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REVIEW

Safety and efficacy of percutaneous nephrolithotomy in elderly patients: a systematic review and meta-analysis by the EAU-YAU urolithiasis and EAU endourology sections

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Abstract

Purpose The aim of this study was to evaluate differences in safety and efficacy outcomes of PCNL between elderly and non-elderly patients, with special focus on commonly applied age cut-off values.

Methods A systematic review and meta-analysis were conducted in accordance with PRISMA guidelines. Comparative studies evaluating outcomes of PCNL in elderly versus non-elderly patients were identified through comprehensive searches of PubMed/MEDLINE, Embase, Web of Science, and the Cochrane Library up to February 2026. Primary outcomes included overall, minor, and major complications, as well as stone-free rate (SFR). Subgroup analyses were performed according to different age thresholds used to define elderly populations (60, 65, and 70 years).

Results Seventeen studies encompassing 45,603 patients, including 10,745 elderly individuals, were included. When pooled across all age definitions, rates of overall complications (OR 1.20, 95%CI 0.95–1.53) and major complications (OR 1.39, 95%CI 0.92–2.10) did not differ significantly between elderly and younger patients. Elderly patients demonstrated a significantly higher risk of postoperative sepsis (OR 3.94, 95%CI 1.83–8.47). SFR were comparable between groups. In subgroup analyses, studies applying a 70-year age cut-off demonstrated a significantly increased risk of overall complications (OR 1.26, 95% CI 1.03–1.55) and major complications (OR 1.95, 95% CI 1.15–3.31), whereas no significant differences were observed in studies using 60- or 65-year thresholds.

Conclusions PCNL can be performed safely in elderly patients, with SFR and complication profiles comparable to those observed in younger individuals when data across different elderly definitions are pooled. However, overall and major complications increases progressively with advancing age within the elderly population, especially among patients aged ≥ 70 years.

Keywords Percutaneous nephrolithotomy · PCNL · Elderly patients · Safety · Efficacy · Complications · Stone-free rate

Introduction

The worldwide demographic shift towards an aging population has led to an increase in elderly patients with urolithiasis, making stone disease an increasingly relevant clinical problem in endourology [1–3]. Several authors have emphasized that advances in medical care and increased life expectancy have expanded the population of older individuals eligible for active stone treatment, including invasive procedures such as percutaneous nephrolithotomy (PCNL) [4].

PCNL remains the standard surgical treatment for large and complex renal calculi; however, its use in geriatric patients has historically raised concerns related to increased

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comorbidity burden, anaesthetic risk, and perioperative complications. Nevertheless, findings regarding perioperative morbidity have been contradictory, with some authors reporting higher rates of haemorrhagic and infectious complications in geriatric patients, while others observed no clinically meaningful differences [5–7]. Interpretation of this evidence is complicated by substantial heterogeneity in the definition of "elderly," with age cut-offs ranging from 60 to 70 years.

The most recent meta-analysis by Haider et al. showed that PCNL is feasible in older individuals, but included a limited number of studies and did not assess several clinically relevant outcomes [8]. Since the publication of that paper, additional larger and more contemporary studies have become available, including multicentre cohorts [6, 9].

Therefore, the present systematic review and meta-analysis aimed to provide an updated evaluation of the safety and efficacy of PCNL in elderly patients compared with younger cohorts. By incorporating subgroup analyses based on different age thresholds used to define elderly populations, we additionally sought to elucidate whether perioperative outcomes and complications differ across commonly applied age cut-offs.

Methods

This systematic review and meta-analysis was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [10]. The study protocol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the registration number CRD420251271524.

Search strategy

Two review authors (Ł.N. and B.B.M.) independently performed a literature search in PubMed/MEDLINE, Embase, Web of Science, and the Cochrane Library databases. This search encompassed the respective databases' inception timeframe up to February 2026. The detailed search terms were provided in Supplementary Table 1. Reference lists of included studies were manually screened to identify any additional eligible publications. No limitations regarding the publication date or language were imposed.

Study selection

Study eligibility was defined according to the PECOS framework:

(P)opulation: Adult patients undergoing percutaneous nephrolithotomy (PCNL) for renal or upper ureteral calculi.

(E)xposure: The exposure group consisted of elderly patients. In the present study, elderly patients were defined as either ≥ 60 or ≥ 65 years of age. Additionally, studies employing a more stringent definition of elderly patients using a cut-off of 70 years or older were also included. The use of such age thresholds reflects prevailing practice in clinical research and allows inclusion of a broader and methodologically consistent body of evidence, while acknowledging the absence of a single universally accepted definition of elderly status [11]. If studies reported multiple elderly subgroups, such as patients aged ≥ 80 years in addition to the primary elderly definition, data from all eligible elderly subgroups were combined into a single elderly group according to the predefined age cut-off (e.g., ≥ 60 or ≥ 65 years) to facilitate quantitative synthesis and meta-analysis.

(C)omparison: The comparison group consisted of non-elderly patients. Studies were excluded if they did not include a clearly defined non-elderly comparison group. Studies lacking a clear and uniform age cut-off for defining elderly patients were excluded, such as those employing selective or non-comparable age groupings.

(O)utcomes: The primary outcomes were complication rates and stone-free rate (SFR). Complications were analysed as: overall complications, minor complications (Clavien-Dindo I–II), and major complications (Clavien-Dindo III–V). SFR was defined according to the criteria used in the original studies. Given the variability in the timing of postoperative assessment, two distinct definitions of SFR were accepted and analysed separately based on the time point of evaluation. Immediate SFR was defined as stone-free status assessed in the early postoperative period, as reported by individual studies, with evaluation time points ranging from 1 to 3 days after surgery. Final SFR was defined as stone-free status assessed at later follow-up, with reported evaluation time points ranging from 4 to 12 weeks postoperatively. The definition of SFR varied between studies but generally referred to the absence of residual stones or the presence of clinically insignificant residual fragments, most commonly defined as stone fragments measuring less than 4 mm, as assessed on postoperative follow-up using a computed tomography (CT), ultrasonography (USG) and/or plain X-ray of kidneys, ureters, and bladder (KUB).

Secondary outcomes were: postoperative fever rate, sepsis rate, blood transfusion rate, embolization rate, operative time (OT), length of hospital stay (LOS), readmission rate, rate of auxiliary procedures.

Studies were eligible for inclusion only if they reported at least one predefined outcome of interest.

(S)tudy design: Prospective and retrospective comparative studies. Reviews, meta-analyses, editorials,

commentaries, authors' replies, meeting abstracts of unpublished studies, and case reports were excluded.

Data extraction

Data extraction was independently performed by two authors (Ł.N. and B.B.M.) using a predefined Excel spreadsheet to collect baseline study and patient characteristics, perioperative variables, and outcome data.

Risk of bias assessment

The methodological quality of included studies was independently assessed by two investigators (Ł.N. and B.B.M.) using the Newcastle–Ottawa Scale (NOS) for non-randomized studies [12]. Articles were evaluated based on selection, comparability, and outcome assessment domains. Studies scoring between 0 and 5 were categorized as being of low quality and excluded, while those with scores ranging from 6 to 9 were considered eligible for inclusion, following established reference criteria [13]. Discrepancies were resolved by consensus with senior coinvestigator (W.K).

