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Patient-Specific Three-Dimensional Reconstruction for Planning Robot-Assisted Radical Prostatectomy: Console Time and Positive Surgical Margins in a Multicenter Cohort

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Abstract

Purpose

To evaluate the association between patient-specific three-dimensional (3D) reconstruction for robot-assisted radical prostatectomy (RARP) planning and perioperative and early oncologic outcomes.

Methods

This ambispective, two-center study included 160 patients undergoing RARP between January 2024 and September 2026: 80 with 3D reconstruction derived from multiparametric magnetic resonance imaging and 80 controls. Positive surgical margin status was the primary outcome. Console time and hospital stay were secondary outcomes. Multivariable analyses assessed adjusted associations.

Results

Positive surgical margins occurred in 17.5% of the 3D group and 20.0% of controls (p = 0.685). The adjusted odds ratio was 0.86 (95% confidence interval [CI] 0.37–2.02; p = 0.735). Median console time was 82.0 versus 95.5 minutes (p < 0.001), with an adjusted difference of − 15.83 minutes (95% CI − 24.63 to − 7.04; p < 0.001), including adjustment for lymphadenectomy. Among patients without lymphadenectomy, the adjusted difference was − 15.93 minutes (95% CI − 28.18 to − 3.67; p = 0.012). Median hospital stay was 24 hours in both groups; adjusted stay was 4.96 hours longer with 3D reconstruction (95% CI 0.64–9.28; p = 0.025).

Conclusion

3D reconstruction for RARP planning was associated with shorter console time, with no demonstrable difference in positive surgical margins. These observational findings suggest potential operative efficiency benefits; prospective randomized studies are needed to establish clinical and oncologic impact.

INTRODUCTION

Prostate cancer (PCa) is the second most frequently diagnosed malignancy among men worldwide, with an estimated 1.55 million new cases in 2024, and represents the fourth leading cause of cancer-related death in the male population, with approximately 420,000 deaths in the same year [1]. The mean age at diagnosis is 66 years, which is influenced by access to healthcare, screening, and imaging, particularly in vulnerable countries [1, 2]. Robot-assisted radical prostatectomy (RARP) has become one of the main surgical approaches for the treatment of prostate cancer due to its greater precision, three-dimensional and magnified visualization, and improved surgical ergonomics [3–5].

Several technologies have been incorporated into RARP with the aim of optimizing oncologic and functional outcomes [6]. Three-dimensional (3D) reconstruction has gained prominence among these innovations by enabling improved surgical planning, which may be associated with a reduction in positive surgical margins (PSM) [3]. 3D reconstruction technology is already widely used in robot-assisted partial nephrectomy (RAPN), where it helps maximize the volume of residual renal parenchyma postoperatively, thereby improving renal function preservation [7, 8]. The integration of this technology with RARP enables precise visualization of the relationship between the tumor and structures that are critical to functional outcomes, such as the neurovascular bundles and the prostatic capsule, thereby supporting efforts to achieve surgical trifecta outcomes [9–10].

Despite the growing interest in the application of personalized three-dimensional models in RARP, limited evidence is available in the literature systematically describing how this technology has been incorporated into clinical practice [3, 9, 10]. Few studies have addressed the institutional experience with 3D reconstruction from an analytical perspective, limiting the understanding of its role in the current clinical setting.

In this context, this study aimed to analyze the rate of PSM in patients undergoing RARP with the support of 3D reconstruction, compared with two-dimensional imaging alone.

METHODS

Study Design and Setting

This was a short-term analysis of an ambispective, observational and multicenter study conducted between January 2024 and September 2026 at two specialized urology centers. The present report describes the perioperative and pathological results of an ongoing cohort, with data analyzed up to September 2026. Postoperative functional outcomes are being collected and will be reported after longer follow-up. All procedures were performed by a single surgeon who had performed more than 1,000 RARP before the study period, with the same assisting team.

Patient Selection and Study Groups

Patients with histologically confirmed localized or locally advanced prostate adenocarcinoma, who underwent RARP with curative intent were eligible. Patients who received neoadjuvant treatment or had a history of previous prostatectomy or pelvic radiotherapy were excluded.

Eligible patients were recruited from those already scheduled to undergo RARP as part of the surgeon's routine clinical practice. The analysis included 160 patients, comprising 80 in the 3D reconstruction group and 80 controls. Group assignment was based on the use of 3D reconstruction for preoperative planning. This technology was not randomized, and its use depended on availability.

