NA
Waldmann et al. [9]	124	Staghorn Large non-staghorn	NA	5/NA/NA	2 days	59	NA	75
Park et al. [11]	53	705.8 \pm 103.8 mm ² Staghorn (52.8)	NA	3/NA/NA	1 month	20.8	NA	41.5
Osman et al. [12]	100	NA	Pelvis Calyceal Staghorn	5/220 mA, 120 kV/NA	2 days	38	NA	NA
Yuruk et al. [29]	31	153.3 \pm 39.5 mm ²	Lower pole	NA/NA/NA	3 months 12 months	96.7 100	NA	NA
Deem et al. [27]	20	10–20 mm	Non-lower pole Renal pelvis	NA/NA/NA	1 week 3 months	95 85	NA	NA
Roy et al. [37]	26	NA	NA	3.75/NA/NA	Direct postop	NA	NA	81
Resorlu et al. [2]	140	17.3 \pm 3.6	Lower pole Non-lower pole Renal pelvis	NA/NA/NA	1–2 months	NA	NA	91.4
Portis et al. [37]	129	412.7 mm ²	NA	NA/NA/NA	1st day or 1 month	54.3	69.0	82.2
Akhavein et al. [38]	122	0–>1600 mm ²	NA	3–5/NA/NA	1–14 days	NA	54.9	76.2
Gokce et al. [14]	173	NA	NA	4/NA/NA	1–2 days	54.9	NA	75.7

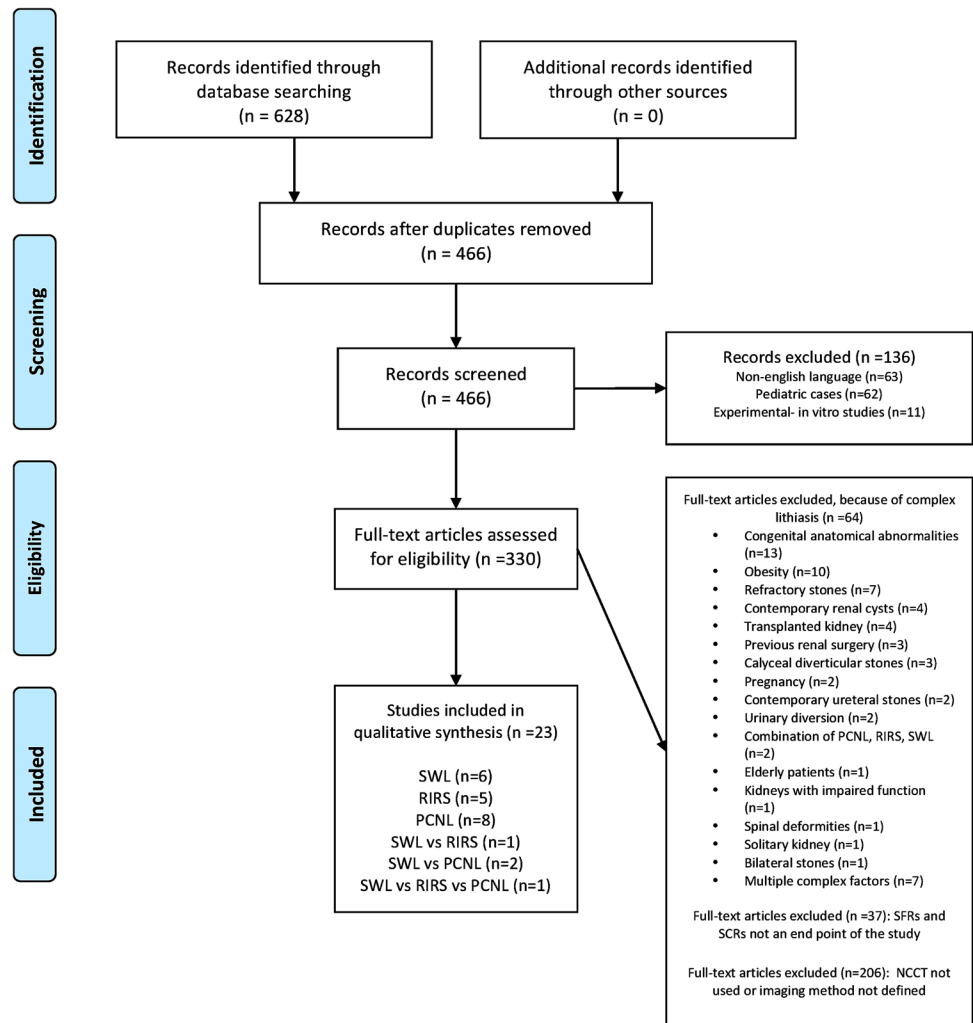
PCNL percutaneous nephrolitholapaxy, NA not available, SFRs stone-free rates, SCR_s stone clearance rates

