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Does the surgeon's learning curve impact pentafecta outcomes in radical prostatectomy? a systematic review and meta-analysis

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Abstract

Introduction Radical prostatectomy is a key treatment for prostate cancer. However, the impact of the learning curve of the surgeon has on the pentafecta is unclear. This meta-analysis aims to determine the impact of a procedure being performed in the initial learning curve has on the surgical results.

Materials and methods A systematic review of MEDLINE, Embase, Scopus, Web of Science, and Google Scholar was conducted up to March 2024, focusing on learning curves in prostatectomy. Primary outcome was biochemical recurrence rate (BCR); secondary outcomes included positive surgical margin (PSM) rate, continence, potency, operative time, blood loss, and complications (Clavien-Dindo classification). Bias was assessed using the ROBINS-I tool, and statistical analysis was done via Review Manager 5.4.

Results Sixteen studies with 21,851 patients were included. No significant difference in BCR rates was found between initial and advanced learning curves (OR1.44;95%CI0.97,2.13;$p=0.07$;I^2=74%). No significant difference in continence rates was also observed. (RD-0.05;95CI-0.10,0.01;$p=0.08$;I^2=86%). However, advanced learning curves showed lower PSM rates (OR1.61;95%CI1.19,2.17;$p=0.002$;I^2=88%), higher potency, less blood loss, shorter operative time, and fewer complications. Although randomized trials are unlikely in this context, further high-quality prospective studies are needed to validate these findings.

Conclusion This meta-analysis highlights that achieving favorable outcomes in key pentafecta parameters—particularly potency, continence, and complication rates—**increases with surgical experience**. These findings emphasize the value of structured mentorship and establishing surgical volume benchmarks in training programs. Our analysis suggests that reaching a threshold of 100 cases may be necessary to consistently attain optimal functional and perioperative results.

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Keywords Learning curve, Prostatectomy, Robotic surgical procedures, laparoscopy, Meta-analysis

Introduction

The management of prostate cancer (PCa) varies significantly and is guided by well-defined clinical factors, including the extent of local tumor invasion, the TNM staging system, and stratified risk assessments that estimate the likelihood of disease progression [1, 2]. Still, when curative therapy for localized and even locally advanced prostate cancer is sought for, radical prostatectomy (RP) remains the treatment of choice [3, 4]. From an oncological standpoint, this surgery aims to excise the tumor with clear surgical margins and to prevent biochemical recurrence (BCR) - which signals recurrent PCa. Further advances in technology, allied with a deeper understanding of anatomy, allowed more precise dissections, adding preservation of continence and erectile function as new parameters for a successful surgery [1, 5].

Given these considerations, it is safe to say that radical prostatectomy is a technically challenging procedure. Achieving optimal oncological and functional results requires extensive practice and increasing expertise, as it involves precise maneuvers and a deep understanding of the pelvic anatomy [4, 5]. In contrast, a surgeon's inexperience can lead to poorer oncological outcomes, more iatrogenic complications, prolonged hospital stays and potential harm to the patient. As a result, establishing a learning curve (LC) that defines when prostatectomy results can be considered adequate and safe is crucial. Some studies have tried to identify the number of procedures needed for a surgeon to attain a high level of efficiency - i.e. the plateau of the LC -, but a definitive answer remains uncertain.

A significant challenge for these studies is that defining a threshold is not easy, as it depends on which surgical outcomes are considered. Traditionally, when intraoperative parameters such as blood loss and operative time were commonly used, the LC plateau was reached rather early [6, 7]. However, more recent studies prefer to adopt oncological endpoints instead, which are more reliable indicators of surgical quality and better predictors of patient prognosis and quality of life. In these cases, the number of operations required to reach optimal results was considerably higher [5, 7]. Even though there is no consensus on whether BCR or positive surgical margins (PSM) are the ideal surrogates for determining the LC, they remain the most reliable metrics [5, 7, 8]. Pentafecta outcomes, by integrating oncological control (BCR and PSM), functional recovery (continence and potency), and absence of major complications, provide a more holistic and patient-centered evaluation of surgical quality compared to isolated metrics. Therefore, it would likely be more reliable to utilize pentafecta outcomes, a tool that provides a more comprehensive approach to reporting prostate surgery outcomes [9].

Additionally, the learning curve trajectory varies substantially among surgical modalities. Open surgery typically requires fewer cases to reach competency, while laparoscopic approaches demand greater technical skill and experience. Robotic-assisted surgery, in contrast, often shortens the learning curve by offering enhanced visualization and instrument dexterity, facilitating faster skill acquisition. When comparing open surgery to laparoscopy, more procedures are generally needed to achieve adequate outcomes in the latter [5, 10]. The same holds true for comparing LRP and RALP, with robotic-assisted surgery often reaching the LC plateau more quickly [7, 11].

Therefore, by conducting a systematic review and meta-analysis, we aim to provide a comprehensive overview of the learning curve for radical prostatectomy. By incorporating oncological, functional, and intraoperative endpoints, as well as various surgical techniques, we seek to better understand how the learning curve correlates with multiple parameters, analyzing the impact of practice on each outcome across different surgical modalities. More specifically, we aim to clarify the impact of the learning curve on pentafecta outcomes following radical prostatectomy, offering insights that can enhance training programs and improve patient outcomes by reducing BCR rates and ensuring more consistent overall results.

Materials and methods

Search strategy

This systematic review and meta-analysis were performed and reported in accordance with the Cochrane Collaboration Handbook for Systematic Review of interventions and the Preferred reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Statement guidelines [12].

We searched MEDLINE, Embase, Scopus, Web of Science and Google Scholar from its inception to March 2024 for trials that evaluated the biochemical recurrence in prostatectomies learning curves. Our summarized search strategy was: ("radical prostatectomy"[MeSH Terms] OR "radical prostatectomy"[All Fields]) AND ("learning curve"[All Fields] OR "surgical learning curve"[All Fields] OR "surgical experience"[All Fields]) AND ("laparoscopy"[MeSH Terms] OR "laparoscopic"[All Fields] OR "robotic"[All Fields] OR "robot-assisted"[All Fields]).

The references from all included studies, previous systematic reviews and meta-analyses were also searched manually for any additional studies. The prospective meta-analysis protocol was registered on PROSPERO under protocol CRD42023459744.

Eligibility criteria for study selection

We included: (1) randomized clinical trials (RCTs) or non-randomized cohorts (non-RCTs); (2) in adult patients (≥ 18 years) undergoing laparoscopic and robot-assisted radical prostatectomy. Additionally, studies were included only if they reported any of the clinical outcomes of interest. In this meta-analysis, we aimed to assess whether the beginning of the learning curve, where the majority of practitioners operate, has a negative impact on recurrence rates and other outcomes compared to surgeons with more extensive experience. To define eligibility, we used the number of cases operated on in each learning curve phase.

For the initial learning curve, we included only studies that involved 0-100 procedures, while advanced learning curves were defined by studies with over 100 surgeries performed. The cutoff of 100 cases was selected based on its prevalence across the included studies. This threshold represented a common benchmark reported by authors and allowed greater homogeneity in comparisons. It also aligns with the learning curve turning point proposed in prior large-scale multicenter analyses.

We excluded (1) studies with patients who did not undergo robot-assisted or laparoscopic radical prostatectomy; (2) or those with patients with persistent disease after RALP. Persistent disease after RALP was defined as a postoperative PSA level ≥ 0.1 ng/mL, measured at least 6 weeks following surgery, indicating incomplete biochemical response and suggesting residual prostate cancer tissue. Additionally, in order to obtain better accuracy of the articles and relevance of the presented data, articles with any of these characteristics were excluded: (a) case report, (b) systematic review, and (c) bibliographic review.

Endpoints

The primary outcome assessed was biochemical recurrence (PSA > 0.2 ng/ml in two distinct measurements after RALP). Secondarily, we analyzed the positive surgical margin rate, continence and potency rates, measured through many international questionnaires, after surgery, as well as operative time, blood loss, and complications assessed using the Clavien-Dindo (CD) classification. We must note that the pentafecta outcomes provide a standardized and comprehensive framework for evaluating prostate surgery, incorporating key measures such as biochemical recurrence-free survival, continence, potency, absence of significant complications, and negative surgical margins. While our study included all pentafecta outcomes, we also extended our analysis to additional factors not traditionally part of this framework, such as operative time and blood loss, to offer a broader perspective on surgical performance and patient recovery.

Screening

After deduplication, in which we used Endnote online™ 20 (Clarivate, Philadelphia, PA) [13], two independent researchers (BP and SO) screened the studies by title and abstract, and disagreements were solved by a third (JC). Following this process, full text screening was performed. No automation tools were used during the screening process.

