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REVIEW

A systematic review and meta-analysis concerning single-site laparoscopic percutaneous extraperitoneal closure for pediatric inguinal hernia and hydrocele

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Abstract
Background Single-site laparoscopic percutaneous extraperitoneal closure (SLPEC) of hernia sac/processus vaginalis has been widely performed for repair of inguinal hernia/hydrocele in children. However, a variety of surgical instruments and techniques were used, and significant differences existed among the SLPEC reports.
Methods A literature search was performed for all available studies concerning SLPEC for pediatric inguinal hernia/hydrocele in PubMed, Embase and Cochrane library. The surgical details and operative outcomes were pooled and analyzed with software StataSE 12.0.
Results 49 studies fulfilled the predefined inclusion criteria of this review and 37 studies were finally included in the meta-analysis. The mean incidence of CPPV was 29.1% (range 5.73–43.0%). The average of mean operative time was 19.56 min (range 8.30–41.19 min) for unilateral SLPEC and 27.23 min (range 12.80–48.19 min) for bilateral SLPEC. The total incidence of injury, conversion, recurrence, hydrocele formation, knot reaction, severe pain, and scrotal swelling was 0.32% (range 0–3.24%), 0.05% (range 0–0.89%), 0.70% (range 0–15.5%), 0.23% (range 0–3.57%), 0.33% (range 0–3.33%), 0.05% (range 0–4.55%), and 0.03% (range 0–1.52%), respectively. There was no development of testicular atrophy. Subgroup analyses showed an inverse correlation between the injury incidence and adoption of assisted forceps, hydrodissection, and blunt puncture device, between the conversion rate and adoption of hydrodissection, between the recurrence/hydrocele incidence and adoption of assisted forceps, hydrodissection, nonabsorbable suture and the preventive measures to avoid ligating the unnecessary subcutaneous tissues, and between the rate of knot reaction and adoption of assisted forceps, hydrodissection, and the preventive measures.
Conclusions SLPEC was a well-developed procedure for repair of pediatric inguinal hernia/hydrocele. Adoption of assisted forceps, hydrodissection, nonabsorbable suture, and the preventive measures to avoid ligating the unnecessary subcutaneous tissues could significantly reduce the intra- and postoperative complications.

Keywords Single-site laparoscopy · Inguinal hernia · Hydrocele · Children · Review · Meta-analysis

Pediatric inguinal hernia and hydrocele are the most common surgical pathologies in children worldwild, of which a congenital patent processus vaginalis (PPV) is the main cause [1]. With the development of minimally invasive surgery, laparoscopic repair of these diseases has progressed rapidly in the past decades [2]. Among the various effective procedures, single-site laparoscopic percutaneous extraperitoneal closure (SLPEC) of the hernia sac and processus vaginalis has been widely used with a minimal risk of injury to the spermatic cord, a low recurrence rate, and satisfactory cosmetic results [3].

As for every procedure, surgical outcomes (e.g., operative time, intra- and postoperative complications, etc.) are the issues of great concern. Numerous studies have evaluated the operative outcomes in large cohort of patients who received SLPEC [3]. However, these studies might be limited by inaccuracies in data collection, which may cause underreporting of complications and heterogeneity in the

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outcomes. We therefore performed a systematic review and meta-analysis of SLPEC on repair of pediatric inguinal hernia and hydrocele, and summarized the surgical details and operative outcomes of this procedure.

Materials and methods

Search strategy

A search was carried out for all studies concerning laparoscopic repair of inguinal hernia and hydrocele in children, which were published in the databases of PubMed, Embase and Cochrane library. Our searches used both free-text protocol and keywords for all databases. The search strategies were as seen in Appendix. No lower date or "language" limits were set. All titles and/or abstracts were reviewed initially to select studies if they contained results of laparoscopic inguinal hernia and hydrocele repair in children. After identification of the titles and/or abstracts, the full text of all potentially relevant studies was retrieved. The reference lists of included studies were examined manually to identify any additional relevant studies. The last search was performed on July 31, 2016.

Eligibility criteria

Studies were included in the systematic review if they met the following criteria: children with inguinal hernia or hydrocele as the study participant; SLPEC or its modification as the surgical method; operative time and complications as the outcomes of interest. Editorials, letters, review articles, technical reports, and abstracts with incomplete data were excluded from meta-analysis. If data were duplicated in more than one study, only the most recent or informative one was included in the final analysis.

Surgical method

The SLPEC procedure was briefly described as follows [3]: a trocar was placed at the umbilicus for the endoscope; a hernia needle with a suture was inserted percutaneously into the preperitoneal space at the corresponding skin of the internal ring; the suture was then introduced extraperitoneally in one side of the ring and extracted through the other side at the same skin incision; the suture was tied externally to obliterate the internal ring; the contralateral PPV (CPPV) was usually repaired by the same procedure; sometimes, an additional forceps and preperitoneal hydrodissection [4] (i.e., injection of isotonic saline into the preperitoneal space to separate the vas deferens and spermatic vessels from the peritoneum) was used to assist the procedure in some studies.

Data extraction

Data were extracted from each study using a predefined extraction form. The extracted data included general characteristics of the studies and patients (first author's surname, publication year, study location, design and duration, patients number, age and gender, patient's disease and its laterality, and length of follow-up), the surgical details (number of working ports, type of endoscope, hernia device and suture material, and whether applying an assisted forceps, hydrodissection, and preventive measures to avoid ligating the unnecessary tissues), and surgical outcomes (number of CPPVs, operative time, intra and postoperative complications) of SLPEC. Level of evidence was assessed according to the Oxford Center for Evidence-Based Medicine [5].