The stone characteristics are not clearly defined in all studies. Regarding stone size, some cohorts use the maximum diameter in mm, while others, mainly PCNL, studies the stone surface in mm² [11, 37, 38]. Additionally, active stone treatment differs according to stone location and size, making a cumulative presentation of outcomes a great challenge. Three of the SWL groups treated single calculi [22–24], while another two reported results by also treating multiple stones [21, 25]. Two studies included only lower pole stones [21, 24], while the rest also reported non-lower and pelvic stones [22, 23, 25]. The stone number range reported in the RIRS studies was 1–3 and all cohorts included lower pole as well as non-lower pole stones. However, the stone number and location in the PCNL groups could not be clearly assessed, possibly because of the high presence of multiple as well as staghorn calculi. Resorlu et al. [2] admit that the size of the stones treated by PCNL was significantly greater than the mean stone sizes of RIRS and SWL. Additionally, especially for SWL, the stone type is an independent predictor for treatment success. However, stone composition is only reported in two studies [2, 29].

The rest of the studies mainly reports stone maximal density in Hounsfield Units [22–25, 27, 28].

Furthermore, no SWL study provides information regarding the possible use of adjuvant expulsive therapy, which can facilitate passage of stones and improve SFRs. Additionally, many SWL studies present their cumulative outcomes and not the SFRs and SCR_s after the first session [2, 21, 26–29]. However, many patients required more than one session in order to achieve the desirable result [2, 21, 26, 27, 29]. Stent placement after RIRS as well as the timing of stent removal in relation to performing NCCT could also add important information. Only two RIRS groups placed stents in all patients [30, 33], the rest leaving stent placement in surgeon discretion [2, 28, 31, 32, 34]. Two groups reported the times of stent removal ranging from 1 to 2 weeks postoperatively [2, 30]. Finally, stone dusting during RIRS could present misleading results, as a possible dust accumulation postoperatively does not necessarily mean the presence of significant residual fragments. The use of CT-magnified bone windows can overcome this impediment [46].

Fig. 1 Flow diagram indicating the records identified through database searching, the records excluded and the total studies included in the review. *SWL* extracorporeal shock-wave lithotripsy, *RIRS* retrograde intrarenal surgery, *PCNL* percutaneous nephrolitholapaxy



Other important intraoperative and postoperative parameters that could influence the results, like surgeon experience, procedure time, CRs, and length of hospitalization constitute possible drawbacks that reflect the greater invasiveness of PCNL [2, 3, 28]. The mean duration of RIRS and PCNL procedures ranged from 43 to 114 min [2, 28–30, 33, 34] and 46.7–149.44 min [2, 28, 29, 38], respectively. However, the authors did not define if the PCNL duration refers to the total duration or the time starting from the kidney puncture and finishing at the end of the procedure. In one study, RIRS had more intraoperative (20 vs. 3 %) but comparable postoperative complications (21.3 vs. 23 %) with SWL [28], and in another, PCNL presented equal complication rates with SWL (6.4 %) [29]. Finally, in the study by Resorlu, the complication rates were significantly higher ($p < 0.001$) for PCNL (22.1 %) in comparison to RIRS (10.9 %) and SWL (7.6 %) [2]. Nevertheless, only one PCNL study used the Clavien classification system to classify complications [38]. The duration of hospitalization was evident only in two comparative studies

ranging 0.06–1.3 days for RIRS and 2.6 days for PCNL [2, 28]. Additionally, as success of PNL is highly surgeon dependent, data on the surgeon experience are of paramount importance for outcome assessment. Unfortunately, this information is unreported in many studies. Finally, although mini-, micro-, and minimally invasive PCNL technology is recently introduced, presenting favorable outcomes and minimizing CRs, no such study presents outcomes according to NCCT follow-up.

