RESEARCH ARTICLE

Editorial Process: Submission:14/01/2026 Acceptance:02/09/2026 Published:28/09/2026

Open, Laparoscopic, Retropubic, or Robotic? A Network Meta-Analysis of Post-Prostatectomy Oncologic Outcomes and Health-Related Quality of Life in Localized Prostate Cancer Patients

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Abstract

Objective: Prostatectomy remains a standard surgical treatment for localized prostate cancer, a malignancy with substantial global incidence and clinical impact in men. Its rapid adoption of surgical modalities has outpaced supporting evidence, resulting in limited consensus in reporting HRQoL and oncologic outcomes. This paper aims to compare the oncologic and Health-Related Quality of Life (HRQoL) outcomes of open (ORP), retropubic (RRP), laparoscopic (LRP), and robot-assisted radical prostatectomy (RARP) in patients with localized prostate cancer. **Methods:** A systematic search of MEDLINE/PubMed, Embase, Cochrane Library, and grey literature for randomised controlled trials and comparative studies was performed from database inception to November 2025. Risk of bias was assessed using RoB 2.0 and ROBINS-I. A network meta-analysis evaluated oncological outcomes that consist of Biochemical Recurrence (BCR) and Positive Surgical Margins (PSM), and HRQoL metrics including urinary incontinence and erectile dysfunction. Ranking probabilities were estimated using Surface Under the Cumulative Ranking (SUCRA) values. **Result:** Thirty-three studies that met the inclusion criteria were included involving 69986 patients. Overall risk of bias for both randomized and observational studies was low. RARP ranked highest for oncologic outcomes, demonstrating the greatest likelihood of minimizing BCR (SUCRA 84.2%; 14 trials, 17,932 patients) and PSM (SUCRA 93%; 29 trials, 38,509 patients). For HRQoL, non-robotic techniques were favored across specific domains: ORP showed a 76% probability of fewer urinary incontinence events; LRP demonstrated an 87% likelihood of requiring fewer pad changes; and RRP demonstrated a 95% probability of being the best-tolerated technique regarding postoperative erectile dysfunction. **Conclusion:** RARP appears as the most favourable oncological outcome, whereas non-robotic approaches showed advantages in HRQoL domains. Future randomized trials are needed to prove the superiority of the techniques.

Keywords: Health Related Quality of Life, Localized Prostate Cancer, Oncological Outcomes, Prostatectomy

Asian Pac J Cancer Prev, **27 (9)**, 3355-3363

Introduction

Prostate cancer (PCa) represents a high-incidence malignancy and a critical driver of cancer-related disease burden in men [1]. Global epidemiologic estimates indicate that the overall PCa exceeded 5 million men living with the disease worldwide in 2022. Surveillance data documented over 1.4 million new cases and approximately 375,000 deaths in 2020, sustaining it as the second most commonly diagnosed cancer among men worldwide [1, 2].

PCa is the most frequently diagnosed male cancer in more than 50% of countries, and represents the leading cause of cancer-specific mortality in about 25% of these nations [3]. In Europe, PCa remains the most commonly diagnosed cancer in men and the third leading cause of cancer-related death, underscoring its substantial regional and global clinical impact [2]. Lifetime cumulative risk of PCa approaches approximately 3.9% in many populations, and its burden continues to increase with aging populations and expanded diagnostic activity [3].

For men with localized PCa, radical prostatectomy remains a cornerstone of curative-intent management, offering durable oncologic control and widespread guideline endorsement [2, 4, 5]. Multiple professional guidelines summarize comparative evidence on surgical approaches such as open (ORP), retropubic (RRP), laparoscopic (LRP), and robot-assisted radical prostatectomy (RARP), largely focusing on peri-operative

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endpoints (e.g., blood loss, length of stay, complication profiles, and recovery time) [2, 4-7].

However, despite the breadth of procedural comparisons, no guideline currently designates a preferred modality based on integrated evaluation of long-term oncologic efficacy and patient-centered outcomes, particularly the Health-Related Quality of Life (HRQoL). This evidence gap is clinically meaningful, as oncologic success (e.g., biochemical recurrence-free survival, metastasis-free survival, and cancer-specific mortality) does not necessarily parallel functional recovery or quality-of-life preservation [8].