Preoperative Imaging Process

Volumetric images in Digital Imaging and Communications in Medicine (DICOM) format were obtained from multiparametric magnetic resonance imaging of the prostate. 3D reconstruction was performed using platform cirurgic3d, with semiautomatic segmentation by a specialist urologist (P.H.O.F). The cost of producing each patient-specific 3D model was approximately US$100.

Following segmentation, the models were validated and provided as simple, interactive virtual models accessible through a web browser on mobile devices. The models represented patient-specific anatomy, including the prostate, urethra, PI-RADS ≥ 3 lesions, seminal vesicles, bladder, neurovascular bundles, and membranous urethra, enabling preoperative visualization of anatomical relationships relevant to surgical planning (Fig. 1).

Data Collection

Data collected included age, body mass index (BMI), American Society of Anesthesiologists (ASA) classification, hypertension, diabetes mellitus, preoperative prostate-specific antigen (PSA), prostate volume, histopathological characteristics, console time, surgical conversion, surgical margins, lymphadenectomy type, and involvement of the seminal vesicles and vas deferens. Console time included lymph node dissection when performed.

Surgical margin status and lymphadenectomy-related pathological findings were obtained from postoperative histopathology reports. ISUP grade group was determined from preoperative biopsy.

Study Outcomes

The primary outcome was the proportion of patients with at least one positive surgical margin. Patients with multiple positive margins were counted only once in the overall analysis. Subanalyses assessed focal and bilateral circumferential margins, bladder neck and urethral margins, and positive-margin rates within pT2 and ≥pT3 disease.

Additional exploratory analyses compared outcomes in patients with PI-RADS ≥ 4. Secondary outcomes included console time, length of stay, conversion to open prostatectomy, blood transfusion, performance and type of lymphadenectomy (obturator or extended), and right- and left-sided involvement of the seminal vesicles and vas deferens.

Statistical Analysis

Continuous variables were summarized as mean ± standard deviation or median (Q1–Q3) and compared using the Mann–Whitney U test. Categorical variables were expressed as n/N (%) and compared using Pearson’s chi-square test without continuity correction, or two-sided Fisher’s exact test when any

expected frequency was < 5; Fisher–Freeman–Halton tests were used for larger tables. All recorded incontinence categories were included.

Positive surgical margins were assessed using Firth's logistic regression, adjusted for group, pathological stage (≥ pT3 versus pT2), grouped biopsy ISUP (≥ 3 versus ≤ 2), and continuous PSA. Sensitivity analysis included group, BMI, categorical ISUP, and PSA. Adjusted ORs, penalized profile-likelihood 95% CIs, and penalized likelihood-ratio p-values were reported.

Multiple linear regression assessed console time, adjusted for group, categorical ASA, BMI, age, PSA, categorical ISUP, prostate volume, and lymphadenectomy type, and hospital stay, adjusted for group, categorical ASA, and BMI. An additional multivariable console-time model was restricted to patients without lymphadenectomy and included the same covariates except lymphadenectomy type. Reference categories were control, ASA I, ISUP 1, and no lymphadenectomy, as applicable. Conventional coefficients and 95% CIs were reported. Supplementary sensitivity analyses used heteroskedasticity-consistent HC3 robust standard errors where estimable. In the subgroup without lymphadenectomy, ISUP was additionally grouped as ≤ 2 versus ≥ 3 because sparse categories prevented HC3 estimation in the fully categorical model; all other covariates were retained.

Additional comparisons assessed console time without lymphadenectomy, pT distribution (pT2/pT3a/pT3b), margin rates within pT2 and ≥pT3, PI-RADS 4 versus 2/3/5, PI-RADS 4–5 versus 2–3, and outcomes within PI-RADS ≥ 4. Available cases were used for each analysis without imputation; multivariable models used complete cases. Statistical analyses were performed using R (version 4.6.1; R Foundation for Statistical Computing, Vienna, Austria) and Python (version 3.12.14; Python Software Foundation)

Ethical Considerations

The study was approved by the Prof. Dr. Celso Figueirôa Research Ethics Committee (CAAE: 92186725.6.1001.5520), which waived the requirement for informed consent.

