Systematic Review and/or Meta-analysis

INTERNATIONAL JOURNAL OF SURGERY

OPEN

Safety and efficacy of enhanced recovery after surgery among patients undergoing percutaneous nephrolithotomy: a systematic review and meta-analysis

Liang Liu, MM[a,b,*], Yu Xiao, MM, PhD[c,d], Xiao Yue, BSM[a,b], Qiang Wang, PhD[a,b]

Background: The enhanced recovery after surgery (ERAS) method has been widely used in surgery and anesthesia worldwide and has been applied to a wide range of surgical specialties, including colorectal surgery, gynecology, liver surgery, breast surgery, urology, and spinal surgery. An increasing number of studies have demonstrated its safety and efficacy in various fields. The safety and effectiveness of ERAS for percutaneous nephrolithotomy (PCNL) remain controversial. This study aimed to review the safety and effectiveness of ERAS for PCNL.

Methods: The Chinese National Knowledge Infrastructure (CNKI), Wan Fang, Chinese Biomedical Literature Service System (SinoMed), Chinese Science and Technology Journal Full Text Database (VIP), Cochrane Library, PubMed, Web of Science, and Embase databases were searched for eligible studies published until 19 September 2022. Outcome measures included postoperative hospital stay, total hospital stay, incidence of postoperative complications, stone-free rate (SFR), operative time, postoperative indwelling nephrostomy tube time, catheter encumbrance time, and nursing satisfaction. All analyses were performed using random-effects or fixed-effects models. Clinical heterogeneity was treated with subgroup, sensitivity, or descriptive analyses only when clinical heterogeneity was not excluded. Publication bias was assessed using funnel plots. Twenty-five studies (1545 observational patients and 1562 controls) were included.

Results: The ERAS group had a shorter postoperative hospital stay [WMD = −2.59, 95% CI = (−3.04, −2.14), $P < 0.001$], total hospital stay [WMD = −2.59, 95% CI = (−3.04, −2.14), $P < 0.001$], and lower complication rate [RR = 0.36, 95% CI = (0.29–0.43), $P < 0.001$] than the control group. The ERAS group had a shorter surgery time [WMD = −3.57, 95% CI = (−5.88, −1.26), $P = 0.003$], postoperative indwelling nephrostomy tube time [WMD = −1.94, 95% CI = (−2.69, −1.19), $P < 0.001$], catheter encumbrance time [WMD = −2.65, 95% CI = (−4.83, −0.46), $P = 0.02$], and higher satisfaction [RR = 1.15, 95% CI = (1.05–1.25), $P = 0.001$] than the control group. The difference in the stone-free rate between the two groups was not statistically significant [RR = 1.03, 95% CI = (0.97–1.09), $P = 0.38$], but the stone-free rate of the observation group (ERAS group) in each study was higher than that of the control group.

Conclusion: ERAS not only ensures the safety of PCNL but also promotes postoperative rehabilitation of patients (shorter surgery time, postoperative indwelling nephrostomy tube time, postoperative hospital time, and lower complication rate). At the same time, differences in the stone-free rate were not statistically significant, but the stone-free rate of ERAS in each study was higher than that of the usual care for PCNL patients.

Keywords: effectiveness, enhanced recovery after surgery, meta-analysis, percutaneous nephrolithotomy, randomized controlled trial, safety, systematic review

[a]Department of Urology, Baoding No.1 Central Hospital, [b]Prostate and Andrology Key Laboratory of Baoding, Baoding, Hebei, [c]Psychosomatic Medical Center, The Fourth People's Hospital of Chengdu and [d]Psychosomatic Medical Center, The Clinical Hospital of Chengdu Brain Science Institute, MOE Key Lab for Neuroinformation, University of Electronic Science and Technology of China, Chengdu, Sichuan, People's Republic of China

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

**Corresponding author. Address: Department of Urology, Baoding No.1 Central Hospital, Changcheng North Street and Number 320, Baoding 071000, People's Republic of China. Tel.: +312 597 5015. E-mail: mnwkll@163.com (L. Liu).*

International Journal of Surgery (2024) 110:3768–3777

Received 22 December 2023; Accepted 26 January 2024

Supplemental Digital Content is available for this article. Direct URL citations are provided in the HTML and PDF versions of this article on the journal's website, www.lww.com/international-journal-of-surgery.

Published online 13 February 2024

http://dx.doi.org/10.1097/JS9.0000000000001158

Introduction

According to a survey, the incidence and prevalence of kidney stones will continue to rise (2– 20%), and the recurrence rate of kidney stones is reported to be 52% after 10 years[1–5]. It can cause severe kidney damage and even kidney loss, and can be accompanied by painful colic, posing a burden on health care in many countries[6–9]. Owing to advancements in medical technology, percutaneous nephrolithotomy (PCNL) is the primary treatment option for kidney calculi. It has high stone clearance rates (85–93%), but postoperative complications occur in up to 18%[10,11]. A study from the United Kingdom reported that PCNL complications include bleeding, inflammation of adjacent organs, and infection[12]. Of these, 1.7% arose from infection and 9.4% from bleeding. Sepsis is the leading cause of perioperative period[13,14]. With the rapid development of medical science, surgical techniques with fewer traumas, faster postoperative rehabilitation, and shorter bed rest requirements have received a great deal of attention. Thus, optimization of therapy for patients with PCNL surgery-related complications has become increasingly important. Enhanced recovery after surgery (ERAS), also called fast track surgery (FTS), which was developed by Danish surgeon Kehlet, has been widely used in various surgery operations, aiming to achieve rapid rehabilitation following surgery, shorten the hospital stay, and reduce the incidence of postoperative complications[15–17]. ERAS is a multimodal perioperative program that includes health education, nutrition assessment, nutrition intervention, postoperative fluid management, epidural or local anesthesia, multimodal analgesia for postoperative pain, early enteral nutrition, early postoperative mobilization, and early removal of indwelling urinary catheters or drainage catheters. It requires the collaborative efforts of nurses, clinicians, anesthesiologists, and physical therapists[15,17].

Some recommendations have been developed for the ERAS guidelines in recent years to ensure that patients receive the best possible care[18]. There have been widely applied in a variety of surgical procedures, including gynecological oncologic surgery[19], thoracic tumor surgery[20], and urologic cancer surgery[21–23]. PCNL can also be surgically treated using ERAS. However, it remains unclear whether ERAS is effective and safe in perioperative PCNL trials. Furthermore, a comprehensive review of ERAS applications has not yet been published for PCNL. This systematic review aimed to conduct a meta-analysis of randomized controlled trials (RCTs) investigating the safety and effectiveness of ERAS during the perioperative period in patients with PCNL.

HIGHLIGHTS

- Several surgical fields have widely adopted enhanced recovery after surgery (ERAS), which is a multimodal and multidisciplinary perioperative care protocol.
- Uncertainty remains regarding the effects of the ERAS protocol on patients undergoing percutaneous nephrolithotomies (PCNL).
- The ERAS protocol was shown to be safe and feasible in the first meta-analysis of this protocol versus standard care for patients undergoing PCNL.