Data extraction and quality assessment

Two authors (BT and FG) independently extracted the data based on a predefined protocol and disagreements were solved by a third (JC). Non-randomized studies were assessed with the Risk of Bias in Non-randomized Studies – of Interventions tool (ROBINS-I) [14]. Two independent authors completed the risk of bias assessment (JD and SO). Disagreements were resolved through a consensus after discussing reasons for discrepancy.

As all included studies were observational, this meta-analysis is subject to limitations inherent to non-randomized designs, such as potential for unmeasured confounding and selection bias. While efforts were made to mitigate these issues through ROBINS-I assessment, results should be interpreted with caution.

Statistical analysis

Continuous outcomes will be presented as mean difference (MD) with a 95% confidence interval (CI). Dichotomous data will be presented as odds ratio (OR) with a 95% CI. Pooled estimates were calculated with the random-effects model, considering that the patients came from different populations.

Review Manager 5.4 (The Cochrane Collaboration, Denmark, Copenhagen) (Review Manager) was used for statistical analysis [15].

Results

Study selection and characteristics

After performing our screening, we retrieved 1403 articles. Following the deduplication and screening process, 16 articles [7, 8, 10, 11, 16–27] were deemed relevant and included in our analysis (Fig. 1/PRISMA flow chart). For a comprehensive overview of the patient demographics across all included studies, please refer to Table 1. Regarding the design of the included studies, all of them were non-RCT. Combining the data from these articles, we analyzed a total of 6483 patients in the initial learning curve (only studies that involved 0-100 procedures by each surgeon) and 15,316 patients that underwent radical prostatectomy in more advanced learning curves (studies

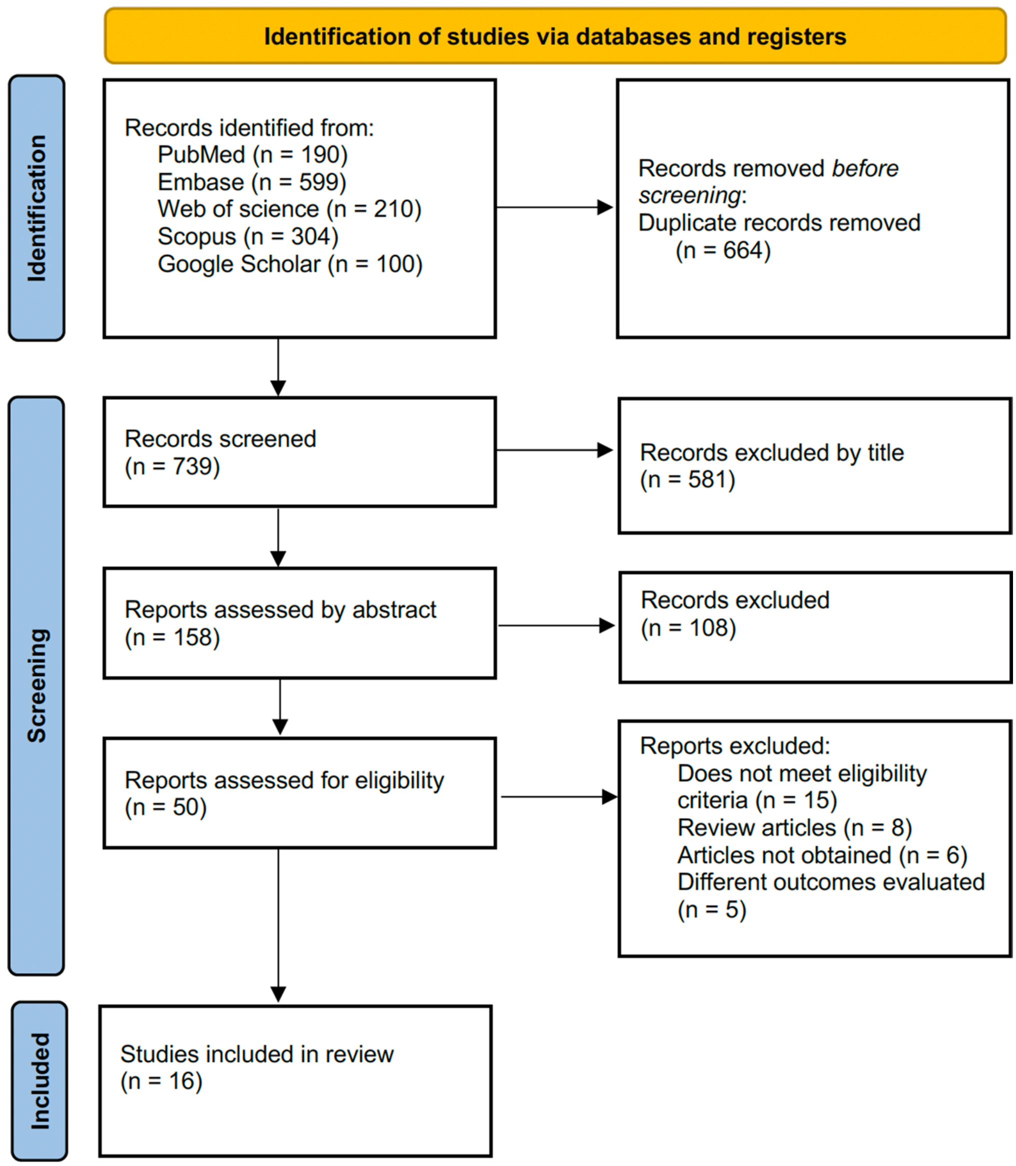

Fig. 1 PRISMA flowchart

with surgeons with more than 100 surgeries completed). The mean age of all patients was 60.8 years old. With respect to the surgical technique, the majority of studies (9 out of 16) utilized RALP to assess learning curves. Additionally, 6 studies focused on LP radical prostatectomy (LRP), while only 1 involved the open approach, which is now generally less common. We must also state that information regarding the specific surgical techniques applied in the included studies was not consistently reported, and therefore could not be extracted or analyzed Table 2.

Meta-analysis

When comparing the BCR rate between initial and advanced learning curves, no differences were seen in the overall result (OR 1.57; 95% CI 0.91–2.71; $p = 0.105$; I^2 = 74%), nor in subgroup analysis (Ralp - OR 1.005; 95% CI 0.897–1.126; $p = 0.93$; I^2 = 35%) (Lap - OR 2.92; 95% CI 0.81–10.57; $p = 0.102$; I^2 = 81%) (Fig. 2A). Given the high overall heterogeneity, a leave-one-out sensitivity analysis was conducted. Upon exclusion of the study by Eden et al. (2009), heterogeneity was substantially reduced (I^2 = 27%), with no statistically significant difference observed (Fig. 2B). A Funnel Plot about the primary outcome can be found in the Fig. 3.

Regarding the secondary outcomes, we observed a lower PSM rate in those surgeons in the advanced learning curve (OR 1.61; 95% CI 1.19–2.18; $p = 0.002$; I^2 = 88%), and the subgroup analysis are the following: (RALP - OR 1.34; 95% CI 1.004–1.799; $p < 0.05$; I^2 = 64%), (LAP