HRQoL after radical prostatectomy, measured by such instruments, encompasses multiple domains, including urinary continence, sexual function, bowel outcomes, and psychosocial well-being [9-11]. The continuous evolution and adoption of minimally invasive and robotic techniques have occurred in the absence of evidence comparing which modality optimally balances oncologic control with HRQoL, highlighting HRQoL as a key consideration in surgical decision-making.

In light of substantial practice variation and the absence of a guideline-endorsed gold standard that integrates both oncologic durability and standardized HRQoL outcomes, high-quality comparative evidence remains essential. This need is amplified by the growing population of PCa survivors after prostatectomy, for whom HRQoL is pivotal in shared decision-making. Therefore, this study aims to compare the oncologic and HRQoL outcomes of ORP, RRP, LRP, and RARP in patients with localized PCa.

Materials and Methods

Literature Search

A comprehensive search of PubMed/MEDLINE, Embase, and the Cochrane Library was conducted for English-language studies published up to November 2025. Search terms included (“prostate cancer” AND “localized”) AND (“Robotic Prostatectomy” OR “Robotic” OR “Robot assisted” OR “Robotic-Assisted Radical Prostatectomy”) AND (“Open Prostatectomy” OR “Open radical retropubic prostatectomy” OR “Laparoscopic radical prostatectomy” OR “Minimally invasive radical prostatectomy” OR “Radical Prostatectomy” OR “Surgery” OR “radical retropubic prostatectomy”) AND (“Quality of Life”[Title/Abstract] OR “HRQOL”[Title/Abstract] OR “Health Related Quality of life”[Title/Abstract] OR “Incontinence”[Title/Abstract] OR “Erectile Dysfunction”[Title/Abstract] OR “Biochemical Recurrence”[Title/Abstract] OR “Positive Surgical Margin”[Title/Abstract]) and related variants. Conference and meeting abstracts were excluded, and no restrictions were placed on study design. The search identified 483 records, of which 33 remained after removal based on the exclusion criteria. Three authors (RM, MIAR, and KTS) independently screened titles and abstracts using predefined inclusion and exclusion criteria, with disagreements resolved by discussion between the authors.

Inclusion and Exclusion Criteria

Study eligibility for full-text review was assessed using the PICOS (Population, Intervention, Comparator, Outcomes, and Study design) framework in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [12]. The study population comprised men with prostate cancer undergoing surgical treatment. The interventions included three surgical approaches: laparoscopic radical prostatectomy (LRP), retropubic radical prostatectomy (RRP), and robot-assisted radical prostatectomy (RARP). Where the comparison is Open Radical Prostatectomy (ORP) as the standard of care. Outcomes of interest encompassed oncologic outcomes (biochemical recurrence and positive surgical margin rate), health related quality of life (urinary continence, pad changes more than once per day and erectile dysfunction rates). Studies included 7 Randomized Controlled Trial (RCT) and 26 cohorts. Where this review was using the Network Meta-Analysis (NMA) as our approach.

Studies were included if they involved human participants, enrolled men with prostate cancer who underwent radical prostatectomy, and reported relevant outcome data. Studies were excluded if they focused on approaches other than our targeted outcomes, lacked extractable data, or compared simple prostatectomy rather than radical prostatectomy. Surgical approaches were categorized into distinct nodes based on how they were reported in the included studies. Open Radical Prostatectomy (ORP) was defined as the reference open surgical approach, encompassing all open techniques when no further specification was provided. Retropubic Radical Prostatectomy (RRP) was defined as a specific open approach performed via a retropubic incision and was classified separately when explicitly reported in the study.

This distinction was intentionally applied to preserve the original reporting of the studies and to improve clarity in treatment classification. As ORP may encompass multiple open techniques, including retropubic and perineal approaches, studies that did not specify the exact method were retained within the ORP category to avoid misclassification. When RRP was clearly stated, it was analyzed as a separate node to allow for more precise comparisons based on surgical technique.

Data Extraction

To indirectly compare the effects of different radical prostatectomy (RP) techniques, a frequentist random-effects model was applied within a network meta-analysis framework. Results were presented using forest plots, network league tables, and node-splitting forest plots. All network meta-analyses were conducted using R version 3.4.3 (R Development Core Team, Vienna, Austria; accessed 15 November 2025) with the netmeta package. All statistical tests were two-sided, and a p-value < 0.05 was considered statistically significant. Pooled effect estimates and heterogeneity statistics for each comparison were derived from pairwise forest plots. Treatment rankings were additionally evaluated, with higher SUCRA indicating a greater probability of ranking among the most effective treatments [13].