Material and methods

Protocol and registration

This systematic review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[24] (Supplemental Digital Content 1, http://links.lww.com/JS9/B925, Supplemental Digital Content 2, http://links.lww.com/JS9/B926) and Assessing the Methodological Quality of Systematic Reviews (AMSTAR) standards[25] (Supplemental Digital Content 3, http://links.lww.com/JS9/B927).

Literature search and inclusion criteria

An electronic search of published literature was performed using the Chinese National Knowledge Infrastructure (CNKI), Wan Fang database, Chinese Biomedical Literature Service System (SinoMed), Chinese Science and Technology Journal Full Text Database (VIP), Cochrane Library, PubMed, Web of Science, and Embase according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Statement[26]. Retrieval words consisted of subject words and free words, determined after repeated prechecking, along with manual retrieval. The search terms included 'enhanced recovery after surgery', 'ERAS', 'FTS', 'hanced postsurgical recovery', 'postsurgical recoveries, enhanced', 'postsurgical recovery, enhanced', 'recovery, enhanced postsurgical', 'nephrolithotomy, percutaneous', 'nephrolithotomies, percutaneous', 'percutaneous nephrolithotomies', 'percutaneous nephrolithotomy', and 'PCNL'. The retrieval time was set as the establishment of the database until 19 September 2022. PubMed is an example and Appendix 1 presents the specific retrieval strategy (Supplemental Digital Content 4, http://links.lww.com/JS9/B928).

The inclusion criteria were as follows: (1) type of study: RCTs. (2) Language: English or Chinese. (3) Diagnosis of upper urinary tract stones was confirmed. (4) Underwent PCNL. (5) Intervention: control group, conventional perioperative care; observation group (ERAS group), ERAS during the perioperative period. The exclusion criteria were as follows: (1) literature reviews and conference papers. (2) Nonrandomized controlled trials. (3) Descriptive statistics. (4) Unable to extract data. (5) Repeat the published literature. Figure 1 illustrates the flow diagram of the literature selection.

The primary outcomes were length of postoperative hospital stay, total hospital stay, and postoperative complication rate. Secondary outcomes included the removal of urethral or drainage catheters, length of surgery, patient satisfaction, postoperative stone-free rate (SFR), and total hospital stay. SFR indicated that there were no residual stones (residual stones <5 mm) or that the residual stones were deeper than 5 mm, but they did not obstruct the urinary system with the need for a second operation. Postoperative complications included bleeding, infection, fever, urinary extravasation, pneumothorax, and hypotension.

Literature screening and data extraction

During the review process, two independent researchers examined the literature and gathered the data independently. Any disagreements during literature screening were settled after a full discussion with the third researcher. The extracted information

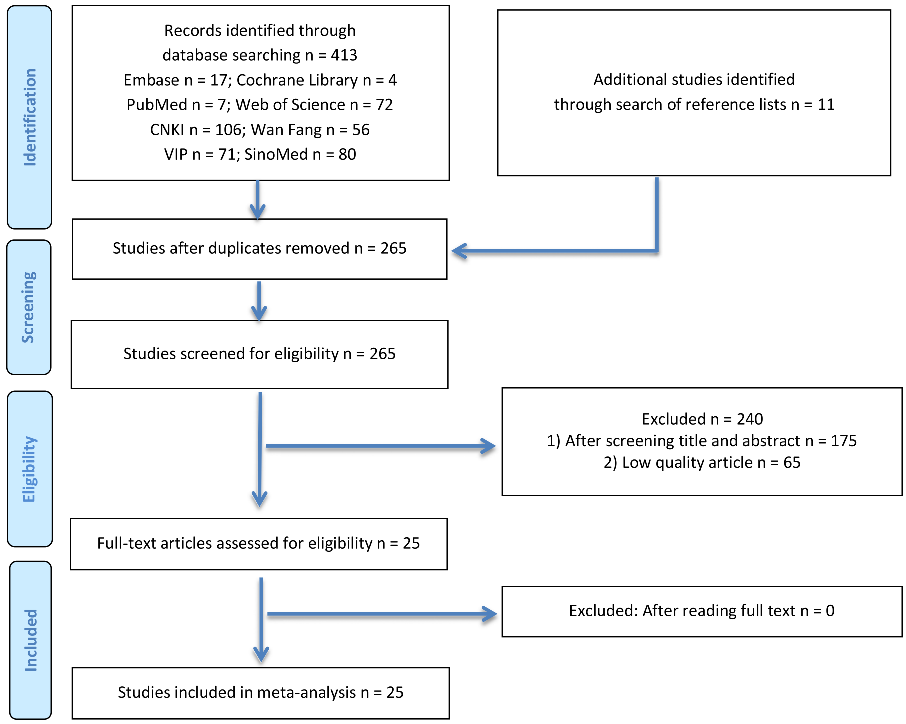

Figure 1. PRISMA diagram showing selection of articles for review.

included (1) basic literature information such as year of publication, first author, sample size, male/female ratio, average age, stone location, and diameter; (2) key factors of bias risk assessment; and (3) outcome indexes such as SFR, operative time, and incidence of postoperative complications. The risk of bias was assessed using the risk of bias tool from the Cochrane Handbook for Systematic Reviews[27].

Statistical analysis

Statistical analyses were conducted using Review Manager, version 5.4.1. The combined statistic used in either a random-effects model or a fixed-effects model when analyzing continuous variables was the weighted mean difference (WMD) or standardized mean difference (SMD). An effect analysis was conducted using the risk ratio (RR). A 95% CI was used for all the effect sizes. χ^2 tests were used to analyze the statistical heterogeneity among the included studies. For quantitative analysis of heterogeneity, the I^2 test was used with a test level of $\alpha = 0.1$. Quantitative I^2 values were combined to determine heterogeneity. Meta-analyses were conducted using fixed-effect models when there was no statistical heterogeneity between the studies ($P > 0.1$ and $I^2 < 50\%$). Meta-analyses were conducted using a random-effects model after clinical heterogeneity was excluded when there was significant heterogeneity. Clinical heterogeneity was treated with subgroup, sensitivity, or descriptive analyses only when clinical heterogeneity was not excluded. Statistical analyses were performed using $\alpha = 0.05$. Publication bias was assessed using funnel plots when more than 10 eligible articles were included according to the Cochrane Handbook of Systematic Reviews.

Results

Study characteristics and quality assessment

Predetermined search strategies were utilized to conduct a methodological search of eight databases: CNKI, Wan Fang, SinoMed, VIP, Cochrane Library, PubMed, Web of Science, and Embase. Initial searches revealed 413 potentially relevant publications (EMbase: $n = 17$; PubMed: $n = 7$; The Cochrane Library: $n = 4$; Web of Science: $n = 72$; CNKI: $n = 106$; Wangfang: $n = 56$; VIP: $n = 71$; SinoMed: $n = 80$). Relevant bibliographies were manually searched for 11 additional articles. Following the exclusion of duplicate studies, we read the abstracts and titles of the remaining studies and selected 25 studies to read the full text. We finally included 25 RCTs involving 3107 patients (male: $n = 1889$; female: $n = 1218$)[28–52]. A total of 1545 patients were in the ERAS group and 1562 patients were in the control group. Figure 1 illustrates the literature selection process. Table 1 shows the baseline characteristics of the studies included in this meta-analysis. All 25 studies were published after 2013, and more than half had been published within the last 5 years. The number of patients enrolled in each study ranged from 32 to 380. Table 2 presents the results of bias risk assessment.

