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Review Article

Comparative outcomes of open and robotic ureteral reimplantation in children with vesicoureteral reflux: A systematic review and meta-analysis

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ABSTRACT

Aim: Open ureteral reimplantation (OUR) is the benchmark for vesicoureteral reflux (VUR). Robotic-assisted laparoscopic ureteral reimplantation (RALUR) has emerged as a minimally invasive alternative, offering potential advantages in recovery, though with more variable reported outcomes. We compared OUR and RALUR in children, focusing on success, complications, length of stay, and analgesia.

Methods: PRISMA-guided systematic review and meta-analysis of comparative pediatric studies (PubMed, Cochrane Library, Web of Science; 1 January 2010–31 March 2025).

Results: Eight retrospective studies met criteria (n = 546; 249 OUR, 297 RALUR). OUR included intravesical and extravesical repairs; RALUR was predominantly extravesical. Mean age/weight were 5.1 years/19.4 kg (OUR) and 7.2 years/26.5 kg (RALUR); mean VUR grade was 3.2 in both groups. Operative time was shorter for OUR (143 vs 193 min), but hospital stay was longer (2.5 vs 1.5 days). Early postoperative complications occurred in 19.1 % (OUR) and 16.6 % (RALUR). Analgesic requirements were lower after RALUR (0.14 vs 0.33 mg/kg morphine equivalents). At a median 15.1-month follow-up, success was 92.5 % (OUR) and 94.1 % (RALUR). Meta-analysis showed no difference in complications (7 studies, n = 434; OR 0.80, 95 % CI 0.32–1.97; p = 0.56; I^2 = 23.7 %) or success (7 studies, n = 433; OR 1.22, 95 % CI 0.42–3.55; p = 0.67; I^2 = 0 %).

Conclusions: RALUR appears to be a safe, feasible alternative to OUR for pediatric VUR, with comparable success and complication rates, shorter hospital stay, and longer operative time. Limitations include heterogeneity in surgical techniques and baseline age differences between cohorts.

1. Introduction

Vesicoureteral reflux (VUR) affects approximately 1–3% of children and up to 30 % of those with urinary tract infections, carrying the risk of recurrent pyelonephritis, renal scarring, and long-term deterioration of renal function [1,2]. When conservative or endoscopic management fails, surgical correction represents the mainstay of treatment [3,4]. Among surgical options, open ureteral reimplantation (OUR) has historically been the gold standard, with success rates consistently reported between 95 % and 100 % [5,6]. However, OUR is associated with morbidity, including postoperative pain, and long hospitalization [5].

In response to these drawbacks, less invasive alternatives were explored, giving rise to laparoscopic ureteral reimplantation. Although early experiences were promising, the complexity of intracorporeal suturing restricted its wider application [7]. The introduction of robotic-assisted platforms helped overcome these limitations, and robotic-assisted laparoscopic ureteral reimplantation (RALUR) has gained increasing popularity in pediatric urology since its first description in 2004 [8,9]. Advantages of robotic surgery may include shorter hospital stay, reduced postoperative analgesic use, and faster recovery compared to the open approach [10,11]. Nevertheless, its efficacy has been variably reported, with success rates ranging from 65 % to 97 % [11]. Moreover, concerns remain regarding longer operative times, higher costs, and the impact of the surgical learning curve [11].

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The present systematic review and meta-analysis aim to compare RALUR and OUR in the management of pediatric VUR, focusing on postoperative complications and surgical success.

2. Materials and methods

2.1. Protocol and registration

This systematic review and meta-analysis were conducted in accordance with the PRISMA 2020 guidelines [12]. The protocol was prospectively developed based on the PICO framework (Population: pediatric patients with VUR; Intervention: robotic-assisted ureteral reimplantation [RALUR]; Comparison: open ureteral reimplantation [OUR]; Outcomes: surgical success, complications, hospital stay, postoperative pain, and operative time). The study protocol was prospectively registered in PROSPERO (CRD42025 1024006) [13].