RESULTS

Sample Characteristics

A total of 160 patients undergoing RARP were included, with 80 in the 3D reconstruction group and 80 controls (Table 1). Preoperative urinary incontinence was recorded in 8/80 (10.0%) and 2/79 (2.5%) patients, respectively (p = 0.098). Among patients with available PI-RADS data, PI-RADS 4 was present in 47/79 (59.5%) patients in the 3D group and 37/75 (49.3%) controls (p = 0.206). The combined frequency of PI-RADS 4–5 was 66/79 (83.5%) versus 61/75 (81.3%) (p = 0.718).

Table 1
Clinical and demographic characteristics of the participants

Variables		3D Group (n = 80)	Control Group (n = 80)	P-value
Age (years)		66.0 ± 9.6	65.2 ± 9.0	0.639
BMI (kg/m²)		27.8 ± 3.9	27.4 ± 3.9	0.687
Hypertension		45/80 (56.3)	39/80 (48.8)	0.342
T2DM		29/80 (36.3)	20/80 (25.0)	0.123
Prostate volume		44.00 (35.90–57.88)	43.40 (32.00–53.03)	0.322
Urinary incontinence		8/80 (10.0)	2/79 (2.5)	0.098
Erectile dysfunction	Potent	51/80 (63.8)	51/77 (66.2)	0.982
	Mild	14/80 (17.5)	11/77 (14.3)	
	Moderate	6/80 (7.5)	5/77 (6.5)	
	Severe	3/80 (3.8)	4/77 (5.2)	
	Impotent	6/80 (7.5)	6/77 (7.8)	
PI-RADS	2	6/79 (7.6)	5/75 (6.7)	0.570
	3	7/79 (8.9)	9/75 (12.0)	
	4	47/79 (59.5)	37/75 (49.3)	
	5	19/79 (24.1)	24/75 (32.0)	
PI-RADS 4–5 versus PI-RADS 2–3		66/79 (83.5)	61/75 (81.3)	0.718
ISUP	1	17/80 (21.3)	16/79 (20.3)	0.296
	2	46/80 (57.5)	40/79 (50.6)	
	3	11/80 (13.8)	10/79 (12.7)	
	4	2/80 (2.5)	9/79 (11.4)	
	5	4/80 (5.0)	4/79 (5.1)	
Total PSA (ng/mL)		5.62 (4.01–9.15)	6.73 (4.18–10.31)	0.425
ASA	I	7/80 (8.8)	9/79 (11.4)	0.855
	II	66/80 (82.5)	63/79 (79.7)	
	III	7/80 (8.8)	7/79 (8.9)	

Variables	3D Group (n = 80)	Control Group (n = 80)	P-value

Continuous variables are presented as mean ± standard deviation (SD) or median (Q1–Q3); categorical variables are n/N (%). Denominators reflect available cases. Available cases (3D/control): age, 80/80; BMI, 80/79; erectile function, 80/77; continence, 80/79; PI-RADS, 79/75; ISUP, 80/79; PSA, 80/78; ASA, 80/79. Other baseline variables had complete data.

The PI-RADS 4–5 versus 2–3 comparison used Pearson's chi-square test. Overall distributions of erectile function, ISUP and ASA were compared using exact Fisher–Freeman–Halton tests when any expected frequency was < 5.

Erectile function was classified as potent (normal erection), mild (tadalafil 5 mg), moderate (tadalafil 20 mg), severe (injectable intracavernosal therapy), and impotent (absence of erection).

Abbreviations: BMI, body mass index; T2DM, type 2 diabetes mellitus; PI-RADS, Prostate Imaging-Reporting and Data System; ISUP, International Society of Urological Pathology; PSA, prostate-specific antigen; ASA, American Society of Anesthesiologists.

Surgical Margins

Positive surgical margins occurred in 14/80 (17.5%) patients in the 3D group and 16/80 (20.0%) controls (p = 0.685). Focal circumferential involvement occurred in 10/80 (12.5%) versus 9/80 (11.3%) patients (p = 0.807), while bilateral involvement occurred in 3/80 (3.8%) versus 6/80 (7.5%) patients (p = 0.495).

Among patients with pT2 disease, positive surgical margins occurred in 7/61 (11.5%) patients in the 3D group and 9/63 (14.3%) in the control group (p = 0.641). Among those with ≥pT3 disease, comprising pT3a and pT3b, positive margins occurred in 7/19 (36.8%) and 7/17 (41.2%), respectively (p = 0.790).

