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REVIEW ARTICLE

Preserving the neurovascular bundle during radical robotic prostatectomy: Tips and tricks

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Abstract

Robot-assisted radical prostatectomy (RARP) has become the standard surgical approach for treating localized prostate cancer. A crucial component of RARP is nerve-sparing surgery (NSS), which significantly improves postoperative erectile function and urinary continence. The primary aim of NSS is to preserve the neurovascular bundles, but this must be balanced with oncological safety, particularly concerning the risk of positive surgical margins when extracapsular extension is present. This review aims to provide an overview of NSS techniques, based on the authors' clinical experience and perspective, while avoiding unnecessary technical overdetail.

KEYWORDS

nerve-sparing, neurovascular bundle preservation, prostate cancer surgery, radical robotic prostatectomy

1 | INTRODUCTION

Robot-assisted radical prostatectomy (RARP) has become the standard treatment for managing localized prostate cancer (PCa). Although RARP provides excellent oncologic outcomes, postoperative urinary incontinence and erectile dysfunction (ED) remain common complications that can significantly impact patients' health-related quality of life[1]. To address these functional issues, nerve-sparing surgery (NSS) has been incorporated into RARP techniques, aiming to preserve the neurovascular bundles (NVBs) responsible for erectile function (EF) and support urinary continence[2,3]. The implementation of NSS, however, requires a careful balance between maximizing functional recovery and maintaining oncologic safety. A key challenge arises when dissection is performed near the prostatic capsule, especially in cases with extracapsular extension (ECE), which increases the risk of positive surgical margins (PSM) and may compromise oncologic outcomes[4]. Therefore, accurate risk assessment and personalized surgical planning are essential in determining the appropriateness and extent of NSS for each patient.

This comprehensive overview aims to examine current perspectives on NSS in RARP based on existing literature. It specifically provides an overview of anatomical knowledge, evaluates various NSS techniques and approaches. Additionally, it covers functional and oncological outcomes, and recent innovations aimed at improving outcomes, incorporating the authors' personal experience.

Abbreviations: AR, augmented reality; CNS, complete nerve sparing; dHACM, dehydrated human amniotic/chorion membrane; DRE, digital rectal examination; ECE, extracapsular extension; FCM, fluorescence confocal microscopy; hRLP, hypothermic nerve-sparing robotic laparoscopic prostatectomy; ICG, indocyanine green; INS, incomplete nerve sparing; mpMRI, multiparametric magnetic resonance imaging; NeuroSAFE, neurovascular structure adjacent frozen section examination; NIRF, near-infrared fluorescence; NSS, nerve-sparing surgery; NVB, neurovascular bundle/neurovascular bundles; PCa, prostate cancer; PSM, positive surgical margin/margins; PSMA-PET, prostate-specific membrane antigen positron emission tomography; RARP, robot-assisted radical prostatectomy; TRUS, transrectal ultrasound.

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2 | BRIEF NEUROANATOMY OF THE PROSTATE AND NERVE-SPARING TECHNIQUES

The NVB, first described by Walsh and Donker, is a crucial anatomical structure for functional outcomes after radical prostatectomy. The NVB, which contains the prostatic plexus of nerves and vessels, is located within a triangular space formed by the prostatic fascia (medially), the lateral pelvic fascia (laterally), and Denonvilliers' fascia (posteriorly). This triangular space is wider near the base of the prostate and narrows toward the apex. Cavernosal nerves, responsible for potency, originate from the caudal pelvic plexus, lie close to the tips of the seminal vesicles, and course along the posterolateral aspect of the prostate toward the apex and membranous urethra[5].

The fascial anatomy of the prostate is very complex, and the literature on this topic is notably inconsistent. In clinical practice, having complete knowledge of every fascial detail usually does not offer practical benefits during radical prostatectomy. Therefore, in this review, we focus on the anatomical structures most important for nerve-sparing procedures and highlight those that are most commonly encountered in daily surgical practice. Detailed fascial anatomy of the prostate has been described elsewhere[6].

Starting from the outermost layer of the anatomy, the endopelvic fascia (also called the lateral pelvic fascia), which anchors the prostate to the pelvic wall, is encountered. When this fascia is incised at its thickest part—near the apex and reflecting the most light (the arcus tendineus fascia pelvis)—it reveals two distinct layers. The lateral layer surrounds the levator ani muscle (parietal component), while the medial layer covers the prostate. This medial layer is fused with the underlying prostatic fascia, making it indistinguishable from it.

The second major fascial structure is the prostatic (or periprostatic) fascia, which completely surrounds the prostate. An important step in NSS during radical prostatectomy is recognizing the loose connective tissue and fat between the prostatic capsule and the prostatic fascia[7]. The NVB lies lateral to this space, outside the prostatic fascia. This area is best visualized at the mid-basal region of the prostate after the pedicle has been ligated. Recognizing this anatomical plane has enabled the development of several NVB dissection techniques, most notably the "Veil of Aphrodite"[8]. Posteriorly, the prostatic fascia fuses with Denonvilliers' fascia and appears as a shiny surface during posterior dissection of the prostate. It should be noted, however, that about two-thirds of the nerve fibers forming the NVB are located posterolaterally to the prostate, while one-third are positioned anteriorly. Therefore, the more anteriorly the dissection is started between the prostatic capsule and the prostatic fascia, the more nerve fibers can be preserved. To enhance this preservation, recent techniques in RARP suggest not opening the endopelvic fascia at all. In summary, successful NSS depends on preserving the NVB by dissecting it carefully without injury while keeping it enclosed medially by the prostatic fascia, laterally by the levator ani fascia, and posteriorly by Denonvilliers' fascia.

Meanwhile, we find Tewari's tri-zonal neural architecture of the NVB, based on cadaver studies, convenient and functional[9]. Proximal zone (Zone 1): Contains the proximal neurovascular plate, located 5–10 mm lateral to the seminal vesicles, connected to the bladder neck and seminal vesicles. This zone is vulnerable to thermal injury or crushing. Mid-zone (Zone 2): Contains the main NVB in the posterolateral groove of the prostate. Its identification can be difficult because of its close proximity to prostate pedicles and fascia, increasing the risk of damage from periprostatic inflammation and ECE. Distal zone (Zone 3): Includes apical nerves and accessory pathways. Retro-apical nerves are especially vulnerable during urethral transection and anastomosis. Accessory nerves may also be found variably around the prostate, between the lateral pelvic fascia, prostatic fascia, and Denonvilliers' fascia.