2.2. Literature search

A comprehensive search of PubMed/MEDLINE, Web of Science, and the Cochrane Library was performed, covering the period from 1 January 2010 to 31 March 2025. The search strategy combined MeSH terms and free-text keywords related to "vesicoureteral reflux," "ureteral reimplantation," "robotic-assisted," and "open" (Supplementary Table 1). Reference lists of included studies were screened for additional relevant articles. Only full-text, peer-reviewed articles published in English were considered; reviews, case reports, conference abstracts, and non-comparative studies were excluded.

2.3. Eligibility criteria

We included randomized controlled trials, prospective or retrospective comparative studies reporting outcomes of robotic versus open ureteral reimplantation in pediatric patients (<18 years) undergoing surgery for vesicoureteral reflux. Studies were excluded if they involved adults or lacked a comparator arm.

Given the expected heterogeneity in operative techniques (intravesical vs extravesical, unilateral vs bilateral), we did not restrict inclusion by specific approach but recorded the surgical technique for each study.

Studies with suspected overlapping cohorts were cross-checked, and when overlap could not be excluded, only the study with the most comprehensive dataset was included.

2.4. Data extraction

Two reviewers (MG and MB) independently screened titles, abstracts, and full texts for eligibility and extracted data into a standardized database. Extracted information included: study design, country, year of publication, sample size, patient demographics (age, gender, VUR grade), surgical technique (intravesical/extravesical, Lich-Gregoir, Cohen, Politano-Leadbetter), perioperative variables (operative time, hospital stay, analgesia), and outcomes (surgical success, postoperative complications, and follow-up duration). Discrepancies were resolved by a third reviewer (GM).

2.5. Quality assessment

The methodological quality of non-randomized studies was assessed using the Newcastle–Ottawa Scale (NOS) across three domains: selection, comparability, and outcome [14]. Quality assessment was performed independently by two reviewers (MG and MB), with disagreements adjudicated by a third reviewer (GM).

2.6. Meta-analysis

Studies were included in the meta-analysis if postoperative complications were comprehensively documented and success rates were reported on a per-patient basis.

Meta-analysis was performed in R (version 2024.12.1 + 563, R Foundation for Statistical Computing, Vienna, Austria) using the meta and metafor packages. Odds ratios (OR) with 95 % confidence intervals (CI) were calculated for dichotomous outcomes (postoperative complications, surgical success). A random-effects model was applied in all analyses due to expected clinical and methodological heterogeneity across studies. Statistical heterogeneity was assessed using the I^2 statistic, with thresholds of 25 %, 50 %, and 75 % representing low, moderate, and high heterogeneity, respectively. Potential publication bias was evaluated using Egger's regression test for funnel plot asymmetry.

3. Results

A total of 546 patients from 8 comparative studies were included (Fig. 1, Table 1)[7,15–21]. Two multicenter studies meeting the inclusion criteria [22,23] were excluded due to potential patient overlap with institutional cohorts from the same centers and study periods (U.S., 2003–2013).

Among the included patients, 214 were males and 332 females (male-to-female ratio 1:1.6).

The open series comprised 249 patients (113 male, 133 female). Laterality was reported in 202 cases, with 95 (47 %) unilateral and 107 (53 %) bilateral cases. Surgical techniques were detailed in 139 cases, including 94 Cohen procedures, 7 Politano–Leadbetter, 1 Glenn–Anderson, and 37 extravesical approaches. The mean age was 5.1 years, and the mean weight 19.44 kg. The mean VUR grade was 3.2. Prior endoscopic treatment, reported in 6 studies, had been attempted in 17 of 212 patients (8 %). The mean operative time was 143.4 min. One intraoperative complication was reported (0.4 %) consisting in a small vaginal injury. Early postoperative morbidity was observed in 44 of 230 patients (19.1 %, 7 studies). According to the Clavien–Madadi classification [24], 7 complications were Grade I, including postoperative fever (n = 5), bladder spasms (n = 2), and one episode of gross hematuria. Six complications were Grade II, comprising febrile urinary tract infections (n 3), pyelonephritis (n = 1), wound infection (n = 1), and one readmission for dehydration requiring intravenous fluids. Three complications were Grade III, namely a urinary leak treated by interventional drainage without general anesthesia (IIIa, n = 1), renal obstruction requiring reoperation under general anesthesia (IIIb, n = 1), and an additional unspecified Grade III event (n = 1). No Grade IV or Grade V complications occurred. The remaining 21 complications were unspecified and therefore could not be categorized. Patients stayed in hospital for a mean of 2.5 days.