Postoperative hospital and total hospital stay

Among the studies, 23 ($n = 2923$)[28–34,36–45,47–52] and two ($n = 220$)[30,35] reported postoperative hospital and total hospital stay times, respectively. A meta-analysis with a random-effects model showed that the ERAS group was associated with a significantly shorter postoperative hospital stay than the control group [WMD = −2.59, 95% CI = (−3.04, −2.14), $P < 0.001$] (Fig. 2A), while the ERAS group spent a shorter amount of time in

Table 1

Summary of baseline characteristics.

References	Country	Sample size (T/N, n)	Male/Female (*n*)	Male/Female (*n*)		Average Age (years)		Stone diameter (mm)		Stone location (Left/Right/Bilateral, n)		Stone location (Kidney/Ureter, n)		Outcome indexes
				T	N	T	N	T	N	T	N	T	N	
Zhang *et al.*,[32]	China	40/40	58/22	30/10	28/12	32.6 + 6.2	32.3 + 6.1	NR	NR	NR	NR	NR	NR	cef
Yang *et al.*,[35]	China	55/55	55/55	28/27	27/28	56.7 + 10.1	55.6 + 11.1	34.1 + 11.1	33.9 + 10.2	NR	NR	NR	NR	eg
Ou *et al.*,[30]	China	58/52	71/39	39/19	32/20	46.0	43.0	NR	NR	NR	NR	NR	NR	bcefg
Chen *et al.*,[36]	China	40/40	53/27	27/13	26/14	43.8 + 6.1	44.1 + 5.3	NR	NR	NR	NR	22/18	21/19	ef
Li *et al.*,[37]	China	54/54	60/48	31/23	29/25	51.6 + 11.2	50.9 + 10.8	NR	NR	28/26	21/33	NR	NR	ef
Shen *et al.*,[38]	China	150/150	199/101	102/48	97/53	51.5 + 20.5	52.5 + 22.5	NR	NR	NR	NR	NR	NR	ef
Cai *et al.*,[51]	China	30/30	33/27	17/13	16/14	41.0 + 5.9	40.3 + 5.9	31.5 + 3.6	31.2 + 3.5	NR	NR	NR	NR	bf
Li *et al.*,[28]	China	117/118	146/89	72/45	74/44	51.0 + 11.0	54.0 + 12.0	21.0 + 9.4	19.2 + 8.2	NR	NR	NR	NR	abcdef
Zhang *et al.*,[29]	China	62/73	88/47	41/21	47/26	53.2 + 12.6	54.3 + 11.7	26.3 + 3.7	24.8 + 4.1	33/29	39/34	NR	NR	acdef
Tan,[39]	China	190/190	222/158	113/77	109/81	47.6 + 8.6	47.9 + 7.8	19.1 + 4.1	18.9 + 3.8	95/81/14	89/91/10	NR	NR	ef
Li,[40]	China	45/45	55/35	27/18	28/17	45.3 + 2.6	45.1 + 2.7	7.6 + 2.0	7.7 + 2.0	NR	NR	32/13	34/11	ef
Luo *et al.*,[31]	China	116/127	128/115	62/54	66/61	42.0 + 13.0	40.0 + 14.0	22.0 + 5.0	21.0 + 4.0	NR	NR	71/79	77/90	bcdef
Ma *et al.*,[41]	China	30/30	37/23	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ef
Hou *et al.*,[33]	China	46/46	57/35	29/17	28/18	50.3 + 5.3	51.6 + 4.7	8.1 + 2.1	7.7 + 2.5	NR	NR	NR	NR	def
Zhuang *et al.*,[34]	China	48/50	66/32	33/15	33/17	52.0 + 13.6	54.6 + 11.9	28.4 + 3.6	27.5 + 2.9	25/19/4	21/236	NR	NR	def
Zhou,[42]	China	16/16	20/12	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ef
Wei,[43]	China	50/50	62/38	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ef
Mao *et al.*,[44]	China	57/57	58/56	28/29	30/27	46.8 + 5.9	47.1 + 6.2	NR	NR	29/28	30/27	NR	NR	ef
Li *et al.*,[45]	China	60/60	76/44	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ef
Yang,[46]	China	37/37	41/33	21/16	20/17	42.9 + 4.2	41.7 + 3.4	NR	NR	NR	NR	NR	NR	e
Lin *et al.*,[47]	China	30/30	38/22	16/14	22/8	38(24-69)	46(32-72)	NR	NR	10/13/7	12/15/3	NR	NR	ef
Ma *et al.*,[48]	China	60/60	72/48	NR	NR	52.1 + 15.5	55.9 + 15.7	37.5 + 15.1	34.6 + 14.7	NR	NR	NR	NR	ef
Dong *et al.*,[49]	China	38/38	48/28	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ef
Chen *et al.*,[52]	China	66/64	82/48	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	f
Qiao *et al.*,[50]	China	50/50	64/36	31/19	33/17	47.2 + 11.5	48.8 + 13.5	NR	NR	18/21/11	23/20/7	NR	NR	ef

T, ERAS group; N, control group; NR, not reported; Outcome Indexes: a. stone-free rate; b. operative time; c. postoperative indwelling nephrostomy tube time; d. catheter encumbrance time; e. incidence of postoperative complications; f. postoperative hospital stay; g. total hospital stay.

Table 2

Risk of bias in the included studies.

References	Random method	Allocation concealment	Blind methods	Completeness of outcome data	Selective outcome report	Other sources of bias
Zhang *et al.*,[32]	Not clear	Not clear	Not clear	Yes	No	Not clear
Yang *et al.*,[35]	Random number table	Not clear	Not clear	Yes	No	Not clear
Ou *et al.*,[30]	Not clear	Not clear	Not clear	Yes	No	Not clear
Chen *et al.*,[36]	Random number table	Not clear	Not clear	Yes	No	Not clear
Li *et al.*,[37]	Random number table	Not clear	Not clear	Yes	No	Not clear
Shen *et al.*,[38]	Not clear	Not clear	Not clear	Yes	No	Not clear
Cai *et al.*,[51]	Not clear	Not clear	Not clear	Yes	No	Not clear
Li *et al.*,[28]	Random number table	Yes	Double-blind	No, withdrawal	No	Not clear
Zhang *et al.*,[29]	Not clear	Not clear	Not clear	Yes	No	Not clear
Tan,[39]	Random number table	Not clear	Not clear	Yes	No	Not clear
Li,[40]	Random number table	Not clear	Not clear	Yes	No	Not clear
Luo *et al.*,[31]	Not clear	Not clear	Not clear	Yes	No	Not clear
Ma *et al.*,[41]	Not clear	No	No	Yes	No	Not clear
Hou *et al.*,[33]	Not clear	Not clear	Not clear	Yes	No	Not clear
Zhuang *et al.*,[34]	Not clear	Not clear	Not clear	Yes	No	Not clear
Zhou,[42]	Not clear	Not clear	Not clear	Yes	No	Not clear
Wei,[43]	Random classification	Not clear	Not clear	Yes	No	Not clear
Mao *et al.*,[44]	Admission time random	Not clear	Not clear	Yes	No	Not clear
Li *et al.*,[45]	Not clear	Not clear	Not clear	Yes	No	Not clear
Yang,[46]	Not clear	Not clear	Not clear	Yes	Yes	Not clear
Lin *et al.*,[47]	Not clear	Not clear	Not clear	Yes	No	Not clear
Ma *et al.*,[48]	Not clear	Not clear	Single-blinded	Yes	Yes	Not clear
Dong *et al.*,[49]	Single/double digital method	Not clear	Not clear	Yes	No	Not clear
Chen *et al.*,[52]	Random number table	Not clear	Not clear	Yes	No	Not clear
Qiao *et al.*,[50]	Single/double digital method	Not clear	Not clear	Yes	No	Not clear

