ARTICLE IN PRESS

EUROPEAN UROLOGY FOCUS xxx (xxxx) xxx

available at www.sciencedirect.com
journal homepage: www.europeanurology.com/eufocus

Review – Stone Disease

Suction in Percutaneous Nephrolithotripsy: Evolution, Development, and Outcomes from Experimental and Clinical studies. Results from a Systematic Review

Virgilio De Stefano [a,], Daniele Castellani [a], Bhaskar K. Somani [b], Carlo Giulioni [a], Angelo Cormio [a], Andrea Benedetto Galosi [a], Kemal Sarica [c], Xavier Glover [d], Rodrigo Donalisio da Silva [e], Yiloren Tanidir [f], Nariman Gadzhiev [g], Giacomo Maria Pirola [h], Prashant Motiram Mulawkar [i,j,k], Jeremy Yuen-Chun Teoh [l], Manoj Monga [m], Thomas R.W. Herrmann [n], Vineet Gauhar [o]*

[a] *Urology Unit, Azienda Ospedaliero-Universitaria delle Marche, Università Politecnica delle Marche, Ancona, Italy;* [b] *Department of Urology, University Hospitals Southampton, NHS Trust, Southampton, UK;* [c] *Department of Urology, Dr. Lutfi Kirdar Kartal Research and Training Hospital, Istanbul, Turkey;* [d] *Urology, University of Colorado Denver School of Medicine, Aurora, CO, USA;* [e] *Department of Urology, University of Colorado, Denver, CO, USA;* [f] *Department of Urology, Marmara University School of Medicine, Istanbul, Turkey;* [g] *Department of Urology, Saint-Petersburg State University Hospital, Petersburg, Russia;* [h] *Urology Unit, San Giuseppe Hospital, Multimedica Group, Milan, Italy;* [i] *Department of Urology, Tirthankar Super Speciality Hospital, Akola, India;* [j] *Professor of Urology, GMC & SSH, Akola, India;* [k] *University of Edinburgh, Edinburgh, UK;* [l] *S.H.Ho Urology Centre, Department of Surgery, The Chinese University of Hong Kong, Hong Kong, China;* [m] *Department of Urology, UC San Diego School of Medicine, La Jolla, CA, USA;* [n] *Department of Urology, Kantonspital Frauenfeld, Spital Thurgau AG, Frauenfeld, Switzerland;* [o] *Department of Urology, Ng Teng Fong General Hospital, Singapore, Singapore*

Article info

Article history:
Accepted June 27, 2023

Associate Editor: Christian Gratzke

Keywords:
Kidney calculi
Percutaneous nephrolithotomy
Suction
Sheath
Lithotripsy, Laser

Abstract

Context: Controversy exists regarding the therapeutic benefit of suction use during percutaneous nephrolithotripsy (PCNL).
Objective: To review and highlight the options available in the use of suction for PCNL, and to discuss their strengths and limitations.
Evidence acquisition: A systematic literature search was performed using Scopus, EMBASE, and PubMed. Thirty four studies were included. There was one ex vivo study. Among clinical studies, 24 used a vacuum/suctioning sheath and nine a handpiece suction device/direct-in-scope suction. The suction technique was employed in standard, mini-PCNL, supermini-PCNL, and enhanced supermini PCNL techniques.
Evidence synthesis: Handpiece suction devices demonstrated better safety and efficiency in treating large stones than nonsuction PCNL and in a much shorter time. Trilogy and ShockPulse-SE were equally effective, safe, and versatile for standard PCNL and mini-PCNL. The heavier handpiece makes Trilogy less ergonomically friendly. Laser suction handpiece devices can potentiate laser lithotripsy by allowing for better laser control with simultaneous suction of small fragments and dust. Integrated suction-based sheaths are available in reusable and disposable forms for mini-PCNL only. Mini-PCNL with suction reported superior outcomes for operative time and stone-free rate to mini-PCNL. This also helped minimize infectious complications by a combination of intrarenal pressure reduction and faster aspiration of irrigation fluid reducing the risk of sepsis, enhance intraoperative vision, and improve lithotripsy efficiency, which makes it a very attractive evolution for PCNL.

* Corresponding author. Urology Unit, Azienda Ospedaliero-Universitaria delle Marche, Università Politecnica delle Marche, Via Conca 71, 60126 Ancona, Italy. Tel. +393889294815.
E-mail address: virgilio.destefano@gmail.com (V. De Stefano).

https://doi.org/10.1016/j.euf.2023.06.010

Please cite this article as: V. De Stefano, D. Castellani, B.K. Somani et al., Suction in Percutaneous Nephrolithotripsy: Evolution, Development, and Outcomes from Experimental and Clinical studies. Results from a Systematic Review, Eur Urol Focus (2023), https://doi.org/10.1016/j.euf.2023.06.010

Conclusions: Suction devices in PCNL are reforming the way PCNL is being done. Adding suction to mini-PCNL reduces infectious complications and improves the stone-free rate. Our review shows that despite the limited evidence, suction techniques appear to improve PCNL outcomes.

Patient summary: In this review, we looked at the intra- and perioperative outcomes of percutaneous nephrolithotripsy (PCNL) with the addition of suction. With better stone fragmentation and fewer postoperative infections, this technology is very useful particularly for mini-PCNL.

1. Introduction

Percutaneous nephrolithotomy (PCNL) is considered the gold standard minimally invasive treatment for renal stones larger than 2 cm in diameter [1,2]. Since its introduction, PCNL has evolved in all aspects from access to exit strategy [3], with efforts to shift postoperative care to ambulatory surgery [4]. Miniaturization has been the key in minimizing morbidity but raises concerns for higher intrarenal pressure (IRP), and efforts to cope with this and related morbidities have emerged [5]. One important innovation has been the addition of suction to PCNL. Studies demonstrated that suction might help decrease procedural time and IRP, and facilitate a decrease in both infection and bleeding-related complications [6].

New lithotripters have evolved, combining ultrasonic or ballistic energy alongside suction via the lithotripsy probe to aid in simultaneous fragment extraction during lithotripsy, allowing for better vision and improved stone clearance [7–9]. Efforts have been made to decrease the invasiveness of PCNL with the advent of smaller and suction-integrated access sheaths that are safe and efficacious even in pediatric populations [10,11].

Previous studies showed that a good outflow can be obtained in mini-PCNL using the purging or vacuum effect since this ensures low IRP [12]. The purging effect allows for efficient fragment extraction, minimizing subsequent reinterventions for residual fragments [13]. The adoption of high-power lasers, stone dust evacuation techniques, new suction-integrated nephrostomy access sheaths, and handpieces is changing the way modern-day PCNL is performed [14–17].

We aim to review and highlight the options available, discuss their strengths and limitations, and provide an overall summary chart of options on the current literature for suction in PCNL as it is being used in day-to-day clinical practice (Fig. 1).

2. Evidence acquisition

2.1. Literature search

We performed a systematic review evaluating the influence of suction on the outcomes of PCNL for kidney stones. A systematic literature search was performed on January 4, 2023, using Scopus, EMBASE, and PubMed. The following terms and Boolean operators were used: (suction OR vacuum OR aspiration OR Amplatz sheath) AND (PCNL or percutaneous nephrolithotomy OR percutaneous) AND (kidney stones OR urolithiasis OR renal stones).

2.2. Selection criteria

Only English papers were included. Both pediatric and adult studies were accepted. Preclinical studies were also included. Duplicate studies, case reports, letters to the editor, and meeting abstracts were excluded.

2.3. Study screening and selection

All retrieved papers were screened by two independent authors through Covidence Systematic Review Management (Veritas Health Innovation, Melbourne, Australia). A third reviewer resolved discrepancies. The full text of the screened papers was selected if found relevant to the purpose of the present review.

3. Evidence synthesis

3.1. Literature screening

The literature search found 994 studies. After deleting 257 duplicates, 737 studies remained for screening against the title and abstract. Among the latter, 625 papers were excluded because these were found to be irrelevant to the purpose of this review. The remaining 112 full-text papers were additionally assessed for eligibility. One full-text paper was retrieved from other sources. Seventy-nine papers were excluded. Finally, 34 studies were eligible and included [7–11,14–42]. Figure 2 summarizes the flow diagram of the literature search.

3.2. Study characteristics

There was one ex vivo study [9]. Among clinical studies, there were ten retrospective [14–19,28,29,31,38] and 23 prospective studies [7,8,10,11,20–27,30,32–37,39–42], and five among the latter were randomized [20,22,24,39,42]. One study was performed on children [10].

Concerning the type of PCNL in clinical studies, there were six studies employing standard PCNL [7,8,14,18,27,29], 19 mini-PCNL [10,15–17,19–22,24–26,28,30,31,34,36,38,39,41], two both mini-PCNL and standard PCNL [32,37], and six supermini-PCNL [11,23,33,35,40,42].