The robotic group included 297 patients (101 male, 196 female), with a mean age of 7.2 years and a mean weight of 26.5 kg. Laterality was reported in 218 cases, with 135 (62 %) unilateral and 83 (38 %) bilateral cases. Most underwent an extravesical Lich–Gregoir procedure (n = 230), while 19 underwent intravesical reimplantation with either the Cohen or Glenn–Anderson technique; in 23 cases the technique was not specified. The mean VUR grade was 3.2. Prior endoscopic treatment, described in 6 studies, was reported in 20 of 261 patients (7.7 %). The mean operative time was 193 min overall, and 318 min for bilateral cases when specified (194; 443).

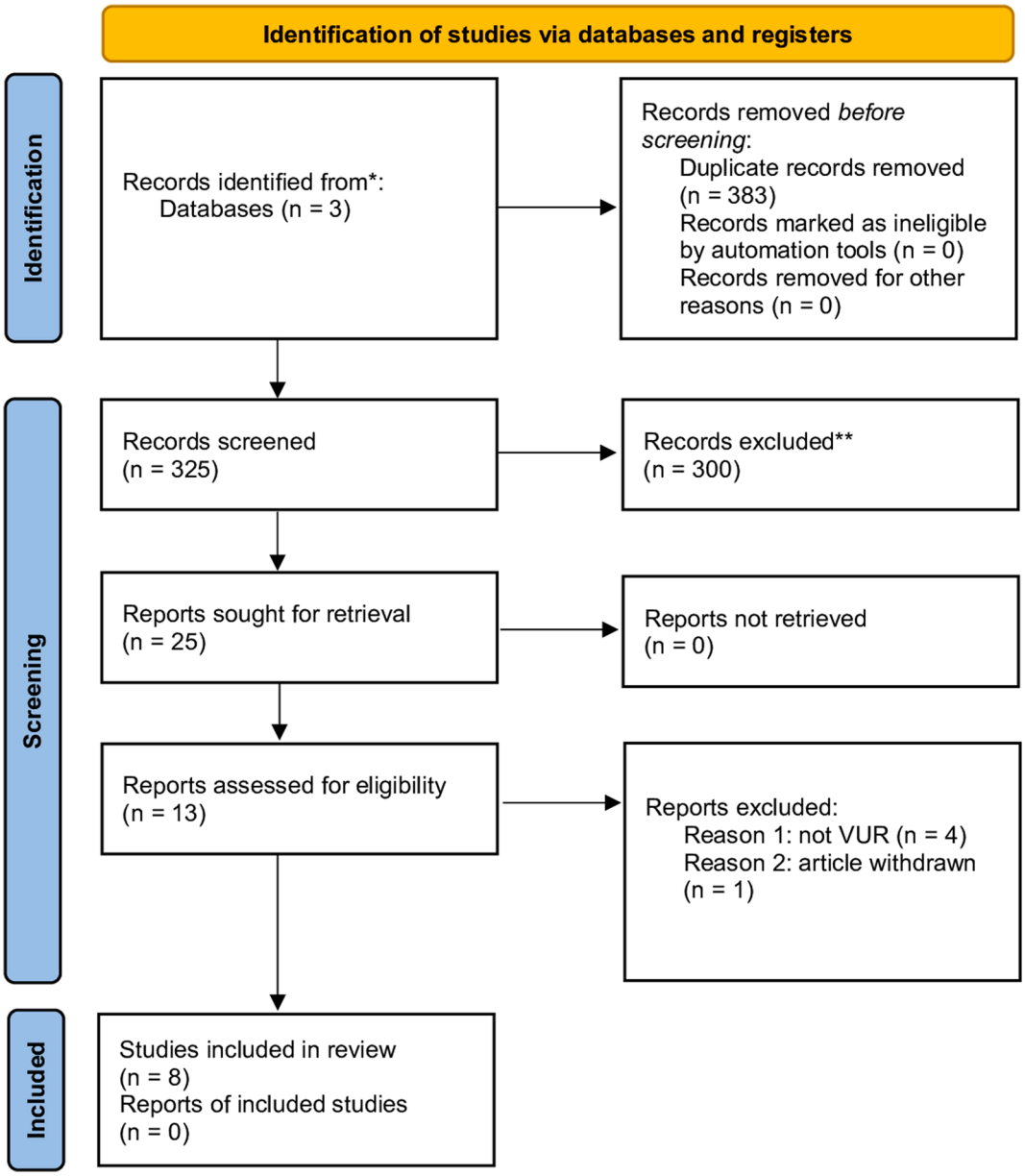

Fig. 1. PRISMA flowchart.

Table 1
Overview of included studies.

Study	Study Design	Sample Size	Number RALUR/OUR	Median Age RALUR/OUR [y]	NOS Grade
Harel et al., 2015 [15]	Single centre retrospective	34	23/11	7.5/7.2	7 - Good
Smith et al., 2011 [20]	Single centre retrospective	50	25/25	5.7/4.1	7 - Good
Arlen et al., 2016 [17]	Single centre retrospective	58	17/41	9/2.4	8 - Good
Sorensen et al., 2010 [19]	Single centre retrospective	39	13/26	8.4/8	7- Good
Schomburg et al., 2014 [16]	Single centre retrospective	40	20/20	6.1/4.3	8 - Good
Sforza et al., 2024 [18]	Multi centre retrospective	135	67/68	4.9/1.5	8 - Good
Babajide et al., 2022 [21]	Single centre retrospective	112	93/19	5.1/3.7	8 - Good
Marchini et al., 2010 [7]	Single centre retrospective	78	39/39	8.6–6.2/8.8–6.1	8 - Good

Five intraoperative complications occurred in the RALUR group (1.7 %), including four mild bleeding episodes and two mucosal injuries during detrusorotomy (one patient with both).