Statistical analysis

All statistical analyses were performed using R software (R Foundation for Statistical Computing, Vienna, Austria).

Dichotomous outcomes were analysed using odds ratios (ORs) with corresponding 95% confidence intervals (CIs). For each binary outcome, pooled effect estimates were calculated using the Mantel–Haenszel method. Continuous variables were analysed using mean differences (MDs) with corresponding 95% CIs. In studies reporting continuous outcomes as medians with interquartile ranges (IQRs) or ranges, these values were converted to means and standard deviations using established statistical methods described by Luo et al. [14]. Between-study variance was estimated using the DerSimonian–Laird method. A random-effects model was selected a priori to account for anticipated between-study clinical and methodological heterogeneity. Expected sources of heterogeneity included differences in study populations, perioperative management, surgical techniques, outcome assessment, and the age thresholds used to define elderly patients.

Statistical heterogeneity was assessed using Cochran's Q test and quantified using the I^2 statistic. Heterogeneity was considered significant when the I^2 value exceeded 50% and the Cochran's Q test yielded a p-value < 0.05. A publication bias was evaluated visually using funnel plots.

All statistical tests were two-sided, and a p-value < 0.05 was considered statistically significant.

Subgroup analysis

Subgroup analyses of primary outcomes were performed only when a sufficient number of studies were available (≥ 10 studies) to ensure the robustness and interpretability of the results. Predefined subgroup analyses were conducted according to the definition of elderly population (age cut-offs of 60, 65, and 70 years). In addition, meta-regression analysis were performed to explore the potential impact of age, publication year, and sample size on the analysed outcomes, allowing assessment of trends beyond categorical subgroup comparisons.

Results

Study selection and characteristics

The study selection process is outlined in the PRISMA flow diagram **(**Fig. 1**)**.

The literature search identified 4420 records through database searching. After removal of 1036 duplicate records, 3384 studies were screened based on titles and abstracts. Of these, 3345 records were excluded for irrelevance to the study topic or inappropriate publication type (reviews, meta-analyses, editorials, conference abstracts, and case reports). Full-text assessment was performed for 39 articles, of which 22 were excluded due to non-comparative design (n = 9), comparison of PCNL with retrograde intrarenal surgery (RIRS) (n = 8), or lack of a uniform age cut-off and use of selective or non-comparable age groupings (n = 5). No study was excluded on the basis of methodological quality assessment. Ultimately, 17 studies met the inclusion criteria and were included in the final systematic review and meta-analysis [5–7, 9, 15–27].

The baseline characteristics of the included studies are presented in Table 1. Overall, the selected articles comprised 45,603 patients, including 10,745 elderly (23.6%) and 34,858 non-elderly (76.4%) individuals. The majority of studies were retrospective observational cohorts, predominantly single-centre [7, 15–19, 21–27], with two multicentre studies [5, 9] and one large national database analysis [20]. One study was based on prospectively collected data derived from the Clinical Research Office of the Endourological Society (CROES) Global PCNL Study database [6]. Three studies [5, 15, 19] defined elderly patients using an age cut-off of 60 years, 9 studies [9, 17, 18, 20, 22, 24–27] applied a cut-off of 65 years, while five studies [6, 7, 16, 21, 23] used a threshold of 70 years.

Methodological quality, evaluated using the Newcastle–Ottawa Scale (NOS), ranged from 6 to 9 points, indicating that the overall quality of the included studies was moderate

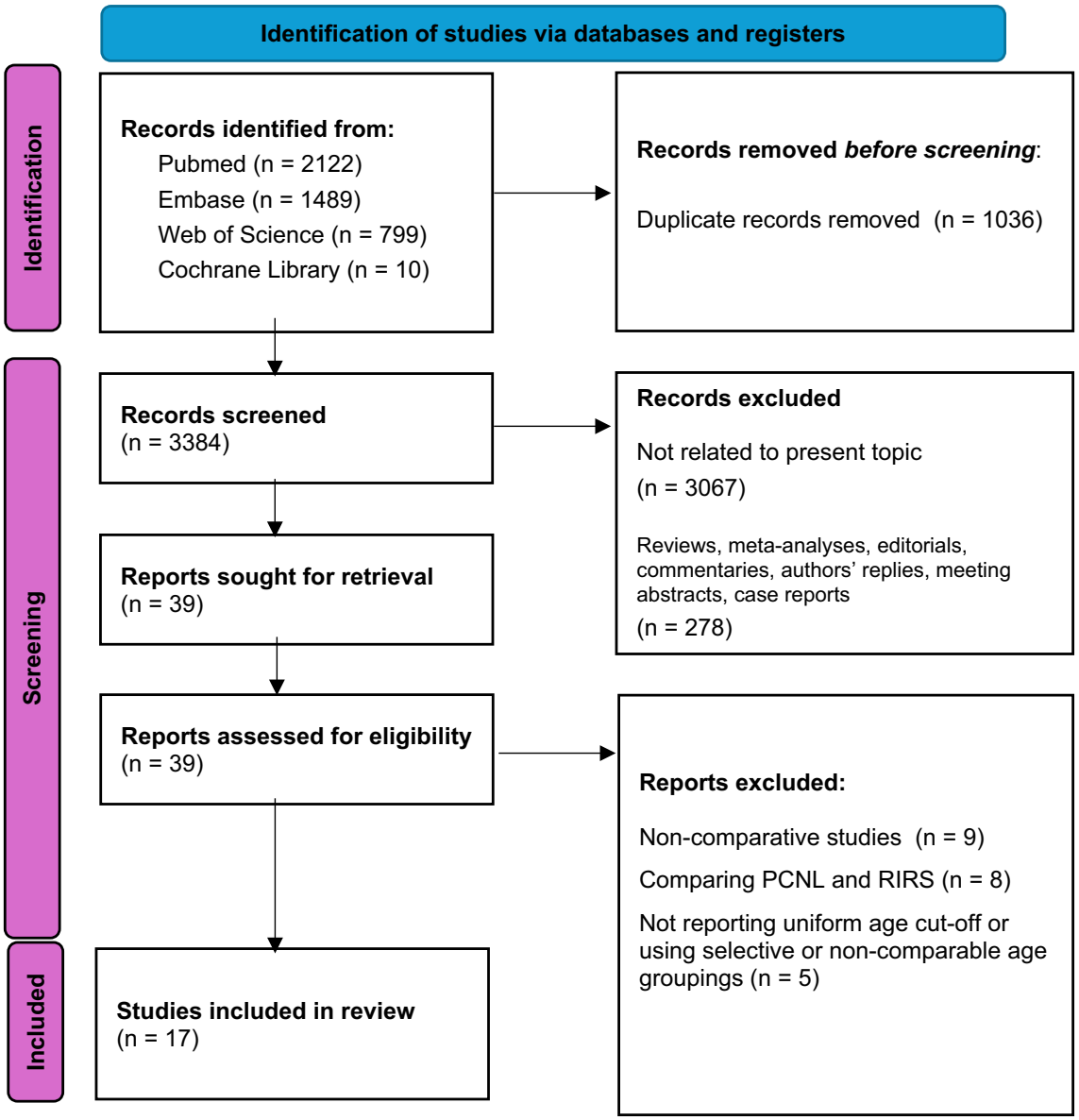


Fig. 1 PRISMA flow diagram of study selection

to high. Detailed quality assessment results are presented in Supplementary Table 2.

