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ORIGINAL PAPER

Early risk stratification after robot-assisted radical prostatectomy: The role of positive surgical margins

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Summary ***Introduction: Positive surgical margins (PSMs) after robot-assisted radical prostatectomy (RARP) are consistently associated with biochemical recurrence (BCR), yet their prognostic heterogeneity and functional implications remain debated. This study aimed to evaluate the oncological and functional impact of PSMs and to explore clinicopathological predictors of margin positivity.***

Methods: We conducted a retrospective single-center study including 93 patients undergoing RARP. Surgical margin status, length, focality, and location were recorded. BCR was defined as PSA ≥ 0.2 ng/mL confirmed by two measurements. Functional outcomes (urinary continence and erectile function) were assessed at 6 months. Multivariable logistic regression identified predictors of PSM, and Kaplan-Meier analysis evaluated BCR-free survival.

Results: PSMs were identified in 48 patients (51.6%). During a median follow-up of 11 months, BCR occurred more frequently in patients with PSMs than in those with negative margins (20.8% vs. 4.4%, p = 0.018). PSMs were associated with significantly worse early BCR-free survival (log-rank p = 0.013). Margin length ≥ 3 mm did not stratify early BCR risk. In multivariable analysis, ISUP Grade Group 3-5 was the only independent predictor of PSM (OR 0.25, p = 0.044). No significant differences in urinary continence or erectile function at 6 months were observed according to margin status.

Conclusions: PSMs are associated with an increased risk of early biochemical recurrence, while early functional outcomes appear independent of margin status. Tumor biology, rather than surgical factors, emerges as the main determinant of margin positivity. These findings support a risk-adapted interpretation of PSMs and align with current guidelines favoring close surveillance and early salvage treatment over routine adjuvant therapy.

KEY WORDS: Prostatic neoplasms; Prostatectomy; Surgical margins; Biochemical recurrence; Robotic surgical procedures.

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INTRODUCTION

Radical prostatectomy remains a mainstay of curative treatment for localized and locally advanced prostate cancer (1), and *robot-assisted radical prostatectomy* (RARP) has become the predominant surgical approach in many centers. Despite advances in imaging, patient selection and surgical technique, *biochemical recurrence* (BCR) still occurs in approximately 20-40% of patients after surgery (2). A *positive surgical margin* (PSM), defined as tumor present at the inked surface of the specimen (3), is a common pathological finding, reported in approximately 6-40% of patients undergoing radical prostatectomy (4, 5). Importantly, PSMs are consistently associated with a higher risk of biochemical recurrence and an increased likelihood of secondary treatment compared with *negative surgical margins* (NSMs) (6, 7). In adjusted analyses, patients with NSMs achieve markedly higher BCR-free survival than those with PSMs. Overall, approximately one-third of men with PSMs develop BCR—compared with about 10% of those with NSMs (8-10).

However, not all PSMs confer the same prognostic impact. While a substantial proportion of patients with PSMs experience biochemical recurrence, only a minority progress to metastatic disease, and prostate cancer-specific mortality remains low at mid to long term follow-up (8-11). This marked heterogeneity has prompted increasing interest in refining risk stratification based on margin characteristics rather than relying solely on their presence. Meta-analyses have demonstrated that the linear extent of a PSM is independently prognostic for BCR, with each additional millimeter conferring an incremental increase in risk (HR ≈ 1.04) (12). Margins measuring ≥ 3 mm are associated with nearly double the likelihood of BCR compared with shorter margins. Accordingly, several authors have proposed categorizing PSMs as favorable (unifocal and < 3 mm) or unfavorable (multifocal or ≥ 3 mm) (13), a distinction that appears particularly relevant in intermediate-risk disease. In Gleason 7 cancers, short unifocal PSMs may approximate the behavior of negative margins, whereas longer or multifocal PSMs are associated with substantially higher rates of biochemical recurrence (12).

The prognostic significance of PSM location remains more controversial. Apical margins are the most frequently involved site and may reflect larger tumor volumes, potentially confounding multivariable analyses. Some studies suggest that apical PSMs exert a greater impact on BCR risk. The second most common location is the posterolateral margin, often resulting from attempts to preserve the neurovascular bundles; this site appears to have a comparatively smaller effect on BCR in several

series (6). Importantly, long-term robotic cohorts with follow-up beyond a decade confirm that margin length, focality and anatomical location continue to influence oncological outcomes in the RARP era (11). By contrast, the prognostic impact of a positive margin on stronger oncologic endpoints, such as clinical recurrence or metastasis-free survival, remains less well established (3).