Anatomical studies demonstrate that cavernosal nerves follow a spray-like distribution along the lateral and anterolateral surfaces of the prostate, extending as far as the 2 and 10 O'clock positions. Although the majority of periprostatic nerves are concentrated posterolaterally, a considerable proportion—up to nearly 20%—can be located anterolaterally, particularly near the apical region (Figure 1)[10,11].

3 | NERVE-SPARING SURGICAL TECHNIQUES IN RARP

Nerve-sparing techniques in RARP mainly rely on choosing the correct fascial dissection plane and surgical approach. A key factor influencing both is the extent of fusion between the prostatic fascia and the prostatic capsule, which affects the path and accessibility of the NVBs.

Three primary fascial dissection planes are typically recognized. Intrafascial dissection involves developing the plane directly along the prostatic capsule, remaining within the prostatic fascia on both the anterior-lateral and posterior-lateral surfaces, and anterior to Denonvilliers' fascia. This technique helps maximize preservation of the NVBs and is associated with the best potency outcomes. However, it carries the greatest risk of iatrogenic capsular injury and PSM, especially in patients with undetected ECE. Interfascial dissection occurs between the two layers of the prostatic fascia. It provides a wider surgical margin than the intrafascial approach and may reduce the likelihood of PSM[12]. Nevertheless, the extent of nerve preservation in this plane varies and is often based on intraoperative

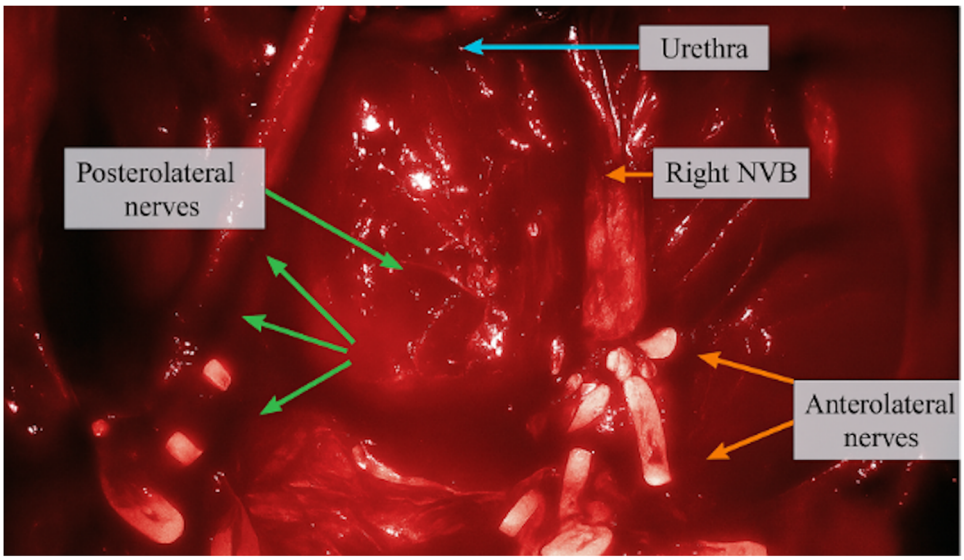

FIGURE 1 Important anatomical structures observed during RARP after prostate removal. NVB, neurovascular bundle/neurovascular bundles; RARP, robot-assisted radical prostatectomy.

judgment, making it more subjective. Extrafascial dissection is a non-nerve-sparing technique performed outside the NVB and lateral pelvic fascia. This approach is usually chosen for patients at high risk of ECE, as it offers the greatest oncological safety by increasing the distance from the prostatic capsule. These three approaches are summarized in Table 1 and illustrated intraoperatively in Figure 2.

During RARP, two main dissection strategies are used for nerve-sparing: the antegrade and retrograde approaches. The antegrade approach involves dissecting from the prostate base toward the apex, with initial control of the prostatic pedicle to lower the risk of thermal injury to the NVB, followed by dissection of the NVB.

Conversely, the retrograde approach starts at the apex. It progresses toward the base by first developing the posterior plane, then identifying and releasing the NVB at the mid-prostate level, and finally controlling the prostatic pedicles. Some nonrandomized studies indicate that the retrograde approach may enable earlier recovery of EF[13].

3.1 | Tips and tricks in nerve-sparing: Insights from the authors

As mentioned earlier, in contemporary NSS, two main approaches are used: the antegrade and retrograde techniques. The choice between these methods mainly depends on the surgeon's experience and preference, as well as the specific pathological features of the prostate. It's also crucial to remember that each patient has a unique anatomy. Variations from the prostate base to the apex can occur, and recognizing these differences is vital for safe and effective nerve preservation. For example, in larger prostates, the NVB might be displaced downward due to gland enlargement and compression. Conversely, in smaller prostates, the NVB may run more laterally or even extend toward the front of the gland. These differences should be expected during dissection.

For high-risk patients, it is advisable not to insist on nerve-sparing at all costs, as RARP remains a cancer-focused procedure where cancer control takes priority. Conversely, in low-risk cases, careful posterior dissection—especially separation from Denonvilliers' fascia—is essential for effective nerve preservation. A central principle of RARP is that each step affects the ease or difficulty of subsequent steps. In this context, a well-performed posterior dissection significantly eases the following stages of nerve-sparing, emphasizing the importance of precise, step-by-step execution throughout the surgery. Retrograde nerve-sparing is generally regarded as offering slightly better oncologic safety, mainly because it maintains the interfascial plane. Additionally, since this technique involves less traction on the NVBs, it may help reduce the risk of neuropraxia. Another benefit is seen in patients with posterolateral tumors, as retrograde dissection allows for the final division of the prostate at the posterolateral base in a more controlled manner, decreasing the chance of PSM in that area.

However, retrograde nerve-sparing may not always be practical. Variations in the periprostatic fascia and capsule, individual prostate vascular arrangements, or previous infectious or inflammatory conditions can make this approach technically difficult. In these cases, it is better to switch to an anterograde nerve-sparing technique instead of insisting on retrograde dissection. Many surgeons prefer anterograde nerve-sparing

TABLE 1 Overview of fascial dissection planes and their clinical implications in nerve-sparing robot-assisted radical prostatectomy.

