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Original Article

Robotic vs laparoscopic radical prostatectomy: the impact of surgeon volume on surgical margins and quality of life

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Abstract: Background: The principal established therapeutic option for localized prostate cancer is the robotic-assisted radical prostatectomy (RARP) over the laparoscopic radical prostatectomy (LRP). Robust data from Chinese hospitals is limited, and the effect of surgeon experience is often overlooked. Objective: This study retrospectively compares outcomes between RARP and LRP, evaluating the impact of surgeon experience. Methods: The clinical information of 252 patients who underwent RARP or LRP between 2019 and 2023 was retrospectively analysed. Multivariable regression models, for both patient characteristics and surgeon volume, were employed to evaluate perioperative metrics, complications, positive surgical margins (PSM), continence, and patient-reported outcomes. Results: RARP demonstrated superior advantages, including a shorter operative time (154.9±28.3 vs. 169.2±23.9 minutes, P<0.001), less blood loss (172.5±56.8 vs. 306.8±82.2 mL, P<0.001), and a shorter hospital stay (2.3 vs. 3.9 days, P<0.001). Multivariable analysis revealed that both surgical approaches and surgeon volume were predictors of outcomes: 66% lower odds of PSM (OR: 0.34, P=0.009) in the RARP group, while high-volume surgeons demonstrated 96% lower odds of PSM compared to low-volume surgeons (OR: 0.039, P<0.001). RARP patients experienced fewer complications (25.4% vs. 39.7%, P=0.016) and a higher continence recovery at 12 months (95.2% vs. 80.2%, P=0.001). Regarding patient-reported outcomes, RARP was consistently favored across all domains (P<0.01). Conclusion: While preserving comparable functional and short-period cancer-related outcomes, RARP outperformed LRP in perioperative outcomes and patients' quality of life. These findings demonstrate that both surgical technology and surgeon volume are critical, independent determinants of surgical quality. The optimal outcomes are achieved by pairing advanced robotic technology with high-volume surgical expertise.

Keywords: Prostate cancer, prostatectomy, laparoscopy, robotic surgery, retrospective study

Introduction

Labelled as one of the most frequent diseases affecting men, Prostate cancer is one of the deadliest cancers worldwide. The frequency of incidence varies greatly between countries, from about 4.5 to 174.1 per 100,000, leading to a significant difference in the socioeconomic management of the disease in terms of treatment [1, 2]. The primary treatment option for the disease is surgery. Over the years, radical prostatectomy (RP) has gained popularity as the main option for localized prostate cancer. Reports from several clinical trials have demonstrated the considerable benefit of RP on patients' outcomes [3, 4].

With recent progress in new technologies, RP has evolved from the traditional open surgery to minimally invasive approaches, which were shown to significantly reduce the risk of surgical trauma. The first was laparoscopic radical prostatectomy (LRP), followed by robotic-assisted radical prostatectomy (RARP). Trials and data from various studies have demonstrated that while those minimally invasive procedures may attain comparable oncological outcomes as RP, they offer better perioperative results, such as much less blood loss (RARP ~228 mL vs. LRP ~408 mL vs. Open ~852 mL) and fewer transfusions [5, 6]. Consequently, the main treatment option for radical prostatectomy has

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shifted from RP to the minimally invasive surgeries, which optimize patient prognosis.

When comparing both minimally invasive approaches, the efficacy of RARP versus LRP has been contradicted and debated. Several meta-analyses have depicted the poor comparative evidence between both surgical approaches, and other systematic reviews have emphasized the lack of high-quality comparative trials [7, 8]. Nevertheless, with the development of robotic-related new technologies such as three-dimensional magnification, wristed instrumentation with great flexibility, and tremor filtration, RARP has been widely adopted as more advantageous [5, 9]. Recent studies have begun to support these claims. A revolutionary 10-year randomized controlled trial found that, while both RARP and LRP had identical rates of urinary and erectile function restoration 10 years after surgery, RARP patients had a visibly higher quality of continence and erectile function [10]. Another recent meta-analysis of 7000 patients demonstrated that RARP patients showed significantly better sexual function recovery, lower biochemical recurrence ratio, and reduced risk of postoperative complications in comparison to LRP [11].

Nevertheless, across all Chinese-urological comparative literature, the evaluation of the influence of surgeon experience, volume, and learning curve effects is still lacking. In most studies, the surgical approach is considered the primary variable of interest, while the significant impact of surgeon expertise is ignored. Given that robotic platforms adopted earlier in specialized centers were generally conducted by higher-volume, specifically trained surgeons, this research gap is particularly relevant. Huan Chen et al. (2019) found that surgeon experience was the principal determinant factor of operational time and blood loss, with notable improvements evident after around 200 practical surgeries [12], and Y. Ou et al. (2014) also observed a significant trend of reducing PSM rates correlating with increasing case number [13]. However, their research only accounted for a single surgeon with over 500 RARP cases, and no comparison was made between RARP and LRP outcomes based on surgeon experience. So, a detailed contrast of the two surgeries' outcomes, highlighting the impact of surgeon-experience metrics, is importantly needed.