Against this background, the present study explores the early oncological and functional implications of positive surgical margins after robot-assisted radical prostatectomy in patients with Gleason 7 prostate cancer, with particular emphasis on the association between margin status and early biochemical recurrence, and on the descriptive role of margin characteristics in postoperative risk stratification.

Material and methods

Study design and patient selection

We performed a retrospective, single-center observational study including consecutive patients who underwent radical prostatectomy at *San Cecilio University Hospital (Granada, Spain)* between January 2024 and May 2025.

During the study period, multiple prostatectomies were performed at our institution; however, for the purpose of the present analysis, only patients treated with RARP were included. Additionally, to ensure procedural homogeneity and minimize variability related to surgical experience, only procedures performed by high-volume, expert robotic surgeons were considered eligible.

Eligible patients were men with histologically confirmed prostate adenocarcinoma classified as ISUP 1-5, pathological stage pT2-pT3, and absence of nodal or distant metastases (pN0M0). Patients were excluded if follow-up duration was shorter than 6 months, if key clinical or pathological data were missing, if postoperative PSA measurements were unavailable, if PSA levels remained persistently elevated after surgery, or if neoadjuvant or adjuvant radiotherapy or androgen deprivation therapy had been administered.

Surgical technique

All procedures were performed using the da Vinci Xi robotic surgical system (*Intuitive Surgical, Sunnyvale, CA, USA*) following a standardized stepwise technique applied consistently throughout the study period by experienced robotic surgeons.

After robotic docking, the procedure was performed according to a predefined sequence: bladder neck dissection, followed by dissection of the vas deferens and seminal vesicles, posterior dissection, and posterolateral dissection at the level of the neurovascular bundles. In all cases, an attempt was made to preserve the neurovascular bundles bilaterally or unilaterally according to preoperative oncological risk assessment, prioritizing nerve preservation in regions with lower tumor burden and adopting a more conservative approach in areas with suspected higher tumor involvement.

The procedure was completed with anterior and posterior apical dissection, urethral transection, and vesicourethral anastomosis using a double-armed barbed suture according to the Van Velthoven technique. No technical variations in anastomotic reconstruction were applied during the study period.

Data collection

Collected variables included preoperative clinical characteristics (age at surgery, biopsy ISUP Grade Group, number of positive biopsy cores, preoperative PSA level, prostate volume, and prostate MRI findings including PI-RADS score), pathological features (pathological tumor stage, prostatectomy ISUP Grade Group, and surgical margin status), and follow-up data (postoperative PSA nadir, serial PSA measurements, and occurrence and timing of biochemical recurrence). Surgical margin status was assessed in terms of presence (positive *vs.* negative), focality (unifocal *vs.* multifocal), linear extent (measured in millimeters), and anatomical location.

Pathological evaluation

All prostatectomy specimens were examined by dedicated genitourinary pathologists using a standardized processing protocol. Specimens were fixed in formalin, embedded in paraffin, and sectioned according to institutional guidelines.

Pathological assessment included pathological tumor stage (pT), ISUP Grade Group, and surgical margin status. A PSM was defined as the presence of tumor cells in direct contact with the inked surface of the prostate specimen ("*tumor on ink*"). The linear extent of tumor involvement at the inked margin was measured in millimeters.

For analytical purposes, PSM length was dichotomized using a 3 mm cut-off (< 3 mm *vs.* ≥ 3 mm). In cases of multifocal margin involvement, margin location was defined according to the dominant margin, corresponding to the site with the greatest linear tumor extent.

Postoperative functional outcomes

Postoperative functional outcomes were evaluated at 6 months after surgery.

Urinary continence was defined as the use of 0-1 safety pads per day (social continence definition).

Erectile function was defined as the ability to achieve erections sufficient for sexual intercourse, with or without the use of oral phosphodiesterase type 5 inhibitors. Patients requiring intracavernosal injections, vacuum devices, or penile prosthesis were classified as having erectile dysfunction.