Regarding suction techniques, 24 studies used a vacuum/suctioning sheath [10,11,14–17,19,20,22–26,29,31,33–36,38–42], six studies used EMS LithoClast Trilogy [7,8,21,32,37] or Master [27], one study used a laser suction

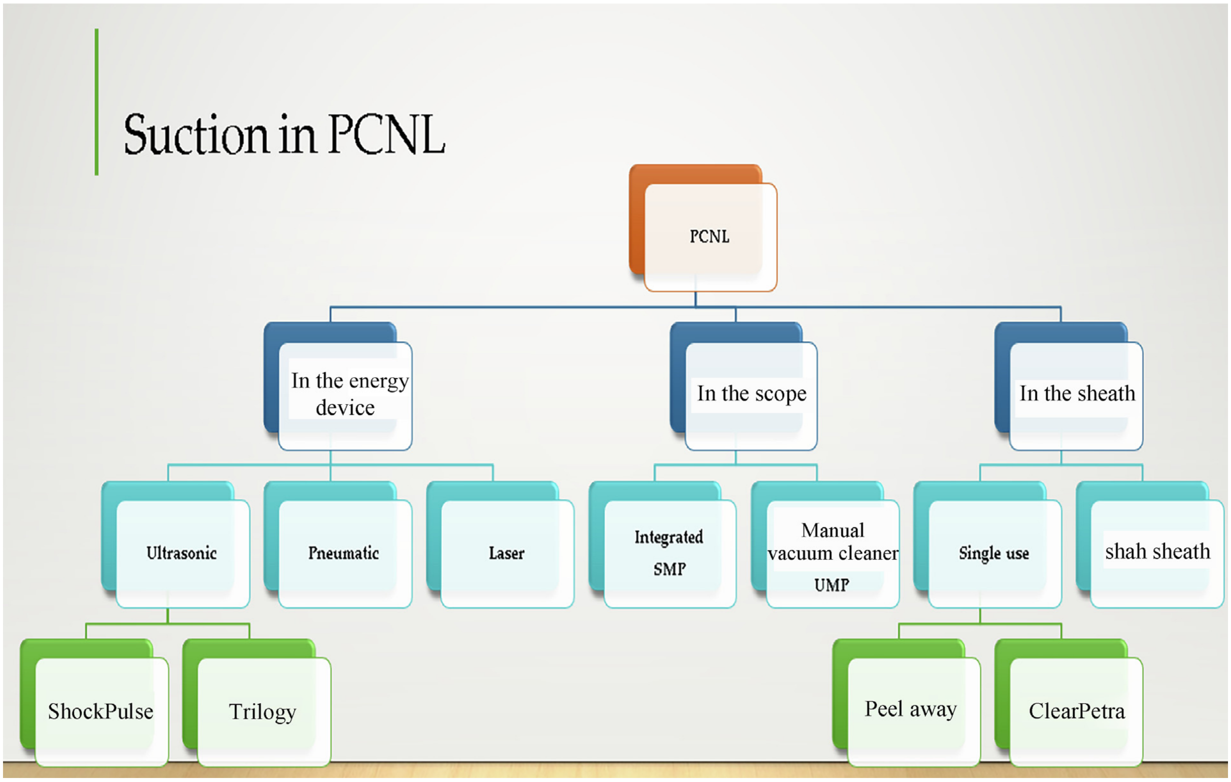

Fig. 1 – Flowchart for available mechanisms of suction in PCNL. PCNL = percutaneous nephrolithotomy; SMP = supermini percutaneous nephrolithotomy; UMP = ultramini percutaneous nephrolithotomy.

handpiece [18], one study used a suction catheter inside a sheath [29], and the remaining one employed a direct in-scope suction technique [30]. Tables 1–3 show the study characteristics according to the suction method.

3.3. Handpiece suction devices

Six clinical studies analyzed the efficiency, efficacy, and safety of EMS LithoClast Trilogy for PCNL [7,8,21,32,37]. These included standard PCNL and mini-PCNL. Sabnis et al. [32] analyzed the device in mini-PCNL and standard PCNL in patients with a mean stone size of 24.1 ± 12.5 mm. The authors reported no complications related to the device as well as no device failure, concluding that the trifecta effect, which is the use of ultrasonic, electromagnetic impact energy, and suction, was safe and efficient in treating large stones in a shorter time duration. Thakare et al. [8] performed a prospective multicentric study to evaluate the safety and efficiency of the LithoClast Trilogy. A total of 157 procedures were performed, and evaluation was based on stone clearance rate, postoperative stone-free rate (SFR), and surgeon satisfaction with the device. The authors concluded that the device was safe, effective, and efficient in managing large renal stones when all aforementioned metrics were considered. Ergonomically, the weight of the handpiece makes this device less favorable than other devices, as also reported in other studies [37].

LithoClast Trilogy has always been pitted against the ShockPulse-SE lithotripter (Olympus, Center Valley, PA, USA) widely adopted since its introduction in 2017. ShockPulse-SE has a unique ultrasonic generator that produces a ballistic force (300 Hz), and in an in vitro study, Carlos and colleagues [43] demonstrated superior stone clearance to the LUS-2 (Olympus), Cyber-Wand (Olympus), and LithoClast (Nyon, Switzerland) devices. In a prospective multi-institutional randomized trial comparing the outcomes of PCNL using these two novel lithotripters, both devices were highly efficient at removing large renal stones. Fewer device malfunctions were noted with LithoClast Trilogy [44].

When performing PCNL, there is no consensus on which energy sources should be used for lithotripsy despite lasers being associated with a significantly lower SFR than non-laser devices in a recent meta-analysis [45].

Current literature shows that authors are using laser energy or combined ultrasonic and ballistic energy with suction for such procedures. With the recent availability of high-power lasers such as the thulium fiber laser (TFL), dusting and fragmenting of larger stones have become more feasible. However, simultaneous laser lithotripsy and suction through the handpiece have not yet been made possible. To enable suction while performing laser lithotripsy, a handpiece, called the laser suction handpiece (LSH), was developed to simultaneously control the laser fiber and provide suction of stone fragments or dust through the handpiece [24]. Bar-Yaakov et al. [18] performed a study comparing the LSH with a traditional ultrasonic lithotripter to assess operative time, length of stay, and SFR. They reported that the LSH performed better than ultrasonic lithotripsy in these aspects; however, the data were not statistically significant, likely due to the small sample size of 40 patients. Despite this result, the similarity in outcomes

Please cite this article as: V. De Stefano, D. Castellani, B.K. Somani et al., Suction in Percutaneous Nephrolithotripsy: Evolution, Development, and Outcomes from Experimental and Clinical studies. Results from a Systematic Review, Eur Urol Focus (2023), https://doi.org/10.1016/j.euf.2023.06.010