Technique	Dissection plane	Degree of NVB preservation	Oncological risk	Description
Intrafascial	Along the prostate capsule, internal to prostatic fascia (anterolateral and posterolateral), anterior to Denonvilliers' fascia	Maximum	High (risk of capsular injury and PSM)	Allows maximal NVB preservation, but carries the highest risk of iatrogenic capsular damage and PSM, especially with undetected ECE
Interfascial	Between the layers of the prostatic fascia	Moderate	Moderate	Provides wider surgical margin than intrafascial dissection, may reduce PSM rates; nerve preservation extent is more variable and subjective
Extrafascial	Outside the NVB and lateral pelvic fascia	Minimal	Lowest (recommended for high-risk ECE)	Nonnerve-sparing technique, offers greatest oncological safety by maximizing margin

Abbreviations: ECE, extracapsular extension; NVB, neurovascular bundle; PSM, positive surgical margin.

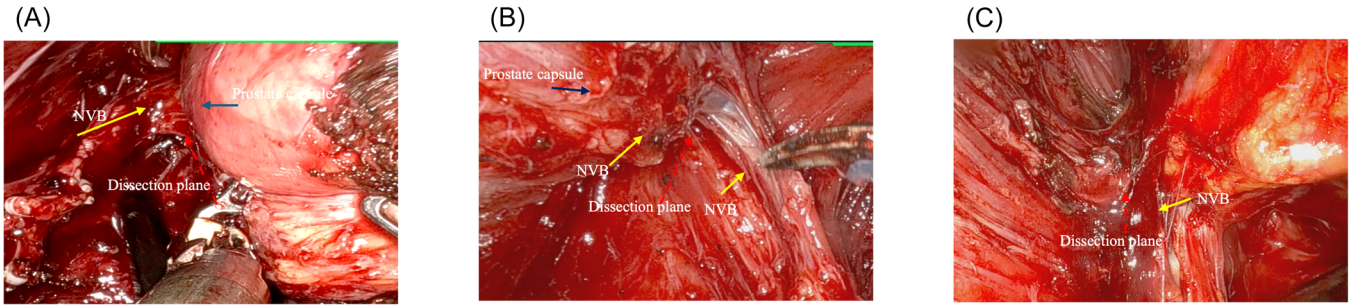

FIGURE 2 Intraoperative demonstration of nerve-sparing dissection planes during robot-assisted radical prostatectomy. (A) Intrafascial plane: dissection immediately adjacent to the prostatic capsule, preserving the entire left neurovascular bundle. (B) Interfascial plane: dissection between the prostatic fascia and levator ani fascia, preserving most neurovascular fibers at right side. (C) Extrafascial plane: dissection lateral to the left neurovascular bundle, typically used in patients with a higher suspicion of extracapsular extension. Yellow arrows: neurovascular bundle. Blue arrows: prostatic capsule. Red dashed line: dissection plane. Abbreviation: NVB = neurovascular bundle.

because it is generally easier to perform. It is especially suitable for cases where partial or incremental nerve-sparing is planned, as the dissection can be more easily adapted to oncologic and functional goals.

Certain patient populations present additional challenges for either approach. These include patients with significant anatomic variations of the prostate, nodules located at the apex or base, or those with a history of multiple prostate biopsies, where repeated procedures increase adhesions and complicate dissection. Similarly, patients with a history of postbiopsy infection, prior pelvic or rectal surgery, radiotherapy, chemotherapy, or focal therapies such as high-intensity focused ultrasound may present with distorted tissue planes. The timing of surgery is also important, as individuals with prior endoscopic enucleation (HoLEP, TUBE–transurethral enucleation with bipolar energy) or open simple prostatectomy may have altered anatomy that makes nerve-sparing procedures more technically demanding.

In our own clinical practice, we prioritize early identification of the prostatic pedicle and maintain an athermal, traction-free dissection around the NVB. A frequent pitfall is excessive traction during apical dissection; we mitigate this by using a 30° down lens, minimizing monopolar energy, and employing short sweeping movements instead of grasping the bundle. In large prostates (> 60–70 mL), the NVB often descends due to gland enlargement, requiring a more inferior entry. In small glands, the bundle tends to be more lateral or even anterolateral, prompting a slightly anterior entry plane. In patients with prior HoLEP, TUBE, or pelvic infection, scarred planes increase difficulty; in these situations, we prefer an antegrade, incremental dissection rather than persisting with a retrograde technique. For example, in one case with a right posterolateral PI-RADS 5 lesion, a retrograde interfascial approach reduced traction and avoided an apical positive margin.

3.2 | Specific techniques and innovations

Several advanced techniques or modifications have been developed to optimize nerve preservation during

RARP, aiming to improve functional outcomes while maintaining oncologic safety. These refinements focus on reducing thermal and mechanical trauma to the NVBs and customizing dissection based on individual anatomical and oncological characteristics.

3.2.1 | The veil of aphrodite technique

The veil of aphrodite technique involves creating an athermal dissection plane between the prostate capsule and surrounding fascia, thereby preserving a thin "curtain" of periprostatic tissue over the NVBs. This method aims to minimize traction and thermal injury[14]. Variants such as the "Super Veil" technique extend dissection more anteriorly, especially in patients with low-risk disease, to further enhance nerve preservation[15].

3.2.2 | Modified clipless antegrade nerve-sparing RARP

Modified clipless antegrade nerve-sparing RARP seeks to eliminate the use of electrocautery and surgical clips during NVB dissection. Instead, bipolar energy is selectively employed to minimize thermal spread, potentially reducing the risk of neuropraxia and enhancing early functional recovery[16].

3.2.3 | Retzius-sparing RARP (RS-RARP)

RS-RARP first described by Galfano et al., is a posterior approach through the pouch of Douglas designed to preserve the Retzius structures, which are critical for continence and potency. The technique involves peritoneal incision, isolation of seminal vesicles and vasa deferentia, and antegrade dissection along the Denonvilliers' fascia aiming for a 360° intrafascial plane, with incremental widening when oncologically necessary[17].