Patient demographics and baseline characteristics

The baseline demographic and clinical characteristics of elderly and non-elderly patients across the included studies are summarised in Table 2**.** Geriatric patients consistently demonstrated a higher comorbidity burden. The proportion of patients with ASA grade≥III varied from 3.7 to 30% in elderly group, compared with 0.3–15.2% in non-elderly group. Hypertension, diabetes mellitus, and chronic kidney disease were more prevalent in elderly patients. Stone-related characteristics were largely comparable between both groups. Mean stone diameter typically ranged from approximately 20 to 40 mm. With the exception of one study [27], no statistically significant differences in stone diameter or stone burden were observed between elderly and non-elderly groups. The prevalence of multiple stones ranged from 30 to 75% in the elderly group and from 32 to 75% in the non-elderly group, indicating comparable distributions between the two cohorts. One study [26] exclusively analysed patients with staghorn calculi, whereas in the remaining studies the prevalence of staghorn stones ranged from 13 to 39% and 11–32% in elderly and non-elderly group, respectively.

Definitions of SFR, imaging modalities employed for SFR assessment, and procedural characteristics varied

Table 1 Characteristics of included studies

Study (year) [ref]	Country	Design	Enrolment period (years)	Elderly group definition	Number of patients elderly/non-elderly	Methodological quality (NOS)
Abedali et al. (2019) [15]	United States	Retrospective single-centre	1999–2019	60 years	625/1022	8
Anagnostou et al. (2008) [16]	United Kingdom	Retrospective single-centre	1991–2003	70 years	126/531	8
Buldu et al. (2015) [5]	Turkey	Retrospective multicentre	2010–2013	60 years	125/395	8
Falahatkar et al. (2023) [17]	Iran	Retrospective single-centre	2009–2021	65 years	83/656	8
Gupta et al. (2020) [18]	India	Retrospective single-centre	2015–2016	65 years	50/50	7
Haberal et al. (2021) [9]	Turkey	Retrospective multicentre	1997–2020	65 years	839/7352	9
Iqbal et al. (2020) [19]	Pakistan	Retrospective single-centre	2010–2018	60 years	137/594	6
Johnston et al. (2019) [20]	United States	Retrospective, NRD	2013–2014	65 years	7721/15351	8
Jou et al. (2009) [21]	Taiwan	Retrospective single-centre	2001–2007	70 years	50/351	6
Kumar et al. (2017) [22]	India	Retrospective single-centre	2009–2015	65 years	67/794	8
Mangiatordi et al. (2018) [23]	Italy	Retrospective single-centre	2005–2018	70 years	85/533	9
Nakamon et al. (2013) [24]	Thailand	Retrospective single-centre	2007–2011	65 years	61/385	7
Okeke et al. (2012) [6]	Netherlands	Prospective multicentre (CROES Global PCNL study database)	2007–2009	70 years	334/2978	8
Onen et al. (2020) [25]	Turkey	Retrospective single-centre	2003–2017	65 years	317/3045	9
Sahan et al. (2021) [26]	Turkey	Retrospective single-centre	2012–2017	65 years	43/139	6
Tok et al. (2009) [27]	Turkey	Retrospective single-centre	2002–2007	65 years	64/647	7
Torricelli et al. (2018) [7]	Brazil	Retrospective single-centre	2009–2015	70 years	18/36	7

NOS Newcastle–Ottawa Scale, *PCNL* percutaneous nephrolithotomy

across included studies (Supplementary Table 3). The prone position and fluoroscopic guidance were predominantly utilised, with sheath diameters most commonly being 30 Fr. In one study that included both prone and supine PCNL, elderly patients more often underwent prone procedures (80% vs 70%) [6]. Pneumatic and/or ultrasonic lithotripsy devices were the most commonly reported. General anaesthesia was the predominant anaesthetic modality. In studies that provided specific rates for both general and regional anaesthesia, no statistically significant differences in the distribution of anaesthesia type were identified between elderly and non-elderly patients [23, 25]. Likewise, in the study including both mini- and standard-PCNL, the proportion of mini-PCNL cases was comparable between age groups [23].

Meta-analysis

Dichotomous outcomes

Summary forest plots for all binary outcomes are shown in Fig. 2. Individual forest plots for all dichotomous outcomes are presented in Supplementary Fig. 1, while the detailed results of the meta-analyses are summarized in Supplementary Table 4.

Overall complication rates did not differ significantly between elderly and non-elderly groups (40.9% vs 24.5%; OR 1.20, 95% CI 0.95–1.53; $p=0.133$). Minor complications occurred at comparable frequencies (15.0% vs 16.9%; OR 1.08, 95% CI 0.94–1.23; $p=0.295$), as did major complications (5.2% vs 4.4%; OR 1.39, 95% CI 0.92–2.10; $p=0.122$). No significant differences between elderly and non-elderly groups were observed across individual Clavien–Dindo grades.

Postoperative fever occurred at similar rates in both groups (6.2% vs 6.0%; OR 1.07, 95% CI 0.76–1.51; $p=0.681$), whereas sepsis was more frequent among elderly patients (0.6% vs 0.3%; OR 3.94, 95% CI 1.83–8.47; $p<0.001$). Rates of blood transfusion, embolization, and auxiliary procedures did not differ significantly, while readmissions were more common in elderly (14.2% vs 11.7%; OR 1.27, 95% CI 1.17–1.37; $p<0.001$).

No significant differences were observed in immediate SFR, whether defined as complete clearance or presence of residual fragments < 4 mm (80.6% vs 80.1%; OR 1.01, 95% CI 0.70–1.45; $p=0.963$). Final SFR likewise did not differ significantly, irrespective of the definition used (no residual stones: 81.6% vs 80.2%, OR 1.19, 95% CI 0.68–2.08; $p=0.536$; no residual stones or residual fragments < 4 mm: 88.1% vs 88.9%, OR 1.12, 95% CI 0.85–1.47; $p=0.421$).

Visual inspection of funnel plots did not reveal evidence of relevant publication bias for most binary outcomes (Supplementary Fig. 2). An exception was observed for final SFR defined as the absence of any residual stones, where asymmetry of the funnel plot suggested the possibility of publication bias, likely related to heterogeneity in methods used to assess stone-free status For all remaining endpoints,

Table 2 Baseline demographic and clinical characteristics of elderly and non-elderly patients across the included studies