All dichotomous outcomes (biochemical recurrence, positive surgical margins, urinary incontinence, pad changes more than once per day, and erectile dysfunction) were modeled for each surgical approach across all included trials. Comparative effectiveness was summarized as Odds Ratios (ORs) for dichotomous outcomes, reported with the number of events per total sample with 95% Confident Intervals (CIs).

Model inconsistency was assessed using the node-splitting approach; inconsistency was considered absent when the 95% confidence interval of the inconsistency factor included zero or when the comparison between direct and indirect estimates yielded a non-significant probability value ($p > 0.05$) [13]. Heterogeneity was assessed for each outcome using the I^2 statistic, with threshold values of 0%, 25%, 50%, and 75% representing insignificant, low, moderate, and high heterogeneity, respectively. A DerSimonian–Laird random-effects model was applied to account for unavoidable heterogeneity, while differences between studies contributing to direct and indirect evidence were assumed.

Quality Assessment

Papers included in this analysis comprised randomized controlled trials (RCTs), as well as prospective and retrospective observational studies. Study quality was assessed separately for RCTs and non-RCTs. The methodological quality of RCTs was evaluated using the Cochrane Risk of Bias tool (RoB). which assesses key domains including random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, completeness of outcome data, selective reporting, and other potential sources of bias [14].

The quality of non-randomized studies was appraised using the Risk Of Bias In Non-Randomized Studies-of Interventions (ROBINS-I) [15], which evaluates bias due to confounding, bias in classification of interventions, reference standard, flow and timing, bias due to missing data, bias in measurement of the outcome, bias in selection of the reported result.

Statistical Analysis

Five authors (RM, MIAR, PMD, MG, and KTS) independently extracted data using a predefined data collection form. Any discrepancies were resolved through discussion whether to include the studies or not between the authors. Extracted variables included the first author, year of publication, study design, country, treatment arms, number of participants, patient age, surgical technique of radical prostatectomy, and reported outcomes.

Outcomes of interest were categorized as oncologic, and health related quality of life. Oncologic outcomes included biochemical recurrence (BCR) and positive surgical margin rates while the Health Quality of Life (HRQoL) occurs incontinence rate, pad changes >1 per day rate, and erectile dysfunction rate.

Results

Literature search results

Figure 1 is the PRISMA chart that summarized our literature selection process in this study. The initial result identified a total of 483 records, which 203 remained

