

Postoperative outcomes of kidney stone surgery in patients with spinal cord injury: a systematic review and meta-analysis

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Abstract

Spinal cord injury (SCI) is associated with an increased risk of nephrolithiasis. We performed a systematic review and meta-analysis to assess stone clearance and complication rates following surgical treatment of kidney stones in this population. We systematically reviewed the Ovid MEDLINE, Embase, CENTRAL, and Web of Science databases for studies examining outcomes of kidney stone procedures in SCI patients. Our primary outcomes were stone-free rate (SFR) and complications, as categorized by Clavien-Dindo classification. A meta-analysis of comparative studies was performed to assess differences in outcomes between SCI and non-SCI patients following PCNL. A total of 27 retrospective and observational articles were included. Interventions for kidney stones included PCNL, shockwave lithotripsy (SWL), and ureteroscopy. Pooled SFR in SCI patients undergoing surgery for kidney stones was 54.1%, for SWL, 73.6% for PCNL, and 36.2% for ureteroscopy. Four studies compared outcomes following PCNL in SCI and non-SCI patients. Meta-analysis found that there were higher rate of grades I (OR 9.54; 95% CI, 3.06-29.79), II (OR 3.38; 95% CI, 1.85-6.18), and III-V (OR 2.38; 95% CI, 1.35-4.19) complications in SCI patients compared to non-SCI patients following PCNL. The rate of infectious complications was also higher in patients with SCI (OR 6.15; 95% CI, 1.86-20.39). However, there was no difference in SFR (OR 0.64; 95% CI, 0.15-2.64) between groups. Patients with SCI are at higher risk of complications following PCNL compared to non-SCI patients. SFR after PCNL was equivalent between groups, suggesting that PCNL is an effective surgery for kidney stones in SCI patients.

Introduction

Spinal cord injury (SCI) is associated with an increased risk of nephrolithiasis [1]. Urologic factors contributing to this association include neurogenic bladder, vesicoureteric reflux, chronic urinary tract infections (UTI), and chronic catheterization [2]. Additionally, limb immobilization in paraplegic and quadriplegic patients is associated with increased bone resorption, which can lead to hypercalciuria and poor urinary drainage due to immobility [3]. Neurologic dysfunction can also dampen the sensation of renal colic, resulting in delayed detection of stones, larger calculi, and more complex disease [4].

Surgical treatment of kidney stones in patients with SCI can be more challenging compared to the general population due to difficulties in patient positioning secondary to limb contractures and spinal deformities, previous history of reconstructive urologic surgery, and the potential for higher anesthetic risks [5]. These factors may lead to suboptimal stone clearance and a greater risk of postoperative complications following surgical intervention in SCI patients.

To investigate the complex nature of stone treatment in this high-risk patient population, we conducted a systematic review and meta-analysis examining the outcomes of shockwave lithotripsy (SWL), ureteroscopy, and percutaneous nephrolithotomy (PCNL) in patients with SCI. We also performed a meta-analysis of comparative studies to compare outcomes of PCNL in SCI and non-SCI patients with kidney stone disease.

Materials And Methods

This review was conducted in accordance with the Cochrane Handbook for Systematic Reviews of Intervention and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, and was prospectively registered on PROSPERO (CRD42021224264) [6, 7].

Search Strategy

A comprehensive literature search of medical databases was conducted for studies assessing the outcomes of SWL, ureteroscopy, and PCNL in patients with SCI. The search strategy was developed in consultation with a medical librarian (Supplemental Fig. S1). The literature search was conducted on December 6, 2020 and databases searched included Ovid MEDLINE, Embase, CENTRAL, and Web of Science. All duplicates were removed and references of included articles were reviewed to identify any published or unpublished studies that may have been missed in the initial literature search.

Eligibility Criteria

The inclusion and exclusion criteria were developed *a priori*. Studies were eligible for inclusion if: (1) they examined outcomes of patients with SCI undergoing SWL, ureteroscopy, or PCNL; (2) included primarily adult patients (age \geq 18 years) with SCI and nephrolithiasis; and (3) reported on postoperative complications or stone-free rate (SFR) as determined by postoperative imaging.

Exclusion criteria included: (1) case reports, expert and narrative reviews, and editorials; (2) studies focusing primarily on pediatric (age < 18 years) patients; (3) basic science and non-human studies; (4) studies that did not include surgical intervention; (5) studies focusing on bladder stones; (6) studies not reporting on our outcomes of interest; and (7) non-English studies.