Study (year) [ref]	Age groups	No. of patients	Age, years, mean (SD)	Gender, female, n (%)	ASA grade ≥ III, n (%)	Hypertension, n (%)	Diabetes, n (%)	CKD, n (%)	Positive preoperative urine culture, n (%)	Preoperative hydronephrosis, n (%)	Stone diameter (mm), mean (SD)	Stone burden (mm^2), mean (SD)	Multiple stones, n (%)	Staghorn stone, n (%)
Abedali et al. (2019) [15]	Non-elderly	1022	46 (18)*	550 (54)	NR	353 (35)	169 (17)	21 (2)	NR	NR	26 (22)	NR	NR	NR
	Elderly	625	NA	296 (47.4)	NR	338 (54.1)	170 (27.2)	14 (2.2)	NR	NR	NA	NR	NR	NR
Anagnostou et al. (2008) [16]	Non-elderly	531 (644 RU)	50.1	244 (45.9)	NR	NR	NR	NR	NR	NR	NR	62.7 mm^3 (25–2400)**	307 (46.2)	105 (16.3)
	Elderly	126 (135 RU)	74.7	54 (42.9)	NR	NR	NR	NR	NR	NR	NR	56.7 mm^3 (2–1500)**	52 (38.5)	21 (15.6)
Buldu et al. (2015) [5]	Non-elderly	395	49.7 (13.6)	126 (31.9)	60 (15.2)	NR	NR	NR	NR	NR	30.1 (15.5)	NR	214 (54.2)	NR
	Elderly	125	67.3 (6.8)	55 (44)	42 (33.6)	NR	NR	NR	NR	NR	31.5 (15.4)	NR	58 (46.4)	NR
Falahatkar et al. (2023) [17]	Non-elderly	656	47.1	291 (44.4)	NR	NR	NR	NR	NR	NR	35 (14)	NR	434 (70.2)	74 (11.9)
	Elderly	83	69.9	43 (51.8)	NR	NR	NR	NR	NR	NR	35 (14)	NR	56 (74.7)	12 (16.2)
Gupta et al. (2020) [18]	Non-elderly	50	38.7 (11)	10 (20)	4 (8)	15 (30)	3 (6)	2 (4)	0 (0)	NR	21 (6.7)	NR	NR	0 (0)
	Elderly	50	66.8 (2.1)	21 (42)	12 (24)	21 (42)	11 (22)	2 (4)	0 (0)	NR	22 (5.8)	NR	NR	0 (0)
Haberal et al. (2021) [9]	Non-elderly	7352	NR	2632 (35.8)	125 (1.7)	NR	NR	NR	NR	NR	NR	400[a]	3948 (53.7)	853 (11.6)
	Elderly	839	NR	373 (44.5)	60 (7.2)	NR	NR	NR	NR	NR	NR	400[a]	433 (51.6)	128 (15.3)
Iqbal et al. (2020) [19]	Non-elderly	594	39.7 (11.2)	171 (28.8)	2 (0.3)	NR	NR	NR	0 (0)	NR	28.3 (13.2)	NR	NR	NR
	Elderly	137	65.7 (4.6)	37 (27)	5 (3.7)	NR	NR	NR	0 (0)	NR	28.1 (10.4)	NR	NR	NR
Johnston et al. (2019) [20]	Non-elderly	15,351	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Elderly	7721	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Jou et al. (2009) [21]	Non-elderly	351	52.2 (11.7)	NR	NR	NR	NR	NR	NR	NR	35	NR	NR	NR
	Elderly	50	76.1 (4.2)	NR	NR	17 (34)	7 (14)	3 (6)	NR	NR	36	NR	NR	NR
Kumar et al. (2017) [22]	Non-elderly	794	40.9 (11.5)	NR	NR	NR	NR	NR	NR	NR	22.4 (7.6)	NR	NR	99 (12.5)
	Elderly	67	68.8 (4.9)	NR	NR	NR	NR	NR	NR	NR	22.7 (8)	NR	NR	15 (22.4)
Mangiatordi et al. (2018) [23]	Non-elderly	533	52.0 (41.5–59.8)*	300 (54.2)	47 (8.5)	NR	NR	NR	56 (10.10	NR	23 (18–30)*	NR	179 (32.4)	100 (18.1)
	Elderly	85	74.4 (72–77.9)*	42 (49.4)	18 (21.2)	NR	NR	NR	12 (13.6)	NR	25 (18–30)*	NR	26 (30.6)	14 (16.5)
Nakamon et al. (2013) [24]	Non-elderly	385	51.4 (8.8)	144 (37.4)	17 (4.4)	43 (11.2)	17 (4.4)	12 (3.1)	115 (29.9)	326 (84.7)	39.4 (1.8)	NR	NR	123 (32.2)
	Elderly	61	70.7 (4.8)	26 (42.6)	7 (11.5)	20 (32.8)	4 (6.6)	3 (4.9)	24 (39.3)	50 (81.9)	40.9 (16)	NR	NR	24 (39.3)
Okeke et al. (2012) [6]	Non-elderly	2976	47.8 (12.3)	1286 (43.2)	217 (7.3)	NR	348 (11.7)	NR	NR	NR	NR	422.8 (377.2)	2241 (75.3)	649 (21.8)

Table 2 (continued)

Study (year) [ref]	Age groups	No. of patients	Age, years, mean (SD)	Gender, female, n (%)	ASA grade ≥ III, n (%)	Hypertension, n (%)	Diabetes, n (%)	CKD, n (%)	Positive preoperative urine culture, n (%)	Preoperative hydronephrosis, n (%)	Stone diameter (mm), mean (SD)	Stone burden (mm^2), mean (SD)	Multiple stones, n (%)	Staghorn stone, n (%)
	Elderly	334	74.7 (4.3)	156 (47.3)	114 (34.2)	NR	79 (23.7)	NR	NR	NR	NR	465 (394.8)	248 (74.3)	93 (27.8)
Onen et al. (2020) [25]	Non-elderly	3045	47 (37–55)*	1145 (37.6)	153 (5)	NR	NR	NR	NR	2233 (73.3)	NR	417 (225–780)*	1568 (51.5)	340 (11.2)
	Elderly	317	69 (66–72)*	133 (42)	32 (10)	NR	NR	NR	NR	234 (73.8)	NR	412 (245.5–700)*	143 (45.1)	41 (12.9)
Sahan et al. (2021) [26]	Non-elderly	139	43.9 (10.6)	42 (30.2)	NR	NR	NR	NR	0 (0)	NR	NR	899 (292)	NA	139 (100)
	Elderly	43	67.8 (2.1)	15 (34.9)	NR	NR	NR	NR	0 (0)	NR	NR	1008 (208)	NA	43 (100)
Tok et al. (2009) [27]	Non-elderly	647	40.9 (12.7)	267	NR	NR	NR	NR	NR	620 (95.8)	8.3 (5.5)	NR	NR	NR
	Elderly	64	70.4 (4)	33	NR	NR	NR	NR	NR	63 (98.4)	10.1 (6.5)	NR	NR	NR
Torricelli et al. (2018) [7]	Non-elderly	36	44.5 (11.8)	10 (27.8)	1 (2.6)	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Elderly	18	73.9 (3.6)	9 (50)	5 (27.8)	NR	NR	NR	NR	NR	NR	NR	NR	NR

NA not applicable, *NR* not reported, *RU* renal units, *SD* standard deviation

*Median (interquartile range)