Statistical analysis

The outcome measures were mean operative time, and the incidence of CPPV, intra-, and postoperative complications. We assumed that the operative outcomes of SLPEC were probably influenced by the specific surgical aspects, such as the type of hernia device and suture material, application of assisted forceps and hydrodissection, and measures to avoid ligating the unnecessary tissues. Given this, subgroup analyses of the primary outcome measures were performed across a variety of the surgical details of SLPEC. The significance of differences between subgroups was evaluated by t test for continuous data and by Chi-squared or Fisher's exact test for dichotomous data, respectively. All analyses were conducted using StataSE 12.0 software (Stata Corporation, College Station, TX), and a two-sided $P < 0.05$ was considered statistically significant.

Results

Selection of the studies and the level of evidence

Figure 1 shows the study selection result of this systematic review and meta-analysis. From the 2262 citations initially identified, 49 studies [3, 4, 6–52] fulfilled the predefined inclusion criteria of this review. Subsequently, five duplicate publications [6, 7, 9, 11, 12], three abstracts with incomplete data [13–15], three technical reports [4, 16, 17], and one review article [3] were excluded. Finally, the remaining 37 studies [8, 10, 18–52] were included in the meta-analysis. There were 26 SLPEC case series [8, 10, 29–52] (level 4); three studies [18, 22, 24] comparing different techniques or subgroups in the context of SLPEC

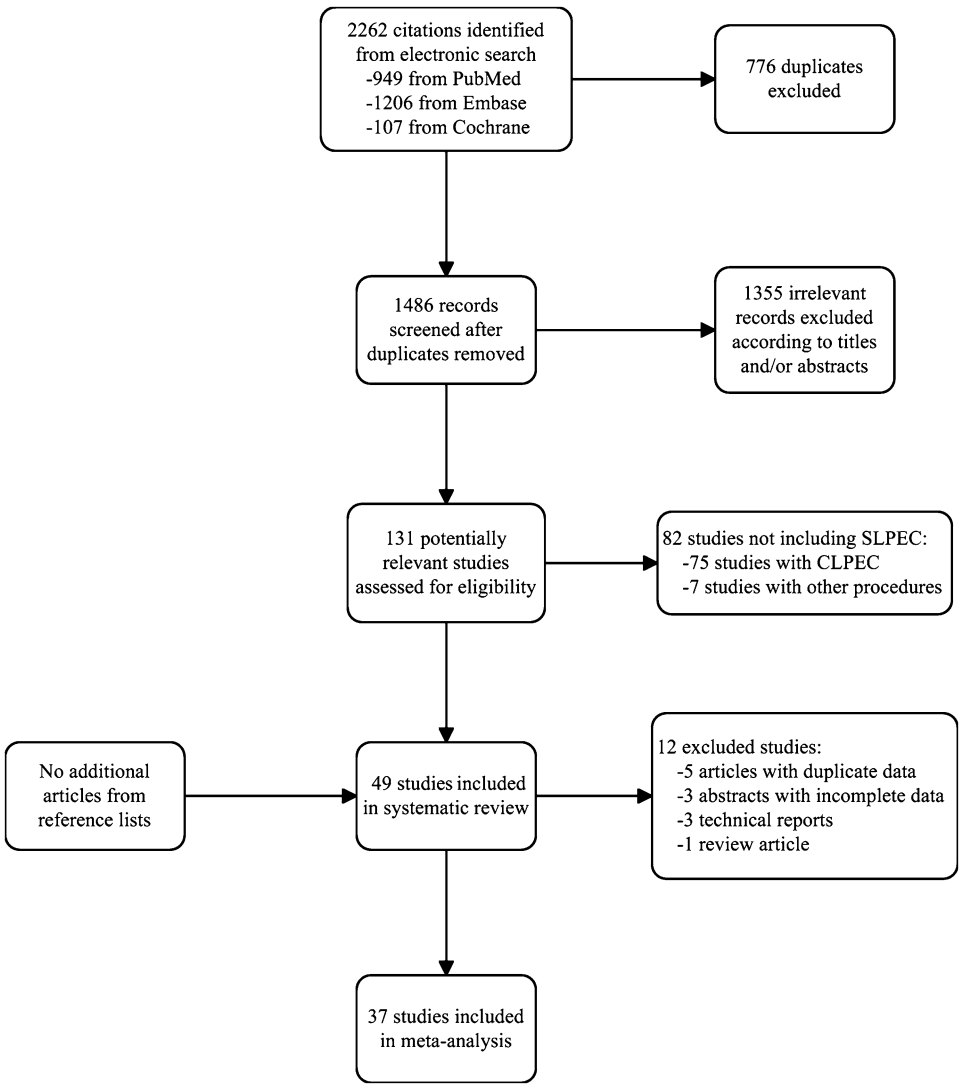

Fig. 1 Flowchart of the search process

(level 3); eight comparative studies [19–21, 23, 25–28] of SLPEC vs. other procedures (one study [20], level 2; seven studies [19, 21, 23, 25–28], level 3).

General characteristics of the studies and patients (Table 1)

Publication dates of the included studies ranged from 2006 to 2016. Sixteen studies were conducted in China, six studies in Japan and USA each, three studies in Turkey, two studies in Egypt and India each, and one study in Russia and Poland each. Overall, these studies comprised 11,815 patients who underwent SLPEC and 1093 patients undergoing other procedures. Of these studies, number of the patients who underwent SLPEC was between 11 and 3507. The age of patients ranged from birth to 17 years. Thirteen-one studies [10, 18–21, 23–28, 30–37, 39–46, 48–52] only included patients with inguinal hernia, two studies [38, 46] only with hydrocele, and four studies [8, 22, 29, 47] with both diseases. Among the 35 studies [8, 10, 18–37, 39–45, 47–52] including inguinal hernias, there were three [20, 31, 44] and two studies [22, 32] each only included female and male patients, respectively.