Moreover, fewer Chinese studies have linked the patient-reported outcomes, including urinary, sexual, and quality of life, to the different surgical approaches. Wei Huang et al. (2019) is the primary study that explicitly analyzes urinary, sexual, and quality of life outcomes across surgical techniques (including both RARP and LRP) in Chinese patients [14]. Other studies that focused on patients' outcomes either only reported outcomes of one surgical approach or compared it with other therapeutic methods [15, 16]. Thus, the present research aims to conduct an extensive and direct comparison of preoperative, functional, oncological, and patient-reported outcomes (PROs) between RARP and LRP, in a Chinese cohort using a multivariable regression analysis, while evaluating the role of surgeon experience as a potential key modifier. By controlling the baseline characteristics of patients and surgeon volume, this study adds a relevant and impactful perspective from a large healthcare system to the worldwide prostatectomy surgical conversation, specifically addressing whether robotic advantages persist after the impact of surgical experience.

Methods

Study design and patient characteristics

This retrospective analysis studied the medical records of 252 patients who received RARP and LRP at Xinxiang Central Hospital, The Fourth Clinical College of Xinxiang Medical University, (Xinxiang, Henan province, China) between January 2019 and December 2023. Following the American Joint Committee on Cancer 8th edition criteria, the patient was diagnosed with localized prostate cancer based on histological confirmation through transrectal ultrasound-guided biopsy, and clinical staging was established by digital rectal examination (DRE), prostate-specific antigen (PSA) levels, and multiparametric magnetic resonance imaging (mpMRI) [17]. The institutional review board of Xinxiang Central Hospital approved the conduct of the study, and the requirement for patients' consent was not considered due to its retrospective aspect. The study was conducted in compliance with the Declaration of Helsinki.

Selection criteria

The study accounted all patients (≥18 years) with confirmed localized (clinical stage T1-T2) prostate cancer who received RARP or LRP as primary therapy between January 1st, 2019 and December 31, 2023 and who had complete medical records including pre-operative characteristics, operative details, and post operation follow-up data of 3 and 12 months, for key outcomes (such as complications, margin status and continence). The choice of surgical approach was made after a multidisciplinary team evaluation and was based on patient preference, surgeon recommendation, and system availability.

Patients were excluded from the analysis for: (1) diagnosis of locally advanced (T3-T4) or metastatic prostate cancer; (2) received neo-adjuvant therapy; (3) concurrent major surgery; or (4) incomplete medical records with missing key outcomes. No patients were excluded based on age alone.

Surgical approach

All RARP procedures were performed using the da Vinci Si Surgical System (Intuitive Surgical, Sunnyvale, CA, USA), and the surgery was done through the transperitoneal route. The surgery followed the usual steps for an anatomic radical prostatectomy. LRP procedures were conducted as a transperitoneal approach using the Montsouris technique [18] with standard laparoscopic equipment.

Data collection

Patients' information was obtained from the hospital-maintained records and electronic medical records. Extraction was performed by two research associates who were blinded to the hypothesis of the study comparing RARP and LRP. Basic characteristics incorporated age, pre-operative Prostate-Specific Antigen (PSA) level, biopsy Gleason Sum, MRI-derived tumor characteristics including the maximum tumor diameter and the prostate imaging reporting and data system (PI-RADS) score, Body Mass Index (BMI), Charlson Comorbidity Index (CCI), clinical level, and the American Society of Anesthesiologists score (ASA).

Surgeon volume assessment

To investigate the surgeon volume's impact on clinical outcomes, we calculated a procedure-specific volume for each surgeon. Surgeon volume was defined as the number of specific RARP or LRP cases performed by the surgeon using the same specific surgical approach before the intervention considered in this study. Critically, each surgeon in our study specialized exclusively in one approach; no surgeon performed both RARP and LRP procedures. This method ensures that the learning curve and proficiency within each distinct surgical technique are specifically assessed. Thus, based on this procedure-specific volume, surgeons were classified into volume categories of low, medium, and high for stratified analyses. The specific parameters for stratification were: low <150 cases, medium 150-250 cases, and high >250 cases. The threshold was set based on our hospital's surgeons' case range and based on previous RARP systematic reviews that reported proficiency plateaus around 200 cases [19, 20].

Outcomes assessment

Outcomes were examined during and post-operation. The primary outcomes of interest were the operation time, the estimated blood loss (EBL), and the positive surgical margin. Secondary outcomes included hospital stay length, postoperative complication types and severity (graded using the Clavien-Dindo classification), urinary continence recovery at 3- and 12-month (using 0 or 1 safety pad per day), and biochemical recurrence (defined as a post-operative PSA ≥0.2 ng/mL).