Table 1 Baseline characteristics of included studies

Study	Surgical technique	Study design	Number of surgeons (N)	Number of surgeries (N), Initial LC/Advanced LC	Number of patients (N), Initial LC/Advanced LC	Mean age (years), Initial LC/Advanced LC	Mean PSA levels (ng/mL), Initial LC/Advanced LC	Gleason score 4-6 (N), Initial LC/Advanced LC	Gleason score 7 (N), Initial LC/Advanced LC	Gleason score 8-10 (N), Initial LC/Advanced LC	Clinical staging T1c (N), Initial LC/Advanced LC	Clinical staging T2 (N), Initial LC/Advanced LC	Clinical staging T3 (N), Initial LC/Advanced LC	Clinical staging T4 (N), Initial LC/Advanced LC	Unilateral nerve sparing (N), Initial LC/Advanced LC	Bilateral nerve sparing (N), Initial LC/Advanced LC	Mean follow-up time (months)
Bock, 2022	Robot-assisted	Multicentric Prospective cohort	25	0-74/>149	606/1426	65 ± 5.93/62.59 ± 6.26	6 ± 3.7/6 ± 3.35	290/747	283/586	30/82	331/857	244/495	14/47	0/0	246/439	252/693	NS
Bravi, 2023	Robot-assisted	Multicentric Retrospective	46	0-99/>100	2286/5815	NS	6.4 ± 47.66/6.35 ± 76.37	618/1457	1432/3812	236/546	NS	NS	NS	NS	NS	NS	33 ± 34.81
Chang, 2016	Robot-assisted	Prospective cohort	2	0-100/80-160	184/79	67.2 ± 6.47/66 ± 6.22	12 ± 11.44/11.39 ± 10.45	51/15	77/35	56/29	33/15	137/57	12-6	2-1	NS	NS	NS
Eden, 2009	Laparoscopic	Retrospective	1	0-100/>100	100/900	62 ± 28.15*	7 ± 36.5*	NS	NS	NS	NS	NS	NS	NS	5*	467*	NS
Galfano, 2013	Robot-assisted	Prospective cohort	1	0-100/101-200	100/100	64 ± 6.67/65 ± 7.41	6.16 ± 2.81/6.6 ± 3.19	67/60	31/34	2-6	69/62	31/38	0/0	0/0	13/13	78/66	15 ± 2.22
Gumus, 2011	Robot-assisted	Prospective cohort	1	0-40/80-120	40/40	62,23/62,51	8.98/9.36	32/33	7-7	1/0	0/0	38/39	2-1	0/0	NS	NS	12
Haapiainen, 2021	Laparoscopic	Prospective cohort	1	0-100/101-200	100/100	63 ± 22.2*	7.7 ± 4.07*	133*	37*	27*	101*	50*	49*	0*	NS	NS	18
Hong, 2010	Robot-assisted	Prospective cohort	1	0-139/140-469	139/329	60*	6.47*	304*	80*	44*	379*	90*	0*	0*	NS	NS	NS
Kim, 2008	Laparoscopic	Retrospective	1	0-50/101-500	50/50	63.4 ± 4.2/63.8 ± 5.6	10.9 ± 7/11.2 ± 8.3	37/25	11/18	2-7	14-8	35/38	1-4	0/0	6-2	3-3	34.6 ± 14.51
Patel, 2005	Robot-assisted	Prospective cohort	1	0-100/101-200	100/100	59.5 ± 28.15*	7.1 ± 65.93*	96*	88*	16*	141*	59*	0/0	0/0	NS	NS	9.7
Raman, 2007	Robot-assisted	Prospective cohort	2	0-70/71-140	70/70	60.4 ± 23.70*	6.7 ± 43.70*	76*	53*	14*	97*	44*	2*	0*	13*	109*	11
Ryan, 2022	Robot-assisted	Retrospective	1	0-40/80-120	40/40	60.15 ± 12/62.29 ± 14	6.72 ± 9.85/8.36 ± 15.11	8-7	25/25	7-8	NS	NS	NS	NS	8/15	25/16	NS
Starling, 2010	Laparoscopic	Retrospective	1	0-70/71-240	70/200	65 ± 8.2*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tobias-Machado, 2018	Laparoscopic	Retrospective	11	0-100/>200	400/200	64.62 ± 16.76/65 ± 21.48	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Vickers, 2010	Open	Multicentric Retrospective cohort	72	0-99/>99	2098/5667	62.67 ± 6.68/57.79 ± 41.33	7.13 ± 4.75/6.68 ± 4.6	959/1506	1010/2790	129/371	NS	NS	NS	NS	NS	NS	NS
Viney, 2009	Laparoscopic	Prospective cohort	1	0-100/101-300	100/200	62 ± 5*	7.37 ± 3.62*	145*	140*	15*	NS	NS	NS	NS	NS	NS	19 ± 6

Note: The continuous variables were represented by mean ± SD

Abbreviations: LC, learning curve; PSA, prostate specific antigen; NS, non specified

*Overall value (initial + advanced LC).

Table 2 Assessment of outcomes of interest from included studies

Study	Mean operative time (min), Initial LC/ Advanced LC	Mean blood loss (mL), Initial LC/Advanced LC	Complications (*N*), Initial LC/ Advanced LC	Potency (*N*), Initial LC/Advanced LC	Continence rate (%), Initial LC/ Advanced LC	Positive surgical margins (*N*), Initial LC/ Advanced LC	Biochemical recurrence (*N*), Initial LC/ Advanced LC
Bock, 2022	NS	NS	NS	230/755	84%/79%	127/342	67/185
Bravi, 2023	NS	NS	NS	NS	NS	522/1066	400/1006
Chang, 2016	219 ± 63/193 ± 49	216 ±. 173.2/201 ± 168.1	NS	NS	60.8%/84.9%	NS	133/51
Eden, 2009	196/167	222/205	48*	25/639	96%/99%	10/16	9-9
Galfano, 2013	210 ± 58.52/190 ± 44.44	300 ± 148.15/200 ± 74.07	13-9	17/14	96%/96%	32/19	11-8
Gumus, 2011	182 ± 155.56/139 ± 147.41	287 ± 851.85/170 ± 481.48	11-4	24/30	72.5%/92.5%	9-2	7/0
Haapiainen, 2021	114 ± 28.15*	150 ± 92.59*	36*	160*	92%*	21/25	13*
Hong, 2010	NS	NS	NS	NS	NS	36/76	NS
Kim, 2008	314 ± 72/246 ± 30	524.8 ± 337.7/646.6 ± 910.5	18-1	NS	93%/85%	24/18	10-5
Patel, 2005	177,65/109,65	107,8/42,7	2*	NS	98%*	13-8	10*
Raman, 2007	318 ± 288.89/209 ± 262.22	387 ± 1295.3/155 ± 437.04	9*	NS	97.3%*	16-8	6*
Ryan, 2022	250 ± 110.37/220 ± 71.85	400 ± 703.70/400 ± 1473.33	5-7	NS	NS	8-7	6-8
Starling, 2010	300 ± 190/180 ± 100	330 ± 210/210 ± 180	21/25	51/140	90%/98%	10/20	7/18
Tobias-Machado, 2018	244 ± 84.47/150 ± 77.78	331.24 ± 422.07/250 ± 296.30	108/48	265/160	92%/98%	NS	NS
Vickers, 2010	NS	NS	NS	NS	NS	819/1242	NS
Viney, 2009	216.88 ± 29.95/161.715 ± 20.99	NS	NS	NS	NS	NS	NS

Note: The continuous variables were represented by mean ± SD

Abbreviations: LC, learning curve; PSA, prostate specific antigen; NS, non specified

*Overall value (initial + advanced LC)

- OR 1.83; 95% CI 0.79–4.25; $p = 0.16$; I^2 = 79%) and (Open - OR 2.28; 95% CI 2.05–2.54; $p < 0.001$; I^2 = not applicable) (Fig. 4A). A leave-one-out sensitivity analysis was conducted, but I^2 remained above 70% in all iterations (Fig. 4B).

About the continence rate, significant differences favoring the advanced learning curve were seen in the overall comparison (OR 0.47; 95% CI 0.24–0.95; $p = 0.034$; I^2 = 85%). However, the subgroup analysis revealed no significant differences at all (RALP - OR 0.57; 95% CI 0.22–1.48; $p = 0.249$; I^2 = 88%) and (LAP - OR 0.38; 95% CI 0.13–1.15; $p = 0.088$; I^2 = 70%) (Fig. 5A). A leave-one-out sensitivity analysis was conducted, but I^2 remained above 50% in all iterations (Fig. 5B).

Regarding potency rates, we found a statistically significant difference favoring the advanced learning curves group (OR 0.51; 95% CI 0.27–0.95; $p = 0.034$; I^2 = 87%), which did not occur in the subgroup analyses (RALP - OR 0.56; 95% CI 0.46–0.67; $p < 0.001$; I^2 = 0%) and (LAP - OR 0.42; 95% CI 0.13–1.41; $p = 0.16$; I^2 = 94%) (Fig. 6A). A leave-one-out sensitivity analysis was conducted, but I^2 remained above 59% in all iterations (Fig. 6B).

Overall, we could also see a reduced operative time in advanced learning curves (MD 55.87; 95% CI 36.76 to 74.98; $p < 0.001$; I^2 = 89%), (RALP - MD 38.75; 95% CI 18.24 to 59.26; $p < 0.05$; I^2 = 66%), (LAP - MD 69.99; 95% CI 42.05 to 97.92; $p < 0.05$; I^2 = 91%) (Fig. 7A). A leave-one-out sensitivity analysis was conducted, but I^2 remained above 80% in all iterations (Fig. 7B).

As for intraoperative blood loss, a significant reduction was observed in the advanced learning curve group (MD 69.13; 95% CI 32.53 to 105.72; $p < 0.001$; I^2 = 46%). Subgroup analyses confirmed this finding for both RALP (MD 66.77; 95% CI 11.34 to 122.19; $p < 0.05$; I^2 = 51%) and Laparoscopic approaches (MD 71.41; 95% CI 15.08 to 127.75; $p < 0.05$; I^2 = 52%) (Fig. 8A). Given the high overall heterogeneity, a leave-one-out sensitivity analysis was conducted. Upon exclusion of the study by Cheng et al. (2016), there was no heterogeneity at all, with a statistically significant difference favoring the advanced learning curves group (MD 91.64; 95% CI 68.29 to 114.99; $p < 0.05$; I^2 = 0%) (Fig. 8B).