Follow-up and definition of biochemical recurrence

Postoperative follow-up included serial PSA measurements at 3, 6, 12, and 18 months after surgery. PSA nadir and all subsequent PSA values were recorded.

BCR was defined as a serum PSA level ≥ 0.2 ng/mL confirmed by two consecutive measurements at any time during follow-up. No patient received adjuvant therapy in the absence of biochemical recurrence; salvage treatment was considered only after BCR occurrence.

In all patients who developed BCR, molecular imaging with prostate-specific membrane antigen positron emission tomography was systematically requested as part of institutional clinical practice to guide subsequent management.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 26.0 (*IBM Corp., Armonk, NY, USA*).

Continuous variables were summarized as mean with standard deviation or median with interquartile range, according to data distribution. Normality was assessed using graphical methods and the Shapiro-Wilk test. Categorical variables were presented as frequencies and percentages.

Comparisons between groups were performed using the chi-square test or Fisher's exact test for categorical variables and the Mann-Whitney U test for continuous variables, as appropriate.

Binary logistic regression analysis was used to identify independent predictors of surgical margin status, with positive surgical margins defined as the dependent event. Model calibration was assessed using the Hosmer-Lemeshow test, and model performance was evaluated using Nagelkerke's R^2 and *receiver operating characteristic* (ROC) curve analysis.

Biochemical recurrence-free survival was estimated using the Kaplan-Meier method, with patients without recurrence censored at the date of last follow-up.

Differences between survival curves were assessed using the log-rank test. A two-sided p value < 0.05 was considered statistically significant.

Table 1.

Baseline characteristics stratified by surgical margin status.

Variable	Positive margins (n = 48)	Negative margins (n = 45)	P-value
Age, years (median, range)	64 (46-76)	65 (49-74)	0.869
Preoperative PSA, ng/mL (median, range)	6.88 (2.86-19.53)	7.0 (3.69-22.18)	0.606
Prostate volume, mL (median, range)	40.5 (15-105)	45 (23-90)	0.092
Positive biopsy cores, n (median, range)	5 (4-8)	4 (2-6)	0.034
Follow up, months (median, range)	11(2-22)	11 (7-24)	0.362
ISUP grade (biopsy)			0.006
ISUP 1	19 (39.6)	24 (53.3)	
ISUP 2	18(37.5)	18 (40)	
ISUP 3-5	11 (22.9)	3 (6.7)	
PI-RADS, n (%)			0.962
PIRADS 3	9 (18.8)	9 (20.0)	
PIRADS 4	25 (52.1)	24 (53.3)	
PIRADS 5	14 (29.2)	12 (26.7)	
Pathological stage, n (%)			0.206
pT2	32 (70.8)	36 (80.0)	
pT3a	11 (22.9)	9 (20.0)	
pT3b	3 (6.3)	0 (0)	
ISUP grade (Prostatectomy)			0.006
ISUP 1	6 (12.5)	18 (40)	
ISUP 2	26 (54.2)	23 (51.1)	
ISUP 3-5	16 (33.3)	4 (8.9)	

** Values are presented as median (range) for continuous variables and as number (percentage) for categorical variables. Continuous variables were compared using the Mann-Whitney U test due to non-normal distribution. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. A two-sided p-value < 0.05 was considered statistically significant. ISUP grade refers to biopsy grade unless otherwise specified.*

Ethical approval

The study was approved by the *Institutional Review Board of San Cecilio University Hospital (Granada, Spain)* (approval code: PR001).

Due to the retrospective nature of the study, informed consent was waived in accordance with institutional regulations.

Results

Study population and surgical margin status

A total of 93 patients undergoing radical prostatectomy were included in the analysis. PSM were identified in 48 patients (51.6%), while 45 patients (48.4%) had NSM. Baseline clinical, radiological, and pathological characteristics according to surgical margin status are summarized in Table 1.

Among patients with PSM, most cases were characterized by unifocal involvement and a margin length shorter than 3 mm.

The most frequent margin locations were the apex and the lateral regions (anterolateral/posterolateral), as detailed in Table 2.

Postoperative functional outcomes and surgical margin status

Urinary continence

No statistically significant association was observed between surgical margin status and urinary continence at 6 months, defined as the use of 0-1 pad per day. Continence rates were comparable between patients with

Table 2.