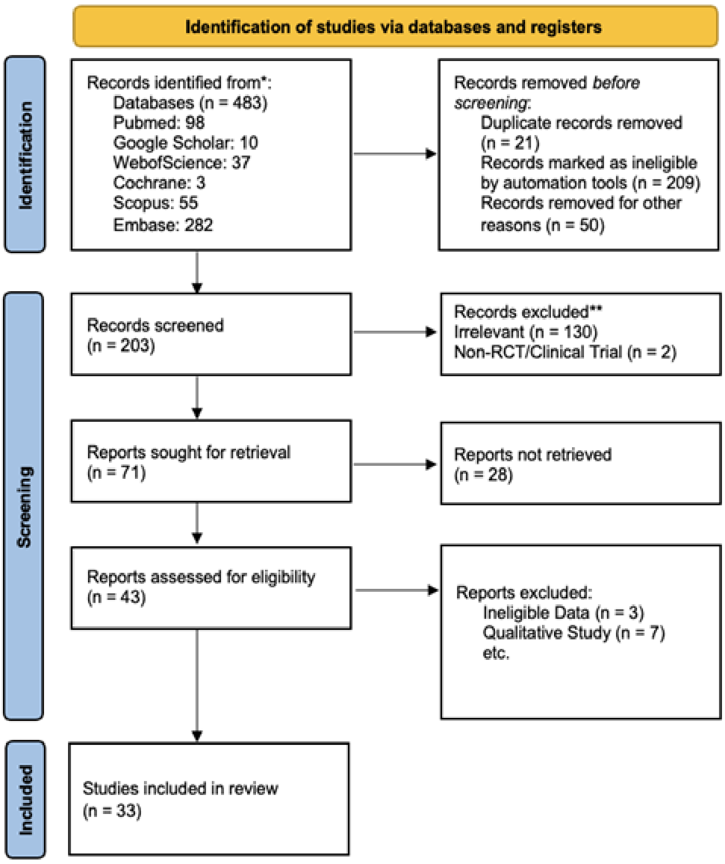

Figure 1. Prisma Flow Chart

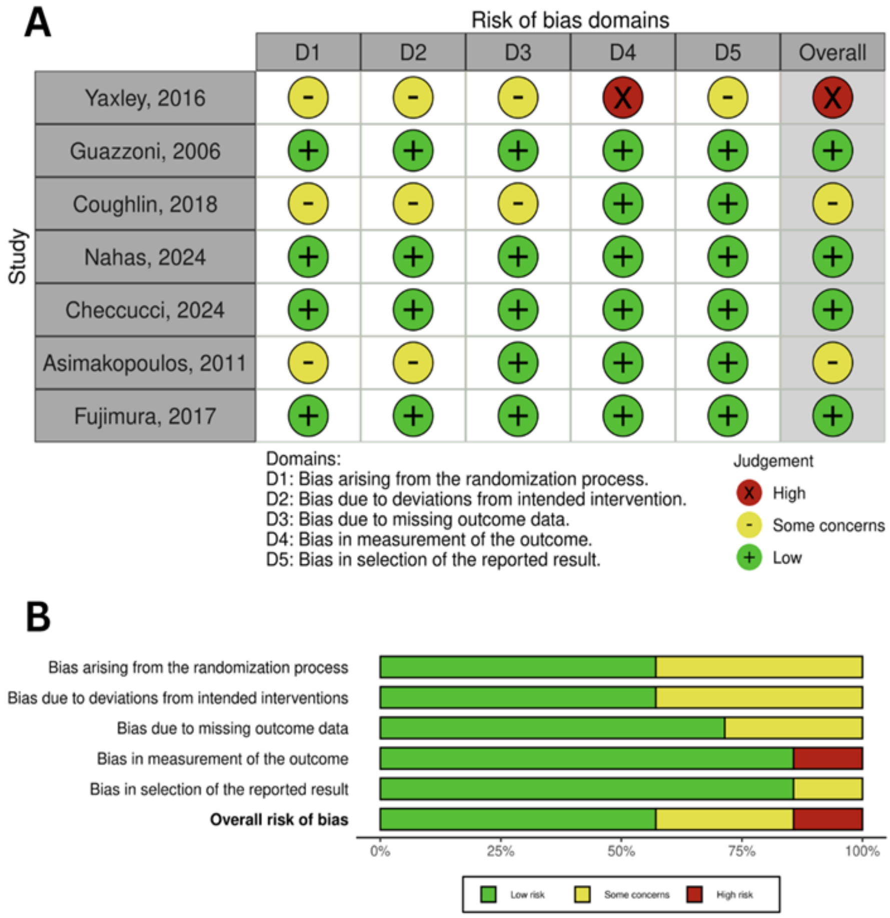

Figure 2. Risk of Bias (RoB) assesment: A) Traffic light plot, B) Summary plot

after duplicate, ineligible studies removal. Following the relevancy and the study design used, 71 articles were retrieved for full-text assessment to determine eligibility based on the predefined inclusion and exclusion criteria. Finally, 33 studies involving a total of 69,986 patients were included in the final analysis. The characteristics of the included studies are presented in Supplementary Table 1.

Quality assessment results

ROB

Seven RCTs were qualitatively assessed using the Cochrane Risk of Bias (RoB) 2.0 tool that were presented in Figure 2. 2A shows that the majority of the studies were low risk of bias, with two studies resulting in some concerns, and one study having a high risk of bias. 2B summarizes the risk of bias in each domain, with the bias in measurement of the outcome domain having a study of high risk. All of the other domains were varied with low risk and some concerns.

ROBINS

The risk of bias assessment using the ROBINS-I framework is presented in Figure 3. Overall, most included studies demonstrated a low to moderate risk of bias across domains, with consistently low risk observed for participant selection, classification of interventions, deviations from intended interventions, outcome measurement, and selective reporting. In contrast, bias due to confounding was the most common concern, with several observational studies rated as having moderate to serious risk, reflecting inherent limitations of non-randomized surgical comparisons. Bias related to missing data also varied across studies. Only a small number of studies were judged to have serious or critical overall risk of bias, primarily driven by confounding and incomplete data. Collectively, these findings indicate an acceptable overall methodological quality, supporting the robustness of the network meta-analysis when interpreted in light of these limitations.