the hospital than the control group in the meta-analysis results of the fixed-effects model [WMD = – 2.59, 95% CI = (– 3.04, – 2.14), $P < 0.001$] (Fig. 2B).

Complications

Twenty-three studies reported on various complications[28–50]. According to the meta-analysis of the fixed-effects model, the incidence rate of postoperative complications in the ERAS group was significantly lower than that in the control group [RR = 0.36, 95% CI = (0.29–0.43), $P < 0.001$] (Fig. 2C).

Stone-free rate

Among these studies, two ($n = 370$)[28,29] reported stone-free rates. Based on the results of the fixed-effects model, there were no significant differences between the ERAS and control groups in SFR [RR = 1.03, 95% CI = (0.97–1.09), $P = 0.38$] (Fig. 2D). Zhang *et al.*[29] found that the SFR between the ERAS and control groups were 95.1 and 94.5%, respectively. At the same time, Li *et al.*[28] also found the SFR were 93.2% (109/117) and 89.8% (106/118), respectively. There was no significant difference in SFR between the ERAS and control groups in the two studies ($P > 0.05$); however, the SFR of the ERAS group was higher than that of the control group.

Operative time

Among the studies, three ($n = 588$)[28,30,31] reported the operative time. According to the fixed-effects meta-analysis, the operative time differed significantly between the groups [WMD = – 3.57, 95% CI = (– 5.88, – 1.26), $P = 0.003$] (Fig. 2E).

Time of postoperative indwelling nephrostomy tube and catheter encumbrance

Among these studies, five ($n = 803$)[28–32] reported postoperative indwelling nephrostomy tube time. According to the fixed-effects meta-analysis, the postoperative indwelling nephrostomy tube time of the ERAS group was significantly shorter than that of the control group [WMD = – 1.94, 95% CI = – 2.69, – 1.19, $P < 0.001$] (Fig. 3A). Similarly, five studies ($n = 803$)[28,29,31,33,34] reported catheter entrance time. Using a random-effects model, we found that the ERAS group had a significantly shorter catheter entrance time than the control group [WMD = – 2.65, 95% CI = (– 4.83, – 0.46), $P = 0.02$] (Fig. 3B).

Nursing satisfaction

Nine studies reported on nursing satisfaction[33,35,36,40,42,43,45,48,49]. The meta-analysis conducted using a random-effects model revealed that the ERAS group had higher nursing satisfaction than the control group [RR = 1.15, 95% CI = (1.05–1.25), $P = 0.001$] (Fig. 3C).

Subgroup analysis

More than 10 studies reported the postoperative duration of hospital stay and showed high heterogeneity among the studies.

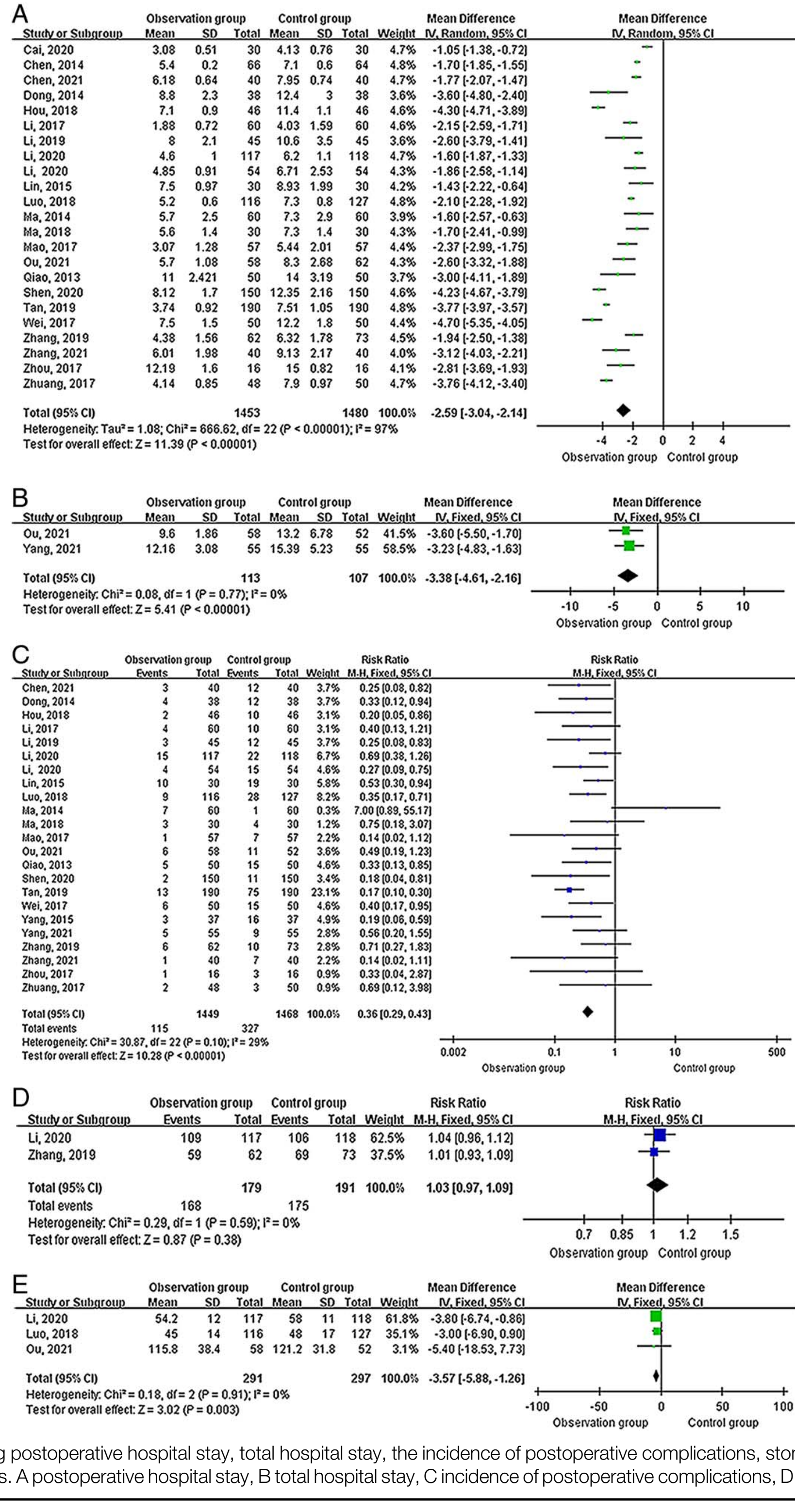

Figure 2. Forest plots showing postoperative hospital stay, total hospital stay, the incidence of postoperative complications, stone-free rate, operative time in the observation and control groups. A postoperative hospital stay, B total hospital stay, C incidence of postoperative complications, D stone-free rate, E operative time.