Screening

Studies identified via the search strategy were independently screened by two reviewers (J.K. and V.S.) utilizing Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia). Conflicts were resolved by a third reviewer (G.T.).

Data Extraction

Two reviewers (J.K. and V.S.) independently extracted data in duplicate in an electronic database, Microsoft Excel 365 (Microsoft, Redmond, Washington). Extracted data included: study characteristics (publication year, study location, design, and period), baseline patient demographics (mean age, percentage of male patients, SCI etiology, bladder management, and rates of preoperative bacteriuria), kidney stone characteristics (number of stones, location, stone composition, laterality, and size), and operative outcomes (number of procedures, number of renal units treated, SFR, and complication rate).

Primary outcomes included pooled SFR and complications; these outcomes were calculated as a proportion per procedure. If the number of procedures was not reported, the assumption was made that the procedures were performed on the reported number of patients or renal units in a 1:1 ratio. Complications

were categorized from grades I to V based on the Clavien-Dindo classification system [8]. For the purposes of this review, Clavien-Dindo grades I and II were categorized as minor complications while grades III-V were categorized as major complications.

The level of agreement between reviewers was calculated at the full text review stage using Cohen's Kappa (κ) with corresponding 95% confidence intervals (CI). Agreement was categorized as $\kappa = 0.81-1.00$ being almost perfect agreement, $\kappa = 0.61-0.80$ being strong agreement, $\kappa = 0.41-0.60$ being moderate agreement, $\kappa = 0.21-0.40$ being slight agreement, and $\kappa \leq 0.20$ being no agreement.

Statistical Analysis

Extracted study data were summarized using descriptive statistics and analyzed using RevMan (Review Manager v5.4, The Cochrane Collaboration, London, United Kingdom) and IBM SPSS Statistics v28.0 (Armonk, United States: IBM Corp.). The normality of continuous variables was tested with the Shapiro-Wilks test; normally distributed data were presented as mean \pm standard deviations, while data within non-normal distributions were presented as a median with interquartile range (IQR). When applicable, dichotomous outcomes were pooled and presented as a proportion. Missing data were excluded from analysis. A p-value of <0.05 was considered statistically significant.

Meta-analysis was carried out on dichotomous variables using the DerSimonian and Laird inverse variance random effects model and resulting odds ratios (OR) were presented with 95% CI. Heterogeneity was assessed using a χ^2 test with N-1 degrees of freedom, with $\alpha = 0.05$ for statistical significance. I^2 test, was used to evaluate variability across studies, with an I^2 value $> 50\%$ indicating high heterogeneity. Variables were pooled using a random effects model. For included studies with a disproportionate number of patients, a sensitivity analysis was performed by excluding such studies from analysis.

Risk of bias for individual studies was assessed using the Methodological Index for Non-Randomized Studies (MINORS) tool [9]. The maximum MINORS score is 16 for non-comparative studies and 24 for comparative studies, with higher scores indicating lower risk of bias. For this review, a study's risk of bias was categorized as high (MINORS score of 0-8 for non-comparative studies and 0-12 for comparative studies), moderate (score of 9-12 for non-comparative studies and 13-18 for comparative studies), or low (score of 13-16 for non-comparative studies and 19-24 for comparative studies).

Results

Study Identification

The initial database search retrieved 4343 articles. After removal of duplicates, abstract review, full text review, and application of inclusion and exclusion criteria, a total of 27 studies, published between 1986 and 2020, were identified. Screening resulted in a total of 26 studies for analysis [10–35]; one additional article from Donnellan et al. (1994) [36] was included after being identified through hand searching the references of included studies. Fig. 1 summarizes the search in a PRISMA flow diagram. The κ was 0.78 (95% CI, 0.70-0.86), indicating strong interrater agreement.

Study Characteristics

Study characteristics, study demographics and urologic history of included patients are summarized in Table 1. Among the 27 included papers, 10 studies included patients undergoing SWL [11–13, 15–19, 27, 36], 17 studies included PCNL [10, 14, 15, 19–25, 27, 28, 30–32, 35, 36], and seven studies included ureteroscopy [19, 26, 27, 29, 33, 34, 36]. Four studies included multiple treatment modalities [15, 19, 27, 36]. The included articles consisted of four studies comparing PCNL between SCI and non-SCI patients [14, 28, 31, 35], and 23 non-comparative studies examining all three interventions [10–13, 15–27, 29, 30, 32–34, 36]. All studies incorporated non-randomized observational designs and were reported retrospectively. Patient data extracted from included studies were from 1986-2018. The mean MINORS scores were 9.4 (± 1.2) for non-comparative studies and 18 (± 1.6) for comparative studies, indicating moderate risk of bias for both study types (Supplemental Table S1).