Postoperative complications occurred in 34 of 204 patients (16.6 %, 7 studies). According to the Clavien–Madadi classification, 7 complications were Grade I, including 4 cases of

voiding difficulty, 2 patients with pain scores >2, and 1 case of bladder spasm. Five complications were Grade II, comprising 2 episodes of urinary retention, 1 urinary tract infection, and 2 unspecified events. Seven complications were Grade III, consisting of 1 acute febrile infection requiring double-J stent placement (IIIb), and 6 ureteral leaks. No Grade IV or V complications were reported. The remaining 18 complications were unspecified and could not be categorized. The mean hospital stay was 1.5 days.

Median analgesic requirements were evaluated in 3 studies and were found to be lower in the robotic group, with morphine equivalent use of 0.14 mg/kg compared to 0.33 mg/kg in the open cohort [15,16,20].

The overall median follow-up duration was 15.1 months (range: 2–51 months).

Definition of "success" varied across studies. Some defined success as reflux resolution on postoperative cystography (VCUG or radionuclide cystogram)[15,19–21], while others required both radiological resolution and absence of febrile urinary tract infections [7,17]. A minority defined success clinically, as the absence of febrile UTI without systematic imaging [18].

In the open series, surgical success was achieved in 212 of 229 patients (92.5 %), while in the robotic series, success was reported in 192 of 204 patients (94.1 %).

Seven studies comprising 433 and 434 patients were included in the meta-analysis.