The post-treatment imaging utilized to detect stone residuals, but also the best time to perform it, are additional but critical parameters that should always be precisely reported. Currently, many studies substantiate the superiority of NCCT over kidney–ureter–bladder (KUB) X-ray, intravenous pyelography, or ultrasonography in detection and evaluation of residual stones after active treatment, as well as prediction of residual stone-related events and detection of complications of treatment [8–12, 14]. Furthermore, in many occasions, trying to detect residual fragments with plain KUB is like throwing a coin. Park et al.

[11] showed that 45.5 % of patients who were stone free with KUB had actually residual stones larger than 4 mm in diameter (mean size: 7.4 mm) detected by CT. In that way, NCCT secures a better treatment plan and the avoidance of unnecessary ancillary treatment. There is also evidence that CT-magnified bone windows are the most accurate method of stone measurement [46]. To our knowledge, this is the first systematic review trying to estimate the treatment outcomes based exclusively on CT findings. Nevertheless, it is of utmost importance to fully describe the technique and equipment used, and the CT exposure data, as well as the length of the sections taken, a factor that also greatly varied in our study. Imaging at the end of the first month after treatment is considered optimal as it gives enough time for stone debris and small insignificant residual fragments to be excreted [11, 47]. Surprisingly, in almost all the PCNL single-arm studies, NCCT was performed before this time period or even direct postoperatively. As a consequence, most probably their presented SFRs and SCRs do not reflect the reality [9, 12, 14, 35–38].

Finally, the most important parameter is the proper definition of the significant residual stone size, as small residual fragments may pass spontaneously without creating stone-related events. In our study, all SWL studies define a cut-off value of 4 mm [21–25] as clinically insignificant. Nevertheless, even smaller residual fragments could cause symptoms and require active intervention [37, 48, 49]. Hence, in the CT-era, and preferably utilizing low-dose CT, trying to achieve a stone-free status should be the absolute target of every endourologist, especially in infected stones. Finally, the need for additional treatment or, in other words, the ancillary procedure rates, are not always reported. Nevertheless, as presented by De et al. [3], the need for further treatment appears to be less in PCNL.

Summarizing the apparent shortcomings of the present review, the selected studies often lack important information regarding stone characteristics like size, number, location, and composition. In particular, for SWL studies, the exact number of sessions is not always reported. Additionally, postoperative CT timing differs between different articles and CT characteristics like quality and collimation are often missing. Finally, heterogeneity of SCRs due to variable definitions of significant residual lithiasis greatly impedes a precise outcome evaluation.

Conclusion

The current data for active stone treatment characteristics and outcomes remain incomplete and greatly heterogeneous. By using NCCT for residual stone size evaluation as a filter, it appears that PCNL offers better SFRs than SWL and RIRS. In light of these results, future studies should

adapt to the suggested standardizations and postoperative NCCT control in order to improve the quality of presented data.

Author's contribution T Tokas contributed to project development, data collection, data analysis and manuscript writing. M Habicher contributed to data collection and data analysis. D Junker helped in manuscript editing. T Herrmann contributed to manuscript editing. JP Jessen contributed to manuscript editing. T Knoll helped in manuscript editing. U Nagele contributed to project development and manuscript editing.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights This review does not involve human participants and/or animals.

Appendix 1

The PubMed search was performed by two independent reviewers (TT, MH) and the keywords used were selected after their consensus and the suggestions of the senior author.

Appendix 2

Criteria for considering studies

- patients/participants: Healthy non-obese adults (mean age: 29.6–62)
- interventions: SWL, RIRS and standard PCNL
- comparators: NCCT
- outcomes: Stone-free rates and stone clearance rates according to NCCT findings.

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