Population Demographics

The pooled population included 4 829 patients, consisting of 2 686 SCI patients and 2 143 non-SCI patients. The majority of patients were included as part of the study by Baldea et al. (2016) [31], which included 1 885 patients in both the SCI and non-SCI cohorts. Removing this study from analysis yielded 901 patients in the SCI patient group and 258 patients in the non-SCI group. Overall, 65.1% ($\pm 10.8\%$) of patients were male, and the average patient age was 52.0 (± 7.4) years.

A total of 19 articles reported the etiology of SCI in their patient cohorts [11–13, 15–18, 20, 22–25, 27, 29, 30, 32, 33, 35, 36]. When pooled, the majority of SCI patients (63.0%) had a traumatic etiology for their spinal cord pathology. 24.4% of patients had spina bifida and two studies focused entirely on spina bifida patients [25, 32]. 14.2% of patients were reported have other etiologies of spinal cord pathology, including multiple sclerosis, malignancy, and infection.

The methods of bladder management in SCI patients was reported in 22 studies [10–14, 16–27, 29, 30, 33, 34, 36]. The most common method of bladder management was indwelling catheter (35.7%), with other reported methods including clean intermittent catheterization (18.8%), condom catheter (18.7%), and suprapubic catheter (SPC) (12.5%). 11.6% of patients did not require any form of bladder management and were able to void spontaneously.

19 studies reported including patients with SCI and a history of urinary diversion or bladder augmentation [11–13, 15, 16, 18, 20–27, 30, 32–34, 36]. Of these studies, 16.5% of patients had a history of urinary diversion while 17.6% of patients reported a history of bladder augmentation.

The results of preoperative urine cultures were reported in 16 studies, with 48.1% of patients with SCI demonstrating preoperative bacteriuria [10–12, 14–16,

Table 1

Study characteristics, patient demographics, and urologic history of patients with spinal cord injury and nephrolithiasis

Study	Patients	Average age (years)	SCI etiology				Bladder management						
			Male (%)	Traumatic (%)	Spina bifida (%)	Other (%)	Indwelling (%)	SPC (%)	CIC (%)	Condom (%)	None (%)	Urinary diversion (%)	Bladder augment. (%)
Culkin et al. (1986) ¹⁰	23	43	100	NR	NR	NR	60.9	NR	NR	NR	NR	NR	NR
Lazare et al. (1988) ¹¹	32	52	100	93.7	0	6.3	28.1	15.7	0	46.9	0	9.4	NR
Spirnak et al. (1988) ¹²	5	39	100	100	0	0	40.0	0	20.0	20.0	0	20.0	NR
Wahle et al. (1988) ¹³	31	34	74	54.8	29.0	16.1	NR	19.4	NR	NR	NR	41.9	NR
Culkin et al. (1990) ¹⁴	35	NR	84	NR	NR	NR	71.4	NR	NR	NR	NR	NR	NR
Irwin et al. (1991) ¹⁵	16	NR	NR	31.2	68.8	0	NR	NR	NR	NR	NR	50.0	NR
Niedrach et al. (1991) ¹⁶	11	31	NR	36.4	36.4	27.2	18.2	0	9.1	45.4	0	27.2	NR
Deliveliotis et al. (1994) ¹⁷	15	39	NR	40.0	33.3	26.7	73.3	0	26.7	0	0	NR	NR
Robert et al. (1995) ¹⁸	15	27	87	93.3	0	6.7	6.7	NR	40.0	NR	13.3	NR	6.7
Donnellan et al. (1999) ³⁶	58	37	88	91.4	0	8.6	48.6	NR	1.4	NR	15.3	4.9	0.7
Chen et al. (2002) ¹⁹	77	50	86	NR	NR	NR	29.0	0	6.7	56.5	1.6	NR	NR
Rubenstein et al. (2004) ²⁰	23	44	57	34.8	39.1	17.4	NR	NR	30.4	NR	NR	34.8	4.3
Lawrentschuk et al. (2005) ²¹	26	43	88	NR	NR	NR	42.3	NR	23.1	42.3	NR	7.7	NR
Symons et al. (2006) ²²	29	39	41	31.0	34.5	20.7	20.7	24.1	20.7	NR	6.9	27.6	3.4
Knox et al. (2012) ²³	47	28	NR	55.3	34.0	10.6	12.8	17.0	19.1	10.6	6.4	27.7	8.5
Nabbout et al. (2012) ²⁴	21	53	62	66.7	33.3	0	52.4	0	38.1	0	0	9.5	NR
Alsinnawi et al. (2013) ²⁵	5	44	60	0	100	0	20.0	0.0	80.0	0.0	0.0	NR	40.0
Wolfe et al. (2013) ²⁶	29	47	100	NR	NR	NR	67.2	17.9	7.5	0	0	4.5	NR
Clifton et al. (2014) ²⁷	95	51	67	58.9	15.8	25.2	29.5	NR	15.8	NR	NR	24.2	NR
Danawala et al. (2015) ²⁸	31	56	61	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Tepeler et al. (2015) ²⁹	19	45	58	52.6	0	42.1	15.8	10.5	31.6	15.8	5.3	NR	NR
Sofimajidpour et al. (2016) ³⁰	29	49	41	82.8	17.2	0	20.7	0	55.2	0	0	24.1	NR
Baldea et al. (2017) ³¹	1885	23	61	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Chaudhry et al. (2017) ³²	23	23	61	0	100	0	NR	NR	NR	NR	NR	4.3	87.0