**Mean (range)

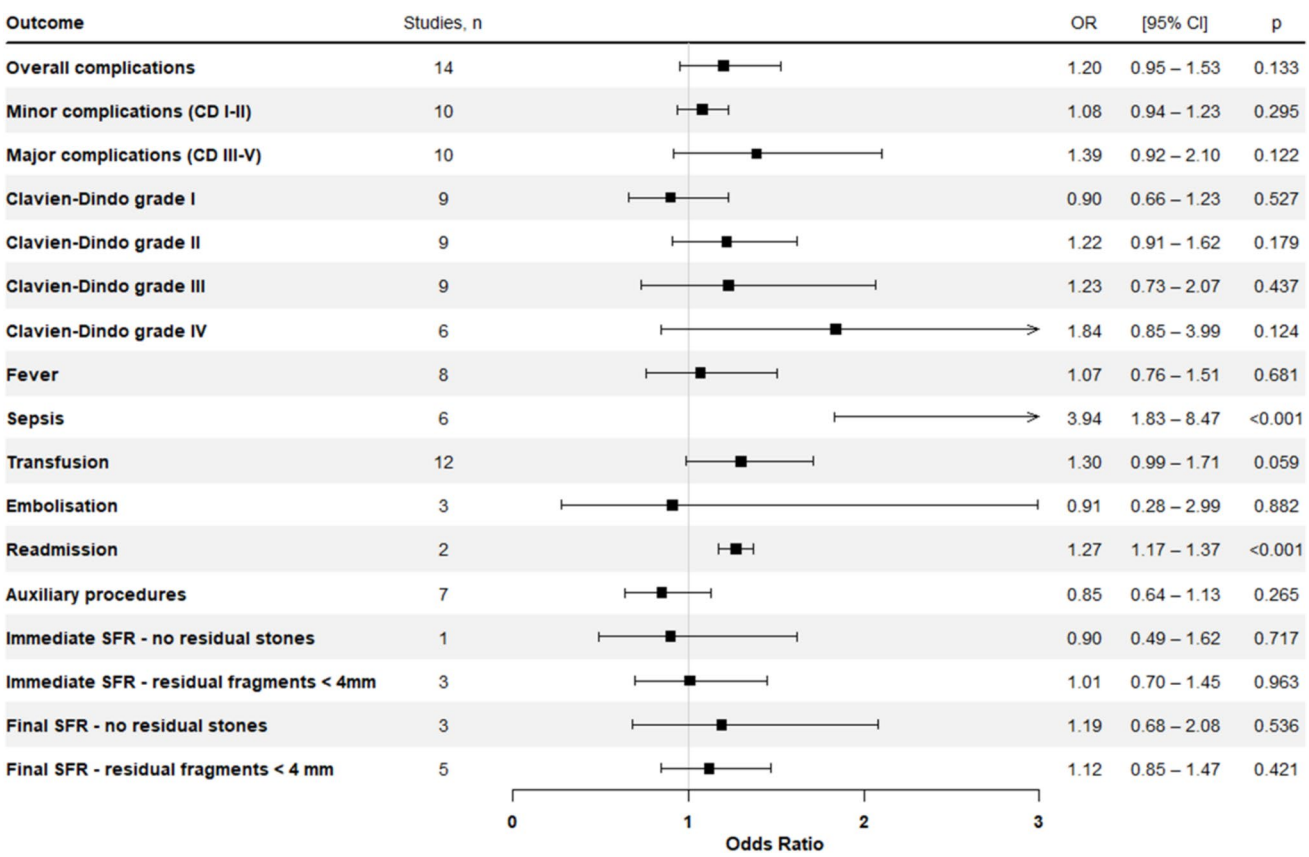


Fig. 2 Forest plot for overall comparative analysis of dichotomous outcomes. Odds ratios (ORs) with 95% confidence intervals (CIs) are shown. The non-elderly group served as the reference category for all comparisons. CD = Clavien-Dindo. SFR = Stone-free rate

the funnel plots appeared largely symmetrical, indicating a low risk of small-study effects.

Continuous outcomes

OT was statistically longer in elderly group, with a pooled MD of 2 min (95% CI 0.6–3.4; $p<0.01$) (Supplementary Fig. 3A). Despite statistical significance, the magnitude of the difference was minimal and unlikely to have clinical implications. The LOS was statistically longer in elderly patients, with a pooled MD of 0.4 days (95% CI 0.2–0.5; $p<0.01$) (Supplementary Fig. 3B). However, the absolute difference was small and corresponds to less than half a day of hospitalization, which is unlikely to be clinically relevant. Visual inspection of funnel plots did not suggest relevant publication bias for OT or LOS, with largely symmetrical distributions observed for both outcomes (Supplementary Fig. 4).

Subgroup analysis and meta-regression

In the subgroup analysis stratified by age (Fig. 3, Supplementary Fig. 5), overall complication rates did not differ significantly between elderly and younger patients in the 60-year and 65-year cut-off subgroups. In contrast, in studies using a 70-year cut-off, elderly patients demonstrated a significantly higher risk of overall complications (OR 1.26, 95% CI 1.03–1.55; $p=0.028$). For minor complications (Clavien–Dindo I–II), no significant differences were observed across any age subgroup, with comparable complication rates between elderly and non-elderly patients regardless of the age threshold applied. Regarding major complications (Clavien–Dindo III–V), no significant differences were identified in the 60-year and 65-year subgroups. However, in the 70-year subgroup, elderly patients had a significantly increased risk of major complications compared with younger patients (OR 1.95, 95% CI 1.15–3.31; $p=0.013$). Separate analyses for other additional age cut-offs (e.g., 75, 80, or 90 years) were not performed because of the limited availability of data, with too few studies and insufficient sample sizes.

In univariable meta-regression (Supplementary Material 1), increasing mean age within the elderly population was significantly associated with a higher risk of major complications ($p=0.039$), but not with minor complications, and showed only a borderline association with overall complications ($p=0.081$). Sample size significantly moderated effect estimates for overall complications ($p=0.047$), while

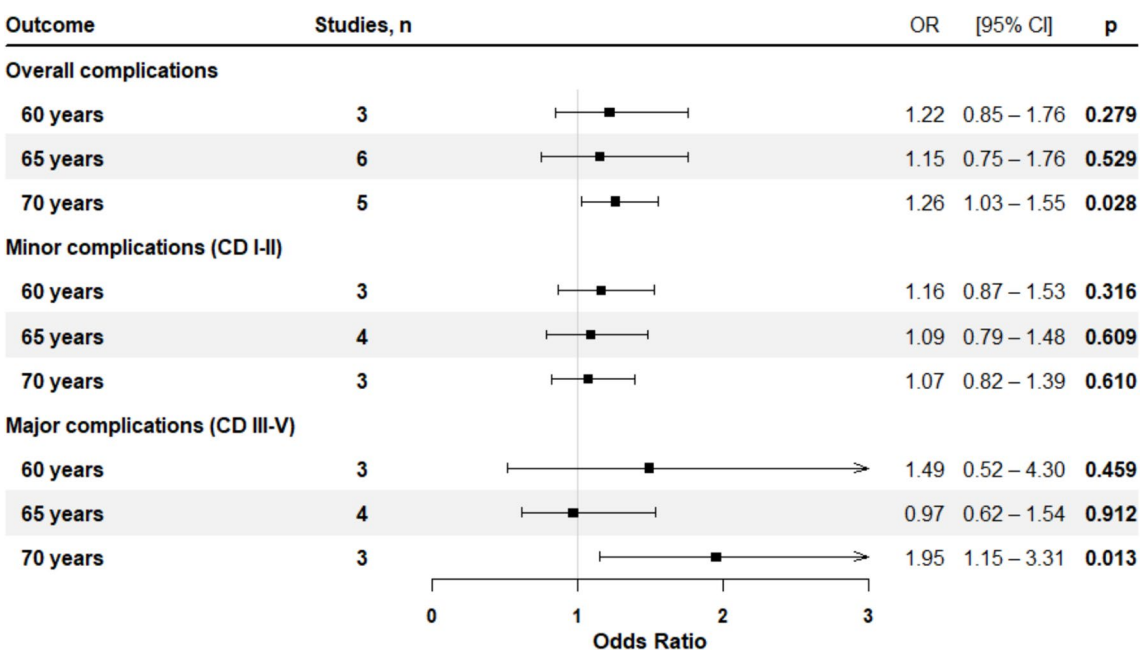


Fig. 3 Forest plot of age-stratified subgroup analyses for complications following percutaneous nephrolithotomy in elderly versus non-elderly patients. Odds ratios (ORs) with 95% confidence intervals (CIs) are presented for subgroups defined by different age cut-offs (60, 65, and 70 years). The non-elderly group served as the reference category for all comparisons

publication year was not associated with any outcome. In multivariable meta-regression (Supplementary Material 1), increasing age among elderly patients remained an independent predictor of major complications ($p = 0.014$), whereas no independent associations were observed for overall or minor complications, and neither sample size nor publication year influenced the pooled estimates.