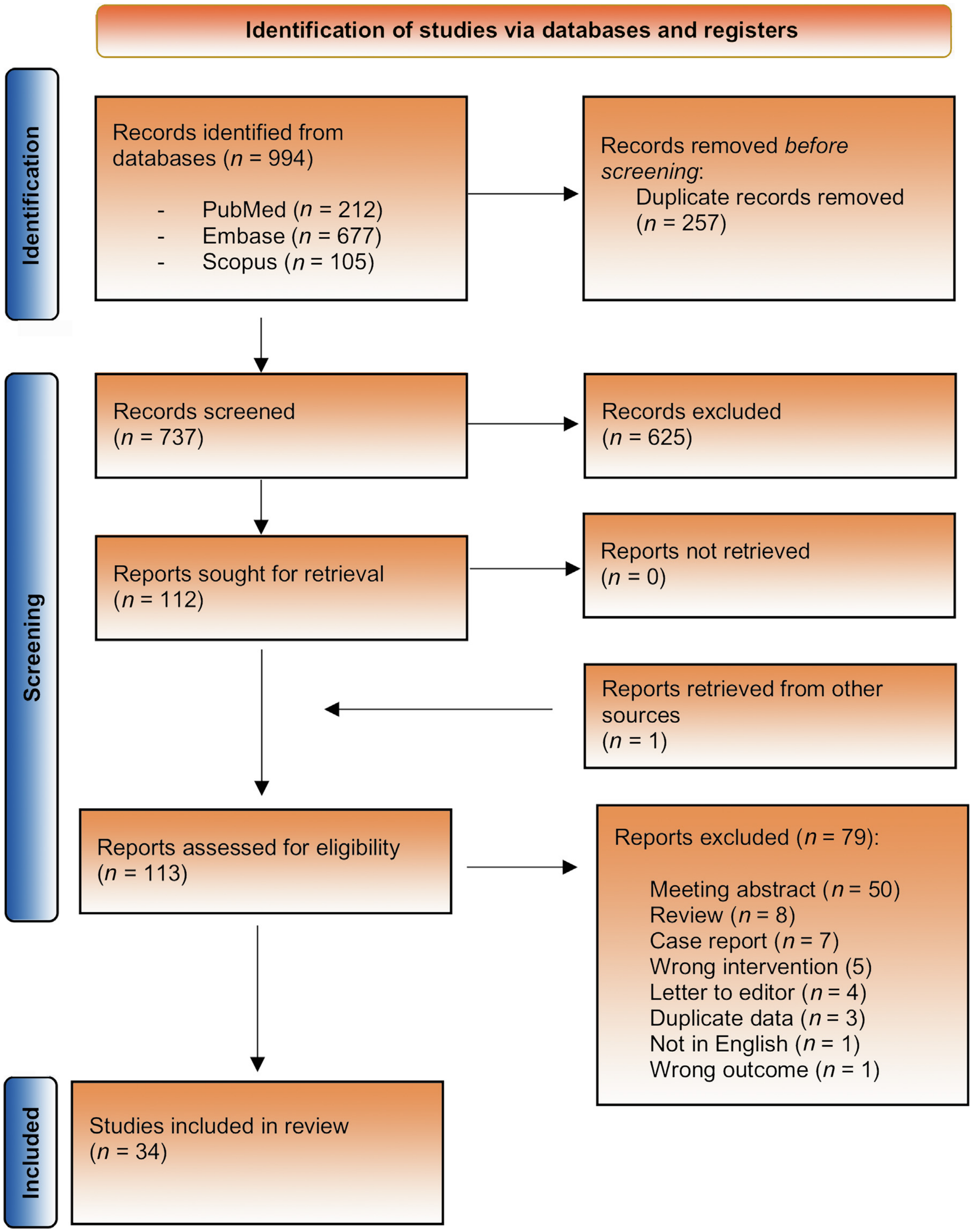

Fig. 2 – Flow diagram of literature search.

and subjective surgeon satisfaction show the potential for high-powered lasers as a sole energy source for PCNL. A study by Reddy et al. [41] showed in a cohort of 110 patients that most fragments produced by holmium laser lithotripsy during PCNL were <1 mm and concluded that stone dusting with a holmium laser may have the potential for improving SFR.

Of note, two studies in this review used handheld suction devices that were fashioned using common operative instruments. Cuellar and Averch [14] first described in 2004 the use of a Sure-Seal endoscopic valve (Applied Medical, Rancho Santa Margarita, CA, USA) attached to suction with a holmium laser fiber passed through its channel. The device was used for both lithotripsy and suction of

Please cite this article as: V. De Stefano, D. Castellani, B.K. Somani et al., Suction in Percutaneous Nephrolithotripsy: Evolution, Development, and Outcomes from Experimental and Clinical studies. Results from a Systematic Review, Eur Urol Focus (2023), https://doi.org/10.1016/j.euf.2023.06.010

Table 1 – Characteristics of studies using vacuum/suctioning sheath as the suctioning method

Author (year)	Country	Type of study	Aim of the study	Group(s)	Stone size (mm)	Suction device	Size tract	SFR definition	SFR	Surgical time (min)	Complications	Role of preoperative UTI in outcomes	Conclusions
Zhong (2021) [42]	China	RCT	To compare eSM-PCNL and M-PCNL, and to test the low IRP and high stone removal efficiency in eSM-PCNL	47 M-PCNL 46 eSM-PCNL	3.28 ± 0.93 3.27 ± 0.85	Peel-away sheath for M-PCNL Multifunction suction sheath for eSM-PCNL	18 Fr	Absence of residual fragments >2 mm on KUB on the 2nd postoperative day and at CT scan 2 wk after surgery	41 (87.2%) 42 (91.3%)	66.9 ± 19.4 51.7 ± 14.4	CD I 10.6% vs 13% CD II 14.8% vs 6.5 Transfusion 2.1 % vs 2.1 Postoperative fever 12.7% vs 4.3%	Not reported	eSM-PCNL is safe in the management of 2–5 cm renal stone. It can keep lower IRP and higher stone removal efficiency when compared with conventional Chinese mini-PCNL
Cuellar (2004) [14]	USA	Retrospective	To evaluate the feasibility of HL use in PCNL with the assistance of a unique suction device	71 PCNL	32.5 mm with HL 21.5 mm without HL	Suction tubing placed on the Sure-seal	Not reported	Absence of residual fragments at noncontrast CT scan 1 d after surgery	83% with HL 73% without HL	167 with HL 104 without HL	14% with HL and 15% without HL	Not reported	HL can be an efficient and successful lithotripsy device in PCNL
Huang (2016) [39]	China	RCT	To explore the value of patented suctioning sheath-assisted M-PCNL	91 Patented sheath-assisted M-PCNL 91 M-PCNL	16.7 ± 5.8 mm 15.1 ± 6.3 mm	A patented sheath connected to a vacuum aspiration machine	16 Fr	Absence of residual fragments >4 mm at KUB or CT scan in patients with radiolucent stones, 1 mo after surgery	96.7% 73.6%	54.5 ± 14.5 70.2 ± 11.7	Fever: 10% vs 25% Bleeding amount ≥800 ml: 0 vs 15% Renal pelvic perforation: 1% vs 7%	Not reported	M-PCNL with the patented suctioning sheath was safe and effective
Zeng (2016) [33]	China	Prospective	To assess safety and efficiency of SM-PCNL with suction	146 SM-PCNL using HL or pneumatic energy	22	Modified sheath with a suction/ evacuation function	10–14 Fr	Absence of residual fragments >2 mm at KUB and noncontrast CT scan 1 d and 3 mo after surgery	At 3 mo: 95.8%	46.6	Fever (CD I): 36.4% Fever (CD II): 36.4% Hematuria: 9%	Not reported	SM-PCNL with suction-evacuation system is safe and effective for stones <25 mm
Zeng (2017) [23]	China	Prospective	To present a novel miniaturized endoscopic system and describe a step-by-step guide for successful implementation of SM-PCNL	59 SM-PCNL using HL or pneumatic energy	24 ± 8	Irrigation-suction sheath connected to an irrigation pump and a negative pressure aspirator	14 Fr	Absence of residual fragments at low-dose CT, with 2-mm section thickness, on 1st postoperative day	91.5%	32.9 ± 23	CD I: 5%	Not reported	SM-PCNL with irrigation-suction sheath is safe, feasible, and effective for stones <3 cm, with great SFR, and low OT and blood loss

(continued on next page)

Please cite this article as: V. De Stefano, D. Castellani, B.K. Somani et al., Suction in Percutaneous Nephrolithotripsy: Evolution, Development, and Outcomes from Experimental and Clinical studies. Results from a Systematic Review, Eur Urol Focus (2023), https://doi.org/10.1016/j.euf.2023.06.010

Table 1 (*continued*)

Author (year)	Country	Type of study	Aim of the study	Group(s)	Stone size (mm)	Suction device	Size tract	SFR definition	SFR	Surgical time (min)	Complications	Role of preoperative UTI in outcomes	Conclusions
Zeng (2017) [11]	China	Prospective	To compare the procedural and clinical results of SM-PCNL with the use of first and new-generation devices	71 1st G SM-PCNL 85 2nd G SM-PCNL	1st generation SM-PCNL: 25 ± 6 2nd G SM-PCNL: 24 ± 10	In 2nd generation, sheath connected to an irrigation pump and a negative pressure aspirator	14 Fr	Absence of residual fragments at low-dose CT, with 2-mm section thickness, on 1st postoperative day	1st generation SM-PCNL: 96.4% 2nd G SM-PCNL: 97.2%	1st generation SM-PCNL: 50.5 ± 27.6 2nd G SM-PCNL: 39.3 ± 29.6	Fever (CD I): 4.7% in 1st and 2.8% in 2nd generation Fever (CD II): 3.5% in 1st and 4.2% in 2nd Bleeding managed by angioembolization: 1.2% in 1st CD IV: 2.4% in 1st	Not reported	2nd generation SM-PCNL with irrigation/suction system is associated with better irrigation and shorter operative time
Shah (2017) [35]	India	Prospective	To describe a new technique of PCNL termed "Superperc" that utilizes suction to remove all the fragments and maintain one-way flow	52 Pediatric ureteroscope as nephroscope with HL	19.1 ± 7.1	Superperc specially designed sheath (Shah sheath) with suction mechanism (suction master + suction cannula)	10/12 Fr	Absence of residual fragments at postoperative x-ray and at US/NCCT 1 mo after surgery	96.5%	40.98 ± 12.09	Fever: 5.8% Significant hematuria: 1.9%	Not reported	Superperc technique using Shah sheath with suction mechanism is associated with a better SFR
Alsmadi (2018) [40]	China	Retrospective	To evaluate the influence of SM-PCNL on IRP in vivo	74 SM-PCNL	306.50 ± 210.65 mm^2	Irrigation suction sheath	14 Fr	Absence of residual fragments at KUB or US on 1st postoperative day and at NCCT 1 mo after surgery	90.5% at 1 mo	39.28 ± 24.40	Fever: 5.4% Hematuria: 2.7%	Not reported	IRP remains low during SM-PCNL via 14 Fr irrigation-suction sheath
Du (2018) [24]	China	RCT	To investigate the safety, efficacy, and practicability of M-PCNL with the aid of a patented irrigation clearance system in treating renal staghorn stones	311 Suctioning M-PCNL 304 Traditional M-PCNL	Staghorn stones	Patented suction sheath	16–18 Fr	Absence of residual fragments >4 mm at KUB or CT 3–5 d after surgery	81% vs 74%	56 ± 32 81 ± 41	Blood transfusion: 3.5% vs 4.6% Fever: 8% vs 14.8% Need for an additional procedure: 12.2% vs 16.1%	Not reported	Suctioning M-PCNL has fewer complications than traditional M-PCNL