Pathological characteristics of positive surgical margins (n = 48).

Variable	N (%)
PSM site, n (%)	
Apex	23 (48.9)
Base	3 (6.4)
Lateral (Posterolateral/anterolateral)	21 (44.7)
PSM Focality, n (%)	
Multifocal margin	11 (22.9)
Unifocal margin	37 (77.1)
PSM length, n (%)	
< 3 mm	34 (70.8)
≥ 3 mm	14 (29.2)
Biochemical recurrence, n (%)	10 (20.8)

** Percentages are calculated over the total number of patients with positive surgical margins (n = 48). In cases of multifocal involvement, PSM site refers to the dominant margin, defined as the margin with the greatest length of tumor contact. PSM length was categorized using a 3 mm cut-off.*

Table 3.
Postoperative functional outcomes and complications at 6 months according to surgical margin status.

Variable	PSM (+) (n = 48)	PSM (−) (n = 45)	P-value
Potency at 6 months, n (%)			
Yes	35 (72.9%)	34 (75.6%)	0.771
No	13 (27.1%)	11 (24.4%)	
Continence at 6 months n (%)			
Continent	41 (85.4%)	39 (86.7%)	0.862
Incontinent	7 (14.6%)	6 (13.3%)	
Anastomotic stricture n (%)			
Yes	4 (8.3%)	4 (8.9%)	0.924
No	44 (91.7%)	41 (91.1%)	

** Values are presented as number (percentage). Potency was defined as the ability to achieve erections sufficient for intercourse, with or without the use of oral phosphodiesterase type 5 inhibitors. Continence was defined as the use of no pads (strict continence definition). Comparisons between groups were performed using the chi-square test or Fisher's exact test, as appropriate. A p-value < 0.05 was considered statistically significant.*

Table 4.
Multivariable logistic regression analysis for predictors of positive surgical margins (n = 93).

Variable	OR (ExpB)	95% CI	P-value
PIRADs	1.10	0.59-2.08	0.762
Surgeon	1.52	0.63-3.65	0.348
ISUP grade (3-5 *vs* 1-2)	0.25	0.06-0.96	0.044

** Model calibration was acceptable, as assessed by the Hosmer–Lemeshow test (p = 0.196). Overall explanatory performance was modest (Nagelkerke R^2 = 0.083), reflecting the multifactorial nature of positive surgical margin occurrence.*

positive and negative surgical margins (Table 3). Pearson's chi-square test showed no significant differences between groups (χ^2 = 0.031, p = 0.862). The odds ratio for achieving social continence in patients with PSM was 1.11 (95% CI 0.34-3.59).

Erectile function

Similarly, no statistically significant association was found between surgical margin status and postoperative erectile function at 6 months (Table 3). Pearson's chi-square test did not reveal significant differences between groups (χ^2 = 0.084, p = 0.771). The odds ratio for recovery of erectile function in patients with PSM was 1.15 (95% CI 0.45-2.91). Concordance analysis demonstrated no agreement between surgical margin status and postoperative potency (Cohen's κ = –0.011).

Multivariable analysis of predictors of surgical margin status

A multivariable binary logistic regression model was constructed to identify independent predictors of surgical margin status. The following covariates were included:
(i) ISUP grade grouped as ISUP 1-2 versus ISUP 3-5,
(ii) highest PI-RADS category in cases with multiple lesions on preoperative MRI, and
(iii) operating surgeon.
The model demonstrated adequate calibration (Hosmer-Lemeshow test: χ^2 = 7.34, p = 0.196) and modest explanatory power (Nagelkerke R^2 = 0.083). The overall correct classification rate was 58.1%.

In the multivariable analysis, ISUP grade 3-5 was the only independent predictor of surgical margin status, being associated with a lower probability of NSM (OR = 0.25, 95% CI 0.06-0.96; p = 0.044). Neither the highest PI-RADS category nor the operating surgeon showed an independent association with surgical margin status (Table 4).

ROC curve analysis

The discriminative performance of the multivariable logistic regression model was evaluated using receiver operating characteristic (ROC) curve analysis. The area under the curve (AUC) was 0.669 (95% CI 0.559-0.779), which was significantly greater than chance (p = 0.005), indicating a moderate ability of the model to discriminate between positive and negative surgical margins.