Surgical details of SLPECs (Table 2)

Twelve studies conventionally introduced two working ports in the umbilicus, of which one [18] inserted three ports for the patients with incarcerated inguinal hernia; 25 studies initially placed one umbilical port, of which nine studies [8, 19, 34, 38, 39, 42, 43, 48, 51] added another port for some patients later. The vast majority of the included studies applied an approximately 3- or 5-mm laparoscope, of which one study each utilized a rigid bronchoscope [37] and ureteroscope [49], respectively. Some studies sutured the internal ring using a specially made or modified

Table 1 General characteristics of the studies and patients

Reference	Study location	Study design	Study duration	Disease	Patient number	Age	Gender (M/F)	Laterality (U/B or R/L/B)
Murase et al. [18]	Japan	Comparative study, retrospective	2014.4–2014.11	IH	RIH: 60 IIH: 6	54.5 (4–132) months 11 (5–104) months	28/32 3/3	41/4 3/1
Xu et al. [19]	China	Comparative study, retrospective	2010.1.1–2015.2.31	IH	SLPEC: 1514 Open: 363	3.5 years (8 months–13 years) 3.2 years (1 month–13 years)	1,301/213 330/33	631/327/610 185/142/36
Li et al. [34]	China	Case series, retrospective	2006.2–2015.6	IH	3507	NA	NA	2435/1072
Ordorica-Flores et al. [33]	USA	Case series, retrospective	NA	IH	34	NA	14/20	29/5
Obata et al. [20]	Japan	Comparative study, prospective	2011.1–2012.12	IH	SLPEC: 37 CLPEC: 72	4.55 ± 2.74 years 4.19 ± 2.68 years	0/109	16/21 39/33
Thomas et al. 2016 [29]	Turkey	Case series, retrospective	2013.6–2015.3	IH, hydrocele	213	5.6 ± 1.2 (8.4–17) years	134/79	113/75/25
Cui et al. 2016 [30]	China	Case series, retrospective	2011.10–2013.9	IH	236	3.3 years (3 months–15 years)	211/25	219/17
Erginel et al. [31]	Turkey	Case series, retrospective	2010–2014	IH	108	5.83 years (1 month–16 years)	0/108	76/41/31
Li et al. [32]	China	Case series, retrospective	2013.6–2014.6	IH	92	21.6 (12–65) months	92/0	NA
Ahmed et al. [35]	Egypt	Case series, prospective	2009.10–2011.3	IH	40	3.4 ± 1.8 years	26/14	28/20/0
Kozlov et al. [21]	Russia	Comparative study, retrospective	2002.1.1–2012.12.31	IH	SLPEC: 180 CLPEC: 80	49.183 ± 21.949 days 55.600 ± 23.021 days	128/52 59/21	87/29/64 37/16/27
Shalaby et al. [36]	Egypt	Case series, retrospective	2009.6–2011.10	IH	150	2 ± 24.2 years	101/49	84/46/20
Yilmaz et al. [37]	Turkey	Case series, retrospective	2012.1–2014.1	IH	79	44.4 ± 35.5 months	51/28	73/6
Grimsby et al. [22]	USA	Comparative study, retrospective	2011.9.1–2013.5.1	IH, hydrocele	94	4.9 years	94/0	81/13
Timberlake et al. [23]	USA	Comparative study, retrospective	2010.1–2016.9	IH	SLPEC: 38 Open: 38	21.5 (2–103) months 23 (1–92) months	34/4 36/2	27/11 27/11
Li et al. [24]	China	Comparative study, retrospective	2008.6–2011.10	IH	1-hooked: 63 2-hooked: 72	3.12 ± 1.37 years 3.26 ± 1.39 years	52/11 58/14	53/10 59/13
Wang et al. [38]	China	Case series, retrospective	2008.6–2012.5	Hydrocele	279	39 (12–139) months	279/0	127/152/0
Li et al. [39]	China	Case series, retrospective	2010.2–2013.7	IH	251	2.21 ± 0.23 years	186/21	163/44

Table 1 (continued)

Reference	Study location	Study design	Study duration	Disease	Patient number	Age	Gender (M/F)	Laterality (U/B or R/L/B)
Liu et al. [8]	China	Case series, retrospective	2010.9–2012.9	RIH Hydrocele	130 81	2.5 years (10 months–11 years) 3.3 (1–9) years	113/17 81/0	82/38/10 50/18/13
Uchida et al. [25]	Japan	Comparative study, retrospective	2009.12–2011.10 2007.2–2009.11	IH	SLPEC: 623 CLPEC: 286	NA	NA	NA
Qi S [40]	China	Case series, retrospective	2011.3–2012.10	IH	1170	NA	NA	NA
Xu et al. [41]	China	Case series, retrospective	2008.7–2012.1	IH	536	39 months (3 months–14 years)	447/89	337/117/82
Kumar et al. [42]	India	Case series, retrospective	2007.9–2009.6	IH	31	3.87 years (8 months–13 years)	29/2	16/14/1
Chang et al. [26]	China (Taiwan)	Comparative study, retrospective	2007.4–2009.3	IH	SLPEC: 116 Open: 86	3.8 ± 4.1 years 2.8 ± 2.9 years	75/41 63/23	59/47/10 35/47/4
Li et al. [43]	China	Case series, retrospective	2006.2–2011.7	IH	1107	51 months (3 months–12 years)	1,028/79	876/160/71
Kimura et al. [44]	Japan	Case series, retrospective	2009.10–2010.3	IH	11	3.9 (1.5–6.5) years	0/11	NA
Muensterer et al. [10]	USA	Case series, retrospective	NA	IH	22	19 (0–106) months	15/7	10/7/5
Kastenberg et al. [45]	USA	Case series, retrospective	2009.1–2010.10	IH	21	38 (1–44) months	12/9	NA
Wang et al. [46]	China	Case series, retrospective	2009.6–2010.7	Hydrocele	56	36 (12–144) months	56/0	34/22/0
Yamoto et al. [47]	Japan	Case series, retrospective	2009.10–2010.4	IH, hydrocele	62	NA	34/28	22/10/30
Chang et al. [48]	China (Taiwan)	Case series, retrospective	2007.4–2010.3	IH	216	3.45 ± 3.8 years	139/77	98/98/20
Shen et al. [49]	China	Case series, retrospective	2006.6–2009.9	IH	86	5.9 (2.5–13) years	NA	39/30/17
Uchida et al. [27]	Japan	Comparative study, retrospective	2009.12–2010.11	IH	SLPEC: 60 CLPEC: 117	51.1 ± 35.0 months 57.9 ± 35.5 months	31/29 50/67	58/2 111/6
Chang et al. [50]	China (Taiwan)	Case series, retrospective	2008.3–2008.4	IH	12	3.7 ± 2.3 years	8/4	12/0
Bharathi et al. [28]	India	Comparative study, retrospective	2006.1–2007.9	IH	SLPEC: 112 CLH: 51	5 (1–14) years 5 (1.5–14) years	98/14 45/6	73/30/11 34/11/6
Ozgediz et al. [51]	USA	Case series, retrospective	2001.11–2003.8	IH	204	27.5 months (30 days–16 years)	156/48	96/75/33