Table 1 (*continued*)

Author (year)	Country	Type of study	Aim of the study	Group(s)	Stone size (mm)	Suction device	Size tract	SFR definition	SFR	Surgical time (min)	Complications	Role of preoperative UTI in outcomes	Conclusions
Zhu (2019) [17]	China	Retrospective	To compare the treatment outcomes of suctioning M-PCNL and traditional M-PCNL for staghorn renal stones	256 M-PCNL with SENS 256 M-PCNL with no suction	Staghorn stones	Modified sheath connected to negative vacuum aspiration machine	20 Fr	Absence of residual fragments at KUB or NCCT 3–5 d after surgery	78.5 % after one session	106.2 ± 18.4	Fever (CD I): 19 UTI (CD II): 9 Blood transfusion :7 Hydrothorax: 1 Prolonged urine leakage: 1 Selective angioembolization: 3 Septic shock: 3	Suctioning M-PCNL has been reported to be safe and efficient for treating renal stones in patients with a UTI and conferred a decreased risk of septic shock	M-PCNL with SENS for staghorn stones is associated with a better SFR and a lower number of complications
Chen (2019) [31]	China	Retrospective	To compare FURS versus M-PCNL in treating renal stones 2–3 cm in size	45 M-PCNL 46 FURS	20–30 mm	suctioning stone clearance sheath	16 Fr	Absence of residual fragments at KUB 4 wk after surgery	95.51% (after 1 mo)	56.23 ± 28.35	Transfusion: 6.7% Fever: 6.6% Renal artery embolization: 4.4%	Not reported	M-PCNL guaranteed similar SFR to FURS, although the latter determined fewer complications and less bleeding
Lai (2020) [20]	China	RCT	To investigate the safety and efficacy of M-PCNL combined with vacuum-assisted access sheath in the treatment of obstructive stones	Group A: 38 M-PCNL with PAAS Group B: 38 M-PCNL with VAAS	20.2 ± 6.5 in group A 23.4 ± 7.3 in group B	1. Vacuum-assisted access sheath with irrigation pump 2. PAAS	18 Fr	Absence of residual fragments at low-dose NCCT 1 and 30 d after surgery	After 1 mo: 86.8% group A; 94.4% group B	70.4 ± 14.83 (A) 56.3 ± 19.83 (B)	Fever: 21.1% (A); 13.2% (B) Blood transfusion: 2.7% in group A and group B Nephrostomy tube retention time extend: 2.7% in group A and group B	Not reported	One-staged M-PCNL combined with VAAS is a safe and simple practical method for patients with obstructive stones
Lai (2020) [15]	China	Retrospective	To assess the safety and efficacy of a novel VAAS in M-PCNL	Group 1: 75 M-PCNL with VAAS Group 2: 75 M-PCNL with PAAS	Group 1: 27.8 (6.3) Group 2: 25.3 (4.5),	1. Vacuum-assisted access sheath 2. PAAS	18 Fr	Absence of residual fragments at low-dose NCCT 1 d and 3 mo after surgery	97.3% vs 98.6%	Group 1: 32 ± 9.6 Group 2: 46.2 ± 11.8	Fever (>38°C) 8% vs 20% UTI (CDII): 2.7% for both Blood transfusion: 2.7% vs 1.3% Collecting system perforation: 1.3 vs 2.7% Sepsis: 1.3% only in	Not reported	Combining VAAS with high-power HL in M-PCNL significantly improves the efficiency of stone retrieval with low IRP

(continued on next page)

Table 1 (*continued*)

Author (year)	Country	Type of study	Aim of the study	Group(s)	Stone size (mm)	Suction device	Size tract	SFR definition	SFR	Surgical time (min)	Complications	Role of preoperative UTI in outcomes	Conclusions
											PAAS group		
Xu (2020) [22]	China	RCT	To compare the safety and efficacy of using a conventional nephrostomy sheath versus a new access sheath with suction and evacuation functions in M-PCNL for the treatment of staghorn stones	30 M-PCNL with SENS 30 M-PCNL with CNS	SENS group: 42 ± 1.0	SENS connected to a negative pressure aspirating system (ClearPetra)	20 Fr	Absence of residual fragments >4 mm at KUB or CT 1 d and 3 mo after surgery	SENS group: 90%	SENS group: 64.3 ± 29.1	CD I: 26.7% CD II: 26.7% CD IIIa: 3.3%	Not reported	M-PCNL with SENS has better efficacy, decreased surgery-related complications, and better SFR
Gökce (2021) [26]	Turkey	Prospective	To evaluate the effects of location of the tip of percutaneous sheath and nephroscope in the collecting system together with active aspiration on the IRP during M-PCNL	20 M-PCNL	27.9 ± 7.1 mm	Metallic sheath with active aspiration	16 Fr	No residual fragments at the end of surgery	100%	Not reported	Transient hematuria: 1 case	Not reported	Active aspiration significantly lowers the IRP regardless of the location of the sheath or nephroscope
Holst (2021) [19]	USA	Retrospective	To evaluate the outcomes of patients who underwent M-PCNL	46 M-PCNL	21.32 ± 16.75 mm	Vacuum technique access sheath	17.5 Fr	Absence of residual fragments at postoperative CT	43.5%	117.8	Within 30 d: 21% Within 60 d: 13%	Not reported	M-PCNL cases report acceptable outcomes comparable with both RIRS and standard PCNL
Shah (2021) [36]	India	Prospective	To report the safety and efficacy of M-PCNL with suction attached to sheath combined with TFL	54 M-PCNL with TFL	18.32 ± 6.37	Sheath connected to a negative pressure suction machine (Shah sheath)	18 Fr	Absence of residual fragments at KUB/CT 48 h and 1 mo after surgery	100%	39.85 ± 20.52	UTI (CD II): 61.1%	Not reported	Use of sheath with a suction system is a safe and effective modality for lithotripsy in M-PCNL
Reddy (2021) [41]	India	Prospective	Reporting the size distribution of fragments formed during HL lithotripsy	110 M-PCNL with HL-M	17.5 ± 8.9	Access sheath with a suction port attached to a negative pressure aspirator (ClearPetra sheath)	18 Fr	No residual fragments of any size at noncontrast CT within 48 h after the procedure	77.3%	38.55 ± 13.48	UTI (CD II): 3.6%	Not reported	Use of suction and high-power HL-M improved SFR

Table 1 (*continued*)

Author (year)	Country	Type of study	Aim of the study	Group(s)	Stone size (mm)	Suction device	Size tract	SFR definition	SFR	Surgical time (min)	Complications	Role of preoperative UTI in outcomes	Conclusions
Wu (2021) [16]	China	Retrospective	To compare DS vacuum suction M-PCNL with vacuum-assisted M-PCNL	117 M-PCNL with DS or vM-PCNL using HL	32.60 ± 8.91 in DS M-PCNL group 31.94 ± 11.94 in vM-PCNL group	DS with negative pressure vacuum suction system (ClearPetra)	20 Fr	No residual fragments at KUB on postoperative day 1 and at KUB and US 1 mo after treatment	DS M-PCNL group: 93.8% vM-PCNL group: 89.1%	DS M-PCNL group: 35.78 ± 7.77 vM-PCNL group: 44.56 ± 13.19	Fever (CD II): 6%	Not reported	DS M-PCNL is safe and effective, with better efficiency of stone extraction and decrease of infectious complications
Berrettini (2021) [10]	Italy	Prospective	To report experience in the use of a semi–closed-circuit vM-PCNL system in pediatric patients	12 M-PCNL	Median 28 mm (range 14 ± 53 mm)	Nephrostomy sheath connected to the ClearPetra system	16 Fr	No residual fragments at US and KUB 4 wk after surgery	80%	117 ± 104	Fever: 33%	Not reported	This system is a safe and effective approach to treat complex kidney stones with a satisfactory SFR
Zanetti (2021) [34]	Italy	Prospective	To describe vM-PCNL with 16Ch ClearPetra sheath, to evaluate its outcomes, and to analyze IRP fluctuations during surgery	122 vM-PCNL with HL	Median total stone volume (IQR), 1.92 (1–3.1) cm^3	ClearPetra system with a Y-shaped nephrostomy sheath connected to a vacuum system	16 Fr	Absence of residual fragments larger than 4 mm at the CT scan or US 1–3 mo after surgery.	87%	90	CD I: 11.5% CD II: 8.2% CD IIIa: 3.3% CD IIIb: 2.5%	Reported 22 patients with a history of recurrent urinary tract infections	vM-PCNL is safe and has a better SFR and a lower number of complications
O'Connor (2022) [9]	Ireland	In vitro	To determine the optimal device settings for the Swiss LithoClast Trilogy lithotrite in PCNL to determine the fastest stone clearance	–	Stone phantoms	Artificial kidney stone production with Begostone and positioning of artificial stones in pig kidneys	26 Fr	–	–	–	–	–	Stone phantoms of hard kidney stones are cleared more efficiently at lower impact and frequency settings. With regard to suction, a setting of ≤50% appears to be the optimal setting
Wu (2022) [28]	China	Retrospective	To describe new DS vacuum suction M-PCNL to overcome the deficiencies of the conventional PCNL	65 M-PCNL with DS using HL	36.3	DS with negative pressure vacuum suction system (ClearPetra)	20 Fr	No residual fragments at KUB and US on postoperative day 1 and 1 mo after treatment	90.8%	50.2	Fever (CD I): 1.5%	Six patients with preoperative positive urine culture, treated with antibiotics	M-PCNL using a DS vacuum suction system is safe and effective, with better efficiency in stone extraction