Morhardt et al. (2018) ³³	46	49	85	84.2	NR	NR	14.7	7.4	38.9	0	25.3	13.7	NR
Prattley et al. (2019) ³⁴	21	49	86	NR	NR	NR	4.8	66.7	19.0	47.6	NR	14.3	42.9
Toricelli et al. (2020) ³⁵	39	45	74	56.4	15.4	15.4	NR	NR	NR	NR	NR	NR	NR

SCI = spinal cord injury; NR = not recorded; SPC = suprapubic catheter; CIC = clean intermittent catheterization.

18, 20, 21, 23–25, 28, 30, 31, 34]. Ten of these papers reported that >90% of their SCI patients had positive preoperative urine cultures [10–12, 14, 16, 20, 23–25, 30].

Kidney Stone Characteristics

The laterality of treated stones was reported in 21 studies, with 21.1% of procedures involving treatment of bilateral kidney stones [10–18, 20–28, 30, 33, 35]. 13 studies described the location of treated kidney stones [11, 12, 14, 16, 18, 21, 22, 24, 26, 27, 29, 33, 34]. 75.5% of procedures were performed on renal stones while 16.2% of procedures were performed on ureteric stones.

Kidney stone size was described in 14 studies [11, 15, 16, 18, 22–24, 27–30, 32–34]. The median stone size was 16.1mm (IQR, 15.6–33.1mm) and 33.8% of procedures involved treatment of staghorn stones. 16 studies reported on kidney stone composition, with 68.1% of analyzed stones being composed of struvite [10, 12–14, 16, 17, 20, 21, 23, 24, 27–29, 33, 34, 36].

Stone-Free Rate

25 studies reported the SFR following surgical therapy for nephrolithiasis for a total of 977 procedures (Supplemental Table S2) [10–26, 28–30, 32–36]. The pooled SFR in SCI patients was 54.1% for patients undergoing SWL, 73.6% for patients undergoing PCNL, and 36.2% for patients undergoing ureteroscopy.

Three studies compared SFR following PCNL in SCI patients to non-SCI patients [14, 28, 35]. Meta-analysis found that there were no significant differences between groups in post-PCNL SFR (OR 0.64; 95% CI, 0.15–2.64; $I^2 = 77%$, $p = 0.01$) (Fig. 2).

Postoperative Complications

23 studies reported the rate of complications following surgical therapy for nephrolithiasis (Supplemental Table S2) [10, 11, 13–17, 20–35]. Meta-analysis was performed on four studies reporting post-PCNL complications and found that patients with SCI reported a significantly greater rate of grade I (OR 9.54; 95% CI, 3.06–29.79; $I^2 = 61%$, $p = 0.08$), grade II (OR 3.38; 95% CI, 1.85–6.18; $I^2 = 58%$, $p = 0.07$), and grades III–V complications (OR 2.38; 95% CI, 1.35–4.19; $I^2 = 50%$, $p = 0.11$) following PCNL compared to the non-SCI cohort (Fig. 3–5).

When infectious complications were pooled, patients with SCI were more likely experience infectious complications compared to SCI patients (OR 6.15; 95% CI, 1.86–20.39; $I^2 = 90%$, $p < 0.00001$) (Fig. 6). Types of complications pooled in this analysis included fever, UTI, pneumonia, abscess, wound infection, and sepsis. Specific complications reported in comparative studies are described in Table 2.