Oncological Outcomes

Biochemical recurrence

When using ORP as the reference comparator, the network meta-analysis showed no statistically significant difference in biochemical recurrence across surgical approaches. Relative to ORP, the odds ratio (OR) for biochemical recurrence was 0.82 (95% CI 0.53–1.26; $p = 0.3635$) for RARP and 1.06 (95% CI 0.48–2.31; $p = 0.8918$) for LRP. The SUCRA probabilities indicated that RARP ranked highest (0.84), followed by LRP (0.52) and ORP (0.08), while the ranking did not correspond to statistically significant differences in effect estimates (Figure 4).

Positive surgical margin

Using ORP as the reference comparator, the network

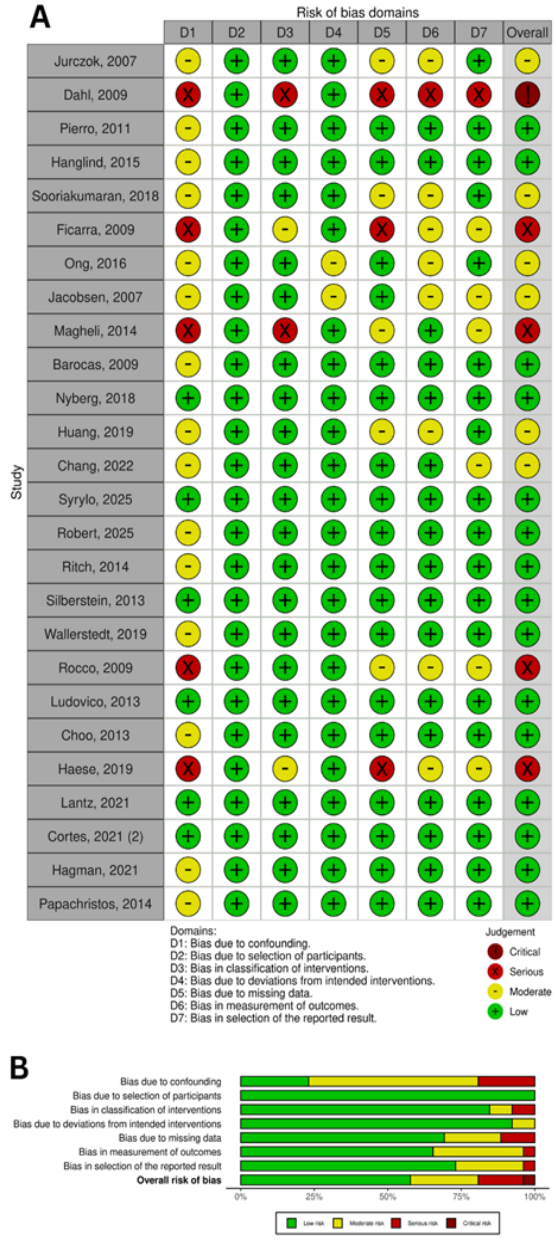

Figure 3. Risk of Bias (ROBINS-I) assesment: A) Traffic light plot, B) Summary plot

meta-analysis showed no statistically significant differences in positive surgical margin rates across surgical approaches. Relative to ORP, the odds ratio for a positive surgical margin was 0.94 (95% CI 0.80–1.11; p = 0.4926) for RARP and 1.04 (95% CI 0.78–1.38; p = 0.7948) for LRP. The estimate for RRP was 1.36 (95% CI 0.95–1.95; p = 0.0956). Based on SUCRA rankings, RARP ranked highest (0.84), followed by LRP (0.52) and RRP (0.06), while these probability rankings were not accompanied by statistically significant differences in effect estimates (Figure 5).

Health Related Quality of Life

Urinary incontinence

In the random-effects model, no statistically significant differences were observed in urinary incontinence across surgical approaches. The odds ratios relative to ORP were 1.04 (95% CI 0.84–1.29; p = 0.7109) for RARP, 1.11 (95% CI 0.79–1.56; p = 0.5568) for LRP, and 1.44 (95% CI 0.85–2.44; p = 0.1805) for RRP. SUCRA rankings indicated that ORP had the highest probability of favorable outcomes (0.767), followed by RARP (0.612), LRP (0.480), and RRP (0.141). However, these rankings were not supported by statistically significant differences and should be interpreted cautiously. (Figure 6).