(continued on next page)

Please cite this article as: V. De Stefano, D. Castellani, B.K. Somani et al., Suction in Percutaneous Nephrolithotripsy: Evolution, Development, and Outcomes from Experimental and Clinical studies. Results from a Systematic Review, Eur Urol Focus (2023), https://doi.org/10.1016/j.euf.2023.06.010

Table 1 (*continued*)

Author (year)	Country	Type of study	Aim of the study	Group(s)	Stone size (mm)	Suction device	Size tract	SFR definition	SFR	Surgical time (min)	Complications	Role of preoperative UTI in outcomes	Conclusions
Patil (2022) [21]	India	Prospective	To compare M-PCNL with Trilogy and TFL with suction in terms of stone fragmentation rates	30 M-PCNL with TFL 30 M-PCNL with Trilogy	22.04 ± 9.69 with TFL 27.60 ± 10.17 with Trilogy	Shah Superperc sheath with a suction system	18 Fr	No residual fragments at KUB/CT 48 h and 1 mo after surgery	TFL group: 76.6% Trilogy group: 96.6%	TFL group: 28.63 ± 18.56 Trilogy group: 32.48 ± 15.39	UTI (CD II): 6.7% in HL-M group and 10% in Trilogy group	Not reported	Trilogy more efficient in clearing large renal stones than TFL, good SFR for both techniques associated with sheath with a suction system
Lievore (2022) [38]	Italy	Retrospective	To perform a cost analysis between vM-PCNL and M-PCNL	108 vM-PCNL 52 M-PCNL with the vacuum cleaner effect	Median stone volume (cm^3) vM-PCNL: 2.2 (1.1–3.7) M-PCNL: 2.2 (1.1–3.5)	Sheath connected with vacuum ClearPetra set	16 Fr	Absence of residual fragments >4 mm in diameter at US or CT 3 mo after surgery	90.7% 79.6%	96 ± 39.8	Overall: 24.1% in vM-PCNL and 38.8% in M-PCNL	Patients with preoperative asymptomatic bacteriuria started a targeted therapy 48–72 h before PCNL	vM-PCNL may represent an attractive option due to clinical and economic benefits

CD = Clavien-Dindo grade; CT = computed tomography; CNS = conventional nephrostomy sheath; DS = double-sheath; eSM-PCNL = enhanced supermini percutaneous nephrolithotomy; Fr = French; FURS = flexible ureteroscopy; 1st G = first generation; 2nd G = second generation; HL = holmium laser; IQR = interquartile range; IRP = intrarenal pressure; KUB = kidney, ureter, and bladder x-ray; M-PCNL = minimally invasive percutaneous nephrolithotomy; NCCT = noncontrast CT; OT = operation time; PAAS = peel-away access sheath; PCNL = percutaneous nephrolithotomy; RCT = randomized clinical trial; RIRS = retrograde intrarenal surgery; SENS = suction-evacuation nephrostomy sheath; SFR = stone-free rate; SM-PCNL = supermini percutaneous nephrolithotomy; TFL = thulium fiber laser; US = ultrasound; UTI = urinary tract infection; VAAS = vacuum-assisted access sheath; vM-PCNL = vacuum-assisted mini percutaneous nephrolithotomy.

Please cite this article as: V. De Stefano, D. Castellani, B.K. Somani et al., Suction in Percutaneous Nephrolithotripsy: Evolution, Development, and Outcomes from Experimental and Clinical studies. Results from a Systematic Review, Eur Urol Focus (2023), https://doi.org/10.1016/j.euf.2023.06.010

Table 2 – Characteristics of studies using EMS LithoClast Trilogy or Master

Author (year)	Country	Type of study	Aim of the study	Group (s)	Stone size (mm)	Suction device	Size tract	SFR definition	SFR	Surgical time (min)	Complications	Role of preoperative UTI in outcomes	Conclusions
Balaji (2019) [7]	India	Prospective	To study safety and clinical efficacy of Trilogy in PCNL	20 PCNL 11 M-PCNL	Mean 24.1 ± 12.5	Suction due to the Trilogy's functional trifecta	22–28/10.2 Fr for PCNL 15/5.7 Fr for M-PCNL	Absence of residual fragments at KUB + US or CT on 1st postoperative day and 1 mo follow-up	100% vs 90.9%	65.2 ± 23.5 53.4 ± 23.8	fever (CD I): 9% for M-PCNL and 5% for standard Fever (CD II): 5% for PCNL	Not reported	Swiss LithoClast Trilogy provides fast stone clearance in standard and M-PCNL procedures
Nottingham (2020) [37]	USA	Prospective	To critically evaluate the initial experience with the Swiss LithoClast Trilogy during PCNL	50 PCNL	22 ± 12	Suction due to the Trilogy's function	30 Fr	Absence of residual fragments at CT scan, KUB, or US on postoperative day 1 or at follow-up outpatient visit (1–8 wk postoperatively)	67.6%		Renal pelvis perforation: 2.3% Blood transfusion: 2.3% Pneumothorax requiring chest tube: 2.3% Renal artery pseudoaneurysm: 2.3%	Not reported	Trilogy was highly satisfactory, with an excellent safety and durability profile
Sabnis (2020) [32]	India	Prospective	To study safety and clinical efficacy of Trilogy in PCNL	31 PCNL or M-PCNL with Trilogy	24.1 ± 12.5	LithoClast Trilogy with integrated suction system	16.5/17.5 Fr for M-PCNL and 20/24 Fr for PCNL	Absence of residual fragments at KUB + US or CT on 1st postoperative day and 1 mo follow-up	93%	61	Fever (CD I): 6.6% Fever (CD II): 3.3%	Not reported	Ultrasonic and electromagnetic energy with suction in PCNL is safe and effective in clearing larger stone bulk in a shorter time duration
Kallidonis (2021) [27]	Greece	Prospective	To evaluate the efficacy and safety of the nonpapillary puncture technique in PCNL for the treatment of staghorn stones	53 PCNL	60.1 ± 16.1 mm	Suction due to the Trilogy's functional trifecta	30 Fr	Absence of residual fragments at KUB and US or at CT scan in case of radiolucent stones	100% at 3 mo	54.57 ± 14.83	Hemorrhage: 1.8% Fever: 13.2% Pseudoaneurysm: 1.8% Persistent urine drain/nephrocutaneous fistula: 3.7%	Not reported	Swiss Trilogy with integrated suction has good results in terms of SFR, operating time, and complication rate
Thakare (2021) [8]	England	Prospective	To determine the efficacy and safety of the Swiss LithoClast Trilogy in PCNL	157 PCNL with Trilogy	24.5 mm	Suction due to the Trilogy's functional trifecta	≥22 Fr in 133 cases <20 Fr in 24 cases	Absence of residual fragments at x-ray, US, or CT scan either in the immediate postoperative period or at follow up, for a duration of up to 6 mo	81.4%	82	Fever: 1.3% Urosepsis: 1.9% Blood transfusion: 1.9% AVF: 0.7% Perirenal hematoma: 1.3%	Not reported	Use of LithoClast Trilogy with active suction system is safe and associated with a higher SFR
Patil (2022) [25]	India	Prospective	To compare high-power HL with MOSES and TFL during M-PCNL, especially evaluating fragmentation efficiency and SFR	110 M-PCNL with HL 54 M-PCNL with TFL	17.5 ± 4.8 in HL group 17.8 ± 5.7 in TFL group	Access sheath with suction port connected to negative pressure aspirator (Shah Superperc sheath)	18 Fr	Absence of any fragment on a noncontrast CT scan 48 h and 1 mo after surgery	HL group: 78.4% TFL group: 68.6%	HL group 41.9 ± 13.2 TFL group: 23.7 ± 11.3	UTI (CD II): 2.7% in HL group and 5.6% in TFL group	Not reported	Good SFR using access sheath with suction system, comparable between HL and TFL

AVF = arteriovenous fistula; CD = Clavien-Dindo grade; CT = computed tomography; Fr = French; HL = holmium laser; KUB = kidney, ureter, and bladder x-ray; M-PCNL = minimally invasive percutaneous nephrolithotomy; PCNL = percutaneous nephrolithotomy; SFR = stone-free rate; TFL = thulium fiber laser; US = ultrasound; UTI = urinary tract infection.