Survival analysis

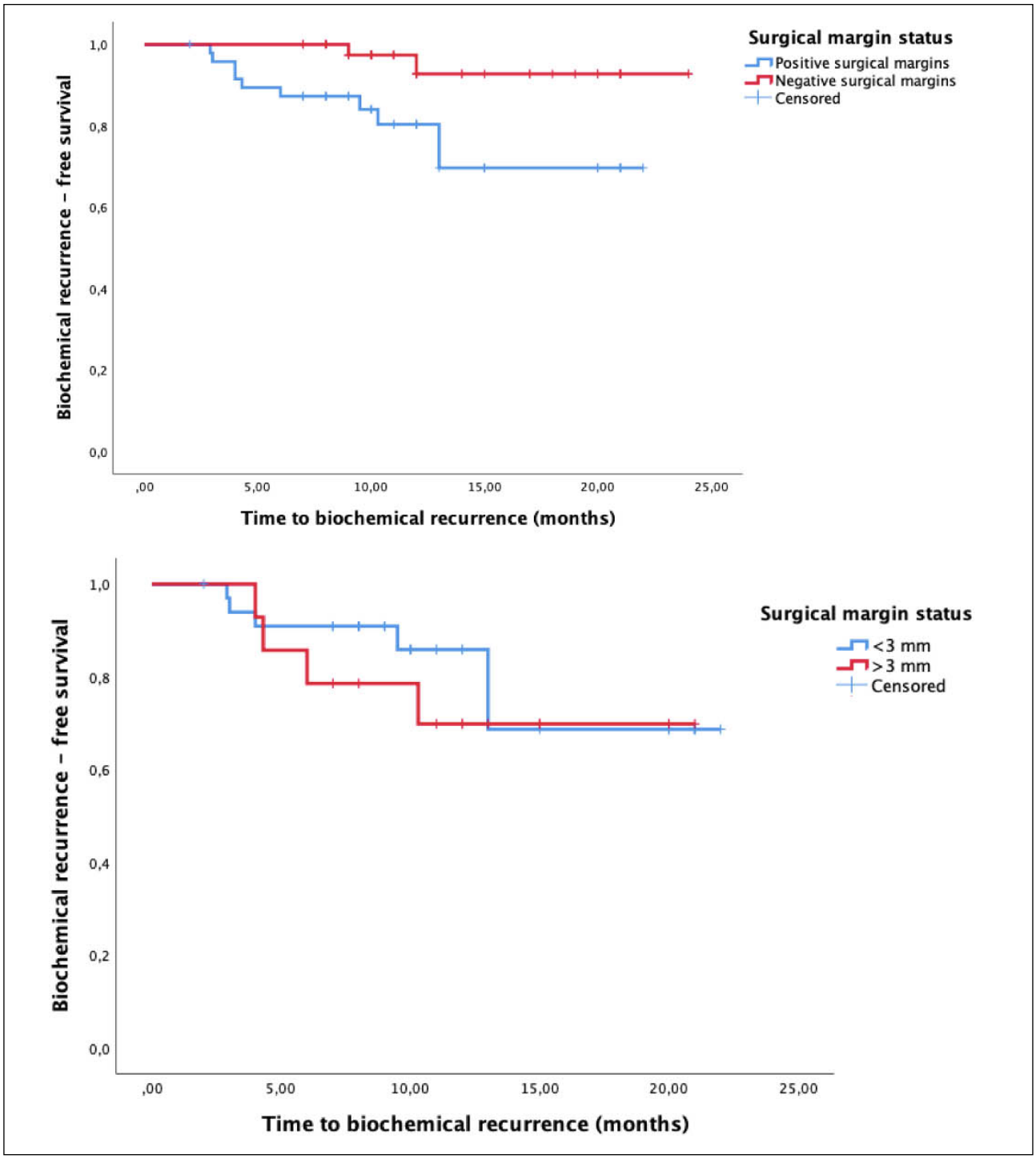
Biochemical recurrence-free survival according to surgical margin status