Patient-reported outcomes

To assess both techniques' impact on patient quality of life, we included validated patient-reported outcomes measures such as the Expanded Prostate Cancer Index Composite (EPIC-26) for urinary and sexual functions and the EQ-5D-5L questionnaire for health-related quality of life. Urinary function was further analyzed by separating EPIC-26 urinary domain scores into urinary incontinence and urinary irritative/obstructive subdomains. Individual item responses were linearly transformed to a 0-100 scale according to the EPIC-26 scoring manual, and subdomain scores were calculated as the mean of corresponding items. PROs were collected at 12 months postoperatively. All included patients completed the 12-month follow-up assessment, and no patients were lost to follow-up during the study period. The final calculation of the EQ-5D-5L was based on the Chinese population-specific index scores [21].

Sample size considerations

Since the full unmatched cohort design was used with all eligible patients in the study, a formal power calculation was not carried out beforehand. The final sample was decided based on the total number of patients who fit the inclusion criteria. Nonetheless, to justify the strength of the obtained sample size, a post hoc sensitivity analysis was conducted.

With a final cohort of 252 patients (126 patients in each group), and an assumed baseline complication rate of 20-30%, the study had over 90% power (alpha = 0.05, two-sided) to find a total risk decrease of 15-18% for major binary outcomes. Furthermore, this sample size provides over 95% power to detect clinically meaningful differences in key continuous outcomes, including a 25-minute reduction in operation time and a 100-mL reduction in blood loss, based on standard deviations from previous comparative studies.

Statistical analysis

All analyses were conducted on the total, unmatched population of 252 patients, in R statistical software (version 4.5.0). Student's t-test was utilized to compare continuous variables, and the results are displayed as mean ± standard deviation. Chi-square or Fisher's exact tests were used to contrast categorical variables, and their results are presented as counts and percentages. Standardized mean differences were calculated to analyse the baseline balance of the two groups. Multivariable logistic regression models were utilized to point out factors independently associated with PSM, complications, and continence recovery. All models incorporated both patient characteristics and surgeon volume categories. The surgical approach was considered the primary variable of interest. The models also took into account pre-operative clinicopathological characteristics recognized as proven risk factors, grounded in biological plausibility and the prevailing literature [22, 23]. To specifically evaluate whether the benefits of robotic operation varied by surgeon experience, interaction analyses were conducted between surgical approach and the volume categories. Thus, the surgical approach and volume category were included in multivariable models, and stratified analyses were performed within each volume category to determine the consistency of RARP impact across experience levels.

Volume-outcome relationships were analyzed across surgeon volume categories using ANOVA and chi-square tests. Patient-reported outcomes were analyzed with a linear regression analysis, and the biochemical recurrence was examined via a Kaplan-Meier analysis. A two-sided p-value <0.05 was considered statistically significant.

Results

Patient selection and baseline characteristics

Of the 415 patients assessed for eligibility, 163 were excluded due to locally advanced disease (n=72), receipt of neoadjuvant therapy (n=35), concurrent major surgery (n=28), or incomplete medical records (n=28), resulting in a final study cohort of 252 patients (**Figure 1**). The study then analyzed 252 individuals who received radical prostatectomy, separated into 126 patients in each LRP and RARP group. No statistical difference was observed between the RARP and LRP groups in age, preoperative PSA, Gleason group, CCI, ASA score, and surgeon volume, tumor size, or PI-RADS score distribution (**Table 1**). However, the RARP group had significantly lower BMI (24.28±1.50 vs. 24.72±1.54 kg/m^2, P=0.025) and different clinical stage distribution (P=0.018), with fewer T1c stage patients in the RARP group (55.6% vs. 65.1%) and more T2a stage patients in the RARP group (12.7% vs. 2.4%). The mean tumor size was comparable between groups (LRP: 17.06±5.49 mm vs. RARP: 17.23±5.46 mm, P=0.450), and PI-RADS score distribution showed no significant difference (P=0.320). In addition, the patients' baseline characteristics of both groups were well-balanced for most, though a slight imbalance was observed for clinical stage (SMD 0.409).

Comparative surgical outcomes

Analysis of surgical outcomes demonstrated significant advantages for the robotic-assisted