Therefore, based on sample size and stone location, we classified the study population into subgroups. The results of each subgroup analysis were consistent with the overall results, and there were no significant differences between the heterogeneity of each subgroup and that of the entire sample (Fig. 3D, E).

Sensitivity analysis and publication bias

A sensitivity analysis was conducted for the seven outcome indicators. Each study was sequentially eliminated individually in the sensitivity analysis, and at each stage, the meta-analysis of the remaining studies was conducted and compared with the results

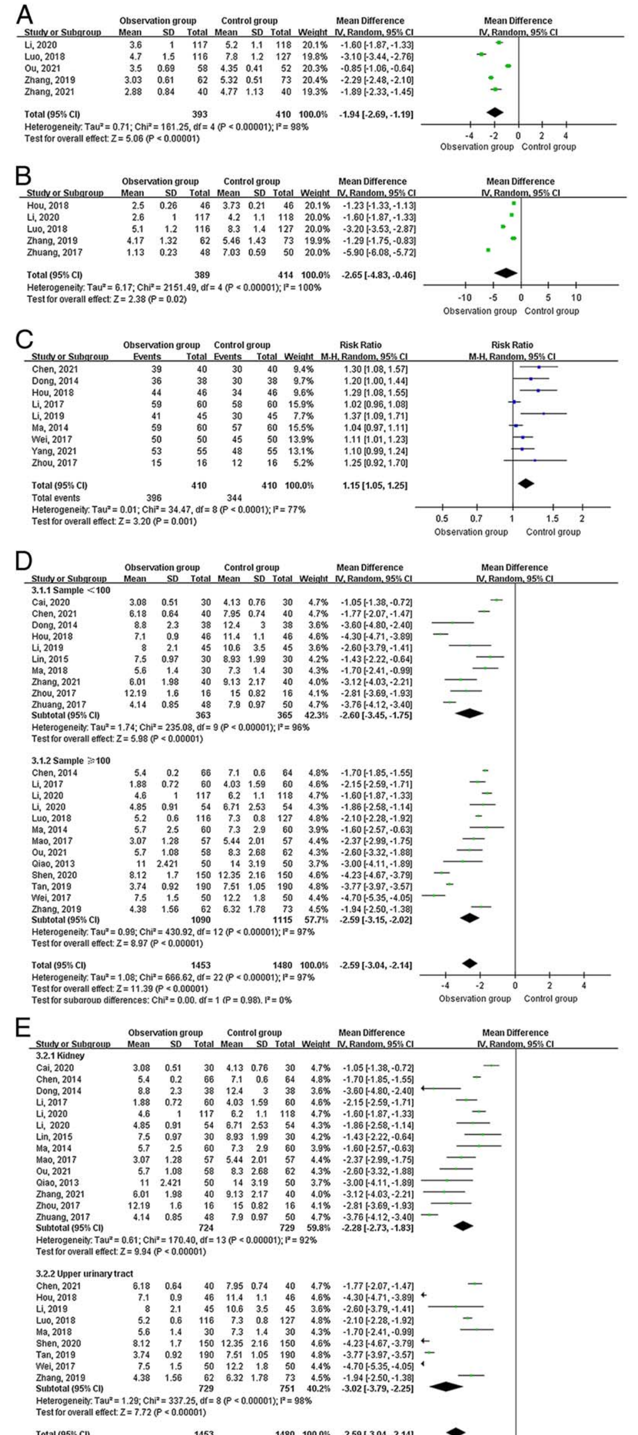

Figure 3. Forest plots showing postoperative indwelling nephrostomy tube time, catheter encumbrance time, nursing satisfaction, postoperative hospital stay for subgroup analysis (according to sample size), postoperative hospital stay for subgroup analysis (according to stone location) in the observation and control groups. A postoperative indwelling nephrostomy tube time, B catheter encumbrance time, C nursing satisfaction, D postoperative hospital stay for subgroup analysis (according to sample size), E postoperative hospital stay for subgroup analysis (according to stone location).

before the previous elimination was performed. One study[51] regarding surgical time had high heterogeneity; therefore, it was removed from the sensitivity analysis. The sensitivity analysis indicated that the results were stable. Publication bias was evaluated using a funnel plot of postoperative complications. The funnel plot showed that most points were in the upper part of the funnel, and it was basically symmetrical, which indicated that the analysis in the present study was relatively stable and credible with little possibility of publication bias (Fig. 4).

Discussion

In addition to being supported by guidelines and having good efficacy[53–55], PCNL for calculi clearance carries a number of risks, including the possibility of hemorrhage[56], complications, and increased likelihood of mortality[57]. The stone clearance rate is a key indicator of the efficacy of PCNL. This can reach 85%[58]. The goal of ERAS is to achieve a high stone-free rate while minimizing recurrence rates and complications, such as pain and bleeding. The ERAS program requires a multidisciplinary approach among the departments of surgery, anesthesia, nursing, nutrition, pain management, and rehabilitation, which includes preoperative, perioperative, and postoperative care. ERAS is a multidisciplinary collaborative process that integrates various effective measures, including preoperative education, optimization of anesthesia, minimally invasive surgery, intraoperative normothermia, and postoperative care. Postoperative care includes minimizing the use of drainage tube placement or early removal of drainage tubes, early postoperative movement, early feeding, and optimization of postoperative pain treatment, etc.[59]. As an increasing number of studies have proven the safety and efficacy of the ERAS concept since Kehlet introduced it in the 1990s[15], this method has become increasingly popular. A recent meta-analysis by Noba *et al*.[60] suggested that the use of ERAS for pancreaticoduodenectomy is safe and feasible, and that it improves clinical outcomes such as length of stay, complications, delayed gastric emptying, and mortality rates without a significant change in readmission and reoperation. Another meta-analysis[61] indicated that the ERAS protocol could be safely and feasibly implemented in the perioperative management of patients undergoing minimally invasive bariatric surgery. Compared with standard care, this protocol resulted in significantly shorter hospital stays, lower 30-day readmission rates, and lower hospitalization costs. No differences were observed in the postoperative complications or mortality. Furthermore, a growing number of meta-analyses have confirmed the feasibility and safety of the ERAS protocol in several surgical fields. However, to date, no systematic review has examined the effects of ERAS in PCNL patients. Moreover, an increasing number of studies on PCNL for ERAS in recent years hold varying opinions. Therefore, we aimed to provide clinical decision-makers with the latest evidence about ERAS's effectiveness in the treatment of PCNL through a comprehensive systematic review and meta-analysis of the latest data.