Discussion

In this systematic review and meta-analysis, we assessed the safety and efficacy of PCNL in elderly patients compared with younger cohorts. Rates of overall, minor, and major complications were similar between elderly and non-elderly groups when data from studies reporting various elderly definitions were pooled together. In the aggregated analysis across all age cut-offs, elderly patients demonstrated an increased risk of selected adverse postoperative outcomes, including sepsis and hospital readmission. Our meta-analysis also demonstrated a trend toward an increased risk of post-procedural blood transfusions in elderly patients; however, this association did not reach statistical significance. Overall, PCNL achieved comparable stone-free rates in elderly and non-elderly patients, irrespective of the timing and definition of SFR assessment.

Notably, subgroup analyses revealed that the risk of complications was not uniform across elderly age definitions, with studies applying higher age thresholds (70 years) showing a more pronounced increase in both overall and major complications. Consistently, meta-regression analyses indicated that increasing age within the elderly population was independently associated with a higher risk of major complications, whereas no such association was observed for minor complications. Taken together, these findings suggest that PCNL can be performed safely in elderly patients, but also indicate that procedural risk increases progressively with advancing age among elderly individuals, rather than abruptly at a single chronological cut-off.

The main results of the present systematic review and meta-analysis are mostly consistent with those reported by Haider et al., who demonstrated comparable SFR and perioperative outcomes between elderly and younger patients undergoing PCNL [8]. In addition, we analysed clinically relevant outcomes not addressed in previous meta-analysis, including postoperative sepsis and hospital readmission, further refining the assessment of procedural risk in elderly patients. Importantly, our study extends previous evidence by including a substantially larger and more contemporary patient population and by applying a more refined age-based analytical approach. We incorporated stratified subgroup analyses using different age cut-offs and performed meta-regression to evaluate the continuous effect of age on outcomes. This approach demonstrated that while pooled results across all age definitions were largely comparable, the risk of overall and major complications increased progressively with higher age thresholds and advancing age within the elderly population.

An important consideration when interpreting outcomes in elderly patients undergoing PCNL is the consistently higher burden of comorbidities observed across elderly cohorts in general, irrespective of the specific age cut-off used to define this population. Across the included studies, elderly patients were more frequently characterized by a higher perioperative risk profile compared with younger cohorts, as reflected by higher ASA physical status scores. This pattern was evident not only in studies focusing on septuagenarians but also in broader elderly populations, and was particularly pronounced in cohorts including patients aged≥70 years [6, 7, 23]. Such baseline differences introduce an inherent possible source of confounding and suggest that treatment outcomes should be assessed in the context of the overall burden of comorbidity and perioperative risk, rather than on the basis of age alone. Several studies have demonstrated that this increased comorbidity burden has direct clinical implications for postoperative outcomes following PCNL. In a large contemporary cohort, Danilovic et al. showed that higher ASA score and Charlson Comorbidity Index were independent predictors of postoperative complications in elderly patients undergoing PCNL, underscoring the role of baseline health status in determining surgical risk [28]. Similarly, Resorlu et al. identified comorbidity burden as a key determinant of postoperative morbidity in elderly PCNL patients [29]. Taken together, these observations may partly explain the increased risk of certain postoperative complications, including sepsis, observed in our pooled analysis. Nevertheless, this finding should be interpreted with caution, as postoperative sepsis remained a rare event in absolute terms, with very low rates in both groups (0.6% vs 0.3%). Thus, although the pooled analysis indicates a higher relative susceptibility to sepsis among elderly patients, the absolute increase in risk appears small and may be of limited clinical relevance.

Within this context, the decision to pursue active stone treatment in elderly patients should be guided by symptom burden, infection risk, and physiological reserve rather than age per se. Studies evaluating active stone management in very elderly populations, including even octogenarians and nonagenarians, have shown that a substantial proportion of patients remain suitable candidates for definitive stone treatment, with acceptable perioperative outcomes when appropriately selected. Notably, Eredics et al. and Mager et al. reported that active intervention was frequently performed even in patients aged≥80 years, and that outcomes were largely driven by comorbidity burden and clinical indication rather than chronological age, supporting a selective but proactive treatment strategy in fit elderly patients [4, 30].

While our pooled analysis indicated a higher risk of readmission in elderly patients, this result should be interpreted cautiously, as this outcome was available from only two studies, albeit including a relatively large overall number of patients. In the study by Johnston et al., which contributed most of the weight to this outcome, readmission was defined broadly and encompassed a wide range of genitourinary-related diagnoses, making it difficult to determine a single predominant cause of rehospitalization [20]. In addition, the administrative nature of that dataset limited adjustment for several potentially important confounders, including differences in follow-up intensity, discharge pathways, and other post-discharge factors. Importantly, the effect of age was attenuated after accounting for comorbidity burden, suggesting that the observed increase in readmission may be driven by the overall health status and vulnerability of elderly patients. This interpretation is supported by broader urological literature indicating that frailty and comorbidity burden are major determinants of readmission risk in older surgical patients [31].

Although larger tract sizes (standard PCNL) were predominantly used in the studies included in the present meta-analysis and are still widely employed in routine practice across many centres worldwide, contemporary PCNL practice shows a clear trend toward progressive miniaturization of the instrumentation and increasing use of smaller access sheaths. Available evidence suggests that smaller tracts (e.g., mini-PCNL) may achieve comparable SFR while potentially reducing selected morbidity parameters, such as bleeding-related outcomes and length of hospital stay, albeit at the expense of longer operative time [32]. On the other hand, a recent multicentre randomized trial by Sheetz et al. comparing mini-PCNL (17.5 Fr) with standard PCNL (30 Fr) for 10–25 mm renal stones did not demonstrate significant differences in SFR or intraoperative and postoperative adverse events, suggesting that tract size selection should be individualized according to patient characteristics, institutional resources, and surgical practice [33]. Importantly, data directly comparing tract sizes specifically in elderly patients remain lacking. Given the potentially greater vulnerability of this population, including a possibly higher susceptibility to renal parenchymal injury, this issue warrants further evaluation in future prospective and randomized studies.