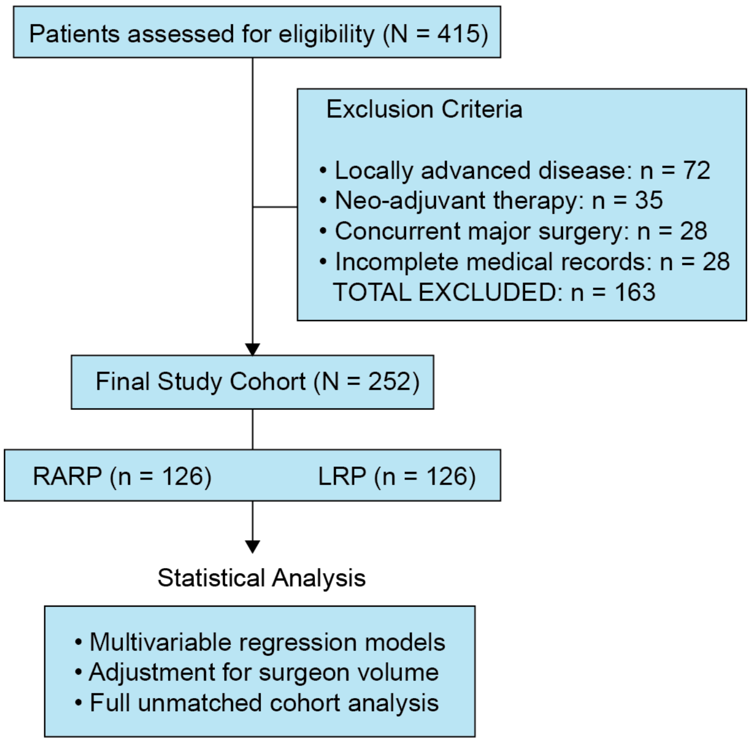

Figure 1. Patient selection flowchart.

surgery (**Table 2**). The mean operation time was remarkably shortened in the RARP group (154.9±28.3 vs. 169.2±23.9 minutes, P<0.001), with significantly lesser blood loss (172.5±56.8 vs. 306.8±82.2 ml, P<0.001). As a result, the RARP patients experienced considerably shorter hospital stays (2.3±1.1 vs. 3.9±1.3 days, P<0.001).

In addition, RARP resulted in significantly lower PSM rates (19.0% vs. 31.0%, P=0.030) and also demonstrated superior safety, with lower overall complication ratio (25.4% vs. 39.7%, P=0.022).

Multivariable analysis of positive surgical margins

Multivariable logistic regression adjusting for surgical approach, preoperative PSA, clinical stage, Gleason sum, Charlson Comorbidity Index, ASA score, surgeon volume and the additional MRI-derived variables of tumor size and PI-RADS score, revealed that RARP resulted in 66% lower odds of PSM (OR: 0.34, 95% CI: 0.15-0.75, P=0.009) (**Table 3**) compared to the LRP approach. Surgeon volume turned out as a powerful independent predictor, with high-volume surgeons yielding 96% lower odds of positive margins compared to low-volume surgeons (OR: 0.039, 95% CI: 0.012-0.12, P<0.001).

Notably, both MRI tumor characteristics emerged as significant predictors of surgical margin status. Larger tumor size was independently associated with increased PSM risk (OR: 1.07 per 1 mm increase, 95% CI: 1.00-1.14, P=0.048). Similarly, higher PI-RADS scores showed a graded relationship with PSM, with PI-RADS 5 lesions demonstrating significantly higher odds of positive margins compared to PI-RADS 3 lesions (OR: 2.10, 95% CI: 1.05-4.20, P=0.036).

Functional recovery and patient-reported outcomes

Functional outcomes strongly confirmed the benefits of RARP (**Table 2**). At 3-month follow-up, RARP patients had remarkably high continence rates (76.2% vs. 62.7%, P=0.021), further increasing at 12 months (95.2% vs. 80.2%, P=0.001).

Patient-reported outcomes likewise consistently favored RARP across all domains (**Table 4**). At 12 months postoperatively, the RARP group demonstrated significantly better urinary function than the LRP group. Subdomain analysis revealed that this difference was primarily driven by superior urinary continence recovery in the RARP group (84.0±15 vs. 70.6±22.1, P<0.001). In contrast, urinary irritative/obstructive symptoms were comparable between groups (P=0.317). The RARP group also showed better sexual function (51.2±7.6 vs. 47.6±12.5, P=0.006). General quality of life assessment with the EQ-5D index also showed superior outcomes for RARP patients (0.877±0.079 vs. 0.834±0.085, P<0.001).

Surgeon volume and outcomes

Stratified analysis by surgeon volume found great differences in surgical outcomes (**Table 5**). Positive surgical margin rates were much greater among low-volume surgeons for both techniques (LRP: 76.9%, RARP: 50.0%), albeit