Pad change >1x per day

When ORP served as the reference, the frequency of pad change >1× per day showed heterogeneous effect estimates across procedures. The odds of requiring pad change >1× per day were 0.84 (95% CI 0.49–1.43; p = 0.5127) for LRP and 1.02 (95% CI 0.75–1.39; p = 0.8875) for RARP, indicating no statistically significant difference compared with ORP. In contrast, RRP demonstrated a higher odds estimate of 7.33 (95% CI 1.55–34.59; p = 0.0119). This comparison was based on 8 studies including 6,925 patients and was associated with moderate heterogeneity (I^2 = 52%). The wide confidence interval suggests limited precision of the estimate (Figure 7).

Erectile dysfunction

For the outcome of erectile dysfunction, several

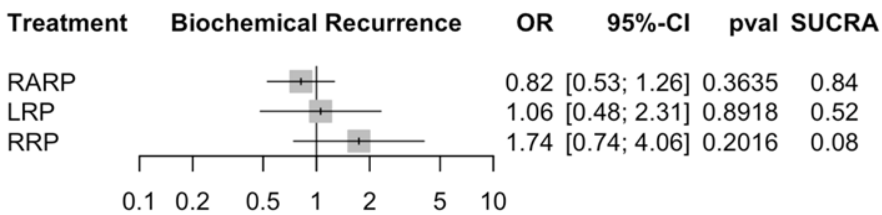

Figure 4. Network Meta-Analysis Biochemical Recurrence

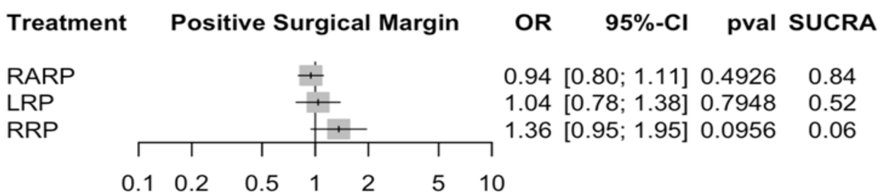

Figure 5. Network Meta-Analysis Positive Surgical Margin

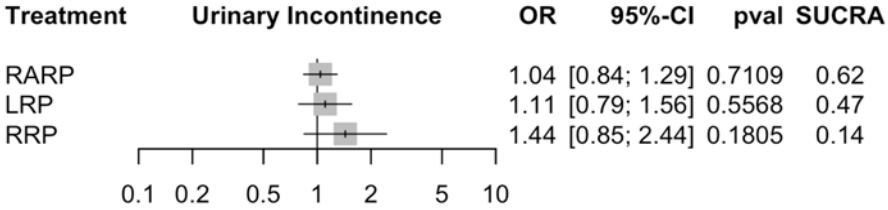

Figure 6. Network Meta-Analysis Urinary Incontinence

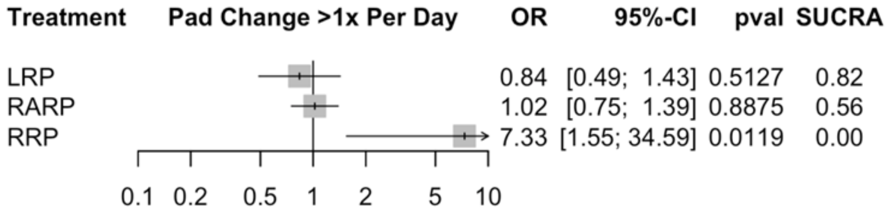

Figure 7. Network Meta-Analysis Pad Change>1x Per Week

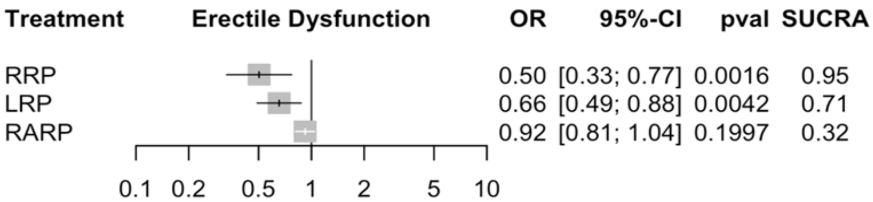

Figure 8. Network Meta-Analysis Erectile Dysfunction

approaches demonstrated lower odds of postoperative dysfunction relative to ORP. The odds ratio (OR) was 0.50 (95% CI 0.33–0.77; $p = 0.0016$) for RRP and 0.66 (95% CI 0.49–0.88; $p = 0.0042$) for LRP, both reaching statistical significance. In contrast, RARP showed no statistically significant difference compared with ORP (OR 0.92; 95% CI 0.81–1.04; $p = 0.1997$). SUCRA rankings were consistent with these findings, with RRP ranking highest (0.951), followed by LRP (0.710), RARP (0.315), and ORP (0.024). Substantial heterogeneity was observed across studies ($I^2 = 75.2\%$). (Figure 8).