In the context of the increased comorbidity burden and heightened susceptibility to overall and major complications observed in patients≥70 years, the choice of stone treatment modality warrants particular attention. Comparative studies evaluating RIRS and PCNL in geriatric cohorts indicate a trade-off between procedural invasiveness and stone clearance rather than a clear superiority of one technique. While PCNL provides higher single-session stone-free rates, RIRS has consistently been associated with lower blood loss and shorter hospitalization, with comparable final SFR after staged procedures in selected patients with

moderate stone burden and non-staghorn calculi, as demonstrated in elderly-specific comparisons by Yarimoglu et al. and Zeng et al. [34, 35]. These data support RIRS as a reasonable alternative in elderly patients with increased anaesthetic risk or limited tolerance for prone positioning and percutaneous renal access. Alongside these comparative outcomes, recent technological developments in RIRS may further influence treatment selection. Advances such as flexible and navigable suction ureteral access sheaths have been associated with reduced haemoglobin drop, shorter hospitalization, and stone-free rates comparable to PCNL for medium-sized renal stones in adult populations, as reported by Degirmentepe et al. [36]. Although these findings suggest that suction-assisted RIRS may offer a more favourable perioperative safety profile, potentially relevant for patients with limited physiological reserve, robust evidence specifically addressing its safety and effectiveness in geriatric populations remains lacking. Further prospective studies focusing on elderly patients are therefore required to determine whether these evolving RIRS technologies can meaningfully reduce infectious and overall complication rates while maintaining adequate stone-free outcomes.

Moreover, owing to its minimally invasive nature, extracorporeal shock wave lithotripsy (ESWL) remains a considerable therapeutic option in elderly patients, especially for frail individuals and those at high anaesthetic risk [37, 38]. Literature data indicate that, after appropriate case selection, satisfactory SFR (even up to 70–80%) may be achieved with a high safety profile [37–39]. Nevertheless, ESWL is frequently a multistep strategy requiring repeated sessions, and its risk profile should not be underestimated, particularly in patients with bleeding disorders or receiving antithrombotic therapy, in whom the risk of haemorrhagic complications is increased. For this reason, ESWL should be considered as part of an individualized treatment strategy, including as an adjunctive modality for the management of residual stone burden.

Our systematic review and meta-analysis has several important strengths. To our knowledge, this is the largest and most comprehensive meta-analysis focusing on PCNL outcomes in elderly patients, incorporating a substantially larger and more contemporary patient population than previously published analysis. In addition, we applied age-stratified subgroup analyses using different elderly cut-offs and performed meta-regression, allowing for a more nuanced assessment of the effect of advancing age within the elderly population rather than treating age as a purely dichotomous variable. Finally, the inclusion of studies from multiple geographic regions enhances the generalizability of our findings across different healthcare settings and practice patterns. Notwithstanding these strengths, several limitations should be acknowledged. First, the majority of included studies were retrospective, which inherently introduces a risk of selection bias and residual confounding, particularly in relation to baseline differences in comorbidity burden, frailty, and possible surgeon selection bias. Second, despite the large overall sample size, the availability of variable procedural data was limited, precluding more detailed subgroup analyses based on technical aspects such as patient positioning (prone vs supine PCNL), sheath diameter (mini vs standard PCNL), number of access tracts, or other specific perioperative strategies. Third, heterogeneity across the included studies in the definition of SFR, timing of SFR assessment, and imaging modalities used may have influenced the pooled SFR outcomes. Fourth, several outcomes of interest were reported only by a limited number of studies, which may reduce the robustness of pooled estimates for these endpoints and warrants cautious interpretation. Fifth, in few studies, continuous data reported as median with IQR/range were converted to mean ± SD for quantitative synthesis, which may have introduced some level of approximation error. Finally, the definition of certain outcomes, including postoperative sepsis, was not clearly specified in some included studies, which may have limited interstudy comparability.

Conclusions

PCNL can be performed safely in elderly patients, with SFR and complication profiles comparable to those observed in younger individuals when data across different elderly definitions are pooled. However, overall and major complications increases progressively with advancing age within the elderly population, especially among patients aged ≥ 70 years. Future prospective studies focusing specifically on geriatric populations are warranted to refine risk stratification and to evaluate the role of evolving minimally invasive technologies in improving safety outcomes.

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Declarations

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References

1. Kittanamongkolchai W, Vaughan LE, Enders FT, Dhondup T, Mehta RA, Krambeck AE, McCollough CH, Vrtiska TJ, Lieske JC, Rule AD (2018) The changing incidence and presentation of urinary stones over 3 decades. Mayo Clin Proc 93(3):291–299
2. Qian X, Wan J, Xu J, Liu C, Zhong M, Zhang J, Zhang Y, Wang S (2022) Epidemiological trends of urolithiasis at the global, regional, and national levels: a population-based study. Int J Clin Pract 2022:6807203
3. Zhu C, Wang DQ, Zi H, Huang Q, Gu JM, Li LY, Guo XP, Li F, Fang C, Li XD, Zeng XT (2021) Epidemiological trends of urinary tract infections, urolithiasis and benign prostatic hyperplasia in 203 countries and territories from 1990 to 2019. Mil Med Res 8(1):64
4. Eredics K, Drerup M, Ozsoy M, Wehrberger C, Lenz M, Ramesmayer C, Stolzlechner P, Zanier J, Falkensammer CE, Handjiev I, Wasserscheid A, Seklehner S (2023) Active stone removal is a safe option for ocotogenarians and nonagenarians with nephrolithiasis. World J Urol 41(3):849–856
5. Ibrahım B, Tepeler A, Karatag T, Bodakci MN, Hatipoglu NK, Penbegul N, Akman T, Istanbulluoglu O, Armagan A (2015) Does aging affect the outcome of percutaneous nephrolithotomy? Urolithiasis 43(2):183–187
6. Okeke Z, Smith AD, Labate G, D'Addessi A, Venkatesh R, Assimos D, Strijbos WEM, La Rosette D (2012) Prospective comparison of outcomes of percutaneous nephrolithotomy in elderly patients versus younger patients. J Endourol 26(8):996–1001
7. Torricelli FC, Miranda GKM, Ogawa FC, Vicentini GS, Marchini AD, Srougi M, Nahas WC, Mazzucchi E (2018) Supine percutaneous nephrolitotripsy in septuagenarian and octogenarian patients: outcomes of a case-control study. Can J Urol 25(2):9245–9249
8. Haider R, Regnier P, Roustan FR, Severac F, Treacy PJ, Mendel L, Bodokh Y, Tibi B, Prader R, Traxer O, Chevallier D, Amiel J, Durand M (2017) Percutaneous nephrolithotomy for kidney stones in elderly patients: meta-analysis of results and complications. Prog Urol 27(2):58–67
9. Haberal HB, Gudeloglu A, Deger M, Gulsen M, Izol V, Bostanci Y, Aridogan IA, Ozden E, Bilen CY (2021) Percutaneous nephrolithotomy in young-old, old-old, and oldest-old patients: a multicenter study. J Laparoendos Adv Surg Tech 31(7):796–802
10. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hrobjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D (2021) The Prisma 2020 statement: an updated guideline for reporting systematic reviews. Int J Surg 88:105906
11. Shenkin SD, Harrison JK, Wilkinson T, Dodds RM, Ioannidis JPA (2017) Systematic reviews: guidance relevant for studies of older people. Age Ageing 46(5):722–728
12. Stang A (2010) Critical evaluation of the Newcastle-Ottawa Scale for the assessment of the quality of nonrandomized studies in meta-analyses. Eur J Epidemiol 25(9):603–605
13. Lo CK, Mertz D, Loeb M (2014) Newcastle-Ottawa Scale: comparing reviewers' to authors' assessments. BMC Med Res Methodol 14:45
14. Luo D, Wan X, Liu J, Tong T (2018) Optimally estimating the sample mean from the sample size, median, mid-range, and/or mid-quartile range. Stat Methods Med Res 27(6):1785–1805
15. Abedali ZA, Large T, Heiman JM, Bandali E, Anderson BB, Lingeman JE, Krambeck AE (2019) Percutaneous nephrolithotomy in the 80 years of age and older population. Urology 134:62–65
16. Anagnostou T, Thompson T, Ng CF, Moussa S, Smith G, Tolley DA (2008) Safety and outcome of percutaneous nephrolithotomy in the elderly: retrospective comparison to a younger patient group. J Endourol 22(9):2139–2145
17. Falahatkar S, Esmaeili S, Javid MR, Aali S, Eslami-Kenarsari H (2023) Outcomes of complete supine percutaneous nephrolithotomy: comparison of elderly and young patients. Urol Sci 34(4):194–198
18. Gupta R, Mahajan A (2020) Outcomes of percutaneous nephrolithotomy in elderly versus young patients under regional anesthesia: a comparative study. Urol Ann 12(3):254–258
19. Iqbal N, Iqbal S, Hasan A, Iqbal A, Blair KAA, Milstein DMJ, Akhter S (2022) Outcome of tubeless percutaneous nephrolithotomy in elder patients: a single-center experience from a developing country. J Clin Transl Res 8(2):160–165
20. Johnston AW, Jiang R, Alkazemi MH, Wolf S, Pomann GM, Lipkin ME, Scales CD, Routh JC (2019) Nationwide readmission rates following percutaneous nephrolithotomy: does age matter? J Endourol 33(9):704–711