During a median follow-up of 11 months (range 2-22), biochemical recurrence occurred in 10 patients overall and was significantly more frequent in patients with positive surgical margins compared with those with negative surgical margins (20.8% *vs.* 4.4%, p = 0.018). Kaplan-Meier analysis demonstrated significantly worse biochemical recurrence-free survival in patients with positive surgical margins compared with those with negative surgical margins (Figure 1).
The mean time to BCR was shorter in the PSM group than in the NSM group (17.9 *vs.* 23.0 months). Median BCR-free survival was not reached in either group due to the limited number of events. The survival curves diverged early and remained separated over time. The log-rank test confirmed a statistically significant difference between groups (χ^2 = 6.157, p = 0.013).
Biochemical recurrence-free survival according to margin length
Among patients with PSMs, BCR-free survival was further analyzed according to margin length using a 3 mm cut-off (< 3 mm *vs.* ≥ 3 mm). Kaplan-Meier curves showed no statistically significant differences in BCRFS between the two subgroups (Figure 1).
The mean BCR-free survival was 18.1 months (95% CI 15.4-20.8) for margins < 3 mm and 16.6 months (95% CI 12.9-20.3) for margins ≥ 3 mm. Median BCR-free survival was not reached in either subgroup. The log-rank test did not reveal significant differences between groups (χ^2 = 0.298, p = 0.585).

Discussion

In this study, PSM status was significantly associated with worse early BCR-free survival, with patients harboring PSM experiencing earlier BCR compared with those with

Figure 1.
Kaplan-Meier estimates of biochemical recurrence–free survival after robot-assisted radical prostatectomy according to surgical margin characteristics.



(A) Biochemical recurrence-free survival stratified by surgical margin status (positive vs. negative surgical margins).
(B) Biochemical recurrence-free survival among patients with positive surgical margins, stratified by margin length (< 3 mm vs. ≥ 3 mm).
Tick marks indicate censored observations. Biochemical recurrence was defined according to standard postoperative PSA criteria.

NSM. Despite the relatively short follow-up and limited number of events, survival curves diverged early and remained separated over time, reinforcing the established prognostic relevance of margin status in the early postoperative period. The magnitude of this effect is consistent with previous large surgical series reporting a two- to three-fold increase in BCR risk associated with margin positivity, supporting the biological significance of residual microscopic disease following radical prostatectomy (9, 10, 14).

Although the association between positive surgical margins and BCR is well established, their impact on cancer-specific mortality and other long-term oncological outcomes remains heterogeneous across studies. This distinction is clinically relevant, as earlier series reported BCR rates approaching 30% among patients with PSMs compared with approximately 10% in NSMs (3, 15), yet without a consistent translation into improved cancer-specific survival when routine adjuvant radiotherapy was applied to all margin-positive patients. This apparent discrepancy reflects the long natural history of prostate cancer and, importantly, the fact that margin positivity represents a spectrum of oncological risk rather than a binary entity.

Within this spectrum, margin characteristics – rather than margin status alone – have emerged as key modifiers of recurrence risk. Among these, margin length appears to be the most robust and reproducible predictor of BCR. Multiple studies have shown that very short margins behave similarly to PSM, whereas margins measuring ≥3 mm are consistently associated with a significantly increased risk of biochemical recurrence, even after multivariable adjustment (15-17).

Meta-analytic data further support this association, reporting a 1.5- to 2-fold increase in recurrence risk for margins ≥ 3 mm, albeit with substantial heterogeneity across cohorts.

In our cohort, dichotomization at a 3 mm cut-off did not stratify early BCR risk. This finding should be interpreted cautiously in the context of limited follow-up duration and a small number of events, which reduces statistical power to detect incremental prognostic effects within the margin-positive subgroup. Moreover, early recurrence may be predominantly driven by underlying tumor biology, potentially attenuating the observable contribution of margin extension during the initial postoperative period (16, 17).

Consistent with this interpretation, ISUP Grade Group 3-5 emerged as the sole independent predictor of PSM in our multivariable analysis, supporting the concept that margin positivity is largely driven by intrinsic tumor aggressiveness rather than technical factors alone (18). The prognostic relevance of tumor biology at the margin is further underscored by growing evidence of frequent discordance between the Gleason grade of the primary tumor and that observed at the positive surgical margin, reported in up to 54% of cases. Several studies have demonstrated that a higher Gleason grade at the margin is independently associated with an increased risk of BCR and may even outperform the grade of the primary tumor in predicting recurrence (18-21).