Table 1 (continued)

Reference	Study location	Study design	Study duration	Disease	Patient number	Age	Gender (M/F)	Laterality (U/B or R/L/B)
Patkowski et al. [52]	Poland	Case series, retrospective	2004–2005.1	IH	106	3.4 years (28 days–14.5 years)	86/20	98/8

M male, *F* female, *U* unilateral, *R* right, *L* left, *B* bilateral, *IH* inguinal hernia, *RIH* reducible inguinal hernia, *IIH* incarcerated inguinal hernia, *SLPEC* single-site laparoscopic percutaneous extraperitoneal closure, *NA* not available, *CLPEC* conventional laparoscopic percutaneous extraperitoneal closure, *CLH* conventional laparoscopic herniorraphy

puncture needle (e.g., Endoclose, Lapaherclosure, Tuohy needle or Kirschner pin, etc.) which had a relatively blunt tip [8, 18–21, 24, 25, 27, 33, 36, 37, 39, 41, 44, 47, 49, 50], while others used ordinary sharp needles [8, 22, 23, 26, 28–32, 34, 35, 38, 40, 42, 43, 45, 46, 48, 50–52] (e.g., taper needle, injection needle, angiocath needle, etc.). Most studies ligated the hernia sac or processus vaginalis with nonabsorbable sutures while very few studies with absorbable [28] or both materials [22, 23, 35, 37, 51].

Ten studies [10, 26, 28, 30, 35, 36, 39, 46, 48, 50] carried out hydrodissection to obtain preperitoneal dissection and avoid subsequent injury to the vas and vessels. Eleven studies adopted the "one-puncture" technique [10, 20, 24, 26, 30, 39, 40, 44, 46, 50] (i.e., withdraw of the puncture needle just to the preperitoneal space on the roof of the internal ring rather than the outside of the abdominal wall, and then reintroduction along the other side of the ring) or other measure [8] (i.e., setting a cannula outside the puncture needle) to avoid ligating the unnecessary subcutaneous tissues, such as muscles and nerves.

Operative outcomes of SLPECs (Table 3)

The mean incidence of CPPV was 29.1% (range 5.73–43.0%) after three studies [25, 26, 43] with duplicate data and 11 studies [10, 20, 21, 23, 32, 33, 36, 40, 44, 45, 47] with insufficient data excluded. The average of mean operative time was 19.56 min (range 8.30–41.19 min) for unilateral SLPEC and 27.23 min (range 12.80–48.19 min) for bilateral SLPEC after three studies [25, 43, 48] with duplicate data and five [22, 31, 32, 40, 51] studies with insufficient data excluded. The total incidence of injury and conversion was 0.32% (range 0–3.24%) and 0.05% (range 0–0.89%), respectively, after three studies [25, 26, 34] with duplicate data excluded. The most commonly injured sites were the external iliac and inferior epigastric vessels. All injuries were treated with observation or by external compression, and no sequela was left.

The overall incidence of recurrence and hydrocele occurrence was 0.70% (range 0–15.5%) and 0.23% (range 0–3.57%), respectively, after three studies [26, 27, 43] with duplicate data removed. Knot reactions with various degrees (e.g., palpable subcutaneous knots, erythema, granulomas, and abscess) were observed at the suture site of internal ring in nine studies, and the total incidence was 0.33% (range 0–3.33%) after three studies [26, 27, 34] with duplicate data and one study [52] with insufficient data removed. Severe pain was found in the ligated region in only three studies [10, 19, 51], and the total incidence was 0.05% (range 0–4.55%). Scrotal swelling was reported in only two studies [18, 38], and the total incidence was 0.03% (range 0–1.52%). There was no development of testicular atrophy.

Aspects of surgery influencing the primary operative outcomes of SLPEC (Table 4)

No comparative studies evaluated the effect of assisted forceps, preperitoneal hydrodissection, and sharpness of puncture needle on the primary operative outcomes of SLPEC (i.e., mean operative time, intra- and postoperative complications). Pooled the results of SLPEC case series [8, 10, 18–25, 28–42, 44–52] showed that an assisted forceps significantly reduced the incidence of injury (0.23% vs. 0.72%, $P=0.007$) and recurrence/hydrocele (0.55% vs. 2.91%, $P=0.000$), but not markedly affected mean operative time and the incidence of conversion and knot reaction. Hydrodissection significantly decreased the incidence of injury (0.82% vs. 0.23%, $P=0.005$), conversion (0.27% vs. 0.03%, $P=0.024$) ,and recurrence/hydrocele (1.64% vs. 0.86%, $P=0.019$), but not markedly affected mean operative time and knot reaction [8, 10, 18–25, 28–42, 44–52]. Furthermore, the injury incidence was significantly higher in the group with sharp puncture needle than in that with blunt device (0.51% vs. 0.11%, $P=0.002$) [8, 10, 18–25, 28–42, 44–52].