Table 1. Patient baseline characteristics

Characteristic	LRP (n=126)	RARP (n=126)	*P*-value	SMD
Age, years	67.33±4.41	66.65±4.51	0.231	0.151
BMI, kg/m^2	24.72±1.54	24.28±1.50	0.025	0.285
Preop PSA, ng/mL	8.98±1.00	9.19±0.94	0.091	0.214
Tumor size (mm)	17.06±5.49	17.23±5.46	0.450	0.092
PI-RADS Score, n (%)			0.32	0.150
3	40 (31.7%)	35 (27.8%)		
4	60 (47.6%)	65 (51.6%)		
5	26 (20.6%)	26 (20.6%)		
Clinical Stage			0.018	0.409
T1c	82 (65.1%)	70 (55.6%)		
T2a	3 (2.4%)	16 (12.7%)		
T2b	9 (7.1%)	7 (5.6%)		
T2c	32 (25.4%)	33 (26.2%)		
Gleason Group			0.758	0.173
1	19 (15.1%)	24 (19.0%)		
2	61 (48.4%)	60 (47.6%)		
3	36 (28.6%)	29 (23.0%)		
4	9 (7.1%)	11 (8.7%)		
5	1 (0.8%)	2 (1.6%)		
CCI	0.40±0.55	0.54±0.63	0.056	0.242
ASA Score			0.631	0.121
1	16 (12.7%)	17 (13.5%)		
2	92 (73.0%)	96 (76.2%)		
3	18 (14.3%)	13 (10.3%)		
Surgeon Volume			0.959	0.036
Low	13 (10.3%)	12 (9.5%)		
Medium	24 (19.0%)	23 (18.3%)		
High	89 (70.6%)	91 (72.2%)		

Baseline demographic and clinical characteristics of the study cohort stratified by surgical approach (LRP vs. RARP). Data are presented as mean ± standard deviation for continuous variables and count (percentage) for categorical variables. *P*-values are from Student's t-test or Chi-square test. Standardized Mean Differences (SMD) are provided to assess baseline balance between groups. Abbreviations: LRP, Laparoscopic Radical Prostatectomy; RARP, Robotic-Assisted Radical Prostatectomy; BMI, Body Mass Index; PSA, Prostate-Specific Antigen; CCI, Charlson Comorbidity Index; ASA, American Society of Anesthesiologists; SMD, Standardized Mean Difference; PI-RADS: Prostate Imaging Reporting and Data System.

the difference was not statistically significant (P=0.169). Both methods provided excellent margin control for high-volume surgeons (LRP: 11.2%, RARP: 5.5%).

At all volume levels, RARP consistently showed advantages. Among high-volume surgeons, RARP demonstrated a substantial decrease in complications (26.4% vs. 41.6%, P=0.032). The continence outcomes also favored RARP across all volume categories, with a statistical significance in the high-volume group (97.8% vs 85.4%, P=0.009).

The advantages of robotic surgery were similar between surgeon volume levels, according to interaction analysis (**Table 6**). The non-statistical significance of the interactions for PSM (P=0.870), complications (P=0.607), and continence (P=0.084) indicates that RARP benefits do not significantly differ based on surgeon volume.

Complications profile

Significant overall safety benefits for the robotic technique were found by the thorough investigation (**Table 7**). RARP patients experienced lower rates of multiple complication types, including lymphoceles (1.6% vs. 7.1%, P=0.060), deep vein thrombosis (DVT) (0.8% vs. 4.0%, P=0.213), and urinary retention (3.2% vs. 7.9%, P=0.163), though these individual comparisons did not reach statistical significance, likely due to sample size limitations.

A non-linear trend was observed for RARP complications across surgeon volumes, with the lowest rate occurring in the medium volume group. While this may suggest an optimal balance of recent training and cumulative experience, this finding is inconclusive due to the smaller sample sizes in the stratified analysis and might require further investigation.

Biochemical recurrence-free survival

There was no discernible difference in biochemical recurrence-free survival between the surgical techniques, according to Kaplan-Meier analysis (Log-Rank P=0.408) (**Figure 2**). With 12-month BCR-free survival rates of 96.0% for

Table 2. Outcomes comparison between surgical approaches

Outcome	LRP (n=126)	RARP (n=126)	Statistical Measure	*P*-value
Perioperative Outcomes				
Operative Time (min)	169.2±23.9	154.9±28.3	Mean Difference: -14.3 min	<0.001
Estimated Blood Loss (ml)	306.8±82.2	172.5±56.8	Mean Difference: -134.3 ml	<0.001
Hospital Stay (days)	3.9±1.3	2.3±1.1	Mean Difference: -1.6 days	<0.001
Oncologic Outcomes				
Positive Surgical Margins	39/126 (31.0%)	24/126 (19.0%)	OR: 0.52 (0.29-0.93)	0.030
Safety Outcomes				
Any Complication	50/126 (39.7%)	32/126 (25.4%)	OR: 0.52 (0.30-0.88)	0.022
Functional Outcomes				
Continence at 3 Months	79/126 (62.7%)	96/126 (76.2%)	OR: 1.90 (1.11-3.31)	0.021
Continence at 12 Months	101/126 (80.2%)	120/126 (95.2%)	OR: 4.95 (2.08-13.75)	0.001

Perioperative, oncologic, safety, and functional outcomes comparing Laparoscopic Radical Prostatectomy (LRP) and Robotic-Assisted Radical Prostatectomy (RARP). Data are presented as mean ± standard deviation or count (percentage). Statistical measures include mean difference for continuous variables and Odds Ratio (OR) with 95% Confidence Interval (CI) for binary outcomes. Abbreviations: LRP, Laparoscopic Radical Prostatectomy; RARP, Robotic-Assisted Radical Prostatectomy; OR, Odds Ratio; CI, Confidence Interval.