All procedures in the present cohort were performed by experienced, high-volume robotic surgeons using a standardized surgical technique with systematic neurovascular bundle preservation whenever oncologically feasible. This procedural homogeneity likely minimized inter-surgeon variability and may explain why surgeon-related factors were not independently associated with margin status. Within such a high-expertise setting, tumor-related characteristics appear to outweigh technical variability as determinants of margin positivity.

The overall rate of PSM observed in our study was higher than that reported in some contemporary series (4, 5). This finding may be explained by enrichment for intermediate- and high-grade tumors, as reflected by the higher prevalence of ISUP Grade Groups 3-5 among patients with positive margins (21, 22) as well as by rigorous pathological assessment using a strict "*tumor on ink*" definition with systematic measurement of margin extent. Notably, despite the high overall margin rate, most margins were short (< 3 mm), further supporting a heterogeneous risk profile among PSM patients.

Margin location has also been explored as a potential prognostic factor, although prior studies have failed to consistently demonstrate a significant association with BCR (23, 24). In our cohort, apical and posterolateral margins predominated, in line with previous robotic series. These locations likely reflect anatomically and technically challenging regions – particularly in the context of nerve-sparing dissection – where margin positivity arises from a complex interplay between surgical constraints and tumor-related factors rather than from tumor biology alone (6).

From a functional perspective, we did not observe significant differences in early urinary continence or erectile function at 6 months according to surgical margin status. Although a trade-off between oncological radicality and functional preservation has frequently been proposed, our findings suggest that margin positivity does not confer a functional advantage in terms of early recovery, which appears to be primarily driven by preservation of key anatomical structures rather than margin status itself (25, 26). This observation aligns with contemporary series reporting comparable functional outcomes regardless of margin status and supports the notion that standardized surgical technique and tumor-related factors outweigh any theoretical functional benefit associated with a margin-positive dissection (27-29).

Importantly, the presence of a PSM should not be interpreted as a rationale for systematically more aggressive resection at the expense of functional preservation, as nerve-sparing approaches remain critical for achieving favorable continence and erectile function outcomes when oncologically feasible (27, 28).

Collectively, these findings support a risk-stratified interpretation of PSM Rather than treating margin positivity as

Declarations

Ethical approval and consent for participate: *The study was approved by the Institutional Review Board of San Cecilio University Hospital (Granada, Spain) (approval code: PR001).*

Availability of data and material: *The datasets used and/or analyzed during the current study are available upon reasonable request from the corresponding author.*

Competing interests: *Authors declare no conflict of interest and nothing to declare.*

Funding: *The authors declare no funding.*

Authors' contributions: *AZM: Write and conception; IMR: Tables; PRP: Bibliography review; FGT: Write; MTMS: Data analysis; MAM: Conception and bibliography review; MAAP: Final review and supervision.*

Acknowledgments: *No.*

a uniform entity, contemporary evidence indicates that oncological outcomes are modulated by specific margin features – particularly margin length and tumor grade at the margin – while the adverse impact on cancer-specific mortality appears largely confined to patients with unfavorable pathological characteristics. This nuanced risk profile underpins current guideline recommendations favoring close surveillance with early salvage radiotherapy over routine adjuvant treatment in patients with PSM (1,30).

Limitations

This study has several limitations. Its retrospective, single-center design and relatively short follow-up limit the assessment of long-term oncological endpoints and reduce statistical power to detect incremental prognostic effects within the margin-positive subgroup. Nerve-sparing status was not systematically recorded and could not be included in functional analyses, potentially resulting in residual confounding.

Although pathological assessment was standardized, additional margin-related features such as three-dimensional margin extent or detailed Gleason pattern composition at the margin were not evaluated. Finally, the exclusive inclusion of patients treated by experienced, high-volume robotic surgeons enhances internal validity but may limit generalizability to other settings.

Conclusions

PSM were associated with an increased risk of early BCR, while early functional outcomes were comparable regardless of margin status. These findings support the interpretation of margin positivity as a heterogeneous biological entity.

Tumor biology, reflected by higher ISUP Grade Groups, emerged as the main determinant of margin positivity, whereas margin length did not independently stratify early recurrence risk within the constraints of short follow-up. Collectively, our results support a risk-adapted approach to margin positivity and align with current guideline recommendations favoring close surveillance with early salvage radiotherapy over routine adjuvant treatment.

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