Please cite this article as: V. De Stefano, D. Castellani, B.K. Somani et al., Suction in Percutaneous Nephrolithotripsy: Evolution, Development, and Outcomes from Experimental and Clinical studies. Results from a Systematic Review, Eur Urol Focus (2023), https://doi.org/10.1016/j.euf.2023.06.010

Table 3 – Characteristics of studies using other suctioning methods (laser suction handpiece, a suction catheter inside a sheath, and a direct in-scope suction technique)

Author (year)	Country	Type of study	Aim of the study	Group(s)	Stone size (mm)	Suction device	Size tract	SFR definition	SFR	Surgical time (min)	Complications	Role of preoperative UTI in outcomes	Conclusions
Bar-Yaakov (2022) [18]	Israel	Retrospective	To report the results of the introduction of the LSH in routine performance of PCNL	20 PCNL with LSH 20 PCNL with ballistic energy	LSH: 15.59 Ballistic: 14.13	LSH with an external sheath attached to a handpiece	11.3 Fr	Absence of residual fragments at low-dose NCCT 2 mo after surgery	95% 90%	78 99	LSH: 0% Ballistic: 10%	Not reported	LSH is safe for performing PCNL, even at high-power settings avoiding retropulsion
Kati (2018) [29]	Turkey	Retrospective	To compare a new irrigation and a new aspiration method in PCNL using an NGT	102 PCNL	23.5 ± 5.1 in the irrigation group 24.4 ± 4.9 in the aspiration group	14 Fr NGT for irrigation 16 Fr NGT with a sponge on to the head for the aspiration	16 Fr	Not reported	Not reported	Not reported	Not reported	Not reported	The aspiration method is a cheaper, more effective, and feasible option
Xu (2016) [30]	China	Retrospective	To evaluate the safety, efficacy, and feasibility of a mini nephroscope connected to pressure suction in M-PCNL to manage intrarenal stones in patients with UTI	683 M-PCNL using HL or pneumatic energy	843 ± 1514 mm^2	Nephroscope connected to a negative pressure suctioning system	20 Fr	Absence of residual fragments at KUB 48 h after surgery	83.2%	71 ± 11.5	Bleeding: 1.6% Fever: 5.6% Sepsis: 0.9% Pleural injury: 0.15%	93% of patients had preoperative positive urine culture, and the others were diagnosed with pyonephrosis intraoperatively	M-PCNL with pressure suction is safe, feasible, and effective especially in patients with UTI

Fr = French; HL = holmium laser; KUB = kidney, ureter, and bladder x-ray; LSH = laser suction handpiece; M-PCNL = minimally invasive percutaneous nephrolithotomy; NCCT = noncontrast computed tomography; NGT = nasogastric tube; PCNL = percutaneous nephrolithotomy; SFR = stone-free rate; UTI = urinary tract infection.

stone fragments. In a retrospective study of 90 PCNL cases, the authors found that the device could feasibly be used for fragment extraction [14]. Kati et al. [29] reported a retrospective series of 102 PCNL evaluating irrigation and aspiration techniques for the removal of residual stone fragments during traditional PCNL. Pertinent to suction during endoscopic procedures, the described aspiration technique used a 16 Fr nasogastric tube with a sterile sponge attached to the head. The tube was placed through the nephrostomy tract following lithotripsy, and an aspirator was placed at the nasogastric tube to remove stone fragments and collect them in the sponge. While both techniques were not widely used in the literature, these may provide low-cost alternatives to the other handpiece suction devices discussed above.

3.3.1. *Take-home messages*

1. LithoClast Trilogy and ShockPulse-SE are equally effective, safe, and versatile, and different probes are available for standard PCNL and mini-PCNL. The heavier handpiece makes Trilogy less ergonomically friendly.
2. LSH devices can potentiate laser lithotripsy by allowing for better laser control with simultaneous suction of small fragments and dust. This may be very useful when using high-power lasers.

3.4. *Nephrostomy access sheaths with suction*

Of the 33 clinical studies included in this review, 24 studies utilized suction sheaths to provide aspiration during PCNL. Compared with the traditional nephrostomy sheath, suction sheaths have a side port to attach a suction tube to regulate the outflow of aspirated irrigation fluid together with stone fragments and dust. When performing minimally invasive PCNL, the outflow around the nephroscope through traditional nephrolithotomy sheaths may be reduced. This reduction can affect dust clearance and, perhaps more importantly, has the potential to increase IRP, a known risk for collecting system damage and infectious complications. Sepsis in endourology is multifactorial, and often kidney stone disease is a precursor and a surrogate to urinary tract infection [46]. Standard PCNL has been the recommended traditional approach to minimize bacteremia and sepsis during PCNL for infected stones [47]. Evidence shows that mini-PCNL can minimize the morbidity of standard PCNL and provide equally good outcomes. Miniaturization of the percutaneous tract may increase the renal pelvic pressure and absorption of irrigation fluid due to limited outflow. This may be a concern when mini-PCNL is performed in infected stones [48]. Indeed, mini-PCNL was associated with higher IRP and a higher risk of end-organ bacterial seeding when used in an infected collecting system [49]. Apart from the appropriate antibiotic treatment of concomitant urinary infections noted by voided urine, stone culture, or pelvic urine cultures [50], suction has been proposed as a way to reduce the intrarenal reflux of infected urine due to high IRP, while simultaneously draining the infected system and minimizing infectious complications [6].

The use of suction during PCNL as it relates to infection was evaluated in both access sheath and handheld suction modalities. For both scenarios, infectious complications were significantly lower when suction was used during PCNL in patients with urinary tract infections [30,39].

The direct effect of suction sheaths on IRP during supermini- and mini-PCNL was specifically evaluated in five clinical studies (two retrospective and three prospective) [15,20,22,40,42]. Alsmadi et al. [40] demonstrated safe and lower than usual backflow IRP during supermini-PCNL, likely attributed to the suction pressure generated within the sheaths. This finding was supported in subsequent studies that analyzed IRP during mini-PCNL [34,42]. Similarly, Xu et al. [22] compared the outcomes of suction sheaths versus traditional access sheaths for mini-PCNL for a series of 60 patients on the metrics of renal pelvic pressure, stone treatment time, use of stone extractors, and SFR. The authors concluded that suction sheaths showed lower average IRP, shorter treatment time, and a higher SFR when than traditional sheaths. It should be noted that while the current literature demonstrates acceptable IRP for mini-PCNL, these results may be affected by other surgical factors such as the location of the tip of the sheath/nephroscope and whether active aspiration is performed during the procedure [28].

Suction sheaths have further been adapted to "double-sheath vacuum suction" and assessed in two retrospective clinical studies [16,28]. The authors found that the use of a single access sheath system, namely, the ClearPetra (Well Lead Medical, Guangzhou, China), may inadvertently force stone fragments back into the collecting system as the cavity for inflow and outflow is shared. When irrigation inflow is greater than the suction pressure, stone gravel may not be extracted efficiently, leading to longer operative times. By separating the cavity in which inflow and outflow occur by using two suction sheaths (16 Fr and 20 Fr), a one-way flow channel is created to prevent this limitation of single-sheath systems. This technique was found to be safe and effective with better efficiency than single-sheath PCNL [23,36].

A similar one-way flow technique deemed the "Superperc" by Shah et al. [35] was developed and studied in a series of patients undergoing minimally invasive PCNL. The Superperc PCNL uses a proprietary "Shah sheath", a 10/12Fr sheath with an accompanying suction mechanism to use with a pediatric ureteroscope as the nephroscope. During the first of two prospective studies, the authors demonstrated that the Superperc technique could be used safely and efficaciously with an SFR of 96.15%, a mean operative time of 40.98 ± 12.09 min, and an acceptable postoperative mean hemoglobin drop of 0.32 g/dl during the treatment of 52 patients. Postoperative fever and significant hematuria were found in 5.8% and 1.9% of patients, respectively. The technique was further studied by the same group to determine the utility for use with TFL as the modality for lithotripsy [36]. This second prospective study included 54 patients with stones up to 3 cm with similar results for SFR and mean operative time. Three patients developed urinary tract infections postoperatively, who were treated with antibiotics and no high-grade complications were reported. In addition, Zhong et al. [42] developed the enhanced supermini PCNL system, specifically designed to lower IRP and improve stone removal efficiency. In their randomized trial using this system, which had an integrated suction port comprising an 18 Fr multifunction suction sheath (Hawk; China) and 11 Fr mini-nephroscope, renal stones were fragmented with either pneumatic lithotripter (LithoClast Master; Switzerland) or holmium laser. The authors reported that lithotripsy efficiency for renal stones between 2 and 5 cm was higher in enhanced supermini PCNL (13.71 ± 1.18 vs 9.82 ± 1.24 mm^3/h). Yet, intraoperative IRP was lower in enhanced supermini PCNL (17.7 ± 3.33 vs 12.03 ± 2.37 mmHg), and intrarenal backflow was much higher (IRP >30 mmHg) in mini-PCNL with a significantly shorter hospital stay in the enhanced supermini PCNL group (2.54 ± 0.72 vs 3.00 ± 0.88 d).