Li et al. [24] performed the SLPEC for pediatric inguinal hernia using an innovative 2-hooked device which overcame the limitations of the 1-hooked apparatus (i.e., inclusion of some upper subcutaneous tissues in the ligature). Compared to the 1-hooked apparatus, the 2-hooked device yielded a relatively low incidence of knot reaction (0 vs. 1.59%, $P=0.28$) and recurrence (0 vs. 1.59%, $P=0.28$), despite no statistical significance. Pooled analysis including

Table 2 Surgical details of single-site laparoscopic percutaneous extraperitoneal closure

Reference	Number of working ports	Endoscope	Puncture device	Suture material	Assisted forceps	Hydrodissection	Preventive measures[a]
Murase et al. [18]	2 or 3 ports	3-mm, 30° laparoscope	19G LPEC needle	Nonabsorbable suture	Yes	No	No
Xu et al. [19]	1 port	5-mm laparoscope	Titanium alloy cannula (1.5 × 80-mm) with an arc head	4/0 prolene suture	For 5 patients	No	No
Li et al. [34]	1 port	3-mm minilaparoscope	Ordinary taper needle and Endoclose needle	2/0 monofilament nonabsorbable suture	For some patients	No	No
Ordorica-Flores et al. [33]	1 port	5-mm, 30° laparoscope	Endo Close™ suturing device	2/0 polypropylene suture	No	No	No
Obata et al. [20]	2 ports	3-mm, 30° laparoscope	19G special needle (Lapaherclosure™)	2/0 nonabsorbable suture	No	No	Yes
Thomas et al. 2016 [29]	1 port	5-mm, 30° laparoscope	18G angiocath needle	2/0 nonabsorbable monofilament suture	No	No	No
Cui et al. [30]	1 port	5-mm, 30° laparoscope	18G puncture needle (1.8-mm × 150-mm)	2/0 polyester braided suture	No	Yes	Yes
Erginel et al. [31]	1 port	5-mm telescope	21G injection needle or 16G spinal catheter	2/0 nonabsorbable monofilament suture	No	No	No
Li et al. [32]	1 port	3-mm minilaparoscope	Taper needle (1/2Arc 11 × 34-mm) and Endoclose needle	2/0 polyester suture	No	No	No
Ahmed et al. [35]	2 ports	3-mm, 30° laparoscope	Taper-ended 25-30-mm needle	2/0 or 3/0 prolene or vicryl suture	Yes	Yes	No
Kozlov et al. [21]	1 port	3.9-mm or 5-mm laparoscope	Tuohy needle	2/0 or 3/0 prolene suture	No	No	No
Shalaby et al. [36]	2 ports	5-mm, 30° laparoscope	18G epidural needle and reverdin Needle	2/0 prolene suture	Yes	Yes	No
Yilmaz et al. [37]	1 port	2.7-mm rigid bronchoscope	22G spinal needle	2/0 polyglicolic acid or polyester multifilament suture	Yes	No	No
Grimsby et al. [22]	1 port	0° laparoscope	CT-1 needle	2/0 polyglactin or polyester suture	No	No	No
Timberlake et al. [23]	1 port	3.3-mm, 0° laparoscope	MH needle	2/0 absorbable or polyester suture	No	No	No
Li et al. [24]	1 port	5-mm, 30° laparoscope	1- or 2-hooked hernia device	2/0 silk suture	No	No	1-hooked: no 2-hooked: yes
Wang et al. [38]	1 port	3-mm laparoscope	Taper needle (1/2 Arc 11 × 34-mm) and endoclose needle	2/0 nonabsorbable monoflament suture	For 5 patients	No	No
Li et al. [39]	1 port	5-mm laparoscope	An 18G tuohy needle and an epidural catheter	2/0 silk suture	For 5 patients	Yes	Yes
Liu et al. [8]	1 port	5-mm laparoscope	18-mm kirschner pin with a hole in one flat terminal	2/0 nonabsorbable suture	For 30 patients	No	Yes

Table 2 (continued)

Reference	Number of working ports	Endoscope	Puncture device	Suture material	Assisted forceps	Hydrodissection	Preventive measures[a]
Uchida et al. [25]	2 ports	3-mm laparoscope	19G LPEC needle	2/0 nonabsorbable polyester suture	Yes	No	No
Qi [40]	2 ports	Ordinary laparoscope	No. 9 syringe needle	A folded no. 1 suture and a no. 7 suture	Yes	No	Yes
Xu et al. [41]	2 ports	4.5-mm, 30° laparoscope	Homemade hooked needle	2/0 or 1/0 nonabsorbable suture	Yes	No	No
Kumar et al. [42]	1 port	5-mm, 30° laparoscope	45-mm curved needle	2/0 silk suture	For 1 patient	No	No
Chang et al. [26]	1 port	5-mm laparoscope or 3-mm needlescope	An 18F vascular catheter (0.95 × 64-mm) and a hooked pin	Nonabsorbable suture	No	Yes	Yes
Li et al. [43]	1 port	5-mm, 30° laparoscope	Taper needle (1/2Arc 11 × 34-mm) and endoclose needle	Nonabsorbable 2/0 monofilament thread	For 45 patients	No	No
Kimura et al. [44]	2 ports	3-mm, 45° laparoscope	19G hooked injection needle (Lapaherclosure)	Nonabsorbable suture	Yes	No	Yes
Muensterer et al. [10]	2 ports	Ordinary endoscope	22G needle	Two strands of braided polyester suture	No	Yes	Yes
Kastenberg et al. [45]	1 port	4-mm, 30° laparoscope	CT-1 needle	2/0 polyester suture	No	No	No
Wang et al. [46]	2 ports	5-mm, 30° laparoscope	18G vascular access needle	A 7/0 silk suture and a 2/0 polyester suture	Yes	Yes	Yes
Yamoto et al. [47]	2 ports	3-mm, 30° laparoscope	19G LPEC needle (Lapaherclosure)	Nonabsorbable 3/0 suture	Yes	No	No
Chang et al. [48]	1 port	5-mm laparoscope or 3-mm needlescope	An 18F vascular catheter (0.95 × 64-mm) and a hooked orthopedic pin (1.8-mm)	Nonabsorbable suture	For 7 patients	Yes	No
Shen et al. [49]	1 port	8.6F/9.8F rigid ureteroscope	Homemade puncture guide	2/0 silk thread	Yes	No	No
Uchida et al. [27]	2 ports	3-mm, 30° laparoscope	19G LPEC needle	2/0 nonabsorbable polyester suture	Yes	No	No
Chang et al. [50]	1 port	5-mm, 30° laparoscope	16G homemade hooked injection needle (1.8 × 50-mm)	Nonabsorbable suture (mostly 3/0 silk)	No	Yes	Yes
Bharathi et al. [28]	1 port	5-mm laparoscope	40-mm swaged needle	1/0 vicryl suture	No	Yes	No
Ozgediz et al. [51]	1 port	2.7-mm, 30° scope	Large needle (T12 or T20)	Absorbable or nonabsorbable suture	For some patients	No	No
Patkowski et al. [52]	1 port	2.5-mm 5°, or 5-mm 5° or 25° telescope	18G injection needle	2/0 nonabsorbable monofilament suture	No	No	No