Our meta-analysis indicated that the ERAS protocol can be safely and feasibly implemented in the perioperative management of patients undergoing PCNL. In addition to increased muscle loss and weakness, bed rest impairs pulmonary function and increases the risk of thromboembolism and venous stasis. It is

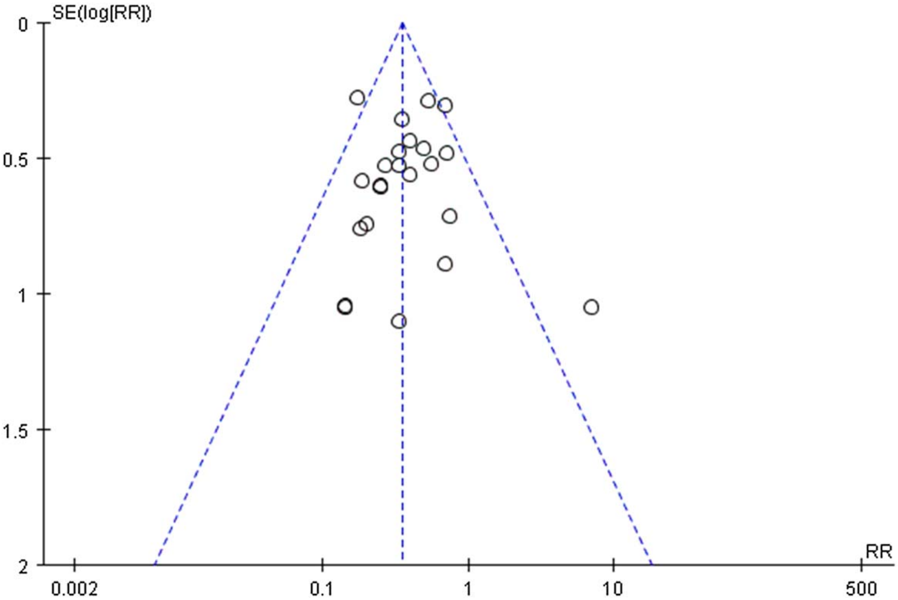

Figure 4. Funnel plot for the rate of complications.

common for postoperative patients to have a restricted oral intake. Currently, no clinically effective drugs are available to enhance gastric emptying, and owing to the attenuation of the ileus caused by epidural anesthesia, oral intake can often be successfully initiated 6 h after surgery, even after colonic surgery with anastomosis. During postoperative care, patients were encouraged to get out of bed as soon as possible to prevent thrombosis and to begin an oral diet as soon as possible to promote the recovery of their gastrointestinal function[62,63].

First, our study found that although ERAS in PCNL did not provide better stone-free rates ($P > 0.05$), it presented with a shorter procedure time ($P < 0.05$). Among the included studies, four[28,30,31,51] reported the time of surgery and found that patients in the ERAS group demonstrated a shorter procedure time than those in the control group ($P < 0.05$) when we excluded the study by Cai *et al.*[51]. Despite the high degree of heterogeneity among the included studies, a sensitivity analysis revealed that Cai *et al.*[51] was the main source of heterogeneity. Therefore, the results should be interpreted with caution. Among the 25 studies included in this review, only two[28,29] reported SFR, and the results of both studies were not statistically significant. However, we found that the SFR in the ERAS group was higher than that in the control group. In addition, the SFR of the two group in the two studies[28,29] substantially were higher than 90% (93.2 vs. 89.8%, $P = 0.7997$; 95.1 vs. 94.5%, $P > 0.05$). Two explanations can be offered for this. Pneumatic lithotripsy and holmium laser lithotripsy have higher efficiencies in PCNL[64]. Preoperative nutritional support allowed patients in the ERAS group to tolerate PCNL for longer periods. However, there was an association between harder stones and higher CT values, which could be helpful for clinicians in selecting appropriate lithotripsy tools to improve SFR[65]. Therefore, it is imperative that these promising findings be explored further.

Second, PCNL under ERAS can shorten the time of hospitalization, reduce postoperative complications and economic burden, and benefit patients. Owing to the high heterogeneity among the groups, we performed a subgroup analysis based on sample size and stone location. In subgroup analyses, the group estimates were similar, and publication bias was not observed. Our study showed that the postoperative hospital stay in the ERAS group was often shorter than that of the control group.

Traditionally, indwelling nephrostomy tubes after PCNL have been considered helpful in pressing the puncture channel, strengthening hemostasis, strengthening drainage, and reducing the risk of urine extravasation and infection. However, indwelling nephrostomy tubes increase patient discomfort, cause breathing-related pain, hinder early exercise, require more painkillers, and increase the postoperative hospitalization time[66]. The ERAS procedure can reduce the duration of the indwelling fistula, reduce pain, improve surgical acceptance, and reduce adverse reactions[67]. In addition to alleviating pain, postoperative active analgesia can reduce the adverse effects of nephrostomy tube removal and urethral catheterization. Consequently, some authors believe that removing the nephrostomy tube early or even not having one will not increase the risk of bleeding, infection, or urine extravasation[68]. In the present study, the total incidence of postoperative complications in the ERAS group was significantly lower than that in the conventional group [RR = 0.36, 95% CI = (0.29–0.43), $P < 0.001$]. The primary consideration for clinical application is safety. An increasing number of studies have shown that[69–71] the ERAS program is promising.

Despite the wide development and use of ERAS in urology, this review has several limitations. First, the publications included in this review had a certain regional nature, among which only one was in English and the rest in Chinese, which may have potential publication bias. Second, in some of the included studies, allocation concealment, blinding methods, and specific randomization methods were not described, which may have reduced the reliability of the results. Finally, the small sample size of the studies reviewed and the poor quality of evidence limited this review.

Conclusion

In conclusion, this meta-analysis indicates that ERAS implementation is safe and effective in percutaneous nephrolithotomy and improves clinical outcomes such as operation time, nephrostomy tube entrance time, urinary catheter entrance time, complications, and length of stay without decreasing the stone-free rate. Data from these studies can be important for improving the quality of evidence so that PCNL protocols can be implemented effectively in patients.

Ethical approval

Ethical approval was not required. This is meta-analysis. PROSPERO ID: CRD42023411520.

Consent for publication

Not applicable.

Sources of funding

Not applicable.

Author contribution

L.L. and X.Y.: contributed substantially to the conception and design of the protocol; X.Y. and Y.X.: performed preliminary searches; L.L., Y.X., and Q.W.: drafted the manuscript; L.L., X.Y., and Q.W.: critically revised the manuscript for intellectual content.

Conflicts of interests disclosure

The authors declare that they have no competing interests.

Guarantor

Liang Liu.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Assistance with the study

Not applicable.

Financial support and sponsorship

Not applicable.

Presentation

Not applicable.