Another group used the Shah Superperc technique while evaluating the efficacy of TFL, holmium laser, and LithoClast Trilogy lithotripsy modalities [21,25]. During two prospective series, Patil et al. [25] found comparable SFRs of 78.4% and 68.6% in the TFL and holmium laser groups, respectively. When comparing SFRs between TFL and LithoClast Trilogy, they found a significant difference in the stone fragmentation rate (5.9 ± 4.25 mm^3/s for Trilogy and 3.95 ± 1.00 mm^3/s for TFL). In addition, SFRs were 96.6% for Trilogy and 76.6% for TFL [21]. Operative times were not statistically different.

Our review findings incorporate those from a meta-analysis by Chen et al. [51]. It seems evident that the suctioning access sheath is a novel modification of access sheath connected to a negative pressure suction device and helps improve mini-PCNL significantly in terms of SFR, operative time, total complication rate, auxiliary procedures, and postoperative fever rate.

The differences in SFRs are also reliant on the fragmentation devices used. Ideally, combining the best of both (fragmentation and suction aspiration) is key. However, this is yet to be standardized as most studies are single-center studies.

The benefit of high-powered lasers may prompt questions regarding the treatment of complex stone disease percutaneously versus flexible retrograde ureteroscopy as both of these use the same method for lithotripsy. While lessons from two large real-life studies [52,53] clearly outline the pros and cons of each, it remains to be seen whether adding a variable of suction tilts the balance to either modality. Chen et al. [31] evaluated the efficacy and safety of both methods in the treatment of renal calculi from 2 to 3 cm in size in a retrospective study of 91 patients who were divided in half by the method of stone treatment. Interestingly, this study found that SFR and operative time were comparable, but there was a statistically significant difference in the length of hospital stay, postoperative pain, and bleeding between the two groups, with flexible ureteroscopy being favored in these aspects [31]. The length of hospitalization and complications play a role in the cost of hospitalization. While some factors regarding operative outcomes may be associated with fixed costs, one study explored the hospitalization costs between standard and vacuum-assisted minimally invasive PCNL [38]. The authors found that vacuum-assisted PCNL decreased overall hospitalization costs despite higher instrumentation costs associated with it. The use of suction may help offset the differential in cost associated with complications during PCNL and ureteroscopic treatment of stones of similar size, but further dedicated studies surrounding cost are warranted.

Please cite this article as: V. De Stefano, D. Castellani, B.K. Somani et al., Suction in Percutaneous Nephrolithotripsy: Evolution, Development, and Outcomes from Experimental and Clinical studies. Results from a Systematic Review, Eur Urol Focus (2023), https://doi.org/10.1016/j.euf.2023.06.010

3.4.1. Take-home messages

1. Suction-aided Mini-PCNL has superior outcomes for SFR and operative time than just mini-PCNL, and it also helps minimize infectious complications by reducing IRP and by a faster aspiration of irrigation.
2. Suction mini-PCNL can be used in any renal stone volume. The choice of the correct lithotripsy device and technique may further aid in improving surgical time vis-à-vis traditional PCNL.
3. Currently, integrated suction-based sheaths are available in reusable and disposable forms for mini-PCNL only.
4. When compared with standard mini-PCNL, suction mini-PCNL reduces the risk of sepsis, enhances vision, and improves lithotripsy efficiency, which make it a very attractive evolution for PCNL in any stone volume.

3.5. Study limitations

While our review clearly outlines how suction devices in PCNL are reforming the way PCNL is being done, our study has some limitations. First, there was only one pediatric study including 12 children and no comparator. Therefore, the role of suction PCNL in children requires more studies. Second, there is a paucity of experimental studies detailing the differences in outcome, efficacy, and safety between suction modalities for PCNL. Third, there were only three prospective randomized trials comparing suction versus traditional PCNL, and further randomized studies are necessary to confirm the superiority of suction PCNL. Finally, a variety of treatment techniques such as the type of PCNL (minimally invasive vs traditional) or patient positioning (supine vs prone) may play a confounding role in the results demonstrated in these studies, and this remains to be evaluated by further experimental and clinical studies.

4. Conclusions

Suction techniques appear to improve PCNL outcomes, but the quality and quantity of evidence are still weak and no definite conclusion can be given. More randomized trials are necessary to help characterize and standardize the role of suction in PCNL, and yet it is evident that addition of suction to miniaturized percutaneous access improves SFR and reduces infectious complications. The lithotripsy technique/device best suited when using suction needs further evaluation.

Author contributions: Virgilio De Stefano had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: De Stefano, Castellani, Gauhar.
Acquisition of data: De Stefano, Giulioni, Cormio, Castellani, Glover, da Silva, Tanidir, Gadzhiev, Pirola, Mulawkar, Teoh.
Analysis and interpretation of data: Castellani, De Stefano, Gauhar.
Drafting of the manuscript: Castellani, De Stefano, Gauhar, da Silva, Tanidir, Gadzhiev, Pirola, Mulawkar, Giulioni, Cormio.
Critical revision of the manuscript for important intellectual content: Castellani, Gauhar, Galosi, Sarica, Somani, Monga, Herrmann.
Statistical analysis: Castellani, Gauhar.
Obtaining funding: None.
Administrative, technical, or material support: Castellani, Gauhar.
Supervision: Castellani, Gauhar, Galosi, Sarica, Somani, Monga, Herrmann.
Other: None.

Financial disclosures: Virgilio De Stefano certifies that all conflicts of interest, including specific financial interests and relationships and affiliations relevant to the subject matter or materials discussed in the manuscript (eg, employment/affiliation, grants or funding, consultancies, honoraria, stock ownership or options, expert testimony, royalties, or patents filed, received, or pending), are the following: None.

Funding/Support and role of the sponsor: None

References

[1] Skolarikos A, A. Neisius A, Petřík A, Somani B, Thomas K, Gambaro G. European Association of Urology guidelines on urolithiasis, 2023. https://d56bochluxqnz.cloudfront.net/documents/full-guideline/EAU-Guidelines-on-Urolithiasis-2023.pdf.
[2] Assimos D, Krambeck A, Miller NL, et al. Surgical management of stones: American Urological Association/Endourological Society guideline, part I. J Urol 2016;196:1153–60.
[3] Gauhar V, Traxer O, García Rojo E, et al. Complications and outcomes of tubeless versus nephrostomy tube in percutaneous nephrolithotomy: a systematic review and meta-analysis of randomized clinical trials. Urolithiasis 2022;50:511–22.
[4] Lee MS, Assmus MA, Agarwal DK, Rivera ME, Large T, Krambeck AE. Ambulatory percutaneous nephrolithotomy may be cost-effective compared to standard percutaneous nephrolithotomy. J Endourol 2022;36:176–82.
[5] Yap LC, Hogan D, Patterson K, et al. Intrarenal pressures during percutaneous nephrolithotomy: a porcine kidney model. Scand J Urol 2022;56:251–4.
[6] Tzelves L, Skolarikos A. Suction use during endourological procedures. Curr Urol Rep 2020;21:46.
[7] Balaji S, Desai M, Sabnis R, Ganpule A, Sharma R. EMS Lithoclast Trilogy™: an effective single probe dual energy lithotripter for mini and standard PCNL. BJU Int 2019;123:16.
[8] Thakare N, Tanase F, Saeb-Parsy K, et al. Efficacy and safety of the EMS Swiss LithoClast® Trilogy for PCNL: results of the European multicentre prospective study on behalf of European Section of UroTechnology. World J Urol 2021;39:4247–53.
[9] O'Connor CJ, Hogan D, Yap LC, Lyons L, Hennessey DB. An ex-vivo assessment of a new single probe triple modality (Trilogy) lithotripter. World J Urol 2022;40:2561–6.
[10] Berrettini A, Sampogna G, Zanetti SP, et al. Semi-closed-circuit vacuum-assisted MiniPCNL system in pediatric patients. J Pediatr Urol 2021;17:275–6.
[11] Zeng G, Zhu W, Liu Y, et al. Prospective comparative study of the efficacy and safety of new-generation versus first-generation system for super-mini-percutaneous nephrolithotomy: a revolutionary approach to improve endoscopic vision and stone removal. J Endourol 2017;31:1157–63.
[12] Tokas T, Tzanaki E, Nagele U, Somani BK. Role of intrarenal pressure in modern day endourology (mini-PCNL and flexible URS): a systematic review of literature. Curr Urol Rep 2021;22:52.
[13] Nagele U, Walcher U, Bader M, Herrmann T, Kruck S, Schilling D. Flow matters 2: how to improve irrigation flow in small-calibre percutaneous procedures-the purging effect. World J Urol 2015;33:1607–11.
[14] Cuellar DC, Averch TD. Holmium laser percutaneous nephrolithotomy using a unique suction device. J Endourol 2004;18:780–2.
[15] Lai D, Chen M, Sheng M, et al. Use of a novel vacuum-assisted access sheath in minimally invasive percutaneous nephrolithotomy: a feasibility study. J Endourol 2020;34:339–44.
[16] Wu Z-H, Liu T-Z, Wang X-H, Wang Y-Z, Zheng H, Zhang Y-G. Double-sheath vacuum suction versus vacuum-assisted sheath minimally invasive percutaneous nephrolithotomy for management of large renal stones: single-center experience. World J Urol 2021;39:4255–60.