The pooled analysis demonstrated no significant difference in postoperative complications between RALUR and OUR (OR 0.80, 95 % CI 0.32–1.97; $p = 0.56$) (Fig. 2). Between-study heterogeneity was low ($I^2 = 23.7$ %), indicating consistent findings across the included reports.

Similarly, no significant difference was observed in surgical success rates between the two approaches (OR 1.22, 95 % CI 0.42–3.55; $p = 0.67$), with no heterogeneity detected ($I^2 = 0$ %) (Fig. 3).

Assessment of publication bias using funnel plots for both outcomes appeared symmetric (Figs. 4 and 5), and Egger's test did not reveal evidence of small-study effects. For surgical success, the regression intercept was −0.55 (95 % CI −3.29 to 2.19; $p = 0.71$), while for postoperative complications, the intercept was 0.44 (95 % CI −2.25 to 3.13; $p = 0.76$).

The study by Babajide et al. [21] was excluded from the meta-analyses, as the only post-operative complication reported was urinary retention and surgical success was reported per ureteral unit rather than per patient, preventing direct comparison with the other studies.

3.1. Quality assessment

All included studies were retrospective cohort studies. Methodological quality assessed with the Newcastle–Ottawa Scale ranged from fair to good, with the main limitation being lack of prospective design and variability in outcome definitions.

4. Discussion

Robotic surgery has seen growing adoption in pediatric urology over the past two decades, particularly in reconstructive procedures. Nevertheless, the role of robot-assisted laparoscopic ureteral reimplantation in the treatment of vesicoureteral reflux remains under debate, with the open technique still considered the historical benchmark[25–27].

Our review, which included 8 studies and evaluated success rates and postoperative complications in 433 patients, showed that both approaches achieve similarly high success rates (92.5 % OUR, 94.1 % RALUR), with no significant difference in overall

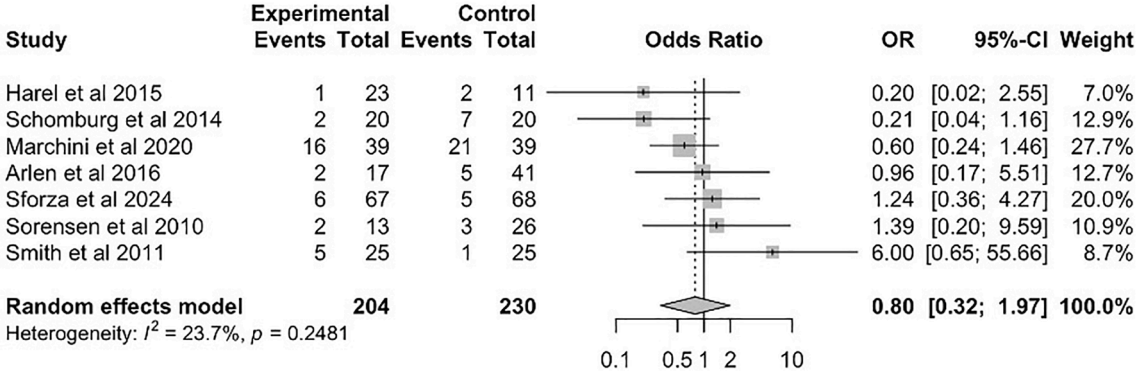

Fig. 2. Forest plot of postoperative complication rates comparing RALUR and OUR.