LPEC laparoscopic percutaneous extraperitoneal closure

[a]Preventive measures were carried out to avoid ligating the unnecessary subcutaneous tissues, such as muscles and nerves

Table 3 Surgical outcomes of single-site laparoscopic percutaneous extraperitoneal closure in cases series and comparative studies

Reference	CPPV/unilateral lesion	Operative time, min (U/B)	Intraoperative complication	Postoperative complication	Length of follow-up
Murase et al. [18]	17/44	RIH: 34 (19–65) IIH: 57 (26–75)	0 0	0 1 scrotal swelling	12 (10–17) months 12 (10–14) months
Xu et al. [19]	143/1285	18.4 ± 4.3/32.8 ± 8.9	3 injuries, 2 conversions	2 recurrences, 11 granulomas[a], 3 pains	40.3 ± 6.4 months
Li et al. [34]	1072/2435	10 (4–16)/17 (11–25)	NA	15 recurrences	3–15 months
Ordorica-Flores et al. [33]	NA/29	10–15/25–30	0	0	12 months
Obata et al. [20]	NA/55	41.19 ± 12.80/48.19 ± 13.29	0	0	1 week–1 year
Thomas et al. [29]	35/188	14.3/20.4	3 iliac vessel punctures	3 recurrences, 1 hydrocele, 1 granuloma[a]	9.6 (4–26) months
Cui et al. [30]	85/219	11 (5–16)/19 (13–29)	0	0	15 (6–29) months
Erginel et al. [31]	26/117	NA	2 haematomas	2 granulomas[a]	3.6 (2.5–6.1) years
Li et al. [32]	NA	NA	0	0	6 months
Ahmed et al. [35]	9/48	25 ± 4 (13–37)/34.6 ± 3.8 (23–48)	0	1 recurrence	18.5 ± 5.4 (12–30) months
Kozlov et al. [21]	NA/169	14.15 ± 2.42/19.36 ± 2.10	0	0	≥6 months
Shalaby et al. [36]	NA/130	12.4 ± 1.7/18.6 ± 1.7	0	1 recurrence, 2 hydroceles	2.2 ± 4.2 year s(10 months–3 years)
Yilmaz et al. [37]	18/73	17.6 ± 5.5 (8–35)	1 hematoma	Absorbable: 6/30 recurrences, nonabsorbable: 0/69 recurrence	17.5 ± 7.1 (8–33) months
Grimsby et al. [22]	6/87	NA	0	Absorbable: 13/50 recurrences, 3/50 hydroceles Nonabsorbable: 2/47 recurrence	10.4 ± 7.9 months 6.9 ± 4.7 months
Timberlake et al. [23]	NA/54	25 (13–85)/31 (25–62)	0	0	51 (37–113) months
Li et al. [24]	20/112	1-hooked: 17.92 ± 4.37/25.36 ± 7.38 2-hooked: 13.21 ± 3.86/17.18 ± 4.69	0 0	1 granuloma[a], 1 recurrence 0	19.7 ± 2.1 months 8.6 ± 1.8 months
Wang et al. [38]	16/279	19.5 (14–31)/24.8 (19–40)	0	2 recurrences, 2 scrotal swellings, 1 abscess[a]	9 (6–29) months
Li et al. [39]	NA/163	18.1 ± 5.4/26.6 ± 4.8	0	1 recurrence	Mean 17 months
Liu et al. [8]	32/188	18 (8–35) min	0	0	12 (5–24) months
Uchida et al. [25]	NA	NA	NA	2 hydroceles	NA
Qi [40]	NA	NA	0	0	NA
Xu et al. [41]	195/454	M: 12.5/18.6, F: 8.3/12.8	0	2 recurrences	20 (6–36) months
Kumar et al. [42]	5/30	13.20 (8–25)/20.66 (17–27)	1 hemorrhage	1 recurrence, 1 hydrocele	21.16 (12–44) months
Chang et al. [26]	46/188	40.1 ± 16.4/46.0 ± 18.3	5 hematomas	0	35.3 ± 6.8 months
Li et al. [43]	221/1036	11 (5–14)/20 (14–27)	1 injury	6 recurrences, 2 abscesses/granulomas[a]	36 (9–74) months
Kimura et al. [44]	NA	24 (20–30)/30 (25–36)	0	0	3.5 (1–5) months
Muensterer et al. [10]	NA/17	27 (18–45)	0	1 pain[a]	≥12 months
Kastenberg et al. [45]	7/NA	18 (6–35)	0	0	1–12 months

Table 3 (continued)