[17] Zhu Z, Cui Y, Zeng H, et al. Suctioning versus traditional minimally invasive percutaneous nephrolithotomy to treat renal staghorn calculi: a case-matched comparative study. Int J Surg 2019;72:85–90.
[18] Bar-Yaakov N, Hertzberg H, Marom R, et al. Introducing in clinical practice a new laser suction handpiece for percutaneous nephrolithotomy. Urologia 2022;89:570–4.
[19] Holst DD, Bechis SK, Zupkas P, et al. Minimally invasive percutaneous nephrolithotomy: initial North American experience. J Endourol 2021;35:596–600.
[20] Lai D, Xu W, Chen M, et al. Minimally invasive percutaneous nephrolithotomy with a novel vacuum-assisted access sheath for obstructive calculous pyonephrosis: a randomized study. Urol J 2020;17:474–9.
[21] Patil A, Sharma R, Shah D, et al. A prospective comparative study of mini-PCNL using Trilogy™ or thulium fibre laser with suction. World J Urol 2022;40:539–43.
[22] Xu G, Liang J, He Y, et al. Comparison of two different minimally invasive percutaneous nephrostomy sheaths for the treatment of staghorn stones. BJU Int 2020;125:898–904.
[23] Zeng G, Zhu W, Liu Y, Fan J, Zhao Z, Cai C. The new generation super-mini percutaneous nephrolithotomy (SMP) system: a step-by-step guide. BJU Int 2017;120:735–8.
[24] Du C, Song L, Wu X, et al. Suctioning minimally invasive percutaneous nephrolithotomy with a patented system is effective to treat renal staghorn calculi: a prospective multicenter study. Urol Int 2018;101:143–9.
[25] Patil A, Reddy N, Shah D, et al. High-power holmium with MOSES technology or thulium fiber laser in MiniPerc with suction: a new curiosity. J Endourol 2022;36:1348–54.
[26] Gökce Mİ, Karaburun MC, Babayiğit M, et al. Effect of active aspiration and sheath location on intrapelvic pressure during miniaturized percutaneous nephrolithotomy. Urology 2021;153:101–6.
[27] Kallidonis P, Vagionis A, Lattarulo M, et al. Non-papillary percutaneous nephrolithotomy for treatment of staghorn stones. Minerva Urol Nephrol 2021;73:649–54.
[28] Wu Z-H, Wang Y-Z, Liu T-Z, Wang X-H, Zheng H, Zhang Y-G. Double-sheath vacuum suction minimally invasive percutaneous nephrolithotomy for management of large renal stones. Urol Int 2022;106:1241–5.
[29] Kati B, Pelit ES, Yagmur I, Akin Y, Ciftci H, Yeni E. Which way is best for stone fragments and dust extraction during percutaneous nephrolithotomy. Urolithiasis 2018;46:297–302.
[30] Xu G, He Y, Zhao H, et al. Mini-nephroscope combined with pressure suction: an effective tool in MPCNL for intrarenal stones in patients with urinary tract infections. Urolithiasis 2016;44:445–50.
[31] Chen H, Qiu X, Du C, et al. The comparison study of flexible ureteroscopic suctioning lithotripsy with intelligent pressure control versus minimally invasive percutaneous suctioning nephrolithotomy in treating renal calculi of 2 to 3 cm in size. Surg Innov 2019;26:528–35.
[32] Sabnis RB, Balaji SS, Sonawane PL, et al. EMS Lithoclast Trilogy™: an effective single-probe dual-energy lithotripter for mini and standard PCNL. World J Urol 2020;38:1043–50.
[33] Zeng G, Wan S, Zhao Z, et al. Super-mini percutaneous nephrolithotomy (SMP): a new concept in technique and instrumentation. BJU Int 2016;117:655–61.
[34] Zanetti SP, Lievore E, Fontana M, et al. Vacuum-assisted mini-percutaneous nephrolithotomy: a new perspective in fragments clearance and intrarenal pressure control. World J Urol 2021;39:1717–23.
[35] Shah K, Agrawal M, Mishra D. Superperc: a new technique in minimally-invasive percutaneous nephrolithotomy. Indian J Urol 2017;33:48–52.
[36] Shah D, Patil A, Reddy N, et al. A clinical experience of thulium fibre laser in miniperc to dust with suction: a new horizon. World J Urol 2021;39:2727–32.
[37] Nottingham CU, Large T, Cobb K, et al. Initial clinical experience with Swiss LithoClast trilogy during percutaneous nephrolithotomy. J Endourol 2020;34:151–5.
[38] Lievore E, Zanetti SP, Fulgheri I, et al. Cost analysis between mini-percutaneous nephrolithotomy with and without vacuum-assisted access sheath. World J Urol 2022;40:201–11.
[39] Huang J, Song L, Xie D, et al. A randomized study of minimally invasive percutaneous nephrolithotomy (MPCNL) with the aid of a patented suctioning sheath in the treatment of renal calculus complicated by pyonephrosis by one surgery. BMC Urol 2016;16:71.
[40] Alsmadi J, Fan J, Zhu W, Wen Z, Zeng G. The influence of super-mini percutaneous nephrolithotomy on renal pelvic pressure in vivo. J Endourol 2018;32:819–23.
[41] Reddy NK, Patil AP, Tak GR, et al. Size distribution of fragments by high-power holmium laser lithotripsy in MiniPCNL with suction. Curr Urol Rep 2021;22:64.
[42] Zhong W, Wen J, Peng L, Zeng G. Enhanced super-mini-PCNL (eSMP): low renal pelvic pressure and high stone removal efficiency in a prospective randomized controlled trial. World J Urol 2021;39:929–34.
[43] Carlos EC, Wollin DA, Winship BB, et al. In vitro comparison of a novel single probe dual-energy lithotripter to current devices. J Endourol 2018;32:534–40.
[44] Large T, Nottingham C, Brinkman E, et al. Multi-institutional prospective randomized control trial of novel intracorporeal lithotripters: ShockPulse-SE vs Trilogy trial. J Endourol 2021;35:1326–32.
[45] Castellani D, Corrales M, Lim EJ, et al. The impact of lasers in percutaneous nephrolithotomy outcomes: results from a systematic review and meta-analysis of randomized comparative trials. J Endourol 2022;36:151–7.
[46] Ripa F, Pietropaolo A, Montanari E, Hameed BMZ, Gauhar V, Somani BK. Association of kidney stones and recurrent UTIs: the chicken and egg situation. A systematic review of literature. Curr Urol Rep 2022;23:165–74.
[47] Kyriazis I, Panagopoulos V, Kallidonis P, Özsoy M, Vasilas M, Liatsikos E. Complications in percutaneous nephrolithotomy. World J Urol 2015;33:1069–77.
[48] Zhong W, Zeng G, Wu K, Li X, Chen W, Yang H. Does a smaller tract in percutaneous nephrolithotomy contribute to high renal pelvic pressure and postoperative fever? J Endourol 2008;22:2147–51.
[49] Loftus CJ, Hinck B, Makovey I, Sivalingam S, Monga M. Mini versus standard percutaneous nephrolithotomy: the impact of sheath size on intrarenal pelvic pressure and infectious complications in a porcine model. J Endourol 2018;32:350–3.
[50] Castellani D, Teoh J-Y-C, Pavia MP, et al. Assessing the optimal urine culture for predicting systemic inflammatory response syndrome after percutaneous nephrolithotomy and retrograde intrarenal surgery: results from a systematic review and meta-analysis. J Endourol 2022;36:158–68.
[51] Chen D, Chen C, Xie Y, Luo Z, Liu G. Suctioning versus traditional access sheath in mini-percutaneous nephrolithotomy: a systematic review and meta-analysis. Urol J 2021;19:1–8.
[52] Kamphuis GM, Baard J, Westendarp M, de la Rosette JJMCH. Lessons learned from the CROES percutaneous nephrolithotomy global study. World J Urol 2015;33:223–33.
[53] Gauhar V, Chew BH, Traxer O, et al. Indications, preferences, global practice patterns and outcomes in retrograde intrarenal surgery (RIRS) for renal stones in adults: results from a multicenter database of 6669 patients of the global FLEXible ureteroscopy Outcomes Registry (FLEXOR). World J Urol 2023;41:567–74.

Please cite this article as: V. De Stefano, D. Castellani, B.K. Somani et al., Suction in Percutaneous Nephrolithotripsy: Evolution, Development, and Outcomes from Experimental and Clinical studies. Results from a Systematic Review, Eur Urol Focus (2023), https://doi.org/10.1016/j.euf.2023.06.010