At the same time, we could see a reduced rate of complications in the group that underwent surgery performed by surgeons more advanced in the learning curve

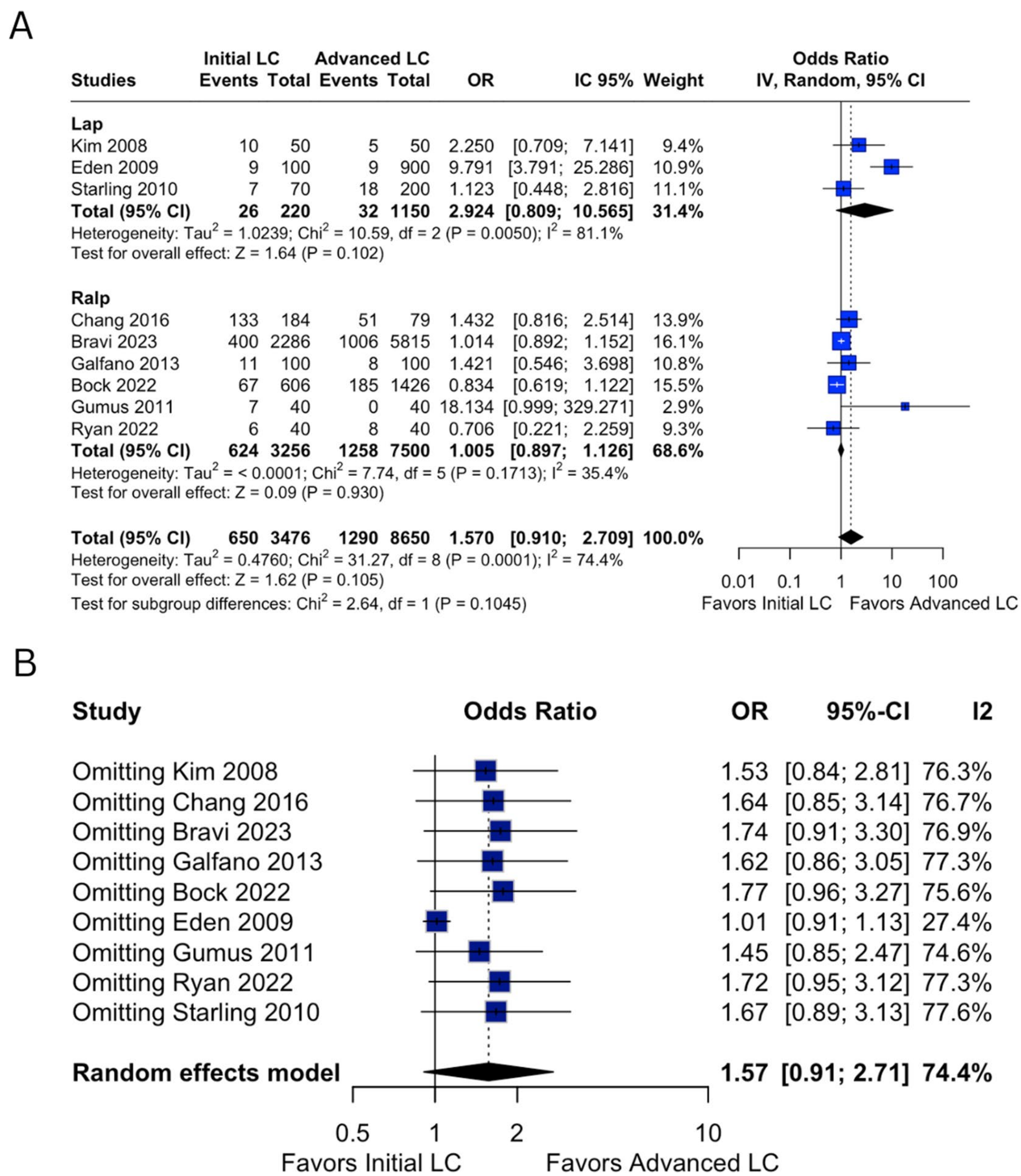

Fig. 2 No difference when assessing BCR between both learning curves

(OR 2.06; 95% CI 1.04–4.09; $p = 0.038$; I^2 = 70%), although the subgroup analysis showed no differences (Ralp - OR 2.06; 95% CI 1.04–4.09; $p = 0.038$; I^2 = 70%), (Lap - OR 3.53; 95% CI 0.72–17.22; $p = 0.119$; I^2 = 85%) (Fig. 9A). A leave-one-out sensitivity analysis was conducted, but I^2 remained above 55% in all iterations (Fig. 9B).

Importantly, patient-level confounders such as comorbidities, tumor risk stratification, and surgeon-specific training background were not uniformly reported and could not be adjusted for in pooled analyses. These factors may have influenced outcomes and contribute to the heterogeneity observed.

Quality assessment

Since all the trials here included were non-RCTs, all of them were assessed through the ROBINS-I tool. Our analysis showed a total of 5 studies with a low risk of bias, 5 with a moderate risk, 5 with serious risk of bias, mainly due to bias in measurement of outcomes, and only one, the Patel's cohort [23], with critical risk, also as a result of bias in measurement of outcomes (Fig. 10).

Discussion

Radical prostatectomy remains the leading surgical treatment, while radiotherapy is also commonly used in the management of locally advanced prostate cancer [3].

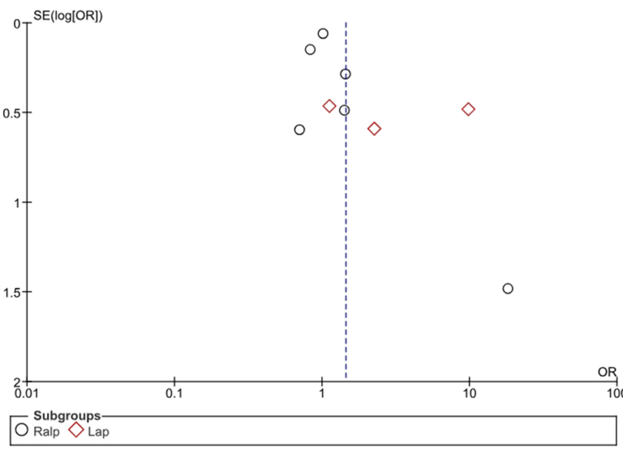

Fig. 3 Funnel Plot of primary outcome

Despite being a technically demanding procedure due to anatomical challenges—particularly its deep pelvic location and the tumor's impact on surgical planes—open surgery has historically delivered excellent curative outcomes. The shift to minimally invasive techniques, including laparoscopic and robotic-assisted approaches, introduced a new challenge for urologists: replicating these outcomes while navigating a steep learning curve [28]. However, with the advent of minimally invasive surgery, urologists faced a new challenge: to replicate these curative outcomes using laparoscopic and robotic-assisted techniques. Consequently, significant learning curve studies were conducted to evaluate whether urologists could enhance their skills in these minimally invasive approaches.

While the 100-case cutoff provided a meaningful reference, further investigation is warranted to determine whether alternative thresholds (e.g., 50 or 200 cases) might offer different predictive validity for specific pentafecta components.

Our main findings indicated no significant difference in BCR between the groups (OR 1.44; 95% CI 0.97, 2.13; $p=0.07$; $I^2=74\%$) and the subgroups evaluated. This observation is crucial to our analysis, as it demonstrates that even though some professionals are at the beginning of their learning curve in prostatectomy surgery, the training of these young surgeons does not compromise the biochemical recurrence of the excised cancer. Additionally, we observed that the surgical technique used does not impact cancer remission. This suggests that it is reasonable for surgeons to perform the techniques with which they are most familiar or that their economic conditions permit. This aligns with current guidelines, which generally do not specify a gold-standard operating technique for radical prostatectomy. While it is true that certain benefits of the robotic-assisted approach are recognized—such as facilitating vesico-urethral anastomosis—these do not impose limitations on the choice of surgical technique in terms of functional and oncological outcomes.

Although the primary outcome showed no significant difference between the groups, it is well-known that repetition improves proficiency. That said, the analysis of secondary endpoints further supports the group of surgeons at more advanced learning curves of their learning curves. The PSM was notably lower among more experienced surgeons, who also demonstrated higher potency rates post-surgery. This can be attributed to the greater dexterity and skills of these surgeons, enabling them to perform more extensive dissections, ensuring clear margins without damaging relevant anatomical structures [29]. However, when considering continence rates, no significant difference was observed between the groups. Although these results may initially seem counterintuitive, we believe that the surgical margin is a parameter that closely reflects the surgeon's proficiency, as it depends both on the extent of the disease and the surgeon's skill. For instance, more aggressive disease requires wider margins, while a more localized and less invasive condition allows for greater preservation of neurovascular bundles. The decision to be more or less invasive often hinges on the surgeon's experience. Continence, on the other hand, while also dependent on the surgeon's ability to preserve neurovascular bundles and perform a better anastomosis, can be compromised in cases of more aggressive disease that require wider resections to ensure a negative surgical margin [30]. Thus, continence outcomes may depend more on the specifics of the case rather than solely on the surgeon's experience.