Acknowledgements

Not applicable.

References

[1] Turney BW, Reynard JM, Noble JG, *et al*. Trends in urological stone disease. BJU Int 2012;109:1082–7.
[2] Hesse A, Br€andle E, Wilbert D, *et al*. Study on the prevalence and incidence of urolithiasis in Germany comparing the years 1979 vs. 2000. Eur Urol 2003;44:709–13.
[3] Romero V, Akpinar H, Assimos DG. Kidney stones: a global picture of prevalence, incidence, and associated risk factors. Rev Urol 2010;12: e86–96.
[4] Scales CDJ, Smith AC, Hanley JM, *et al*. Prevalence of kidney stones in the United States. Eur Urol 2012;62:160–5.
[5] Uribarri J, Man S, Carroll JH. Thefirst kidney stone. Ann Intern Med 1989;111:1006–9.
[6] Alexander RT, Hemmelgarn BR, Wiebe N, *et al*. Kidney stones and kidney function loss: a cohort study. BMJ 2012;345:e5287.
[7] El-Zoghby ZM, Lieske JC, Foley RN, *et al*. Urolithiasis and the risk of ESRD. Clin J Am Soc Nephrol 2012;7:1409–15.
[8] Mao S, Jiang H, Wu Z, *et al*. Urolithiasis: the most risk for nephrectomy in nonrenal tumor patients. J Endourol 2012;26:1356–60.
[9] Pearle MS, Calhoun EA, Curhan GC. Urologic diseases in America project: urolithiasis. J Urol 2005;173:848–57.
[10] Tunc L, Kupeli B, Senocak C, *et al*. Pneumatic lithotripsy for large ureteral stones:is it the first line treatment? Int Urol Nephrol 2007;39:759–64.
[11] Wang Y, Jiang F, Wang Y, *et al*. Post-percutaneous nephrolithotomy septic shock and severe hemorrhage:a study of risk factors. Urol Int 2012; 88:307–10.
[12] Armitage JN, Irving SO, Burgess NA. British association of urological surgeons section of endourology. Eur Urol 2012;61:1188–93.
[13] Lai WS, Assimos D. Factors associated with postoperative infection after percutaneous nephrolithotomy. Rev Urol 2018;20:7–11.
[14] Koras O, Bozkurt IH, Yonguc T, *et al*. Risk factors for postoperative infectious complications following percutaneous nephrolithotomy:a prospective clinical study. Urolithiasis 2015;43:55–60.
[15] Kehlet H. Enhanced postoperative recovery: good from afar, but far from good? Anaesthesia 2020;75(suppl 1):e54–61.
[16] Brodner G, Pogatzki E, Van AH, *et al*. A multimodal approach to control postoperative pathophysiology and rehabilitation in patients undergoing abdominothoracic esophagectomy. Anesth Analg 1998;86:228–34.
[17] Kehlet H, Wilmore DW. Evidence-based surgical care and the evolution of fast-track surgery. Ann Surg 2008;248:189–98.
[18] Batchelor TJP, Rasburn NJ, Abdelnour-Berchtold E, *et al*. Guidelines for enhanced recovery after lung surgery: recommendations of the enhanced recovery after surgery (ERAS®) Society and the European Society of thoracic surgeons (ESTs). Eur J Cardiothorac Surg 2019;55:91–115.
[19] Chiewhatpong P, Charoenkwan K, Smithiseth K, *et al*. Effectiveness of enhanced recovery after surgery protocol in open gynecologic oncology surgery: a randomized controlled trial. Int J Gynecol Obstetr 2022;159: 568–76.
[20] Qi L, Chen K, Luo B, *et al*. Clinical application of preserving spontaneous breathing non-intubation anesthesia in thoracoscopic surgery for lung cancer under ERAS concept. Asia-Pacific J Clin Oncol 2022;18:e329–37.
[21] Stangl-Kremser J, Lambertini L, Di MF, *et al*. Enhancing recovery after major bladder cancer surgery: comprehensive review and assessment of application of the enhanced recovery after surgery guidelines. Eur Urol Focus 2022;8:1622–6.
[22] Williams SB, Cumberbatch MGK, Kamat AM, *et al*. Reporting radical cystectomy outcomes following implementation of enhanced recovery after surgery protocols: a systematic review and individual patient data meta-analysis. Eur Urol 2020;78:719–30.
[23] Brooks NA, Kokorovic A, McGrath JS, *et al*. Critical analysis of quality of life and cost-effectiveness of enhanced recovery after surgery (ERAS) for patient's undergoing urologic oncology surgery: a systematic review. World J Urol 2022;40:1325–42.