21. Jou YC, Te Lin C, Shen CH, Cheng MC, Chen PC (2009) Tubeless percutaneous nephrolithotomy for geriatric patients. Urol Int 82(3):346–349
22. Kumar S, Keshavamurthy R, Karthikeyan VS, Mallya A (2017) Complications after prone pcnl in pediatric, adult and geriatric patients—a single center experience over 7 years. Int Braz J Urol 43(4):704–712
23. Mangiatordi A, Auciello M, Stallone G, Saita A, Hoznek A, Cormio L (2018) Is percutaneous nephrolithotomy effective and safe in elderly patients? outcomes of a case-control study. J Gerontol Geriatr 2018(4):173–177
24. Nakamon T, Kitirattrakarn P, Lojanapiwat B (2013) Outcomes of percutaneous nephrolithotomy: comparison of elderly and younger patients. Int Braz J Urol 39(5):692–701
25. Önen E, Çağlayan V (2020) Comparison of percutaneous nephrolithotomy outcomes in the elderly and young population. J Urol Surg 7(4):263–270
26. Sahan, Murat, Serkan Yarımoğlu, Metin Savun, Onur Erdemoglu, and Tansu Degirmenci 2021 "The Influence of Aging on Outcomes in Patients Undergoing Percutaneous Nephrolithotomy for Complete Staghorn Stones: A Retrospective Comparative Study." Cureus 13, 11
27. Tok A, Ozturk S, Tepeler A, Tefekli AH, Kazancioglu R, Muslumanoglu AY (2009) The effects of percutaneous nephrolithotomy on renal function in geriatric patients in the early postoperative period. Int Urol Nephrol 41(1):219–223
28. Danilovic A, Perrone G, Dias L, Marchini G, Torricelli F, Batagello C, Vicentini F, Nahas WC, Mazzucchi E (2024) Is it worth using the comprehensive complication index over the Clavien-Dindo classification in elderly patients who underwent percutaneous nephrolithotomy? World J Urol 42(1):599
29. Resorlu B, Diri A, Atmaca AF, Tuygun C, Oztuna D, Bozkurt OF, Unsal A (2012) Can we avoid percutaneous nephrolithotomy in high-risk elderly patients using the Charlson comorbidity index? Urology 79(5):1042–1047
30. Mager R, Brauers C, Kurosch M, Dotzauer R, Borgmann H, Haferkamp A (2022) Outcomes for geriatric urolithiasis patients aged >/=80 years compared to patients in their seventies. Eur Urol Focus 8(4):1103–1109
31. Suskind AM, Walter LC, Jin C, Boscardin J, Sen S, Cooperberg MR, Finlayson E (2016) Impact of frailty on complications in patients undergoing common urological procedures: a study from the American college of surgeons national surgical quality improvement database. BJU Int 117(5):836–842
32. Wan C, Wang D, Xiang J, Yang B, Xu J, Zhou G, Zhou Y, Zhao Y, Zhong J, Liu J (2022) Comparison of postoperative outcomes of mini percutaneous nephrolithotomy and standard percutaneous nephrolithotomy: a meta-analysis. Urolithiasis 50(5):523–533
33. Sheetz T, Finegan JL, Sivalingam S, Chew BH, Forbes CM, Paterson RF, Hsi RS, Miller NL, Knudsen BE, Sourial MW, Lee MS, Wong VKF, Bresee C, Wymer KM, Sur RL, Monga M, Bechis SK (2026) Clinical outcomes comparing mini versus standard Pcnl without postoperative nephrostomy tube: a multi-institutional randomized controlled trial from the Edge Consortium. Urology 209:32–38
34. Yarimoglu S, Sahan M, Polat S, Koras O, Erdemoglu O, Degirmenci T (2021) The comparison of perioperative outcomes between percutaneous nephrolithotomy and retrograde intrarenal surgery in elderly patients. Int J Clin Pract 75(7):e14221
35. Zeng W, Zhao Z, Li G, Yao X, Yuan F (2025) Clinical efficacy of flexible ureteroscopy with holmium laser lithotripsy for geriatric patients with complex upper urinary tract calculi. Medicine (Baltimore) 104(1):e41116
36. Degirmentepe RB, YM Akca, S Alp, HI Cimen, D Gul, M Erkoc, M Bozkurt, T Toprak, and F Halis. 2025 "Retrograde intrarenal surgery with flexible and navigable suction ureteral access sheaths vs. percutaneous nephrolithotomy for 2–3 cm kidney stones: is less invasive better?" Can Urol Assoc J
37. Philippou P, Lamrani D, Moraitis K, Wazait H, Masood J, Buchholz N (2011) Shock-wave lithotripsy in the elderly: safety, efficacy and special considerations. Arab J Urol 9(1):29–33
38. Lamacchia GB, Korkes F, Baccaglini W, de Mello LGM, Szwarc M, Tobias-Machado M (2019) A large series of extracorporeal shockwave lithotripsy in the very elderly. Ther Adv Urol 11:1756287219870412
39. Chen YZ, Lin WR, Lee CC, Sun FJ, Chow YC, Tsai WK, Chiang PK, Lin TP, Chen M, Chiu AW (2017) Comparison of safety and outcomes of shock wave lithotripsy between elderly and non-elderly patients. Clin Interv Aging 12:667–672

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