In addition, the intraoperative outcomes, including operative time and blood loss, were also lower in the group at more advanced learning curves of prostatectomy. This is attributable to the extended experience and refined skills of these surgeons compared to their younger counterparts. Experienced surgeons typically have more practiced techniques, which allow them to operate more efficiently and manage intraoperative challenges more effectively [31]. Finally, when considering postoperative complications, a higher rate was observed among surgeons who performed fewer prostatectomies. This may be due to less developed surgical techniques, limited experience in managing intraoperative and postoperative complications, and a lower overall volume of procedures, which can impact the proficiency and confidence needed to handle complex cases effectively [32].

In summary, our analysis highlights that, while young surgeons often achieve BCRs comparable to more experienced practitioners, key elements of the pentafecta outcomes—such as continence, potency, and the absence of significant complications—are negatively impacted during the early phases of the learning curve. In addition, metrics like surgical margins, operative times, and

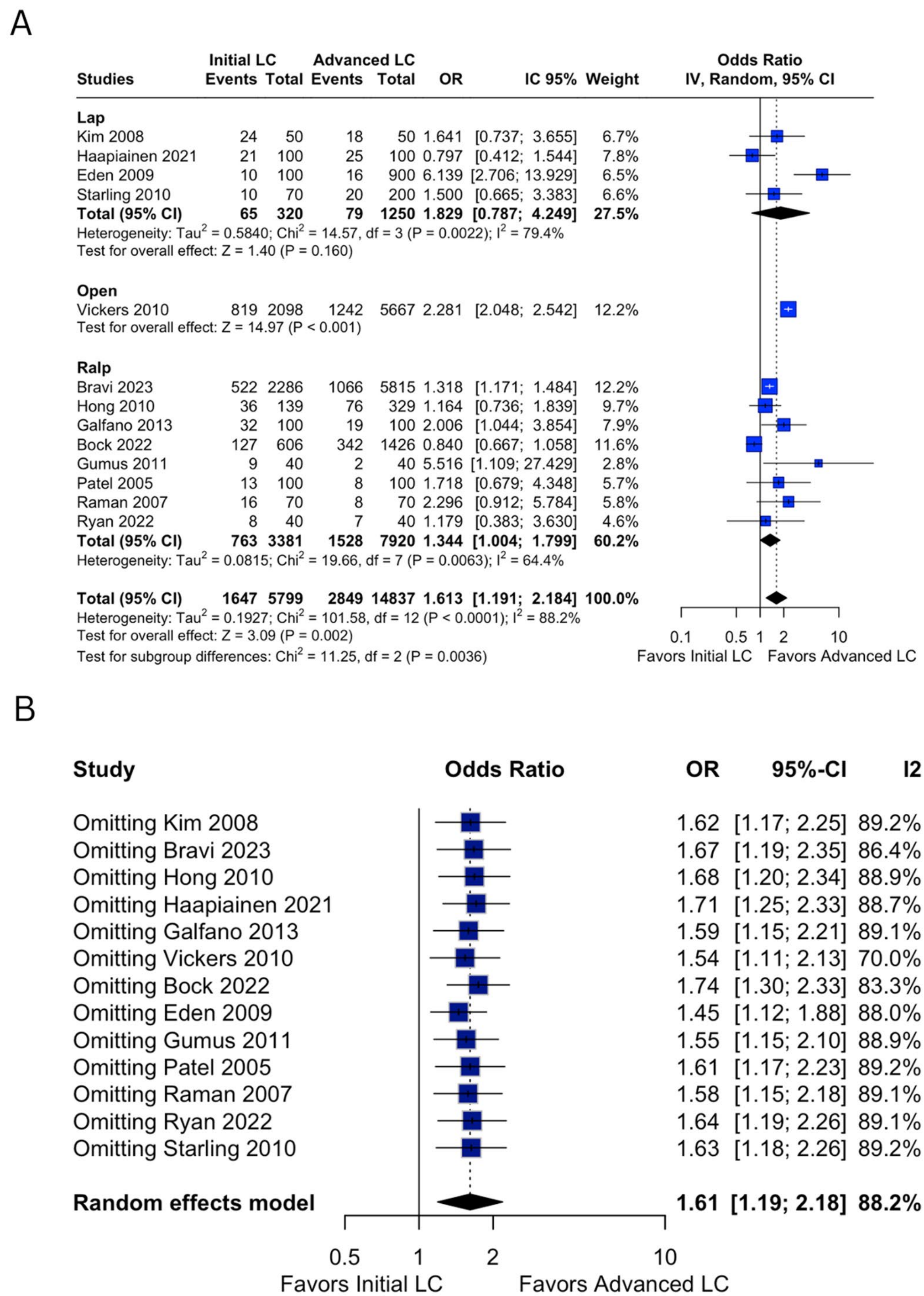

Fig. 4 Higher PSM was observed in patients whose surgery was performed by a surgeon in his initial learning curve

bleeding rates are also suboptimal, further underscoring the importance of extensive training to master these techniques. This raises an important consideration: weighing the trade-offs between patient outcomes and the cost of training new surgeons in robotic-assisted radical prostatectomy. A structured approach to training, coupled with appropriate mentorship and case volume progression, is essential to balance these priorities effectively. Interventions such as high-fidelity simulation, structured mentorship programs, and modular training have shown promise in reducing learning curves in surgical education. Implementation of these strategies, especially in

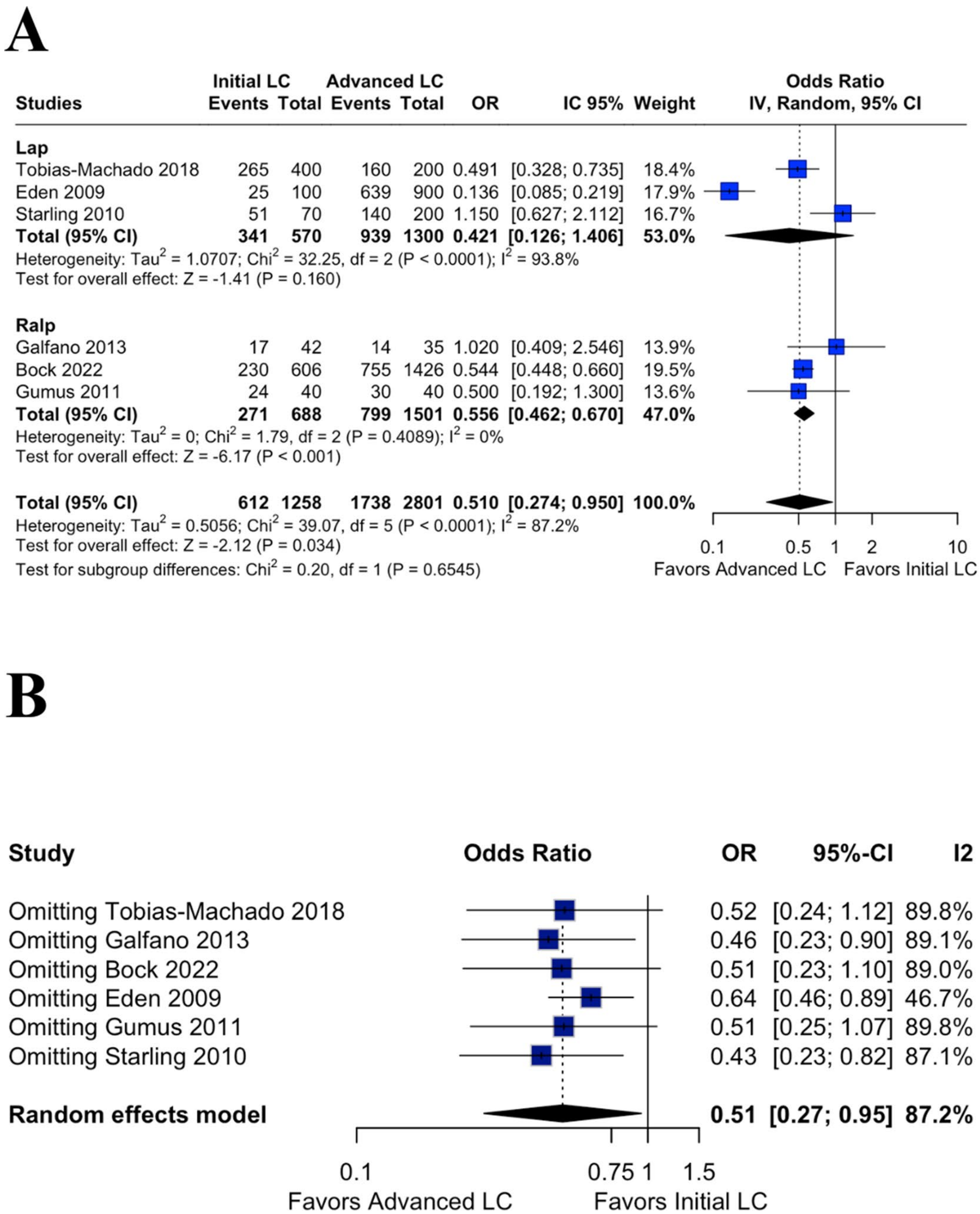

Fig. 5 The assessment of continence showed no difference between initial and advanced learning curves

robotic training pathways, may help accelerate technical proficiency and improve early patient outcomes.