Positive bladder neck margins occurred in 3/80 (3.8%) patients in the 3D group and 5/80 (6.3%) controls (p = 0.719). Positive urethral margins occurred in 4/80 (5.0%) and 1/80 (1.3%), respectively (p = 0.367).

Right-sided seminal vesicle and vas deferens involvement was recorded in 4/80 (5.0%) patients in the 3D group and 7/80 (8.8%) controls (p = 0.349). Left-sided involvement occurred in 5/80 (6.3%) patients in each group (p = 1.000). No blood transfusions or conversions to open prostatectomy occurred in either group (0/80 in each group).

In the primary multivariable Firth logistic regression analysis, which included 157 patients and 30 positive-margin events, 3D reconstruction was not independently associated with positive surgical margins after adjustment for pathological stage (pT2 versus ≥pT3), biopsy ISUP grade group (≤ 2 versus ≥ 3), and preoperative total PSA (adjusted OR = 0.86; 95% CI: 0.37–2.02; p = 0.735). Higher PSA levels were associated with greater odds of positive margins (adjusted OR per 1 ng/mL increase = 1.05; 95% CI: 1.01–1.11; p = 0.019), whereas pathological stage and grouped ISUP grade were not statistically significant.

In the sensitivity analysis adjusted for BMI, categorical ISUP grade group, and total PSA, the association between 3D reconstruction and positive margins remained nonsignificant (adjusted OR = 1.05; 95% CI:

0.44–2.55; p = 0.914; n = 156). The full results of the primary and sensitivity analyses are presented in Table 4.

Console Time

Regarding console time, the 3D group had a shorter procedure duration, with a median of 82.0 minutes (IQR 65.0–100.5), compared with 95.5 minutes (IQR 79.75–128.5) in the control group (p < 0.001).

In the multivariable analysis of 154 patients, after adjustment for ASA classification, BMI, age, total PSA, biopsy ISUP grade group, prostate volume, and lymphadenectomy type, the 3D group had a mean console time 15.83 minutes shorter than controls (β = −15.83 minutes; 95% CI: −24.63 to − 7.04; p < 0.001). Compared with ISUP 1, ISUP 3 (β = 21.28 minutes; 95% CI: 5.08 to 37.48; p = 0.010) and ISUP 4 (β = 35.43 minutes; 95% CI: 15.51 to 55.34; p < 0.001) were associated with longer console time. Neither obturator (β = −3.06 minutes; 95% CI: −16.59 to 10.46; p = 0.655) nor extended lymphadenectomy (β = −4.92 minutes; 95% CI: −15.37 to 5.52; p = 0.353), compared with no lymphadenectomy, was independently associated with console time.

Among patients without lymphadenectomy, median console time was 75.0 minutes (IQR 63.5–99.5; n = 47) in the 3D group versus 93.0 minutes (IQR 85.0–111.75; n = 36) in controls (p = 0.002). In the restricted multivariable analysis of 80 patients, the adjusted difference remained significant (β = −15.93 minutes; 95% CI: −28.18 to − 3.67; p = 0.012). The full-cohort association remained significant using HC3 robust standard errors (95% CI: −25.15 to − 6.51; p = 0.001). HC3 was not estimable in the restricted model with categorical ISUP because some categories contained a single patient. In the supplementary restricted model with grouped ISUP, the HC3 estimate was − 15.79 minutes (95% CI: −30.14 to − 1.43; p = 0.032).

Length of Hospital Stay

Both groups had a median hospital stay of 24 hours; however, the distributions differed significantly, with an IQR of 24–48 hours in the 3D group and 24–24 hours in the control group (p = 0.013).

In the multivariable analysis of 155 patients, after adjustment for ASA classification and BMI, the 3D group had a mean hospital stay 4.96 hours longer than the control group (β = 4.96 hours; 95% CI: 0.64–9.28; p = 0.025). Compared with ASA I, ASA III was associated with longer hospital stay (β = 16.19 hours; 95% CI: 5.77–26.61; p = 0.003), whereas ASA II and BMI were not significantly associated with length of stay.

Pathological Stage

Pathological stage distribution did not differ significantly between groups (p = 0.593). In the 3D group, 61/80 (76.3%) patients had pT2, 13/80 (16.3%) pT3a, and 6/80 (7.5%) pT3b disease; corresponding counts in controls were 63/80 (78.8%), 9/80 (11.3%), and 8/80 (10.0%).