A meta-analysis of 17 studies involving 2751 patients (1221 RS-RARP, 1530 RARP) confirmed the functional advantages of this approach. RS-RARP was associated with significantly higher continence recovery at 1 month (0 pad: odds ratio [OR] = 4.57; safety pad: OR = 13.19) and 3 months (0 pad: OR = 2.93; safety pad: OR = 5.31). By 12 months, continence remained better in the safety pad group (OR = 4.37). Oncological outcomes were similar, with no significant differences in overall PSMs (OR = 1.13), stage-specific margins (pT2: OR = 1.46; pT3: OR = 1.41), potency (OR = 0.98), or biochemical recurrence (BCR) (OR = 0.99). Perioperative parameters—including blood loss, operative time, hospital stay, and complication rates—were also comparable[18]. A systematic review of six studies, combined with a meta-analysis, previously supported these findings, showing significantly better continence at 1 month (risk ratio [RR] = 1.72, $p = 0.0005$) and 3 months (RR = 1.39, $p = 0.03$), with faster recovery, less pad use, and lower pad weight. However, beyond 6–12 months, no differences were observed in continence rates or oncologic outcomes. Thus, the main benefit of RS-RARP is earlier functional recovery, while long-term cancer control remains similar to that of standard RARP[19]. Overall, this technique is feasible for experienced robotic surgeons, and its potential benefit seems to be greater for continence than for EF.

3.2.4 | Hypothermic nerve-sparing RARP (hRLP)

hRLP uses an endorectal cooling balloon to produce localized pelvic hypothermia. This method may reduce perioperative inflammation and tissue swelling, leading to earlier continence recovery and better nerve recovery. In the hRLP group (47 patients), the 3-month pad-free continence rate was 86.8%, compared to 68.6% in the control group. The median time to regain continence was shorter with hRLP (39 days) than in controls (59 days)[20].

3.2.5 | Biological membrane applications

Biological membrane applications, including dehydrated human amnion/chorion membrane (dHACM) and chitosan-based scaffolds, have been studied as NVB wraps. Early research suggests these biomaterials may accelerate the initial recovery of continence and EF by supporting neuroregeneration and reducing fibrosis[21]. In a propensity-matched study, Patel et al. investigated the effect of placing a dHACM (AmnioFix) around the NVBs in 58 men, compared with a matched group of 58 men who did not receive the graft[22]. While continence and potency rates at 8 weeks were similar between groups, dHACM use significantly sped up the return of continence (1.21 months vs. 1.83 months, $p = 0.03$) and potency (1.34 months vs. 3.39 months, $p = 0.007$)[23].

Alongside technical advancements over time, grading systems for nerve-sparing have been introduced to standardize intraoperative assessment. For example, Tewari et al. proposed a four-grade classification based on the preservation of periprostatic veins[24]. Simultaneously, Schatloff et al. described a five-grade system using the lateral "landmark artery" of the prostate[25]. These systems provide structured guidance for choosing dissection planes and promote objective reporting. Importantly, higher grades of nerve-sparing are associated with less removal of periprostatic nerve fibers and improved postoperative potency (Table 2).

TABLE 2 Proposed grading system for robotic radical prostatectomy

Aspect	Tewari et al.[24]	Schatloff et al.[25]
Purpose	Risk-stratified, anatomy-based plan to balance oncologic safety with functional recovery.	Standardized intraoperative scoring of the amount of nerve preserved, correlated with pathology.
Scale	4 grades (1–4)	5 grades (1–5)
Anatomic/visual landmarks	Fascial planes and venous landmarks around the prostate ("neural hammock" concept).	Relationship of dissection plane to the landmark artery within the NVB; % of NVB preserved.
How assigned	Preplanned from pre-op risk of ipsilateral ECE (MRI, biopsy, PSA, etc.), then executed intraoperatively if feasible.	Assigned intraoperatively per side immediately after dissection, based on observed plane and estimated % NS.
Grade definitions	G1 (maximal/intrafascial): Incise Denonvilliers' & LPF just outside capsule—"medial venous plane"; complete hammock preservation. G2 (peri-venous/high NS): Incision just outside capsular veins; preserves most large neural trunks. G3 (incremental/partial NS): Incision through outer LPF; all Denonvilliers' layers excised; medial trunks sacrificed, lateral trunks preserved. G4 (non-NS/extrafascial): Wide excision of LPF & Denonvilliers' with most periprostatic NV tissue removed.	NSS-1: No NS (0%). NSS-2: < 50% NS; plane several mm lateral to landmark artery. NSS-3: around 50% NS; plane at lateral aspect of landmark artery. NSS-4: around 75% NS; plane between artery and capsule (fat strip over prostate, no arteries). NSS-5: ≥ 95% NS; plane medial to artery, just outside prostatic fascia (interfascial look; "pink" capsule, no fat).
Typical use case	Tailors planned dissection depth by ECE risk (G1 for minimal-risk; G4 for high-risk).	Documents achieved nerve preservation and helps audit outcomes (PSM/nerve area).
Reported outcome	Greater NS grade (G1 → G4) associated with higher potency recovery without higher PSMs in their cohort.	Lower residual nerve area and low PSMs with higher NSS (e.g., PSM 3.6% at NSS-5 vs. 7.5% at NSS-4).

Abbreviations: ECE, extracapsular extension; LPF, lateral pelvic fascia; mm, millimetre; MRI, magnetic resonance imaging; NS, nerve sparing; NSS, nerve-sparing score; NV, neurovascular; NVB, neurovascular bundle; PSA, prostate-specific antigen; PSM, positive surgical margin.

4 | PATIENT SELECTION AND RISK STRATIFICATION FOR NSS

For NSS, patient selection involves a careful balance between oncological risk and functional goals. NSS is mainly recommended for men with adequate EF and a low risk of ECE on the NSS side. Patients with a high risk of ECE should generally avoid NSS to preserve cancer control.

4.1 | Diagnostic tools for patient selection

Historically, tumor staging depended on digital rectal examination (DRE), transrectal ultrasound (TRUS), and biopsy Gleason score. However, these separate factors have limited accuracy for local staging[26]. In the past decade, multiparametric magnetic resonance imaging (mpMRI) has become a vital tool for detecting prostate cancer, and nearly all patients now undergo mpMRI before surgery. It can also improve clinical staging and surgical planning by providing a more precise assessment of ECE, pelvic anatomy, and tumor features or location. While mpMRI can enhance surgical planning and potentially reduce PSM rates, its sensitivity for detecting ECE (around 0.57) indicates that ECE may still be present even without MRI evidence, suggesting that mpMRI alone cannot reliably rule out T3 tumors for NSS[27].

4.2 | Factors predicting intraoperative deviation

Even with careful planning, nearly half of nerve-sparing surgeries require intraoperative adjustments. Factors predicting unplanned incomplete nerve sparing (INS) include older age, prior postbiopsy sepsis (caused by inflammation and fibrosis), larger prostate volume, and left-sided dissection—possibly impacted by surgeon handedness. Conversely, the number of previous biopsies does not appear to influence INS risk[26].