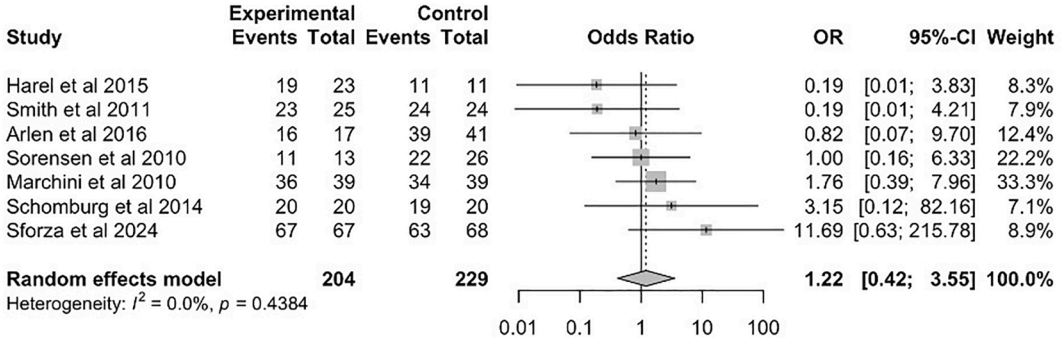

Fig. 3. Forest plot of surgical success rates comparing RALUR and OUR.

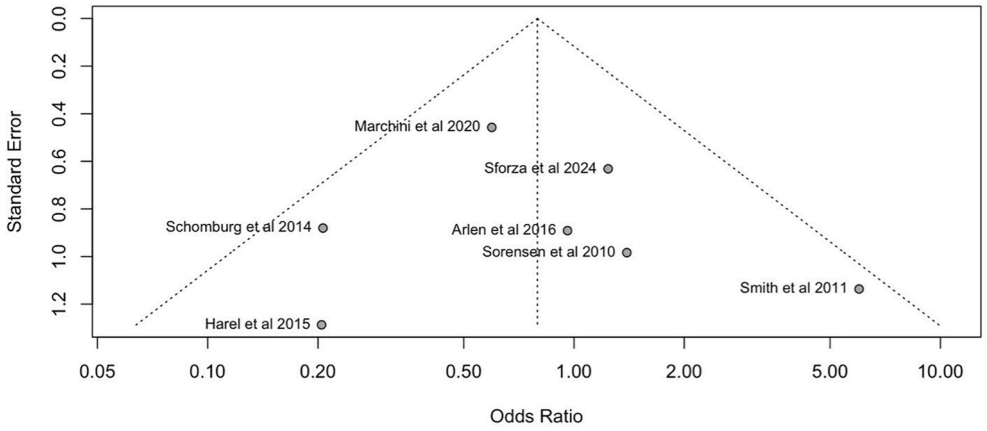

Fig. 4. Funnel plot of postoperative complication rates comparing RALUR and OUR.

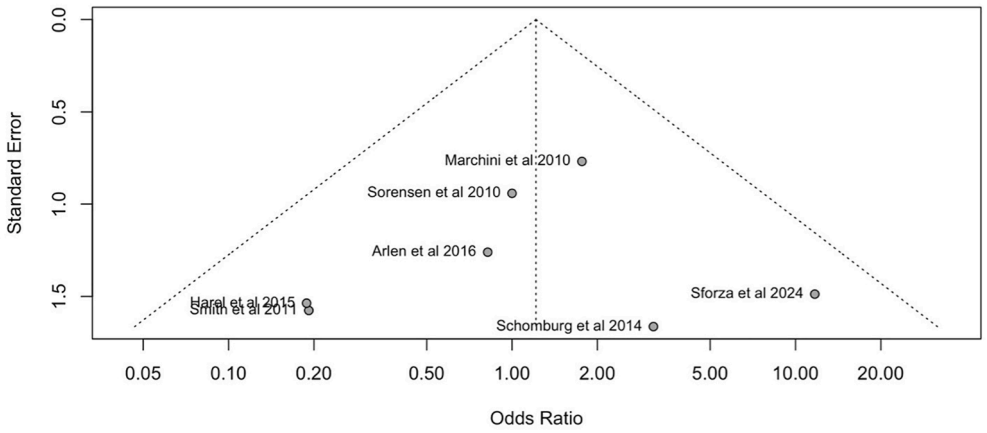

Fig. 5. Funnel plot of surgical success rates comparing RALUR and OUR.