The perioperative and pathological outcomes are summarized in Table 2.

Table 2
Perioperative and pathological outcomes

Variables		3D Group (n = 80)	Control Group (n = 80)	*P-value*
Console time (min)		82.00 (65.00–100.50)	95.50 (79.75–128.50)	< 0.001
Without lymphadenectomy		75.00 (63.50–99.50)	93.00 (85.00–111.75)	0.002
Length of hospital stay (hours)		24.00 (24.00–48.00)	24.00 (24.00–24.00)	0.013
Positive Surgical margin		14/80 (17.5)	16/80 (20.0)	0.685
Focal		10/80 (12.5)	9/80 (11.3)	0.807
Bilateral		3/80 (3.8)	6/80 (7.5)	0.495
Bladder neck margin		3/80 (3.8)	5/80 (6.3)	0.719
Urethral margin		4/80 (5.0)	1/80 (1.3)	0.367
Lymphadenectomy		33/80 (41.3)	44/80 (55.0)	0.082
Obturator		12/80 (15.0)	14/80 (17.5)	0.202
Extended		21/80 (26.3)	30/80 (37.5)	
Seminal vesicle and vas deferens involvement	Right	4/80 (5.0)	7/80 (8.8)	0.349
	Left	5/80 (6.3)	5/80 (6.3)	1.000
Conversion to open prostatectomy		0/80 (0.0)	0/80 (0.0)	1.000
Hemotransfusion		0/80 (0.0)	0/80 (0.0)	—
Pathological T stage	**pT2**	61/80 (76.3)	63/80 (78.8)	0.593
	pT3a	13/80 (16.3)	9/80 (11.3)	
	pT3b	6/80 (7.5)	8/80 (10.0)	

Continuous variables are median (Q1–Q3); categorical variables are n/N (%). Available cases (3D/control): console time, 79/80; hospital stay, 79/77. All listed categorical outcomes had complete data (80/80). Overall positive margins were counted once per patient. The no-lymphadenectomy console-time comparison included 47 patients in the 3D group and 36 controls. The P-value for lymphadenectomy type compares no, obturator and extended dissection jointly. No conversions occurred in either group; p = 1.000 is conventional and does not demonstrate equivalence. No blood transfusions occurred in either group; a between-group P-value was not calculated for this outcome.

PI-RADS ≥ 4 Subgroup analysis

The PI-RADS ≥ 4 subgroup comprised 66 patients in the 3D group and 61 controls. Console time was shorter in the 3D group, at 83 minutes (IQR 65–101) versus 101 minutes (IQR 78–130; p < 0.001).

Median hospital stay was 24 hours in both groups, with IQRs of 24–48 and 24–24 hours, respectively (p = 0.085).

Positive surgical margins occurred in 13/66 (19.7%) patients in the 3D group and 15/61 (24.6%) controls (p = 0.506). Positive bladder neck margins occurred in 3/66 (4.5%) versus 4/61 (6.6%) (p = 0.710). Other margin comparisons and lymphadenectomy frequency were not statistically significant. These subgroup comparisons were exploratory and unadjusted.

The perioperative and pathological outcomes among patients with PI-RADS ≥ 4 are summarized in Table 3.

Table 3
Perioperative and pathological outcomes in patients with PI-RADS ≥ 4

Variables	**3D Group (n = 66)**	**Control Group (n = 61)**	***P-value***
Console time (min)	83.00 (65.00–101.00)	101.00 (78.00–130.00)	< 0.001
Length of hospital stay (hours)	24.00 (24.00–48.00)	24.00 (24.00–24.00)	0.085
Positive Surgical margin	13/66 (19.7)	15/61 (24.6)	0.506
Focal	9/66 (13.6)	9/61 (14.8)	0.857
Bilateral	3/66 (4.5)	5/61 (8.2)	0.479
Bladder neck margin	3/66 (4.5)	4/61 (6.6)	0.710
Urethral margin	4/66 (6.1)	1/61 (1.6)	0.367
Lymphadenectomy	33/66 (50.0)	38/61 (62.3)	0.163
Available cases (3D/control): console time, 65/61; hospital stay, 65/59. All categorical outcomes listed have complete data (66/61), including focal, bilateral and urethral margins.			