Due its disproportionately large study population, sensitivity analysis performed by removing the study by Baldea et al. (2016) [31] from the meta-analysis. Excluding this study did not have a significant impact on SFR, minor complications, or infectious complications, but did have a significant impact on the observed difference in major complication rates.

Discussion

It is well established that SCI is associated with an increased risk of nephrolithiasis, with the reported risk of kidney stone formation being as high as 38% in this subpopulation of patients [37]. In the long-term, the association between urolithiasis and SCI can increase the risk of renal failure and urosepsis in this patient population, necessitating surgical intervention to reduce morbidity [1]. Our meta-analysis of comparative studies found that SCI patients were more likely to experience both minor (Clavien-Dindo grades I and II) and major (Clavien-Dindo grades III to V) complications compared to non-SCI patients following PCNL. The increased rate of complications in patients with SCI undergoing surgical intervention for kidney stones is similar to that of patients with spina bifida, spinal deformity, and neurogenic bladder [38–40]. This suggests that this elevated postoperative morbidity may be related to shared factors between these populations, such as a tendency towards high rates of bacteriuria and heavy stone burden.

The urinary stasis associated with SCI promotes bacterial colonization of the urinary tract, a risk that is further amplified by the use of catheters for bladder management and poor mobility resulting in insufficient drainage of the urinary tract [41, 42]. We found that, among the 16 studies that reported the results of preoperative urine cultures, ten described bacteriuria rates of >90% in SCI patients prior to surgery [10–12, 14, 16, 20, 23–25, 30]. Additionally, we found that 68.1% of analyzed stones in included studies were struvite in composition, which aligns with the 37.5–98% reported rate of struvite stones kidney in spinal cord injury patients described in the literature [43, 44]. High rates of bacterial colonization in SCI patients not only promote struvite stone formation but can increase the risk of infection following surgical intervention for nephrolithiasis [45]. Accordingly, when pooled together, our meta-analysis found that patients

Table 2

Summary of the most common postoperative complications reported in comparative studies examining percutaneous nephrolithotomy in patients with and without spinal cord injury

	Complication	SCI	Non-SCI
Grade I	Fever	43/87 (49.4%)	17/226 (7.5%)
	Acute kidney injury	5/91 (5.5%)	15/161 (9.3%)
	Ileus	2/52 (3.8%)	0/161 (0%)
Grade II	Bleed requiring transfusion	26/126 (20.6%)	19/304 (6.3%)
	Urinary tract infection	4/39 (10.2%)	2/78 (2.6%)
	Pneumonia	101/1972 (5.1%)	55/2111 (2.6%)
	Wound infections	2/52 (3.8%)	2/161 (1.2%)
	Venous thromboembolism	1/91 (1.1%)	1/161 (0.6%)
Grade III	Hemothorax	1/126 (0.8%)	2/226 (0.9%)
	Abscess	3/87 (2.4%)	1/226 (0.4%)
	Complication requiring another procedure*	16/87 (18.4%)	19/304 (6.3%)
Grade IV	Sepsis	147/2011 (7.3%)	67/2189 (3.1%)
	Acute respiratory distress syndrome	3/87 (3.4%)	0/226 (0%)
	Myocardial infarction	21/1937 (1.1%)	22/2045 (1.1%)
	Cerebrovascular accident	30/1885 (1.6%)	5/1885 (0.3%)
	Multiorgan failure	3/52 (5.8%)	3/161 (1.9%)
Grade V	Death	81/2011 (4.0%)	60/2111 (2.8%)

SCI = spinal cord injury; * = urinary fistula, pyelocutaneous fistula, nephroenteric fistula, ureteral edema, urinoma/hematoma requiring drainage, nephrostomy tube dislodgement, ureteropelvic junction (UPJ) obstruction, and UPJ injury.

SCI were more likely to experience infectious complications after PCNL compared to non-SCI patients (Fig. 6). As prophylactic antibiotics have been shown to reduce postoperative infectious complications following PCNL, urologists should consider the judicious utilization of antibiotics tailored to preoperative urine cultures both pre- and postoperatively when planning surgical intervention in patients with SCI [46].