4.3 | Extent individualization (bilateral vs. unilateral vs. partial nerve-sparing)

For patients with cT1–cT2 disease presenting favorable biopsy features and no MRI or PSMA-PET evidence of ECE, bilateral intrafascial nerve preservation is preferred. When the tumor on MRI demonstrates close proximity to the prostatic capsule, adopting an interfascial dissection may be prudent to ensure a safer margin. In cases with side-specific suspicion of ECE, unilateral or partial (incremental) intrafascial nerve-sparing may be performed on the contralateral side, while a wider dissection plane—either interfascial or extrafascial, depending on the disease extent—should be maintained on the affected side. If frank ECE is

anticipated, an extrafascial, non–nerve-sparing approach is warranted. Intraoperative findings, including capsular tethering and characteristic bleeding patterns, remain critical for side-specific judgment, while adjunctive techniques such as fluorescence confocal microscopy (FCM) or the NeuroSAFE protocol can further refine real-time decision-making.

5 | OUTCOMES OF NERVE-SPARING RARP

Nerve-sparing techniques during RARP are crucial for enhancing functional outcomes like potency and continence in patients with localized and locally advanced PCa.

5.1 | Oncological outcomes

The primary concern with nerve-sparing approaches, especially in high-risk PCa, is their potential impact on cancer control. Several studies have focused on biochemical recurrence (BCR) and PSMs.

5.1.1 | BCR

NSS can be performed even in selected high-risk patients. A large prospective single-center study of 779 men with high-risk localized PCa found no significant difference in BCR between those who underwent NSS and those who did not, with a median follow-up of 192 months. Both univariable and multivariable analyses confirmed that NSS was not an independent predictor of BCR after adjusting for pathological stage, Gleason score, and preoperative PSA, and Kaplan–Meier analysis showed no difference in BCR-free survival among non-NSS, unilateral, and bilateral NSS groups[27]. However, oncological safety concerns remain. In a multicenter cohort of 2574 patients (5148 lobes) undergoing RARP, nerve-sparing was identified as an independent predictor of ipsilateral PSM (OR = 1.42, 95% confidence interval [CI] = 1.14–1.82). Other significant predictors included PSA density, the highest ISUP biopsy grade on the affected side, extraprostatic extension (EPE) on MRI, and the proportion of positive biopsy cores[28].

5.1.2 | PSMs

PSMs, defined as the presence of tumor cells on the inked surface of the specimen, are a crucial indicator of surgical quality and are strongly associated with the risk of recurrence and the need for adjuvant therapy[29]. Data on the relationship between NSS and PSMs in high-risk PCa remain somewhat conflicting. A large prospective trial found no difference in PSM rates or characteristics (focality, length, and localization) between NSS and non-NSS patients (143 vs. 111; $p = 0.5$)[27]. In contrast, a systematic review and meta-analysis reported a modest but significant increase in PSM risk with NSS (RR = 1.31; 95% CI: 1.01–1.69; $p = 0.042$)[30]. Notably, subgroup analysis showed that bilateral NSS was associated with significantly lower PSM rates compared to both non-nerve-sparing and unilateral/partial NSS, suggesting that surgical strategy and extent of dissection may play an important role (RR = 0.54, 95% CI: 0.39–0.73; $p = 0.004$) and unilateral/partial NSS (RR = 0.55, 95% CI: 0.38–0.78; $p = 0.001$)[30]. The presence of PSMs is recognized as a negative prognostic factor, often linked to an increased risk of BCR and the need for adjuvant therapy. Predictors of PSMs include PSA level, age, tumor stage, surgical technique, and experience[31].

The NeuroSAFE technique, which uses intraoperative frozen section analysis of the prostate margin next to the NVB, is an innovative approach that balances cancer control with the preservation of function. If a positive margin is detected during surgery, the ipsilateral NVB can be removed, reducing the risk of remaining disease while trying to preserve nerves when possible. Large comparative studies have shown that NeuroSAFE increases the rates of unilateral and bilateral nerve-sparing even in high-risk cases and lowers PSM rates in pT3 disease (51% vs. 42%). Importantly, patients treated with NeuroSAFE had better BCR-free survival compared to those treated with standard methods (HR = 0.62, 95% CI: 0.45–0.84; $p = 0.002$)[32].

These findings suggest that while the method may not entirely eliminate the risk of positive margins, it offers a meaningful balance between functional preservation and oncological safety, especially in higher-stage disease[33]. These results are supported by a recent systematic review and meta-analysis of over 4200 patients, confirming that NeuroSAFE not only increases the chance of nerve preservation (OR = 5.49, 95% CI: 2.48–12.12) but also significantly lowers PSM rates (OR = 0.55, 95% CI: 0.39–0.79) and reduces BCR risk (OR = 0.47, 95% CI: 0.35–0.62). In addition to oncological safety, the technique is linked to better functional outcomes, including higher rates of continence and EF recovery at 12 months[34].

Together, these data indicate that while NSS in high-risk disease may increase the risk of PSM with traditional methods, NeuroSAFE strategies can reduce this risk, offering an optimal balance between cancer control and functional preservation[35]. Similarly, the authors of this review argue that, in high-risk PCa, nerve-sparing radical prostatectomy can be performed in a carefully selected group of patients, as long as their prior mpMRI and PSMA PET/CT have been thoroughly reviewed.

5.2 | Functional outcomes

5.2.1 | EF

A meta-analysis showed that nerve-sparing during RARP significantly improved postoperative EF at 12 months, with better results in NSS groups (RR = 0.32, 95% CI: 0.16–0.63; $p = 0.001$)[30]. EF recovery depends on multiple factors, including the extent of nerve-sparing, age, baseline sexual function, comorbidities, use of pelvic lymphadenectomy, testosterone levels, and surgical expertise[36]. As expected, bilateral NSS consistently correlates with higher rates of potency recovery. One study reported EF recovery rates of 19.6%, 19.6%, and 39.7% at 12 months, 24 months, and 36 months respectively in non-NSS patients, compared to 42.1%, 67.1%, and 75.3% in bilateral NSS cases[22]. Moreover, intrafascial dissection, which preserves nerves to the greatest extent, has demonstrated superior outcomes in EF and continence recovery compared to interfascial approaches, likely due to less nerve damage[37]. In a meta-analysis of 2096 patients from seven studies, intrafascial radical prostatectomy was significantly better for EF recovery than nonintrafascial procedures. Specifically, intrafascial surgery showed higher potency rates at 6 months post-op (RR: 1.53; 95% CI: 1.07–2.18; $p = 0.02$) and at 12 months (RR = 1.38; 95% CI: 1.11–1.73; $p = 0.005$). The benefits were more notable in men aged ≤ 65 years, who experienced higher postoperative potency recovery than older men, suggesting that younger age may confer an advantage in EF recovery after intrafascial radical prostatectomy[38].