Table 4
Firth logistic regression analyses of positive surgical margins

Model	Predictor and reference	Adjusted OR	95% CI	P-value	n / events
Primary	3D vs control	0.86	0.37–2.02	0.735	157 / 30
Primary	≥pT3 vs pT2	2.28	0.86–5.87	0.097	157 / 30
Primary	ISUP ≥ 3 vs ≤ 2	1.74	0.68–4.30	0.243	157 / 30
Primary	PSA per 1 ng/mL	1.05	1.01–1.11	0.019	157 / 30
Sensitivity	3D vs control	1.05	0.44–2.55	0.914	156 / 29
Sensitivity	BMI per 1 kg/m²	1.04	0.94–1.16	0.423	156 / 29
Sensitivity	ISUP 2 vs 1	1.92	0.56–8.85	0.318	156 / 29
Sensitivity	ISUP 3 vs 1	3.09	0.69–16.14	0.142	156 / 29
Sensitivity	ISUP 4 vs 1	6.71	1.28–41.33	0.024	156 / 29
Sensitivity	ISUP 5 vs 1	1.92	0.18–15.57	0.561	156 / 29
Sensitivity	PSA per 1 ng/mL	1.07	1.02–1.12	0.002	156 / 29

The primary model included group, pathological stage, grouped biopsy ISUP and PSA. The sensitivity model included group, BMI, categorical biopsy ISUP and PSA. Confidence intervals and P-values were based on penalized profile likelihood and penalized likelihood-ratio tests, respectively. Complete cases were used; control was the reference surgical group.

DISCUSSION

In this study of 160 patients undergoing RARP, 3D reconstruction was associated with shorter console time. Positive surgical margin rates were 17.5% in the 3D group and 20.0% in controls, with no statistically significant difference. Positive bladder neck margins were numerically less frequent in the 3D group, although this difference was also nonsignificant. These findings suggest a potential association with operative efficiency without a demonstrable improvement in the early oncologic outcomes assessed.

Console time was shorter in the 3D group, and this association was maintained in the adjusted analysis. In Checcucci et al. [11], mean console time was also numerically shorter with the use of three-dimensional models, at 113 minutes in the 3D group and 118 minutes in the control group, although the difference was not statistically significant (p = 0.07) [11]. A similar result was reported by Wake et al. [12], with console times of 213 ± 42 and 222 ± 47 minutes, respectively (p = 0.17) [12]. These findings may be explained by the fact that prior visualization of the relationships between the tumor and adjacent structures may facilitate orientation during dissection. In the study by Saba et al. [13], lesion localization during surgical planning was faster with digital and printed three-dimensional models than with

conventional magnetic resonance imaging [13]. This finding supports the hypothesis that improved anatomical understanding may contribute to surgical execution, although this relationship was not directly investigated in our analysis.

Positive surgical margin rates were 17.5% in the 3D group and 20.0% in controls (p = 0.685), with no association between the use of three-dimensional reconstruction and this outcome after multivariable adjustment. Similarly, the randomized trial by Shirk et al. [14] found no significant difference, although positive margins were numerically lower in the 3D group compared to the control group (25% vs. 33%, p = 0.40) [14]. In contrast, in the propensity-matched cohort reported by Checcucci et al. (160 3D patients vs. 640 controls), positive surgical margin rates were 25% vs. 35.1% (p = 0.01), with this association persisting in multivariable analysis (OR = 0.50, 95% CI: 0.30–0.80, p = 0.005) [11]. Comparison between these series requires consideration of how surgical margins were assessed and how the models were used. Checcucci et al. included the assessment of clinically significant margins, defined as multifocal or with an extension ≥ 3 mm, and used augmented reality overlay in some procedures [11]. These methodological characteristics may contribute to the differences between the results and preclude attributing them exclusively to the 3D reconstruction technology itself. In our sample, the adjusted estimate was imprecise (OR = 0.86; 95% CI: 0.37–2.02; p = 0.735); therefore, the absence of statistical significance does not allow equivalence between the groups to be concluded.

Positive bladder neck margins were numerically less frequent in the 3D group than in controls (3.8% versus 6.3%), but the difference was not statistically significant (p = 0.719). Bianchi et al. similarly reported almost zero positive bladder neck margins among 20 patients in the intervention group versus one in the control group (n = 20); however, augmented reality was combined with intraoperative frozen section analysis, precluding attribution solely to 3D technology [15]. Kang et al. demonstrated an association between positive basal margins and anterior/lateral extraprostatic extension, highlighting the influence of tumor distribution on margin status [16]. The lower rate in our 3D cohort therefore requires cautious interpretation, considering the small number of events and potential residual confounding.