Reference	CPPV/unilateral lesion	Operative time, min (U/B)	Intraoperative complication	Postoperative complication	Length of follow-up
Wang et al. [46]	17/56	25 ± 6/36 ± 5	0	0	6 (1–12) months
Yamoto et al. [47]	NA	M: 23.5 (21–29)/36.1 (27–65), F: 21.3 (17–30)/25 (18–34)	0	0	1–8 months
Chang et al. [48]	74/196	M: 40.1 ± 16.7, F: 33.0 ± 13.7	2 conversions, 7 hematomas	2 recurrences, 4 abscesses/granulomas[a]	NA
Shen et al. [49]	19/69	11 (8–15)/16 (12–20)	0	0	15 (12–24) months
Uchida et al. [27]	59/169	29.9 ± 8.4/41.4 ± 12.6	0	0	1.4 ± 1.2 months
Chang et al. [50]	4/12	25.1 ± 4.3 (18–31)/41.5 ± 5.8 (34–47)	0	0	6.1 ± 0.7 (6–7) months
Bharathi et al. [28]	34/148	15 (8–20)/25 (25–30)	2 injuries, 1 conversion	7 recurrences, 4 hydroceles, 3 erythemas[a]	Average 3 months
Ozgediz et al. [51]	63/171	NA	1 hematoma	13 recurrences, 7 hydroceles, 10 abscesses/granulomas[a], 1 femoral nerve injury	6 months
Patkowski et al. [52]	22/98	19.36 ± 7.30/24 ± 7.96	3 injuries	3 recurrences, 5 hydroceles, some granulomas[a]	18–29 months

CPPV contralateral patent processus vaginalis, *U* unilateral, *B* bilateral, *RIH* reducible inguinal hernia, *IIH* incarcerated inguinal hernia, *NA*, not available, *M* male, *F* female

[a]The complications were developed at the suture site of internal ring

the SLPEC case series [8, 10, 18–25, 28–42, 44–52] showed that whether or not taking the measures to avoid ligating the unnecessary subcutaneous tissues markedly affected the incidence of recurrence/hydrocele (0.05% vs. 1.15%, $P = 0.000$) and knot reaction (0 vs. 0.41%, $P = 0.001$). Grimsby et al. [22] compared the outcomes of absorbable vs. nonabsorbable sutures during SLPEC for pediatric inguinal hernias and found a significant difference of the recurrence incidence (26% vs. 4%, $P = 0.004$). Meta-analysis of the included 32 studies [8, 10, 18–22, 24, 25, 28–34, 36–42, 44–52] demonstrated that nonabsorbable suture remarkably reduced the incidence of recurrence/hydrocele compared with absorbable suture (0.51% vs. 19.0%, $P = 0.000$).

Discussion

SLPEC was a well-developed surgical procedure in the past decade, which has been wildly used as a treatment for pediatric inguinal hernias and hydroceles [3]. By systematically searching the literature, we found that there were at least 51 relevant reports concerning this procedure [3, 4, 6–52]. SLPEC has been reported to be easy and effective. The unilateral and bilateral mean operative time was about 20 and 27 min, respectively, while the overall incidence of recurrence and hydrocele was 0.70% and 0.23%, respectively. Furthermore, SLPEC also had the significant advantages of minimal invasion and cosmesis. There were only a concealed umbilical incision and a tiny puncture hole which left no obvious scars. However, significant differences existed among the SLPEC studies, and a variety of surgical instruments and techniques were used. Given this, we performed this meta-analysis to pool the surgical details and operative outcomes of SLPEC, and explore the surgical aspects affecting the primary operative outcomes.

The included studies showed that accident puncture of the external iliac [29, 34, 52] and inferior epigastric vessels [19] was the most common injury during SLPEC, which could be cured with conservative treatment (e.g., observation and external compression). A working forceps could greatly facilitate the meticulous manipulation of puncture needle and then reduce the risk of injury in abdominal cavity [53]. Application of the hydrodissection technique could add the preperitoneal safe space around the internal ring [4]. A blunt hernia needle helped prevent the accident damage to the extraperitoneal tissues [4, 19, 53] (e.g., the external iliac and inferior epigastric vessels, and spermatic cord). Therefore, all these surgical details were significantly associated with the low incidence of injury. It was

Table 4 Aspects of surgery and primary operative outcomes

	Assisted forceps		Hydrodissection		Puncture device		Protective measures[a]		Suture materials	
	Yes	No	Yes	No	Sharp	Blunt	Yes	No	Absorbable	Nonabsorbable
Intraoperative outcomes										
Unilateral mean operative time										
Number of studies	14	9	8	15	NA	NA	NA	NA	NA	NA
Mean ± SD, min	19.58 ± 8.60	19.51 ± 8.67	21.46 ± 9.49	18.71 ± 8.09	NA	NA	NA	NA	NA	NA
P value	0.985		0.454		NA		NA		NA	
Bilateral mean operative time										
Number of studies	14	9	8	15	NA	NA	NA	NA	NA	NA
Mean ± SD, min	27.45 ± 10.10	26.88 ± 9.80	30.91 ± 10.19	25.59 ± 9.44	NA	NA	NA	NA	NA	NA
P value	0.889		0.207		NA		NA		NA	
Injury										
Number of studies	21	13	9	25	18	16	NA	NA	NA	NA
Cases/all patients	14/6178	10/1381	9/1095	15/6464	20/3921	4/3638	NA	NA	NA	NA
P value	0.007		0.005		0.002		NA		NA	
Conversion					NA	NA				
Number of studies	21	13	9	25	NA	NA	NA	NA	NA	NA
Cases/all patients	4/6178	1/1381	3/1095	2/6464	NA		NA	NA	NA	NA
P value	1.000		0.024				NA		NA	
Postoperative complications										
Recurrence and hydrocele										
Number of studies	19	15	9	25	NA	NA	10	25	4	31
Cases/all patients	51/9208	42/1443	18/1095	82/9556	NA	NA	1/2078	99/8573	39/205	53/10368
P value	0.000		0.019		NA		0.000		0.000	
Knot reaction[b]										
Number of studies	19	14	9	24	NA	NA	10	24	NA	NA
Cases/all patients	28/9208	7/1337	7/1095	28/9450	NA	NA	0/2078	35/8467	NA	NA
P value	0.200		0.087		NA		0.001		NA	