complication rates. As reported in previous literature, RALUR was found to have longer operative times, likely reflecting the technical demands of intracorporeal suturing and the learning curve associated with adopting a relatively new approach. Encouragingly, reports indicate that operative efficiency improves with experience, suggesting that this difference may decrease as robotic expertise becomes more widespread [11]. In addition, RALUR has generally been performed in older and heavier children than OUR. This reflects a common limitation across pediatric robotic surgery: existing platforms were not originally designed for the smaller body size of infants, with port size and instrument dimensions restricting use in this age group. Over time, with growing experience and gradual technological and technical improvements, robotic approaches are becoming more widely applied in the pediatric practice [28,29]. Moreover, emerging platforms with smaller instruments and reduced port sizes, as well as single-port technology may further shorten the learning curve and expand eligibility to younger and smaller patients [30,31].

Current EAU/ESPU guidelines (2023 update) acknowledge that both open and minimally invasive reimplantation achieve very high and comparable success rates. However, minimally invasive techniques, particularly RALUR, are recommended primarily in centers with established expertise, and their routine use is not yet endorsed. The choice of approach should therefore be individualized, considering reflux grade, bladder and bowel dysfunction, renal status, patient age, and surgeon experience [32], although evidence remains limited.

Our results indicate that patients undergoing robotic surgery may benefit from shorter hospital stays and reduced postoperative analgesic requirements compared to those treated with OUR. However, analgesia outcomes were reported in only three studies [15,16,20]. These findings are consistent with previous meta-analyses and single-center studies reporting faster recovery after minimally invasive repair [26,27,33].

Interestingly, only a minority of patients had undergone prior endoscopic injection: 8 % in the OUR cohort and 7.7 % in the RALUR cohort. Given that endoscopic treatment is widely regarded as a first-line minimally invasive option for lower grades of reflux, this low rate suggests that our included cohorts largely represent children with higher-grade or persistent VUR, for whom surgical reimplantation is most clearly indicated[32].

This review has several limitations. A key methodological limitation is the substantial heterogeneity in operative techniques across studies, which is to some extent intrinsic when comparing open and robotic approaches. OUR includes both intravesical and extravesical procedures, which differ in morbidity, catheterization protocols, risk of hematuria and urinary retention [34,35]. By contrast, RALUR is almost exclusively extravesical, which generally reduces postoperative pain and bladder spasms, but carries higher risk of urinary retention [34]. Moreover, this review included both unilateral and bilateral cases. The latter, especially when performed with an extravesical approach carries a higher risk of urinary retention [35]. Subgroup analysis for technique and laterality was not possible due to lack of stratified outcomes and insufficient

eligible studies. As a result, our pooled estimates combine distinct techniques, and some observed similarities or differences between RALUR and OUR may be driven by surgical technique rather than by the open versus robotic approach itself, which limits the strength of direct comparisons.

All included studies were retrospective, with variability in patient selection, follow-up protocols, and definitions of success. The lack of standardized outcome reporting, particularly regarding success criteria, further restricts the strength of the conclusions [7,11,36].

Finally, cost data remain limited. Useful context is provided by two large U.S. based studies excluded by this analysis due to possible overlaps [22,23]. Bowen et al. reported that RALUR had shorter hospital stay but higher median charges ($32,409 vs $22,703) and represented ~5 % of reimplantations by 2012, concentrated in a few centers [24]. Kurtz et al. found RALUR to have longer OR times, higher 90-day complications, and higher direct costs (median $9,128 vs $7,273) despite shorter hospital stay [23]. Taken together, these observations indicate shorter hospitalization but higher procedural expenses with RALUR in these datasets. Definitive cost-effectiveness remains undetermined and may vary with local pricing, pathways, and case mix.

Despite these limitations, available data demonstrate that RALUR is a safe and effective alternative to OUR, with comparable success and complication rates, shorter hospitalization, and reduced postoperative analgesic use. Future prospective multicenter registries with standardized definitions and cost-effectiveness analyses are needed to further define the role of robotic surgery in pediatric VUR.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpedsurg.2025.162883.

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