We also found that SCI patients requiring surgery for nephrolithiasis tended to have a higher stone burden in terms of stone size, complexity, and laterality. The median stone size was 16.1mm among SCI patients and a substantial proportion of this subpopulation were treated for staghorn stones (33.8%) and bilateral stone disease (21.1%). Since bilateral obstructive stones, renal failure, and obstructive urosepsis are indications for emergent surgical intervention, SCI patients may also be less likely to be medically optimized for surgery, thereby increasing the risk of postoperative complications [47]. Additionally, due to sensory deficits, patients with SCI often do not present with renal colic; nephrolithiasis may only be identified incidentally or when the patient develops systemic symptoms of obstructive uropathy or urosepsis, allowing for stones to grow large and complex and delaying treatment [5]. Despite these risk factors, studies have shown inconsistent urologic follow up of patients with SCI; urologists should focus on routine assessment and regular imaging of these patients in order to screen for stone development and recurrence [48].

While we suspected that the presence of larger and bilateral stones may necessitate multiple procedures to achieve stone clearance, we did not find a significant difference in SFR between SCI and non-SCI patients undergoing PCNL. In general, achievement of stone-free status following PCNL is primarily influenced by stone complexity, with greater stone burden and staghorn stones being associated with reduced SFR [49]. This suggests that, when comparing SCI and non-SCI patients with similar stone burden, PCNL has similar success rates regardless of neurologic status. This is compounded by the fact that, unlike in retrograde ureteroscopy, a history of bladder augmentation or urinary diversion, which we found to be quite prevalent in SCI patients, does not impact PCNL technique, which utilizes an antegrade approach [50]. This similarity in SFR between groups may indicate that, despite their propensity for heavier stone burden, patients within this subpopulation may not be more likely to require multiple procedures compared to patients without SCI. As a result, the increased complication rate amongst SCI patients may not be heavily influenced by a need for multiple consecutive interventions to achieve stone clearance.

Overall, SFR was lower for ureteroscopy (36.2%) and SWL (54.1%) than for PCNL (73.6%) in SCI patients. However, the lack of comparative studies makes it difficult to directly compare outcomes between these interventions. In addition, the choice of intervention is highly dependent on characteristics such as stone burden and location; for example, PCNL is generally only considered in patients with large (>2cm) renal stones, while ureteroscopy and SWL are the technique

of choice for smaller renal and ureteric stones [49]. This may further hinder the ability to make direct comparisons of different interventions in SCI patients in the future.

To our knowledge, our study is the first to systematically review outcomes of kidney stone surgery in patients with SCI; however, it is not without its limitations. Firstly, our comparisons of SFR, grade I complications, grade II complications, and infectious complications had high heterogeneity ($I^2 > 50\%$). Sensitivity analysis also showed that the study by Baldea et al. (2017) may have a disproportionate impact on the higher major complication rate observed in SCI patients undergoing PCNL. Furthermore, all included studies in the were retrospective and observational in nature. We also lacked comparative studies for SWL and ureteroscopy as well as comparisons between these interventions among SCI patients. It is clear that further prospective and randomized comparative studies examining multiple surgical interventions for nephrolithiasis in SCI patients are required to better characterize postoperative outcomes in this patient population.

Conclusion

SCI is associated with an increased risk of nephrolithiasis. Our systematic review and meta-analysis found that, when compared to non-SCI patients, SCI patients are more likely to experience minor, major, and infectious complications following PCNL. This increased risk of postoperative complications may be because patients with SCI are more likely to have more complex stone disease, as SCI is associated with bilateral disease, greater stone burden, staghorn stones, preoperative bacteriuria, and struvite stones. However, we found no difference in SFR following PCNL when comparing SCI and non-SCI patients, suggesting that PCNL is an effective surgical treatment for kidney stones in both populations. Comparative studies investigating outcomes of other surgical interventions for nephrolithiasis, such as SWL and ureteroscopy, are required to shed further light on optimal management of SCI patients with kidney stone disease.

Declarations

Statements and Declarations

All authors have no conflicts of interest to disclose. No funding was received for this article.