For every surgical procedure, there is a learning curve that improves over time and with the number of procedures performed. Particularly in Urology, studies like this one are not new, as analyzing the viability of a novel technique through its learning curve is crucial. In this context, Pecoraro et al. [33] published a systematic review on the learning curve of open and minimally invasive kidney transplantation. They found that both open and robotic-assisted kidney transplantation have a learning curve of approximately 30 cases to achieve safety and optimal operative times, which suggests that the robotic-assisted approach in urological surgeries is indeed a viable alternative. Additionally, Tasian et al. [34] conducted a prospective cohort study evaluating the learning curve of urology fellows performing robotic pediatric pyeloplasty. Despite the study being somewhat dated for robotic-assisted procedures - it was conducted between 2006 and 2010 - they concluded that 37 cases are the optimal number for a fellow to match an assistant's operative time. Once again, this highlights that robotic-assisted procedures are a

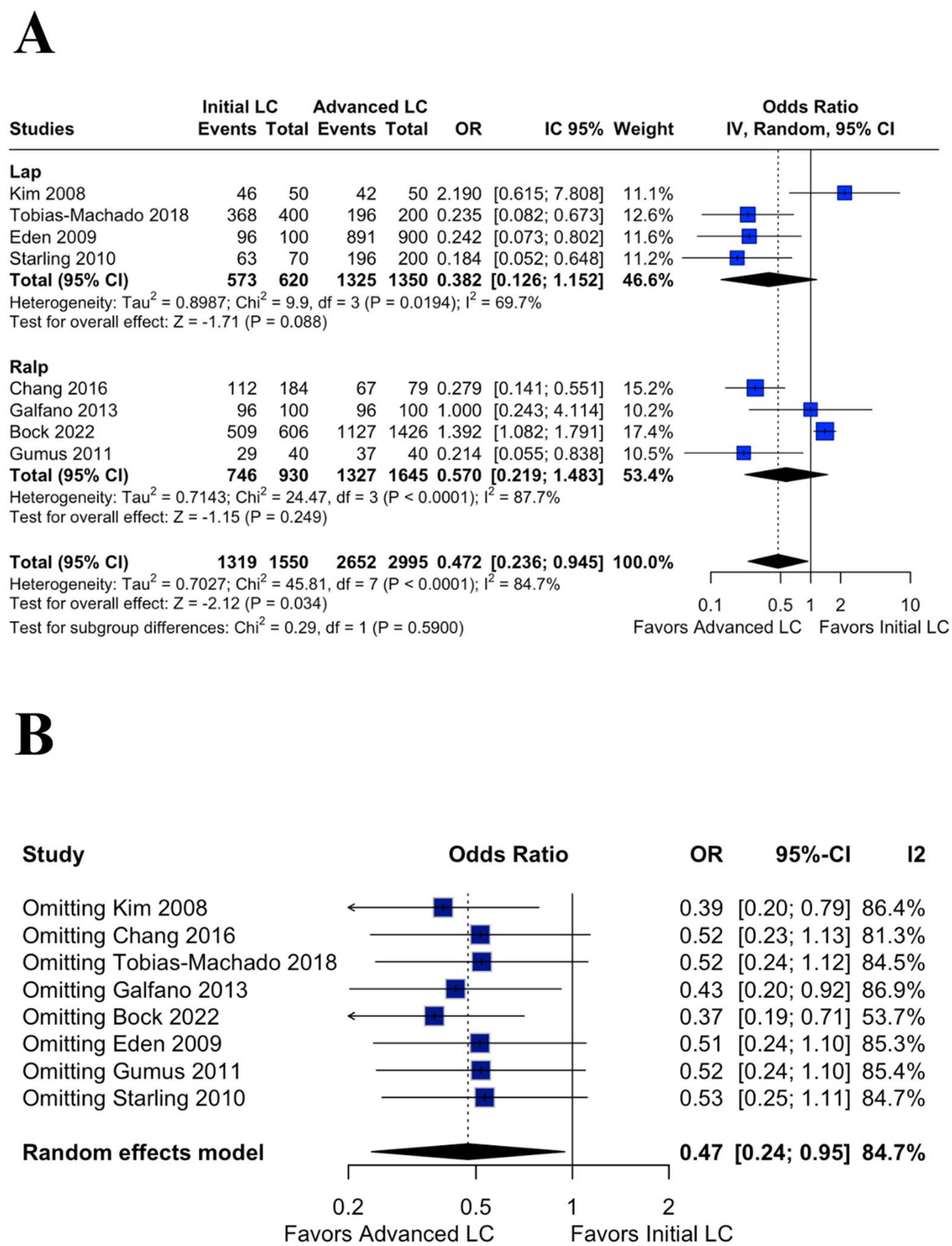

Fig. 6 Higher potency after surgery was observed when the patient was operated by a surgeon in more advanced learning curves

viable option in urology. Although studies as these above exists in the current literature, approaching the impact of surgeon experience on outcomes in RALP, none have conducted a meta-analysis with our specific approach. Our analysis uniquely compares outcomes between cases operated on within a surgeon's initial 100 procedures and those performed after achieving at least 100 cases, with some in this latter group reaching 1,000 or even 2,000 surgeries, which significantly strengthens the robustness of our findings. Our results suggest that undergoing surgery in an academic setting or being operated on by a less experienced surgeon does not negatively impact the likelihood of cure or postoperative recovery. Additionally, comparisons with other urologic procedures reveal similar patterns. In robotic kidney transplantation, a 30-case learning curve was reported for safe outcomes. Pediatric robotic pyeloplasty studies suggest proficiency is attained after approximately 37 procedures. These findings support the use of structured case-volume milestones across different urologic subspecialties.

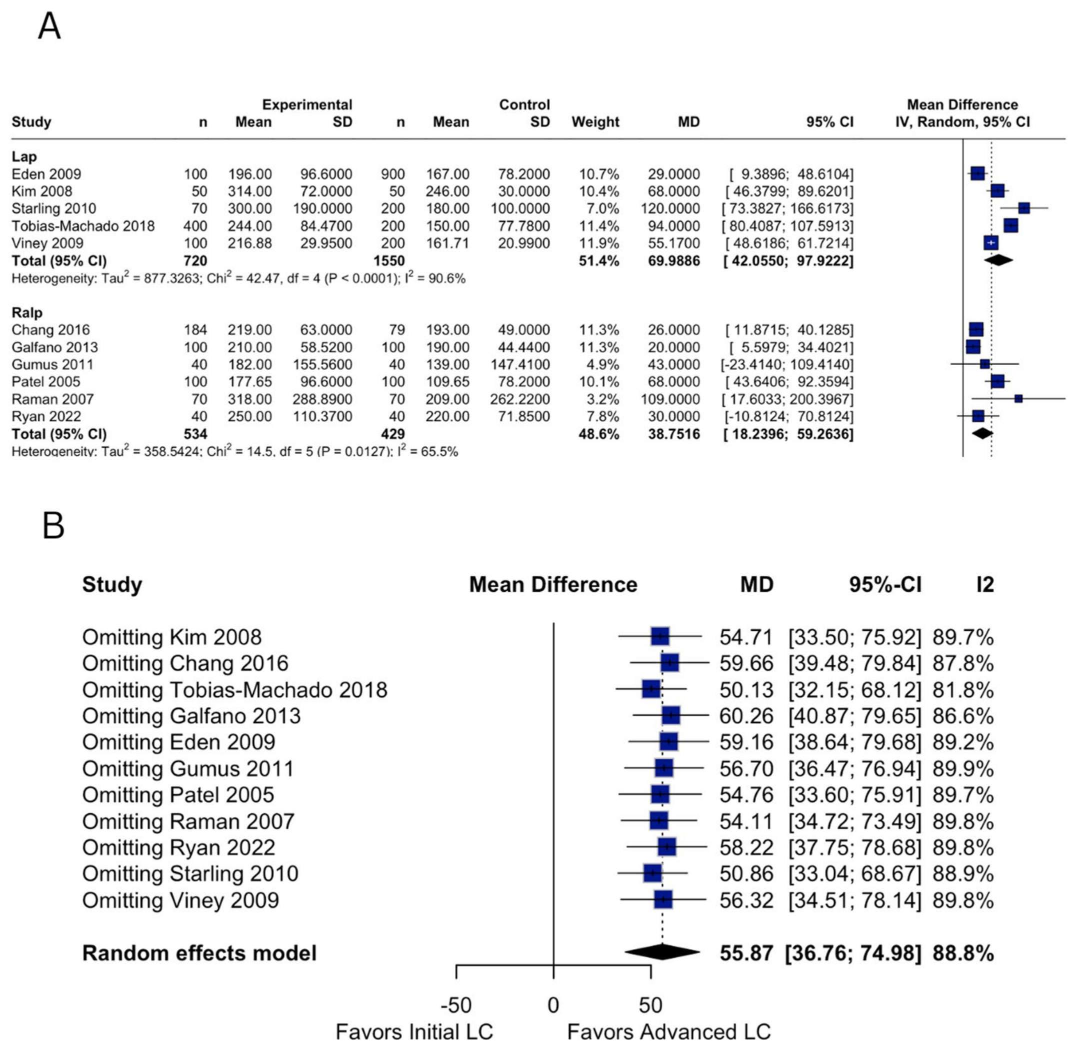

Fig. 7 Lower operative times were found in cases performed in advanced learning curves