From a surgical technique perspective, several key aspects can be summarized as follows: Athermal techniques that minimize the use of electrocautery are essential for reducing thermal injury to the NVBs. Multiple studies have demonstrated improved postoperative potency outcomes with such approaches. For example, Ahlering et al. reported significantly higher potency rates at 24 months in patients who underwent bilateral nerve-sparing without cautery compared to those with cautery use (92% vs. 67.9%)[39]. Similarly, traction-free dissection methods have been linked to faster EF recovery. In a study by Kowalczyk et al. involving 610 patients undergoing RARP, 342 patients underwent nerve-sparing with complete avoidance of countertraction on the neurovascular bundles. The traction-free group showed earlier recovery of sexual function, with potency rates of 45% versus 28% at five months. However, at 1 year, there was no significant difference in potency rates between the two groups[40]. Lastly, advanced surgical techniques like the “Veil of Aphrodite” and “Super Veil” aim to preserve the entire NVB and surrounding tissues. In one study, 70% of patients undergoing bilateral NSS with the “Veil” technique regained potency at 1 year, while the “Super Veil” group achieved 94% recovery at 18 months[15].

5.2.2 | Urinary continence

Regarding urinary incontinence, RS-RARP consistently shows better early continence outcomes compared to conventional RARP. A meta-analysis by Liu et al. indicated that intraoperative nerve-sparing also improved continence at 12 months (RR = 0.46, 95% CI: 0.22–0.96; $p = 0.045$)[30]. Surgical refinements, such as athermal dissection and reduced traction, aimed at preserving periurethral nerves, further support early recovery. One study reported complete continence in 80% of patients one week after catheter removal and in 92.4% at 4 months[41]. Adjunct strategies targeting the neurovascular bundle have also shown promise. Placement of dHACM during nerve-sparing RARP shortened the time to continence recovery (1.21 months vs. 1.83 months, $p = 0.033$), although 8-week continence rates were not significantly different (81.0% vs. 74.1%, $p = 0.373$). Similarly, applying hyaluronic acid/carboxymethyl cellulose (HA/CMC) membrane around the NVB and prostatic bed reduced the duration of postoperative incontinence[23].

6 | RECENT INNOVATIONS AND FUTURE DIRECTIONS

6.1 | Near-infrared fluorescence (NIRF) with indocyanine green (ICG)

This technology has been introduced to improve visualization of the neurovascular bundle (NVB) during RARP. After intravenous injection, ICG binds to plasma proteins and emits fluorescence under infrared light, allowing real-time identification of the “landmark prostate artery” on the lateral surface of the prostate. In a clinical evaluation, the artery was visualized in 85% of cases, with the rest identified through standard dissection. Significantly, NIRF did not increase operative time or cause complications, suggesting it may enhance the precision and safety of NVB preservation[42].

6.2 | Ex vivo FCM

Several recent studies have investigated the potential of ex vivo FCM to distinguish PCa from nearby benign tissue, building on its proven use in diagnosing skin cancers[43]. In an initial study, Puliatti et al. reported a strong correlation between FCM and traditional histopathology, with a kappa value of 0.75. The diagnostic performance was characterized by an AUC of 0.884, a sensitivity of 83.3%, a specificity of 93.5%, and an overall accuracy of 91.0%, indicating that FCM could be a promising rapid diagnostic tool during prostate cancer surgery[44].

Both ex vivo FCM and the NeuroSAFE approach share the same rationale: to provide rapid, intraoperative margin assessment adjacent to the NVB and guide the extent of preservation. FCM offers near-

real-time optical histology on the excised surface, whereas NeuroSAFE uses frozen-section pathology to enable immediate secondary resection if a positive margin is detected. In practice, these methods complement each other by allowing the surgeon to individualize nerve-sparing decisions while maintaining oncologic safety, particularly in cases at risk for ECE.

6.3 | Augmented reality (AR) RARP (AR-RAPP)

AR has been tested by integrating mpMRI-based 3D prostate models into the robotic console. In a pilot study, intrafascial nerve-sparing was guided by lesion marking in cT2 cases, while cT3 patients received standard RARP with targeted biopsies. The method proved feasible and safe, with a PSM rate of 30% overall but 0% in pT2 disease. AR-guided biopsies confirmed ECE in 78% of suspected lesions, and the spatial accuracy of the 3D models was within 3 mm of the prostate surface in 85% of cases. Despite these promising findings, current limitations include manual orientation and model rigidity, which require further technological improvements[45].

6.4 | PSMA-PET (prostate-specific membrane antigen positron emission tomography)

Incorporating modern PSMA-PET imaging into predictive nomograms can enhance the accuracy of ECE localization, enabling more precise side-specific NSS. This technique may help decrease PSM and improve functional outcomes, even in cases of nonorgan-confined prostate cancer[46]. A prospective study involving 50 patients at risk for extraprostatic extension (EPE) demonstrated that PSMA-PET outperformed mpMRI in detecting EPE along the posterior neurovascular bundles, with a sensitivity of 86% compared to 57% ($p = 0.03$). PSMA-PET also improved surgical planning, allowing correct NSS decisions in 74% of cases compared to 65% with mpMRI alone ($p = 0.01$). These results highlight the utility of PSMA-PET for preoperative identification of EPE and optimization of nerve-sparing strategies, supporting its importance as a tool in surgical planning for prostate cancer[47].

7 | CONCLUSIONS

NSS in the context of RARP is an advanced and continually evolving aspect of surgical management for localized PCa. While it plays a crucial role in preserving postoperative EF and urinary continence, its success heavily depends on careful patient selection and precise intraoperative decision-making. However, there is still no consensus on standardized risk thresholds and universal decision-making algorithms for NSS. The high rate of intraoperative changes to NSS strategies underscores the complexity of the procedure and highlights the importance of surgical expertise. Ultimately, a patient-centered approach that considers individual anatomy, tumor characteristics, baseline functional status, and patient preferences is essential for achieving the optimal balance between cancer control and functional preservation. Future randomized controlled trials are necessary to clarify the effectiveness of specific NSS techniques and to develop refined, evidence-based guidelines.