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Figures

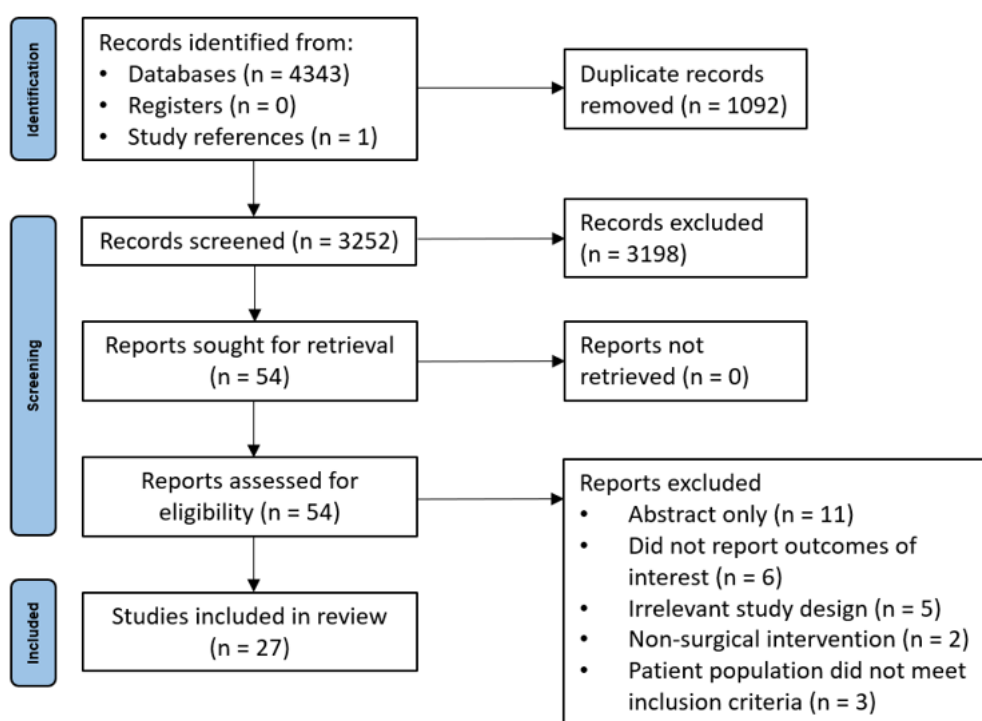


Figure 1

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

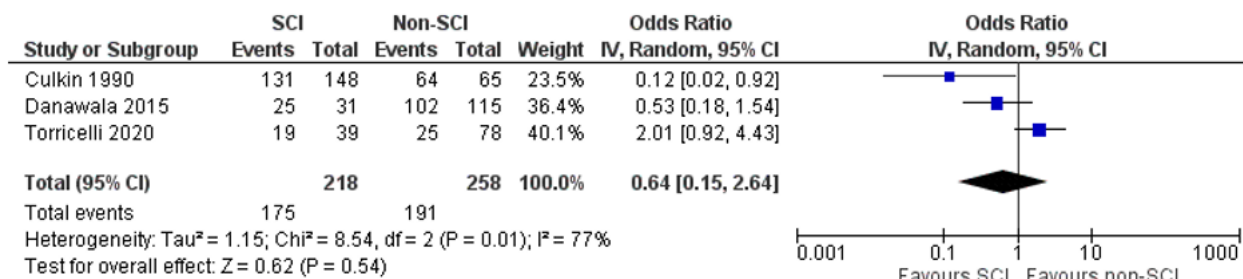


Figure 2

Forest plot comparing stone-free rate (SFR) following percutaneous nephrolithotomy (PCNL) between SCI patients and non-SCI patients.

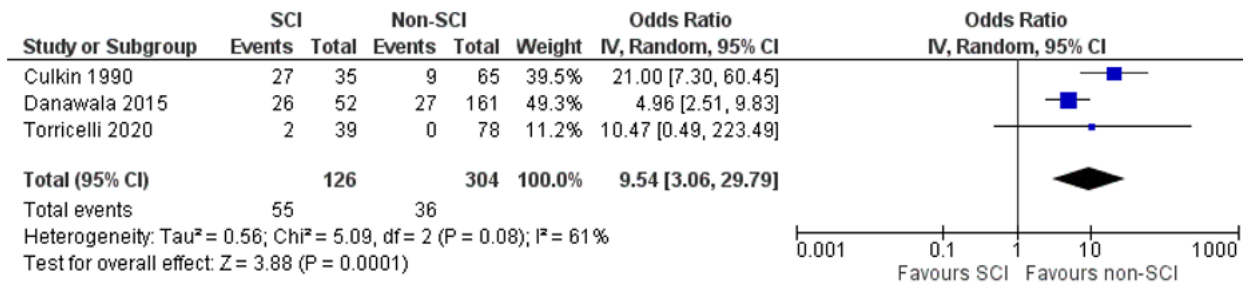


Figure 3
Forest plots comparing complications by type I complications following percutaneous nephrolithotomy (PCNL) between SCI patients and non-SCI patients. Complications were categorized based on Clavien-Dindo classification