[24] Page MJ, McKenzie JE, Bossuyt PM, *et al*. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Int J Surg 2021;88: 105906.
[25] Shea BJ, Reeves BC, Wells G, *et al*. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ 2017;358:j4008.
[26] Panic N, Leoncini E, de Belvis G, *et al*. Evaluation of the endorsement of the preferred reporting items for systematic reviews and meta-analysis (PRISMA) statement on the quality of published systematic review and meta-analyses. PLoS ONE 2013;8:e83138.
[27] Higgins JPT, Green S. Cochrane handbook for systematic reviews of interventions (version 5.1. 0). The Cochrane Collaboration, 2011. http://www.cochrane-handbook.org
[28] Li Q, Wan L, Liu S, *et al*. Clinical efficacy of enhanced recovery after surgery in percutaneous nephrolithotripsy: a randomized controlled trial. BMC Urol 2020;20:162.
[29] Zhang H, Mao P, Jiang T, *et al*. Application of enhanced recovery after surgery in percutaneous nephrolithotomy. J Fujian Med Univ 2019;53: 187–90.
[30] Ou M, Li R, Lv F, *et al*. The effect of fast track surgery protocol combined with cluster nursing on postoperative outcomes in percutaneous nephrolithotomy. J Qilu Nurs 2021;27:29–30.
[31] Luo H, Chen X, Li W, *et al*. Efficacy of enhanced recovery after surgery in minimally invasive percutaneous nephrolithotomy. Chinese J Endourol 2018;12:240–3.
[32] Zhang H, Li Q, Chen W. Application of fast track surgery nursing based on evidence-based practice in percutaneous nephrolithotomy. J Qilu Nursing 2021;27:130–2.
[33] Hou Y, Bai L, Liu C, *et al*. Effect of Nursing Intervention based on FTS Concept on Postoperative Rehabilitation and Nursing Satisfaction of Patients with Upper Urinary Calculi. Chin General Practice 2018;21(z1): 418–20.
[34] Zhuang G, Yu L, Dong L, *et al*. Application of enhanced recovery after surgery on percutaneous nephrolithotomy. Chin J Front Med Sci (Electronic Version) 2017;9:12–5.
[35] Yang L, Wu X, Lai W. Application of fast track surgery nursing in percutaneous nephrolithotomy. J Qilu Nursing 2021;27:72–4.
[36] Chen M, Yan X, Wang H, *et al*. Influence of fast track surgery combined with postoperative predictive nursing on the prognosis condition of patients undergoing percutaneous nephrolithotomy. China Modern Med 2021;28:212–5.
[37] Li Y, Yin Q, Ma X. ERAS Concept in Perioperative Nursing of Tubelss mPCNL:a clinical study. J Urol Clin (Electronic Version) 2020;12:42–5.
[38] Shen L, Yang F, Long Y, *et al*. Application of enhanced recovery after surgery in the perioperative period of urolithiasis. Chinese Community Doctors 2020;36:17–8.
[39] Tan L. Rapid rehabilitation surgical nursing for patients after percutaneous nephrolithotomy holmium laser lithotripsy. China Med Pharmacy 2019;9:153–6.
[40] Li W. The effect of fast track surgery nursing in postoperative rehabilitation of upper urinary stone patients. Chinese J Rural Med Pharmacy 2019;26:60–1.
[41] Ma Y, Chen D, Chang F. Application of fast track surgery concept in perioperative nursing of percutaneous nephrolithotomy. J Bengbu Med College 2018;43:547–9.
[42] Zhou H, Liu J. Efficacy analysis of the clinical application of ERAS nursing concept in patients with percutaneous nephrolithotomy. Chinese J General Practice 2017;15:2145–7.
[43] Wei Z. Application of FTS concept in perioperative nursing of percutaneous nephrolithotomy. Chinese Community Doctors 2017;33:133–4.
[44] Mao Y, Chen J, Luo M, *et al*. Application of fast track surgery concept in the treatment of percutaneous nephrolithotomy during the perioperative period. Chinese J Woman Child Health Res 2017;28(S3):612–3.
[45] Li F, Zhang M, Feng Q, *et al*. Application of fast track surgery concept to the nursing of patients undergoing superminimally invasive percutaneous nephrolithotomy. Int J Nurs 2017;36:1430–3.
[46] Yang J. Observation of complications and nursing countermeasures after percutaneous nephrolithotomy. China Practical Med 2015;10:254–5.
[47] Lin Y, Qiu J, Lin N, *et al*. Rapid rehabilitation surgical nursing for patients after percutaneous nephrolithotomy holmium laser lithotripsy. Int J Nursing 2015;34:2437–9.
[48] Ma L, Chen J, Li X. The effect of fast-track surgery on anxious in percutaneous nephrolithotomy. Guangdong Med J 2014;35:1969–70.
[49] Dong C, Fu W, Fu Y, *et al*. Application of fast-track surgery in perioperative nursing of patients with percutaneous nephrolithotomy lithotomy with upper-pole access. Chinese J Modern Nursing 2014;20:2102–5.
[50] Qiao G, Wang Y, Xing L, *et al*. Fast-track surgery in percutaneous nephrolithotomy nursing application. Chinese J Endourol (Electronic Edition) 2013;7:41–3.
[51] Cai J, Wang Z, Gao X, *et al*. Application effect of nursing intervention based on ERAS nursing concept in patients with renal stone surgery. J Gannan Med Univ 2020;40:964–6.
[52] Chen X, Cai M, Qiu L, *et al*. Application of fast track surgery concept plus traditional Chinese medicine nursing in the treatment of percutaneous nephrolithotomy. Chinese J Geriatric Care 2014;12:96–8.
[53] Turk C, Neisius A, Petrik A, *et al*. European Association of Urology (EAU). Guidelines on urolithiasis 2020. Accessed August 16, 2021. https://uroweb.org/guideline/urolithiasis/
[54] Khan SR, Pearle MS, Robertson WG, *et al*. Kidney stones. Nat Rev Dis Primers 2016;2:16008.
[55] Assimos D, Krambeck A, Miller NL, *et al*. Surgical Management of Stones: American Urological Association/Endourological Society Guideline, PART II. J Urol 2016;196:1161–9.
[56] Seitz C, Desai M, Hacker A, *et al*. Incidence, prevention, and management of complications following percutaneous nephrolitholapaxy. Eur Urol 2012;61:146–58.
[57] El-Nahas AR, Shokeir AA, El-Assmy AM, *et al*. Post-percutaneous nephrolithotomy extensive hemorrhage: a study of risk factors. J Urol 2007;177:576–9.
[58] Guddeti RS, Hegde P, Chawla A, *et al*. Super-mini percutaneous nephrolithotomy (PCNL) vs standard PCNL for the management of renal calculi of <2 cm: a randomised controlled study. BJU Int 2020;126: 273–9.
[59] Wilmore DW, Kehlet H. Management of patients in fast track surgery. BMJ (Clinical research ed) 2001;322:473–6.
[60] Noba L, Rodgers S, Doi L, *et al*. Costs and clinical benefits of enhanced recovery after surgery (ERAS) in pancreaticoduodenectomy: an updated systematic review and meta-analysis. J Cancer Res Clin Oncol 2023;149: 6639–60.
[61] Gao B, Chen J, Liu Y, *et al*. Efficacy and safety of enhanced recovery after surgery protocol on minimally invasive bariatric surgery: a meta-analysis. Int J Surg 2023;109:1015–28.
[62] Edwards PK, Mears SC, Lowry BC. Preoperative education for hip and knee replacement: never stop learning. Curr Rev Musculoskelet Med 2017;10:356–64.
[63] Nikniaz Z, Somi MH, Nagashi S, *et al*. Impact of early enteral nutrition on nutritional and immunological outcomes of gastric cancer patients undergoing gastrostomy: a systematic review and meta-analysis. Nutrition Cancer-An Int J 2017;69:693–701.
[64] Wollin DA, Lipkin ME. Emerging technologies in ultrasonic and pneumatic lithotripsy. Urol Clin North Am 2019;46:207–13.
[65] Karalar M, Tuzel E, Keles I, *et al*. Effects of parenchymal thickness and stone density values on percutaneous nephrolithotomy outcomes. Med Sci Monitor 2016;22:4363–8.
[66] Sac W, Rizkala E, Liu X. Tubeless percutaneous nephrolithotomy: outcomes with expanded indications. Int Braz J Urol 2014;40:204–11.
[67] Jiang ZW, Li N, Li JS. The concept and clinical significance of fast tract surgery. Chin J Surg Pract 2007;27:131–3.
[68] Etemadian M, Soleimani MJ, Haghighi R, *et al*. Does bleeding during percutaneous nephrolithotomy necessitate keeping the nephrostomy tube? A randomized controlled clinical trial. Urol J 2011;8:21–6.
[69] Frees SK, Aning J, Black P, *et al*. A prospective randomized pilot study evaluating an ERAS protocol versus a standard protocol for patients treated with radical cystectomy and urinary diversion for bladder cancer. World J Urol 2018;36:215–20.
[70] Singh PM, Panwar R, Borle A, *et al*. Efficiency and safety effects of applying eras protocols to bariatric surgery: a systematic review with meta-analysis and trial sequential analysis of evidence. Obes Surg 2017; 27:489–501.
[71] Offodile AC, Gu C, Boukovalas S, *et al*. Enhanced recovery after surgery (ERAS) pathways in breast reconstruction: systematic review and meta-analysis of the literature. Breast Cancer Res Treat 2019;173:65–77.