Despite the shorter console time, length of stay was slightly longer in the 3D group. Although the median stay was 24 hours in both groups, the distribution differed significantly (p = 0.013), and this difference persisted after adjustment for ASA classification and BMI, with the 3D group showing a mean increase of 4.96 hours compared with controls (β = 4.96 hours; 95% CI: 0.64–9.28; p = 0.025). In contrast, Bianchi et al. [15] and Porpiglia et al. [17] reported no significant differences in length of stay between groups, with median hospitalizations of three and five days, respectively (p = 0.40 for both). The magnitude of the difference observed in our cohort, less than 5 hours with a median stay of one day in both groups, is of limited clinical relevance and may reflect discharge logistics rather than differences in postoperative recovery. However, the specific reasons for discharge delays were not prospectively captured.

Lymph node dissection was performed less frequently in the 3D group than in controls (41.3% versus 55.0%; p = 0.082), including extended dissection (26.3% versus 37.5%). This imbalance could contribute

to differences in console time. The association with shorter console time persisted after adjustment for lymphadenectomy type and in both unadjusted and multivariable analyses restricted to patients without lymphadenectomy. These findings support the consistency of the observed association, but do not exclude residual confounding. All procedures were performed by a single surgeon, and controls were selected to approximate the distribution of biopsy ISUP grade group and PI-RADS score. A similar strategy was adopted by Checcucci et al. [11], who used propensity score matching and procedures performed by a single surgeon.

In exploratory analyses restricted to PI-RADS ≥ 4, the association with shorter console time was also observed, whereas differences in surgical margins were nonsignificant. Stage-stratified margin rates were numerically lower with 3D planning in both pT2 and ≥pT3 disease, but neither comparison was significant. These analyses were not adjusted for multiple testing and should not be interpreted as evidence of subgroup-specific efficacy or equivalence.

Beyond console time, our experience supports the feasibility of incorporating patient-specific 3D reconstruction into routine RARP planning. The models were generated from standard multiparametric MRI at a cost of approximately US$100 per patient and were accessed through a web browser on mobile devices, without the need for printing or dedicated hardware. From an anatomical perspective, individualized models allow visualization of the relationship between the tumor and structures relevant to oncologic and functional outcomes, such as the neurovascular bundles, the prostatic capsule, and the membranous urethra, which is closely related to the external urinary sphincter, providing a rationale for their use in planning the extent of dissection. However, this study did not assess whether such visualization changed intraoperative decisions or improved the preservation of these structures, and these potential benefits remain to be demonstrated.

This study has some limitations. The absence of randomization and the dependence of 3D reconstruction on availability may have introduced selection bias, despite the adjustments performed. The partially retrospective data collection is also subject to incomplete information in the medical records. In addition, some clinically relevant variables could not be analyzed: clinical stage, nerve-sparing status, and tumor location were not consistently available and were therefore not included in the comparative or multivariable analyses. Nerve-sparing technique is a well-recognized determinant of positive surgical margins, and tumor location may influence the risk of margins at specific sites, such as the apex or bladder neck; their absence may have resulted in residual confounding. The no-lymphadenectomy model contained sparse ISUP categories, limiting precision and preventing estimation of HC3 standard errors in the fully categorical model; the grouped-ISUP analysis was exploratory.

Another potential source of bias relates to the ambispective design. Because 3D reconstruction was incorporated into clinical practice more recently, patients in the 3D group were predominantly enrolled prospectively and operated on later in the study period, whereas most controls were identified retrospectively from earlier procedures. Temporal improvements in surgical performance could therefore have favored the 3D group. However, this effect is likely limited, since all procedures were performed by

a single surgeon who had already performed more than 1,000 RARPs before the study period. In a large prospective multicenter study, Bock et al. demonstrated that the learning curve for positive surgical margins after RARP was relatively flat, with similar adjusted rates among surgeons with fewer than 75 and more than 300 procedures [18]. Nevertheless, a residual temporal effect on console time cannot be entirely excluded, and the results obtained by a single highly experienced surgeon may not be reproducible in other settings. Finally, the small number of events limits the precision of comparisons of surgical margins. Because this report presents short-term results of an ongoing cohort, biochemical recurrence, urinary continence, and erectile function could not yet be assessed; these outcomes will be addressed in a subsequent analysis with longer follow-up.