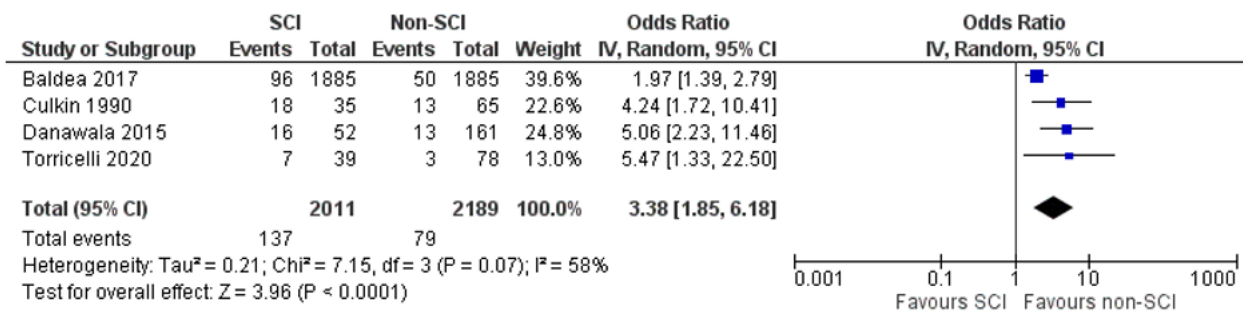


Figure 4
Forest plots comparing complications by type II complications following percutaneous nephrolithotomy (PCNL) between SCI patients and non-SCI patients. Complications were categorized based on Clavien-Dindo classification

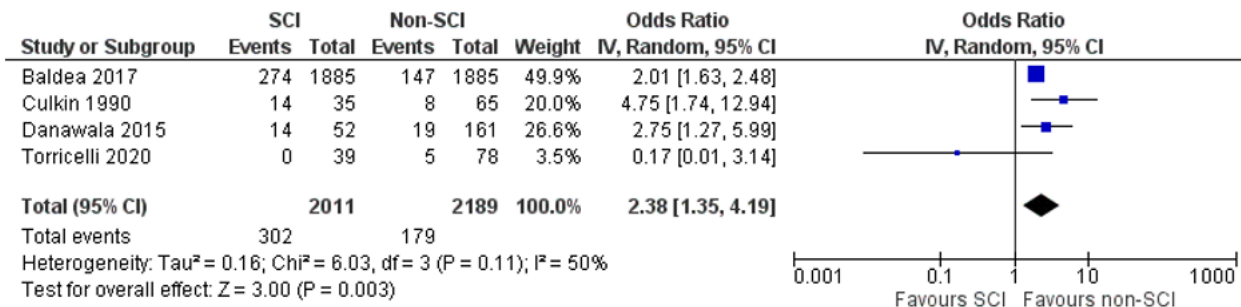


Figure 5
Forest plots comparing complications by type III-V complications following percutaneous nephrolithotomy (PCNL) between SCI patients and non-SCI patients. Complications were categorized based on Clavien-Dindo classification

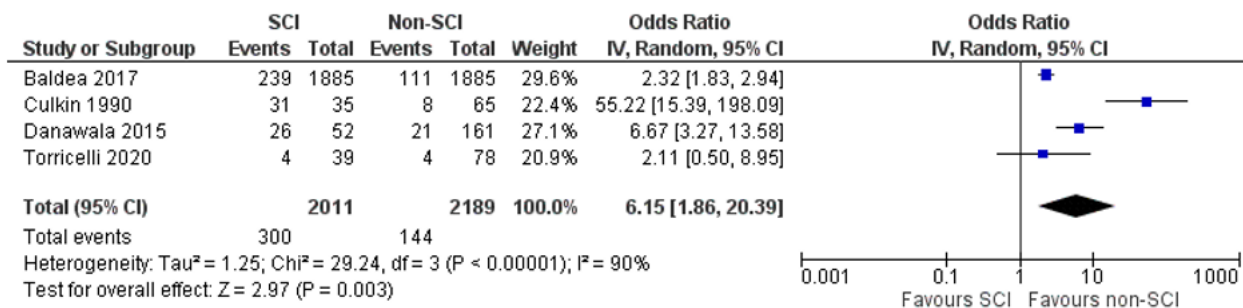


Figure 6

Forest plot comparing infectious complications following percutaneous nephrolithotomy (PCNL) between SCI patients and non-SCI patients. The rate of such complications was determined by pooling the reported rates of postoperative fever, urinary tract infection, pneumonia, abscesses, wound infections, and sepsis.

Supplementary Files

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