Our study has certain limitations that warrant consideration. Firstly, due to the scarcity of existing literature on the specific topic of the learning curve in prostatectomy, all sixteen studies included in our analysis were observational and non-randomized, raising the possibility of selection bias and limited control over confounding variables. The complete absence of RCTs is a notable limitation, as it may impact the robustness of our findings. Secondly, there was notable heterogeneity in practically all evaluated outcomes. We attribute this partly to the differences in the prior knowledge that young surgeons bring to their practice, obviously the varying volumes of surgeries performed in different surgical services, since not all residencies have a consistent patient flow, which can hinder the development of diverse surgical techniques, as well as the instructor's previous experience and patience in knowledge transfer, which are a constant limitation, inherent in this type of study, although it represents a fundamental factor in the learning process. Thirdly, we observed discrepancies in study design, with some studies assessing the performance of a single surgeon from the beginning to the end of their learning curve, while others compared the performance of young surgeons with that of experienced surgeons. This diversity in study design may limit our results and the generalizability of our conclusions, contributing to the high heterogeneity observed. Additionally, another limitation of our study is the inability to fully address the nuanced impact of positive surgical margins across different risk groups, as biochemical recurrence is influenced not only by surgical margins but also by independent high-risk factors and adverse prognostic features in pathological anatomy, which vary significantly between intermediate, high, and very high-risk patients. Moreover, institutional differences likely influenced outcomes, as high-volume centers often provide superior mentorship, support systems, and operative standardization. These factors may

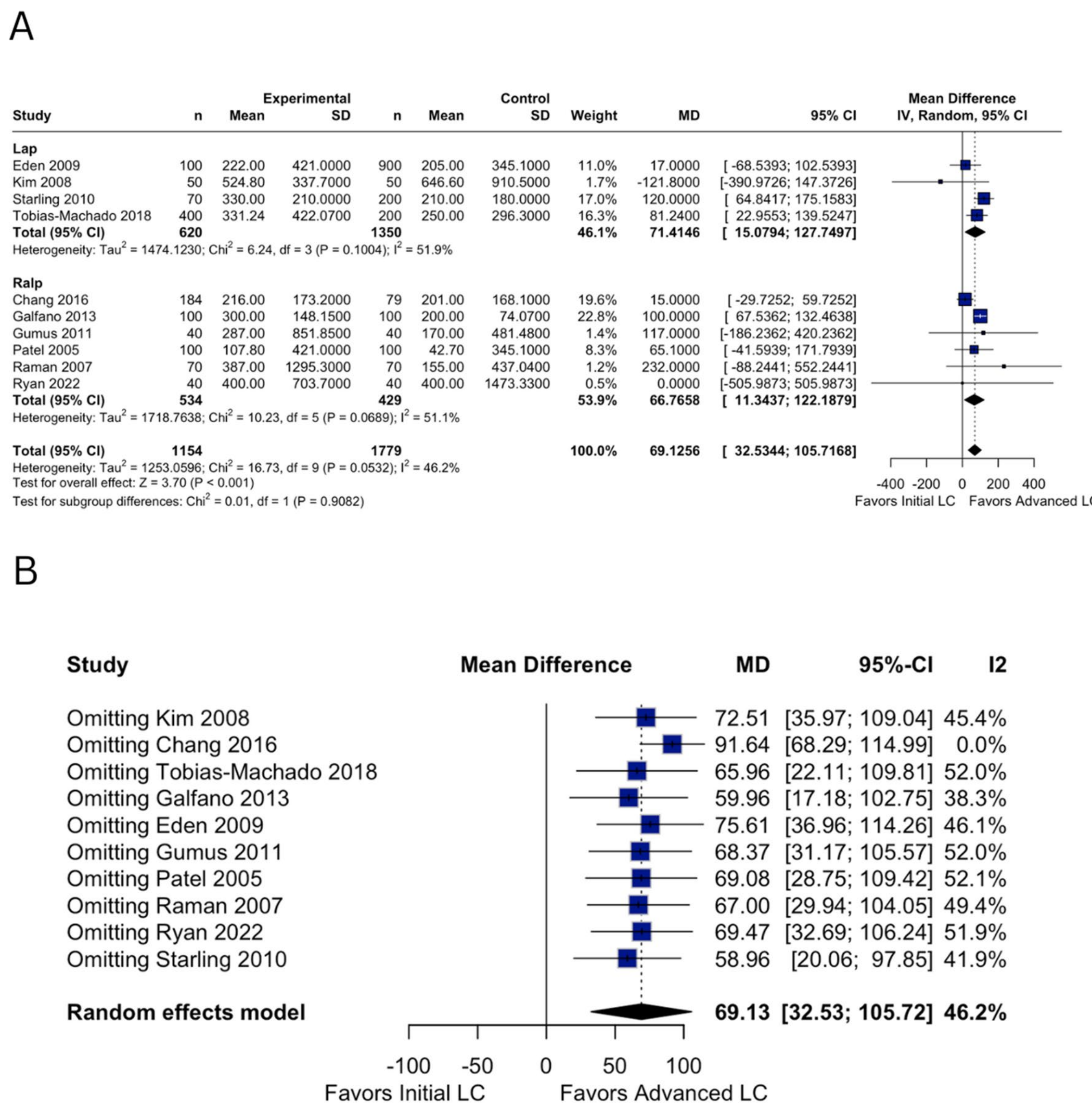

Fig. 8 Assessment of blood loss between initial and advanced learning curve also revealed a more blood loss in cases performed in the initial learning curve

partially explain better results seen among surgeons in advanced phases of their learning curve.

The results of this meta-analysis reinforce the importance of structured training and mentorship in surgical education. Beyond case volume, supervised learning environments and standardized mentorship programs have been shown to significantly improve both functional and oncological outcomes in radical prostatectomy. Prior studies demonstrate that surgeons trained under mentorship protocols exhibit lower rates of positive surgical margins and improved continence and potency outcomes compared to those trained independently [10, 20]. These findings support the integration of mentorship and formal training curricula as essential components to optimize the learning curve in robot-assisted radical prostatectomy and ensure consistent, high-quality patient care across institutions [35, 36].

As demonstrated in this study, young urologists are now able to perform successful radical prostatectomies, with biochemical recurrence rates that are non-inferior to those achieved by more experienced surgeons. However, we cannot yet confirm that these outcomes are obtained with the same level of safety, as we observed worse surgical margins, longer operative times, and increased bleeding. Therefore, moving forward, we hope that young urologists will not settle for merely achieving favorable Benefit-Risk Ratios, but will actively engage in ongoing training programs, such as European robotic training initiatives and specialized fellowships. These programs aim to enhance their surgical skills and ensure