Table 3. Multivariable analysis of factors associated with PSM

Factor	Category	OR (95% CI)	*P*-value
Surgical Approach	RARP vs. LRP	0.34 (0.15-0.75)	0.009
Surgeon Volume (ref: Low)	Medium	1.40 (0.42-4.65)	0.585
	High	0.039 (0.012-0.12)	<0.001
MRI Tumor Size (per 1 mm)		1.07 (1.00-1.14)	0.048
PI-RADS Score (ref: 3)	4	1.45 (0.72-2.95)	0.295
	5	2.10 (1.05-4.20)	0.036
Clinical Stage (ref: T1c)	T2a	1.65 (0.29-8.55)	0.550
	T2b	0.60 (0.11-2.88)	0.535
	T2c	0.52 (0.18-1.43)	0.210
Gleason Group (ref: 1)	2	1.85 (0.59-6.20)	0.305
	3	1.75 (0.53-5.98)	0.365
	4	4.40 (0.73-25.10)	0.095
	5	1.25 (0.04-32.50)	0.890
Preoperative PSA (per ng/mL)		0.99 (0.65-1.49)	0.945
Charlson Comorbidity Index (per point)		0.96 (0.46-1.98)	0.910
ASA Score (ref: 1)	2	1.33 (0.38-5.10)	0.655
	3	2.80 (0.56-14.20)	0.215

Multivariable logistic regression analysis identifying factors independently associated with PSM (PSM). The model is adjusted for surgical approach, patient characteristics, and surgeon volume. Abbreviations: OR, Odds Ratio; CI, Confidence Interval; PSA, Prostate-Specific Antigen; ASA, American Society of Anesthesiologists; ref, reference category.

RARP and 95.7% for LRP, as well as 24-month rates of 93.6% for RARP and 90.0% for LRP, both approaches produced good oncologic control. The comparable survival curves show comparable cancer control over the course of the trial.

Discussion

In a Chinese healthcare context, this comprehensive multivariable analysis offers a detailed, up-to-date comparison of RARP and LRP and adds to our understanding of advanced

Table 4. Patient-reported outcomes at 12 months postoperatively

Domain	LRP (n=126)	RARP (n=126)	*P*-value
EPIC-26 Domains			
Urinary Function	72.3±19.1	80.2±7.6	<0.001
Urinary Incontinence	*70.6±22.1*	*84.0±15*	*<0.001*
Urinary irritative/obstructive symptoms	*74.0±25*	*76.4±10*	*0.317*
Sexual Function	47.6±12.5	51.2±7.6	0.006
EQ-5D Domains			
Mobility	1.3±0.6	1.1±0.4	0.002
Self-Care	1.4±0.6	1.2±0.5	0.011
Usual Activities	2.1±0.9	1.7±1.0	0.005
Pain/Discomfort	1.5±0.6	1.3±0.6	0.032
Anxiety/Depression	1.1±0.3	1.1±0.3	0.699
Overall Health Utility			
EQ-5D Index Score	0.834±0.085	0.877±0.079	<0.001

Patient-reported outcomes assessed at the 12-month postoperative follow-up, stratified by surgical approach. Data from the Expanded Prostate Cancer Index Composite (EPIC-26) domains and the EQ-5D-5L questionnaire are presented as mean ± standard deviation. *P*-values are from linear regression analysis. Abbreviations: LRP, Laparoscopic Radical Prostatectomy; RARP, Robotic-Assisted Radical Prostatectomy; EPIC-26, Expanded Prostate Cancer Index Composite-26.

Table 5. Outcomes stratified by surgical approach and surgeon volume

Volume Category	Surgical Approach	n	PSM	*P*-value	Any Complication	*P*-value	Continence at 12 Months	*P*-value
Low Volume								
	LRP	13	10/13 (76.9%)		5/13 (38.5%)		7/13 (53.8%)	
	RARP	12	6/12 (50.0%)	0.169	5/12 (41.7%)	0.870	8/12 (66.7%)	0.515
Medium Volume								
	LRP	24	19/24 (79.2%)		8/24 (33.3%)		18/24 (75.0%)	
	RARP	23	13/23 (56.5%)	0.102	3/23 (13.0%)	0.111	23/23 (100.0%)	0.993
High Volume								
	LRP	89	10/89 (11.2%)		37/89 (41.6%)		76/89 (85.4%)	
	RARP	91	5/91 (5.5%)	0.172	24/91 (26.4%)	0.032	89/91 (97.8%)	0.009

Stratified analysis of key outcomes by surgeon volume category (Low: <150 cases, Medium: 150-250 cases, High: >250 cases) and surgical approach. The subgroup sample sizes should be considered when interpreting rates, as they are subject to greater variability. Data are presented as a count (percentage). *P*-values are from Chi-square or Fisher's exact tests comparing RARP vs. LRP within each volume category.

minimally invasive prostatectomy. While reconfirming the benefits of RARP over LRP [24], our study presents critical new perspectives on the interaction of surgical technology and surgeon experience. In this particular study, surgeon volume emerged as a similarly important determinant of positive outcomes alongside the robotic technique itself.