AUTHOR CONTRIBUTIONS

Enes Degirmenci, Oner Sanli, and Fatih Atug contributed equally to conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, and project administration.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

No new data were generated or analyzed in this study. Data sharing is not applicable to this article.

ETHICS STATEMENT

This article is a narrative review and does not involve human participants or animal subjects. Therefore, institutional ethical approval was not required.

REFERENCES

1. Ficarra V, Novara G, Ahlering TE, Costello A, Eastham JA, Graefen M, et al. Systematic review and meta-analysis of studies reporting potency rates after robot-assisted radical prostatectomy. Eur Urol. 2012;62(3):418–30.
2. Moschovas MC, Patel V. Neurovascular bundle preservation in robotic-assisted radical prostatectomy: how I do it after 15.000 cases. Int Braz J Urol. 2022;48(2):212–9.
3. Reeves F, Preece P, Kapoor J, Everaerts W, Murphy DG, Corcoran NM, et al. Preservation of the neurovascular bundles is associated with improved time to continence after radical prostatectomy but not long-term continence rates: results of a systematic review and meta-analysis. Eur Urol. 2015;68(4):692–704.
4. Rajan P, Hagman A, Sooriakumaran P, Nyberg T, Wallerstedt A, Adding C, et al. Oncologic outcomes after robot-assisted radical prostatectomy: a large European single-centre cohort with median 10-year follow-up. Eur Urol Focus. 2018;4(3):351–9.
5. Walsh PC, Donker PJ. Impotence following radical prostatectomy: insight into etiology and prevention. J Urol. 2017;197(2s):S165–70.
6. Tavukçu HH, Aytac O, Atug F. Nerve-sparing techniques and results in robot-assisted radical prostatectomy. Investig Clin Urol. 2016;57(Suppl 2):S172–84.
7. Menon M, Tewari A, Peabody J. Vattikuti Institute Prostatectomy: technique. J Urol. 2003;169(6):2289–92.
8. Menon M, Hemal AK. Vattikuti Institute prostatectomy: a technique of robotic radical prostatectomy: experience in more than 1000 cases. J Endourol. 2004;18(7):611–9.
9. Tewari A, Takenaka A, Mtui E, Horninger W, Peschel R, Bartsch G, et al. The proximal neurovascular plate and the trizonal neural architecture around the prostate gland: importance