Future prospective studies, ideally randomized, are needed to better define the role of 3D reconstruction in RARP planning, particularly in more complex subgroups and in settings with less surgical experience. The combination of 3D technology with surgical navigation systems and augmented reality may further enhance intraoperative anatomical guidance, allowing more precise identification of critical structures and potentially improving surgical decision-making. In addition, longer follow-up of the present cohort will allow assessment of whether 3D-assisted planning is associated with earlier recovery of urinary continence and erectile function.

CONCLUSION

Preoperative planning with patient-specific 3D models was associated with shorter console time during RARP, including among patients without lymphadenectomy. No statistically significant difference in positive surgical margins was demonstrated, either overall or within pathological stage strata. These observational findings support further evaluation of 3D reconstruction as a surgical planning aid; however, prospective randomized trials are needed to establish its clinical impact.

Declarations

Competing Interests

P.H.O.F. developed the software used for three-dimensional reconstruction and performed the reconstructions included in this study. The other authors declare no competing financial or non-financial interests.

Author Contribution

NJCLB and RBS conceived and designed the study. NJCLB performed all surgical procedures, assisted by LMC, GSR, WSK, EDMF, and FPA. PHOF and MWSC developed the software and produced and validated the three-dimensional reconstructions. RBS, RMVG, FPGP, PRQ, VFF, JCCV, ALBABR, and MPA contributed to data collection and patient follow-up. RBS, RMVG, FPA, EDMF, ALBABR, and MPA organized and verified the database. RMVG, RBS, and LMC performed the statistical analyses. RMVG,

RBS, NJCLB, GSR, and WSK interpreted the results. RBS, NJCLB, RMVG, and GSR drafted the manuscript. NJCLB, PHOF, and MWSC critically revised the manuscript for important intellectual content. NJCLB and RBS supervised and coordinated the research.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to ethical and privacy restrictions.

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Figures

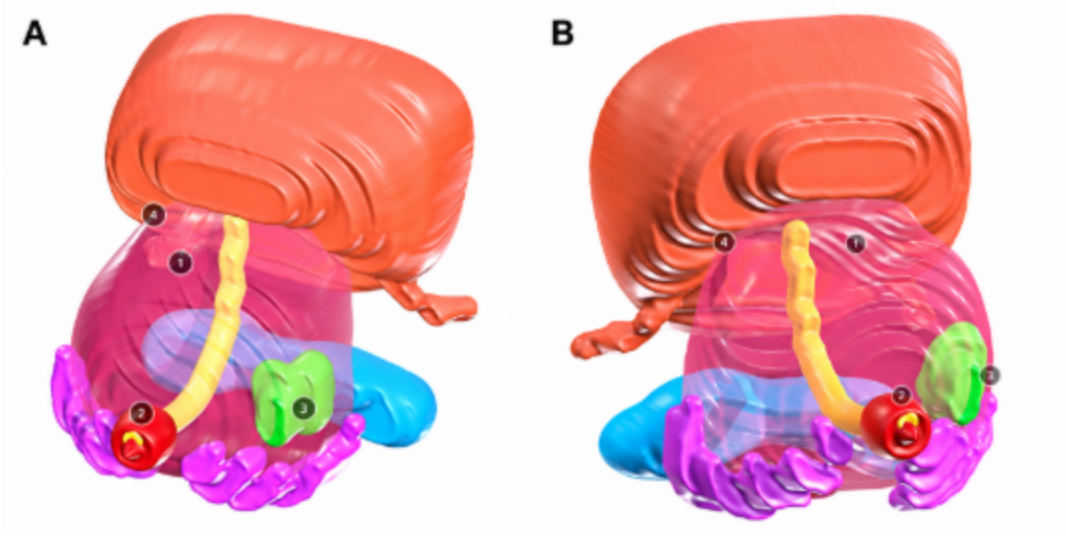


Figure 1

Patient-specific three-dimensional reconstruction model derived from preoperative multiparametric magnetic resonance imaging. (a) and (b) lateral views of the prostate. 1, prostate; 2, membranous urethra; 3, tumor (PI-RADS ≥3 lesion); 4, intravesical prostatic protrusion (IPP). The bladder is shown in orange, the prostatic urethra in yellow, the neurovascular bundles in purple, and the seminal vesicles in blue