Summary of Outcomes

Across health-related quality of life outcomes, the pattern of results was not consistent across domains. Erectile dysfunction outcomes favored RRP and LRP, whereas urinary continence and pad-use outcomes did not demonstrate a consistent advantage for any single technique. These findings should be interpreted in the context of substantial between-study heterogeneity observed across analyses.

Discussion

In this network meta-analysis, we observed distinct patterns in both oncologic and HRQoL outcomes. While RARP ranked highest for oncologic outcomes, non-robotic approaches especially RRP, were associated with favorable HRQoL profiles in certain functional domains. These findings align with, and extend, prior comparative evidence in the literature.

All four surgical approaches share the common goal of complete cancer excision but differ substantially in surgical technique, visualization, and tissue handling. ORP and RRP are traditional open approaches requiring a larger incision and direct manual dissection. Minimally invasive techniques like LRP and RARP rely on smaller ports and visual magnification, with RARP providing enhanced three-dimensional visualization and robotically-mediated instrument control that can improve precision. Previous systematic reviews have described similar patterns in comparative outcomes. Meta-analyses have shown that RARP is consistently associated with lower blood loss, shorter hospitalization, and lower transfusion rates compared with ORP and LRP, though overall oncologic outcomes such as biochemical recurrence (BCR) and positive surgical margins (PSM) often show overlapping confidence intervals between techniques in many studies [6]. Our network meta-analysis mirrored this complexity: although RARP had the highest SUCRA probabilities for minimizing BCR and PSM, statistical differences compared with ORP and LRP were not significant. This pattern ranking superiority without clear significance highlights the nuanced interplay between modeled probabilities and clinical effect sizes.

Several systematic reviews have compared RARP with other approaches. Du et al. [16] found that RARP often demonstrates better continence and potency recovery than ORP and LRP, along with lower overall PSM and blood loss, though the quality of evidence was limited by retrospective designs and heterogeneity . Conversely, some analyses show no significant difference in long-term oncologic outcomes between robotic and open techniques, suggesting that minimally invasive platforms may not always translate to improved cancer control, especially when confounding factors such as surgeon skill and case volume are unaccounted for [6].

In our HRQoL comparisons, urinary incontinence and pad changes >1 time per day did not differ significantly among most techniques. Other population-based studies similarly report only modest differences in patient-reported functional outcomes between robotic and open approaches, with clinically small effect sizes [17]. Importantly, for erectile dysfunction, our findings showed significantly lower odds of postoperative dysfunction with RRP and LRP relative to ORP, whereas RARP did not differ significantly. These functional outcome patterns echo earlier literature indicating that nerve-sparing, patient selection, and perioperative rehabilitation significantly influence potency outcomes beyond the choice of surgical platform alone [16].

Several mechanistic factors may explain why RARP ranked highest for oncologic endpoints in our analysis, even in the absence of clear statistical superiority. First, the robotic platform provides three-dimensional, high-definition visualization and instruments with seven degrees of freedom, which enable meticulous dissection and may reduce inadvertent positive margins [16]. Moreover, these technical capabilities facilitate nerve-sparing and precise apical dissection, particularly in challenging anatomical regions where margins are more difficult to control. Nerve-sparing itself may preserve peri-prostatic structures that contribute to oncologic control and functional preservation, although its direct impact on BCR has been debated [18]. Another explanation involves the learning curve and surgical standardization inherent to robotic systems. The ergonomics and reproducibility of robot-assisted techniques can make complex dissections more consistent across surgeons, potentially contributing to lower variability in oncologic performance at high-volume centers. However, these advantages may be attenuated in low-volume settings or when surgeon experience is limited [19]. Interestingly, RRP ranked highest for erectile function outcomes, while showing less favorable performance in certain continence-related domains. This apparent discrepancy, whereby RRP demonstrates favorable erectile function outcomes yet comparatively poorer continence-related outcomes, is likely attributable to heterogeneity across the included studies rather than a true physiological trade-off. First, many RRP cohorts originate from earlier surgical eras, when techniques for sphincter preservation and apical reconstruction were less refined, whereas nerve-sparing principles were already well established in open surgery [19]. Second, definitions of urinary continence varied considerably between studies, with some older RRP series applying stricter or non-standardized criteria, potentially inflating incontinence rates [17]. Third, differences in patient selection may have led to more extensive resections in RRP cohorts, particularly in higher-risk disease, adversely affecting continence outcomes while still allowing selective nerve preservation [16]. Finally, the wide confidence intervals observed for RRP in continence-related outcomes suggest substantial heterogeneity and possible influence of outlier studies. Taken together, these factors likely explain the counterintuitive pattern observed and warrant cautious interpretation of the findings.