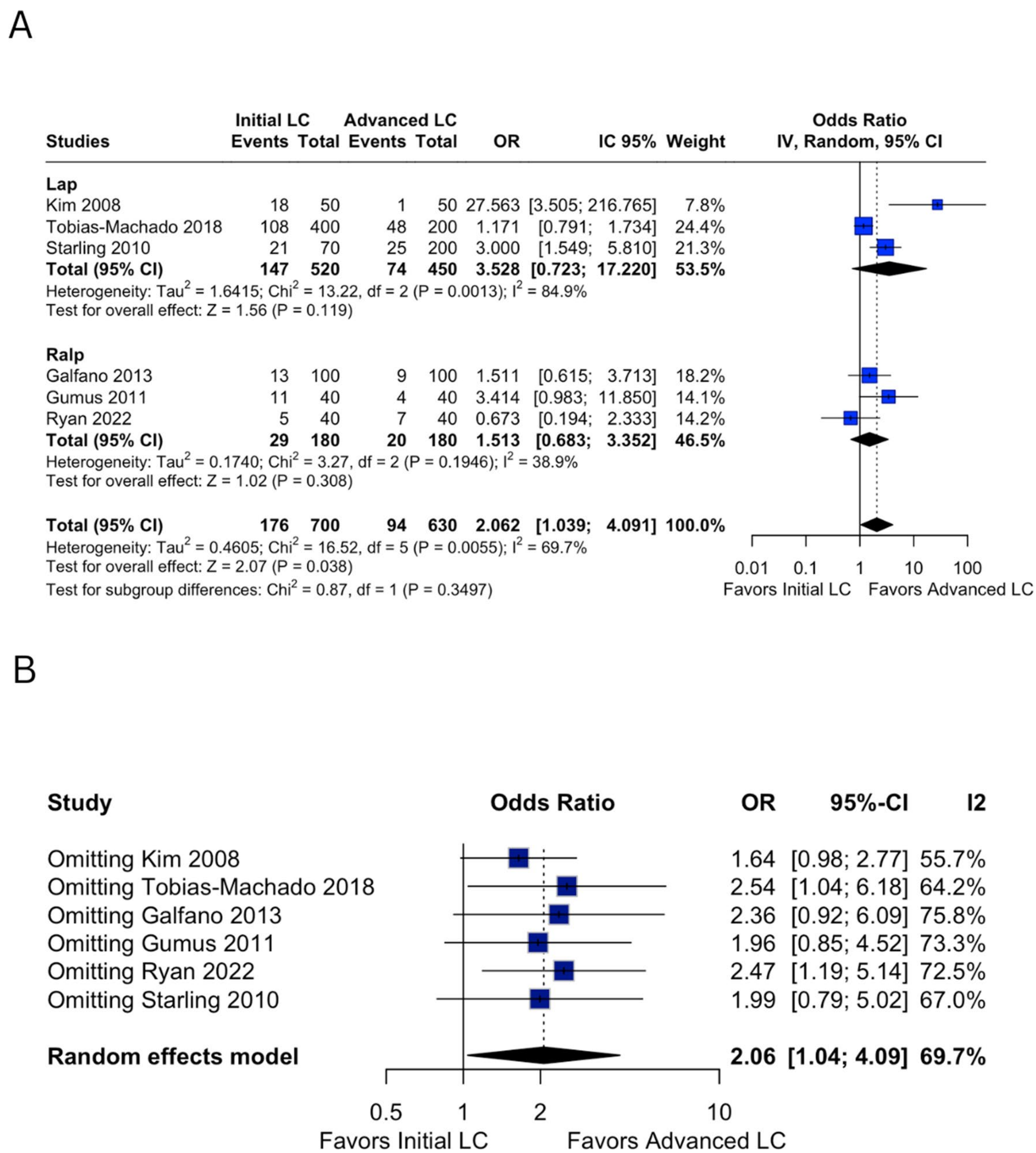

Fig. 9 Complication rate between initial and advanced learning curves revealing more complications in cases performed in the initial learning curve of the surgeon

procedural safety, fostering a culture of continuous improvement and excellence in urological care.

Despite the meticulous nature of this analysis, it is important to acknowledge the lack of RCTs within our dataset. Therefore, further research and larger-scale trials are essential to validate and build upon the promising outcomes observed in our study, minimizing biases inherent in retrospective studies. It would be particularly interesting to compare less initial learning curves (100–200 cases) with longer curves (300 or more) to provide a deeper understanding of the impact of extended training on the efficacy and safety of robotic radical prostatectomy.

Conclusion

This meta-analysis supports the 100-case threshold as a relevant benchmark for achieving technical proficiency in robotic-assisted radical prostatectomy. Notably, we observed statistically significant improvements in potency, continence, and complication rates beyond this threshold, highlighting its clinical importance. These findings underscore the critical role of structured training

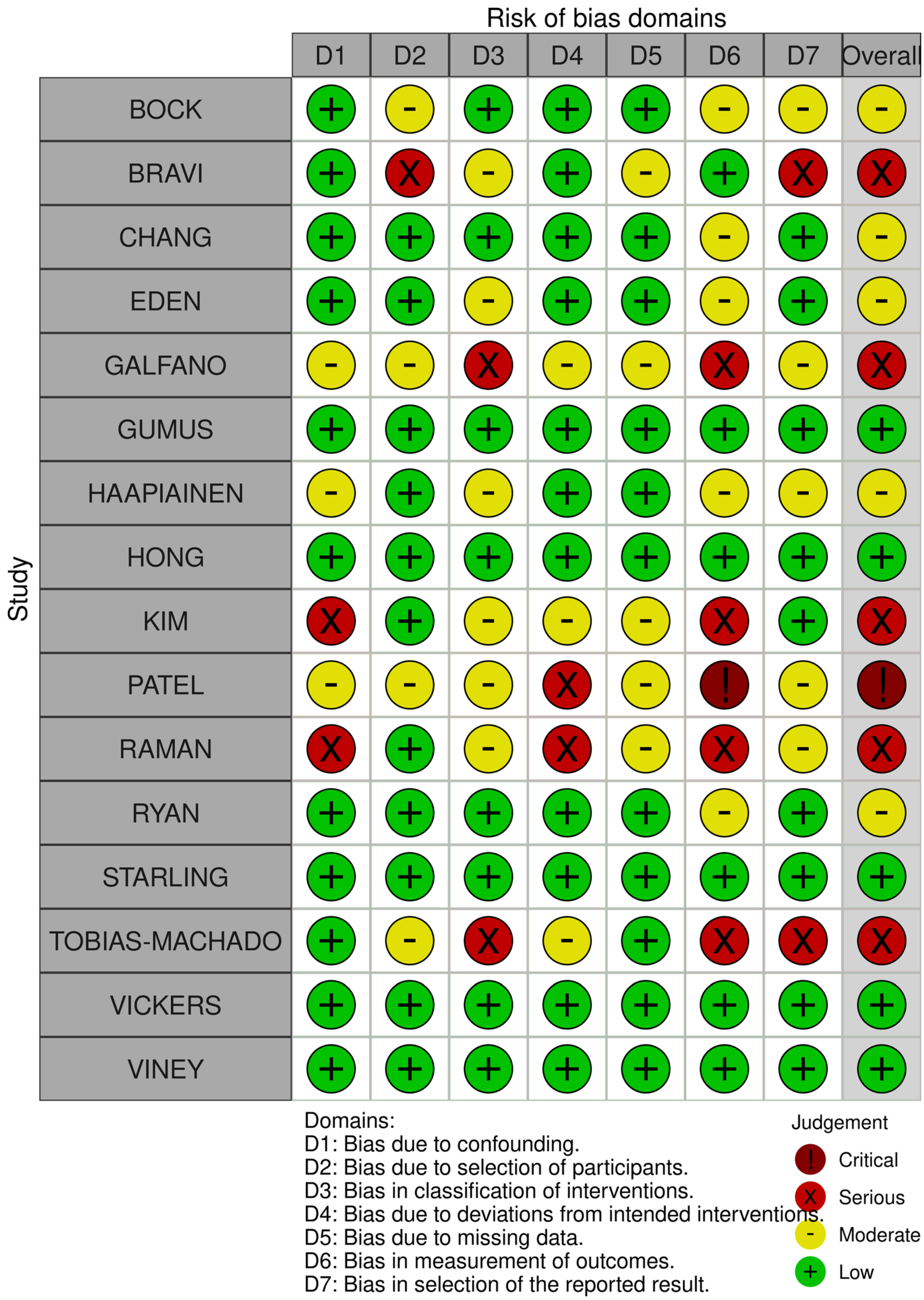

Fig. 10 Risk of bias of included studies through ROBINS-I toll

in optimizing surgical results, particularly during the early stages of the learning curve when functional outcomes are most vulnerable. Balancing the investment in training with patient safety remains essential, and future research should assess the feasibility of achieving comparable outcomes with lower case thresholds. Structured mentorship programs and simulation-based training may help young surgeons overcome early technical challenges. Additionally, personalized learning trajectories, guided by performance metrics, could further optimize surgical outcomes and reduce variability in care delivery.

Supplementary Information

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Supplementary Material 1

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Author contributions
Substantive scientific and intellectual contributions to the study: Conception and design: José A. S. da Cruz, Breno C. Porto and Felipe G. A. Gonçalves; Acquisition of data: Felipe G. A. Gonçalves, Breno C. Porto and Juan Victor Nabhan Martinez; Analysis and interpretation of data Bruno D. Terada, Soraya Hussein Orra and Carlo C. Passerotti; Technical procedures: Felipe G. A. Gonçalves, Juan Victor Nabhan Martinez, Breno C. Porto and Kenneth Nunes Tavares De Almeida; Statistics analysis: Everson L. A. Artifon, Bruno D. Terada and José A. S. da Cruz; Manuscript preparation: Felipe G. A. Gonçalves, Breno C. Porto, Rodrigo A. S. Sardenberg and José A. S. da Cruz; Manuscript writing: Soraya Hussein Orra, Breno C. Porto, and José P. Otoch; Critical revision: José P. Otoch, Kenneth Nunes Tavares De Almeida and José A. S. da Cruz.

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Data availability
Data is provided within the manuscript and in Tables 1 and 2.

Declarations

Human ethics and consent to participate declarations
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Competing interests
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