Our research showed that the surgeon's experience favorably impacted surgical margins. One of the most significant volume-outcome associations is the 96% difference in PSM odds ratio between low and high-volume surgeons. The mechanism behind this volume-outcome relationship is likely multifactorial, involving cumulative experiential learning. As a surgeon's volume increases, they develop a superior mental map of the pelvic anatomy, leading to more precise apical dissection and more confident preservation of the neurovascular bundles, as explored in the technique-focused review by Dilme et al. (2022) [9]. This notable volume effect is more impactful than the benefits related to surgical technology, even though both parameters proved independent relevance. The likely mechanisms underlying this consistent advantage are the improved dexter-

Table 6. Interaction analysis between surgical approach and surgeon volume

Outcome	Interaction Term	*P*-value
PSM	Group × Volume_Tertile	0.870
Any Complication	Group × Volume_Tertile	0.607
Continence at 12 Months	Group × Volume_Tertile	0.084

Results of the interaction analysis evaluating whether the effect of the surgical approach (RARP vs. LRP) on key outcomes is modified by surgeon volume category. A non-significant *p*-value for the interaction term indicates that the effect of the surgical approach is consistent across different surgeon volume levels.

Table 7. Postoperative complication types by surgical approach

Complication Type	LRP (n=126)	RARP (n=126)	*P* Value
Any Complication	50 (39.7%)	32 (25.4%)	0.022
Ileus	12 (9.5%)	13 (10.3%)	0.833
Wound Infection	10 (7.9%)	8 (6.3%)	0.809
Urinary Retention	10 (7.9%)	4 (3.2%)	0.163
Lymphocele	7 (5.6%)	2 (1.6%)	0.174
DVT	5 (4.0%)	1 (0.8%)	0.213
UTI	4 (3.2%)	2 (1.6%)	0.684
Bleeding	2 (1.6%)	2 (1.6%)	1.000

Postoperative complication types and their frequencies, stratified by surgical approach. Complications were graded using the Clavien-Dindo classification. Data are presented as count (percentage). *P*-values are from Chi-square or Fisher's exact tests. Abbreviations: LRP, Laparoscopic Radical Prostatectomy; RARP, Robotic-Assisted Radical Prostatectomy; DVT, Deep Vein Thrombosis; UTI, Urinary Tract Infection.

ity and visualization inherent to the robotic platform. Our formal interaction analysis particularly showed that the relative benefits of RARP were similar in all experience levels, with no significant interaction for PSM (P=0.870), complications (P=0.607), or continence (P=0.084). This indicates that the technological benefits of RARP prevail regardless of the surgeon's level of competence, even if the surgeon's experience could significantly improve the results. In this regard, our findings follow a growing consensus that the surgeon's ability may be as important as the surgery, in contrast to conventional conventions that only compare the technological aspect of LRP and RARP [20, 25].

Our multivariable analysis demonstrated that the surgical technique and surgeon experience independently predict surgical outcomes. RARP yielded a 67% lower PSM odds ratio (OR: 0.33, P=0.008), while highly experienced doctors displayed 96% lower odds compared to low-volume surgeons (OR: 0.038, P<0.001). This dual effect suggests that prior comparative studies' results may have been affected by surgeon selection, as noted by Bravi et al. (2019) [26], who indicated that surgeon experience, rather than the kind of surgery, was the principal key to improved oncological outcomes in RARP. Researchers in other surgical fields also reported this connection between surgeon volume and surgical outcomes [27, 28].

Furthermore, our findings clearly showed that RARP significantly improves perioperative outcomes, such as hospital stays, operational times, and blood loss across all surgeon volume levels, providing strong support for the robotic platform's inherent benefits. These findings are consistent with previous studies, such as Moretti et al.'s (2022) large-scale reverse systematic evaluation, which looked at outcomes in over 1.3 million patients [5, 29]. The stability of these results across different geographical populations highlights the inherent advantages of the robotic platform, which are likely due to the improved manual dexterity and vision, resulting in a more efficient dissection and bleeding control [30]. Additionally, the 12-month continence rates and the noticeable positive patient-reported outcomes (EPIC-26, E-5D-5L) showed the benefits of RARP from the patient's perspective, and supported earlier results of improved functional outcomes with RARP [31, 32]. These results hold a particular importance in the Chinese medical system, where quality-of-life outcomes are highly valued.