While robotic and minimally invasive platforms often tout superior functional recovery, early literature and real-world data suggest that refined open retropubic techniques, particularly those emphasizing nerve preservation that remains highly effective, especially when performed by experienced surgeons [16].

Cost and resource considerations may also influence HRQoL patterns. RRP and LRP generally incur lower procedural costs compared with robot-assisted procedures, which require expensive capital equipment and maintenance. These economic factors may affect surgeon choice, patient selection, and perioperative care pathways, indirectly influencing functional recovery and HRQoL [20]. Moreover, HRQoL outcomes are multifactorial. Patient education, rehabilitation programs (e.g., pelvic floor therapy), and expectations can modulate reported outcomes independently of surgical platform. Thus, the superior HRQoL metrics observed with RRP in this analysis should be interpreted with caution: they likely reflect a combination of technique quality, patient selection, and postoperative care, not merely the surgical approach itself.

This study represents a comprehensive network meta-analysis comparing four radical prostatectomy techniques by integrating oncologic and HRQoL outcomes. The network approach enabled indirect comparisons across modalities lacking head-to-head trials, while the large pooled sample size and systematic risk-of-bias assessment strengthen the reliability of the findings. However, most included studies were observational, making the results susceptible to confounding related to surgeon experience, case volume, nerve-sparing technique, and patient selection. Variability in HRQoL definitions and follow-up duration further contributed to heterogeneity. Additionally, SUCRA rankings indicate relative probabilities rather than absolute superiority and should be interpreted cautiously when effect estimates are not statistically significant. These limitations highlight the need for standardized, long-term randomized studies to confirm these findings

Collectively, our findings reinforce that no single surgical technique is universally superior across all outcomes. RARP may provide nuanced advantages in precision and oncologic ranking probabilities, whereas traditional techniques like RRP can achieve excellent functional preservation when expertly executed. Future randomized trials with standardized reporting of nerve-sparing techniques, surgeon experience, and patient-reported outcomes are needed to disentangle the effects of surgical modality from these critical confounders.

In conclusion, this network meta-analysis provides a comprehensive comparison of oncologic and health-related quality of life (HRQoL) outcomes across four radical prostatectomy techniques open (ORP), retropubic (RRP), laparoscopic (LRP), and robot-assisted radical prostatectomy (RARP) in patients with localized prostate cancer. Based on SUCRA rankings, RARP demonstrated the highest probability of favorable oncologic outcomes, particularly in minimizing biochemical recurrence and positive surgical margins, although these advantages were not consistently supported by statistically significant differences when compared with non-robotic approaches. These findings suggest that while robotic platforms may offer technical advantages that translate into improved oncologic ranking probabilities, absolute superiority in long-term cancer control remains unproven.

In contrast, non-robotic techniques showed relative advantages in selected HRQoL domains. ORP and LRP were associated with more favorable urinary continence-related outcomes, while RRP demonstrated the lowest odds of postoperative erectile dysfunction. These results underscore that functional recovery after prostatectomy is multifactorial and influenced by surgeon experience, nerve-sparing technique, patient selection, and postoperative rehabilitation, rather than surgical modality alone. Overall, no single prostatectomy approach was universally superior across all oncologic and HRQoL outcomes. Therefore, surgical decision-making should be individualized, balancing oncologic risk, patient preferences, functional priorities, resource availability, and surgeon expertise. High-quality randomized controlled trials with standardized reporting of oncologic and patient-reported outcomes are still needed to definitively establish the comparative effectiveness of prostatectomy techniques in localized prostate cancer.

Author Contribution Statement

All authors contributed equally in this study.

Acknowledgements

None.

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