NA not applied

[a]Protective measures were performed to avoid ligating the unnecessary subcutaneous tissues, such as muscles and nerves

[b]Knot reactions included palpable subcutaneous knots, erythemas, granulomas, and abscesses at the suture site of internal ring

rare to see conversions, which were usually caused by difficult operations of the inguinal hernias with giant hernia sac or excessive peritoneal folds [19, 28, 48]. Hydrodissection brought great convenience to perform a complete circumferential closure of the sac at the level of the internal ring, and consequently led to a significant decrease of conversion. Unexpectedly, we did not found the remarkable reduction of conversion using the assisted forceps. Although the convenience from these surgical details reduced the operation time in abdominal cavity, they also added the time of these techniques themselves. Therefore, there was no significant difference of the total operative time.

Recurrence and hydrocele formation were mainly caused by low patient number, inexperienced surgeon, leaving a peritoneal gap in the encircling suture, loosing of ligation due to inappropriate or inadequate knotting, and use of absorbable sutures [2]. Adoption of the grasping forceps and hydrodissection technique ensured the complete closure of mere hernia sac/processus vaginalis, leaving no peritoneal gaps [3]. Some preventive measures could effectively avoid ligating the unnecessary subcutaneous tissues, and thus reduce the loose knots during surgery and the knot loosening thereafter due to excessive tissues in the ligature [3]. These measures included the "one-puncture" technique [10, 20, 24, 26, 30, 39, 40, 44, 46, 50] and setting a cannula outside the puncture needle [8]. The nonabsorbable suture could avoid later split of the internal ring due to absorption of the suture material after the operation [22, 28, 51]. The current meta-analysis showed that these surgical details significantly reduced the recurrence and hydrocele formation. Various knot reactions were mostly caused by the knots which were not buried deeply. The preventive measures to avoid ligating the subcutaneous tissues (e.g., muscles and fascias) ensured that the knot could be buried below the muscular layer. Our meta-analysis showed that these techniques markedly reduced the knot reactions at the suture site of internal ring.

The current review still had some limitations. Firstly, there were various hernia devices applied in the studies, of which most were designed by the authors themselves. Even though for the same device, the detailed use methods might vary among the different studies. These aspects probably affected the surgical outcomes of SLPEC. Therefore, the SLPEC methods required to be unified and standardized. Next, population composition of the patients and surgery experience of the operator [47, 48] might be significantly related to the operative time. Murase et al. [18] reported a markedly longer operative time for incarcerated inguinal hernia than for reducible hernia. Yamoto et al. [47] reported a shorter operative time for the girls and the surgeons with more experience. Chang et al. [48] found that female patients, reducible hernias, maturity, surgery volume, and weight >5 kg would decrease the operative time. Accordingly, these nonsurgical factors should also be considered when assessing the perioperative outcomes of SLPEC. Finally, some hernia recurrence and hydrocele formation probably developed very late. Shalaby et al. [54] reported a cohort of 38 children with 42 recurrent hernias, of which the time interval between surgery and recurrence ranged from 1 day to 2.5 years. Consequently, a relatively long-term follow-up was necessary to accurately evaluate the postoperative complications.

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Compliance with ethical standards

Disclosures Furan Wang has no conflicts of interest or financial ties to disclose.

Appendix

PubMed

("hernia, inguinal"[mh] OR hydrocele[mh] OR "inguinal hernia" OR "inguinal hernias" OR hydrocele OR hydroceles) AND (child[mh] OR infant[mh] OR adolescent[mh] OR child OR children OR infant OR infants OR baby OR babies OR pediatric OR pediatrics OR paediatric OR paediatrics OR adolescent OR adolescents) AND (laparoscopy[mh] OR laparoscopes[mh] OR laparoscopy OR laparoscopic OR coelioscopy OR coelioscopic OR celioscopy OR celioscopic OR peritoneoscopy OR peritoneoscopic OR endoscopy OR endoscopic OR laparoendoscopy OR laparoendoscopic OR minilaparoscopy OR minilaparoscopic OR laparoscope OR laparoscopes).

Embase

('inguinal hernia'/exp OR hydrocele/exp OR 'inguinal hernia' OR 'inguinal hernias' OR hydrocele OR hydroceles) AND (child/exp OR infant/exp OR adolescent/exp OR baby/exp OR child OR children OR infant OR infants OR baby OR babies OR pediatric OR pediatrics OR paediatric OR paediatrics OR adolescent OR adolescents) AND (laparoscopy/exp OR laparoscope/exp OR laparoscopy OR laparoscopic OR coelioscopy OR coelioscopic OR celioscopy OR celioscopic OR peritoneoscopy OR peritoneoscopic OR endoscopy OR endoscopic OR laparoendoscopy OR laparoendoscopic OR minilaparoscopy OR minilaparoscopic OR laparoscope OR laparoscopes).

Cochrane library

("hernia, inguinal"[mh] OR hydrocele[mh] OR "inguinal hernia" OR "inguinal hernias" OR hydrocele OR hydroceles) AND (child[mh] OR infant[mh] OR adolescent[mh] OR child OR children OR infant OR infants OR baby OR babies OR pediatric OR pediatrics OR paediatric OR paediatrics OR adolescent OR adolescents) AND (laparoscopy[mh] OR laparoscopes[mh] OR laparoscopy OR laparoscopic OR coelioscopy OR coelioscopic OR celioscopy OR celioscopic OR peritoneoscopy OR peritoneoscopic OR endoscopy OR endoscopic OR laparoendoscopy OR laparoendoscopic OR minilaparoscopy OR minilaparoscopic OR laparoscope OR laparoscopes).

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