Interesting trends in the volume-outcome association were found by our research and should be further explored. For RARP complications, we found a U-shaped pattern, with medium-volume surgeons having the lowest rates (13.0% vs. 41.7% for low-volume and 26.4% for high-volume). This implies that there might be an ideal volume range that strikes a compromise between cumulative experience and current training intensity, but further research is needed to confirm this conclusion. The superior

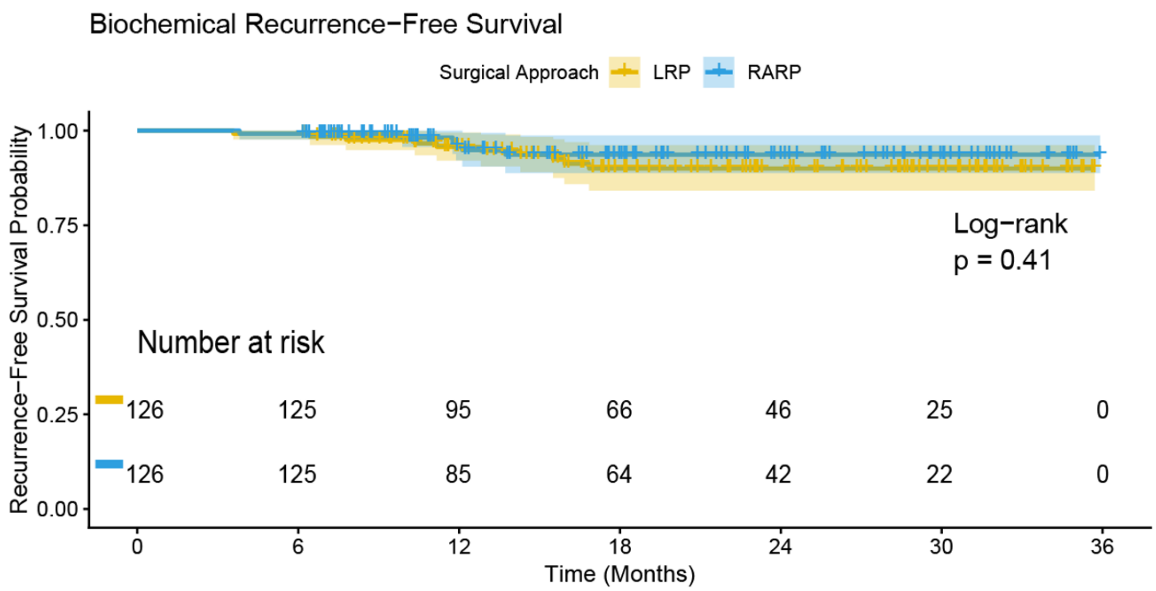

Figure 2. Kaplan-Meier curves comparing biochemical recurrence-free survival between robotic-assisted radical prostatectomy (RARP) and laparoscopic radical prostatectomy (LRP) over 36 months of follow-up. The log-rank *p*-value is provided to compare the survival curves.

performance of the high-volume group merits consideration, even though the advantage over low-volume surgeons is in line with anticipated learning curve effects. Selection bias, in which high-volume surgeons are assigned to more difficult patients, or the idea that medium-volume physicians represent the best combination of recent training intensity and cumulative expertise, are two potential causes. In a recent retrospective analysis, Kelsey S. Romatoski et al. (2023) elaborated on similar outcomes by comparing hospital volumes and associated the U-shaped relationship with a balance between surgical cases and surgeon experience [33].

The prevalence of RARP advantages at all volume levels has great implications for technology adoption strategies. The analysis outcome indirectly indicates that robotic technology implementation must be accompanied by a well-structured program that includes rigorous quality performance reviews, standardized care pathways, and continuous mentorship [34, 35].

There are several limitations in our research. The retrospective and single-center methodology increases the likelihood of unquantified bias, even though we utilized a complete multivariable regression analysis to account for both patient characteristics and surgeon volume. Furthermore, our assessment of patient-reported outcomes was limited by the use of EPIC-26 summary domain scores rather than the subdomain analyses, and the 12-month follow-up period for these PROs prevents assessment of long-term quality-of-life trends. While perioperative outcomes have been favorable during the current follow-up period, the data are still insufficient to assess critical long-term parameters such as cancer-related mortality and biochemical relapse-free survival. Our Kaplan-Meier analysis revealed that both procedures had comparable biochemical recurrence-free survival during the trial period, but more follow-up is required.

Conclusion

Overall, this study provides good evidence from a Chinese cohort, supporting the global consensus on minimally invasive prostatectomy. The study offers convincing evidence that RARP results in better perioperative outcomes, fewer complications, and improved functional recovery than LRP, using rigorous multivariable analysis that directly addresses surgeon volume concerns. Our findings add an important dimension to the current discussion: the surgeon's experience is a valid independent predictor of surgical quality, particularly for oncological outcomes. The dramatic effect of surgery volume on PSM rates shows that the optimal strategy for prostate cancer surgery is the combination of advanced technologies with specialized training and adequate procedural volume. With breakthroughs and continuous improvements in robotic procedures, it is vital to maintain a certain level of surgical expertise in order to maximize the benefits of new technologies for patients.

Disclosure of conflict of interest

None.

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