in the athermal robotic technique of nerve-sparing prostatectomy. BJU Int. 2006;98(2):314–23.
10. Costello AJ, Brooks M, Cole OJ. Anatomical studies of the neurovascular bundle and cavernosal nerves. BJU Int. 2004;94(7):1071–6.
11. Lunacek A, Schwentner C, Fritsch H, Bartsch G, Strasser H. Anatomical radical retropubic prostatectomy: 'curtain dissection' of the neurovascular bundle. BJU Int. 2005;95(9):1226–31.
12. Walz J, Burnett AL, Costello AJ, Eastham JA, Graefen M, Guillonneau B, et al. A critical analysis of the current knowledge of surgical anatomy related to optimization of cancer control and preservation of continence and erection in candidates for radical prostatectomy. Eur Urol. 2010;57(2):179–92.
13. Ko YH, Coelho RF, Sivaraman A, Schatloff O, Chauhan S, Abdul-Muhsin HM, et al. Retrograde versus antegrade nerve sparing during robot-assisted radical prostatectomy: which is better for achieving early functional recovery? Eur Urol. 2013;63(1):169–77.
14. Kaul S, Savera A, Badani K, Fumo M, Bhandari A, Menon M. Functional outcomes and oncological efficacy of Vattikuti Institute prostatectomy with veil of aphrodite nerve-sparing: an analysis of 154 consecutive patients. BJU Int. 2006;97(3):467–72.
15. Menon M, Shrivastava A, Bhandari M, Satyanarayana R, Siva S, Agarwal PK. Vattikuti Institute prostatectomy: technical modifications in 2009. Eur Urol. 2009;56(1):89–96.
16. Chien GW, Mikhail AA, Orvieto MA, Zagaja GP, Sokoloff MH, Brendler CB, et al. Modified clipless antegrade nerve preservation in robotic-assisted laparoscopic radical prostatectomy with validated sexual function evaluation. Urology. 2005;66(2):419–23.
17. Galfano A, Di Trapani D, Sozzi F, Strada E, Petralia G, Bramerio M, et al. Beyond the learning curve of the Retzius-sparing approach for robot-assisted laparoscopic radical prostatectomy: oncologic and functional results of the first 200 patients with ≥ 1 year of follow-up. Eur Urol. 2013;64(6):974–80.
18. O'Connor-Cordova MA, Macías AGO, Sancen-Herrera JP, Altamirano-Lamarque F, Vargas Del Toro A, Peddinani BK, et al. Surgical and functional outcomes of Retzius-sparing robotic-assisted radical prostatectomy versus conventional robotic-assisted radical prostatectomy in patients with biopsy-confirmed prostate cancer. Are outcomes worth it? Systematic review and meta-analysis. Prostate. 2023;83(15):1395–414.
19. Phukan C, McLean A, Nambiar A, Mukherjee A, Somani B, Krishnamoorthy R, et al. Retzius sparing robotic assisted radical prostatectomy vs. conventional robotic assisted radical prostatectomy: a systematic review and meta-analysis. World J Urol. 2020;38(5):1123–34.
20. Finley DS, Osann K, Skarecky D, Ahlering TE. Hypothermic nerve-sparing radical prostatectomy: rationale, feasibility, and effect on early continence. Urology. 2009;73(4):691–6.
21. Ogaya-Pinies G, Palayapalam-Ganapathi H, Rogers T, Hernandez-Cardona E, Rocco B, Coelho RF, et al. Can dehydrated human amnion/chorion membrane accelerate the return to potency after a nerve-sparing robotic-assisted radical prostatectomy? Propensity score-matched analysis. J Rob Surg. 2018;12(2):235–43.
22. Novara G, Ficarra V, D'Elia C, Secco S, De Gobbi A, Cavalleri S, et al. Preoperative criteria to select patients for bilateral nerve-sparing robotic-assisted radical prostatectomy. J Sex Med. 2010;7(2 Pt 1):839–45.
23. Patel VR, Samavedi S, Bates AS, Kumar A, Coelho R, Rocco B, et al. Dehydrated human amnion/chorion membrane allograft nerve wrap around the prostatic neurovascular bundle accelerates early return to continence and potency following robot-assisted radical prostatectomy: propensity score-matched analysis. Eur Urol. 2015;67(6):977–80.
24. Tewari AK, Srivastava A, Huang MW, Robinson BD, Shevchuk MM, Durand M, et al. Anatomical grades of nerve sparing: a risk-stratified approach to neural-hammock sparing during robot-assisted radical prostatectomy (RARP). BJU Int. 2011;108(6 Pt 2):984–92.
25. Schatloff O, Chauhan S, Sivaraman A, Kameh D, Palmer KJ, Patel VR. Anatomic grading of nerve sparing during robot-assisted radical prostatectomy. Eur Urol. 2012;61(4):796–802.
26. Couture F, Polesello S, Tholomier C, Bondarenko HD, Karakiewicz PI, Nazzani S, et al. Predictors of deviation in neurovascular bundle preservation during robotic prostatectomy. Can J Urol. 2019;26(1):9644–53.
27. Spirito L, Chessa F, Hagman A, Lantz A, Celentano G, Sanchez-Salas R, et al. Long-term oncological outcomes after nerve-sparing robot-assisted radical prostatectomy for high-risk localized prostate cancer: a single-center, two-arm prospective study. Diagnostics (Basel, Switzerland). 2024;14(8):803.
28. Soeterik TFW, van Melick HHE, Dijksman LM, Stomps S, Witjes JA, van Basten JPA. Nerve sparing during robot-assisted radical prostatectomy increases the risk of ipsilateral positive surgical margins. J Urol. 2020;204(1):91–5.
29. Choo R, Danjoux C, Gardner S, Morton G, Szumacher E, Loblaw DA, et al. Prospective study evaluating postoperative radiotherapy plus 2-year androgen suppression for post-radical prostatectomy patients with pathologic T3 disease and/or positive surgical margins. Int J Radiat Oncol Biol Phys. 2009;75(2):407–12.
30. Liu Y, Deng XZ, Qin J, Wen Z, Jiang Y, Huang J, et al. Erectile function, urinary continence and oncologic outcomes of neurovascular bundle sparing robot-assisted radical prostatectomy for high-risk prostate cancer: a systematic review and meta-analysis. Front Oncol. 2023;13:1161544.
31. Yossepowitch O, Briganti A, Eastham JA, Epstein J, Graefen M, Montironi R, et al. Positive surgical margins after radical prostatectomy: a systematic review and contemporary update. Eur Urol. 2014;65(2):303–13.
32. Dinneen E, Haider A, Allen C, Freeman A, Briggs T, Nathan S, et al. NeuroSAFE robot-assisted laparoscopic prostatectomy versus standard robot-assisted laparoscopic prostatectomy for men with localised prostate cancer (NeuroSAFE PROOF): protocol for a randomised controlled feasibility study. BMJ Open. 2019;9(6):e028132.
33. van der Slot MA, den Bakker MA, Tan TSC, Remmers S, Busstra MB, Gan M, et al. NeuroSAFE in radical prostatectomy increases the rate of nerve-sparing surgery without affecting oncological outcome. BJU Int. 2022;130(5):628–36.
34. Ditonno F, Bologna E, Licari LC, Franco A, Cannoletta D, Checucci E, et al. Neurovascular structure-adjacent frozen-section examination (NeuroSAFE) during robot-assisted radical prostatectomy: a systematic review and meta-analysis of comparative studies. Prostate Cancer Prostatic Dis. 2025;28(3):623–31.
35. Maruo M, Goto Y, Miyazaki K, Inoue A, Kurokawa K, Enomoto A, et al. Novel nerve-sparing robot-assisted radical prostatectomy with endopelvic fascia preservation and long-term outcomes for a single surgeon. Sci Rep. 2024;14(1):926.
36. Holze S, Mende M, Healy KV, Koehler N, Gansera L, Truss MC, et al. Comparison of various continence definitions in a large group of patients undergoing radical prostatectomy: a multicentre, prospective study. BMC Urol. 2019;19(1):70.
37. Potdevin L, Ercolani M, Jeong J, Kim IY. Functional and oncologic outcomes comparing interfascial and intrafascial nerve sparing in robot-assisted laparoscopic radical prostatectomies. J Endourol. 2009;23(9):1479–84.
38. Zhao Z, Zhu H, Yu H, Kong Q, Fan C, Meng L, et al. Comparison of intrafascial and non-intrafascial radical prostatectomy for low risk localized prostate cancer. Sci Rep. 2017;7(1):17604.
39. Ahlering TE, Eichel L, Chou D, Skarecky DW. Feasibility study for robotic radical prostatectomy cautery-free neurovascular bundle preservation. Urology. 2005;65(5):994–7.
40. Kowalczyk KJ, Huang AC, Hevelone ND, Lipsitz SR, Yu H, Ulmer WD, et al. Stepwise approach for nerve sparing without countertraction during robot-assisted radical prostatectomy: technique and outcomes. Eur Urol. 2011;60(3):536–47.

41. Mattei A, Naspro R, Annino F, Burke D, Guida Jr. R, Gaston R. Tension and energy-free robotic-assisted laparoscopic radical prostatectomy with interfascial dissection of the neurovascular bundles. Eur Urol. 2007;52(3):687–95.
42. Kumar A, Samavedi S, Bates A, Coelho R, Rocco B, Marquinez J, et al. Using indocyanine green and near-infrared fluorescence technology to identify the "landmark artery" during robot-assisted radical prostatectomy. Videourology. 2015;29(3): vid.2014.0071.
43. Titze U, Sommerkamp J, Stege C, Schneider F, Brochhausen C, Schulz B, et al. Ex vivo fluorescence confocal microscopy (FCM) ensures representative tissue in prostate cancer biobanking: a feasibility study. Int J Mol Sci. 2022;23(20):12103.
44. Puliatti S, Bertoni L, Pirola GM, Azzoni P, Bevilacqua L, Eissa A, et al. Ex vivo fluorescence confocal microscopy: the first application for real-time pathological examination of prostatic tissue. BJU Int. 2019;124(3):469–76.
45. Porpiglia F, Fiori C, Checcucci E, Amparore D, Bertolo R. Augmented reality robot-assisted radical prostatectomy: preliminary experience. Urology. 2018;115:184.
46. Ceci F, Oprea-Lager DE, Emmett L, Adam JA, Bomanji J, Czernin J, et al. E-PSMA: the EANM standardized reporting guidelines v1.0 for PSMA-PET. Eur J Nucl Med Mol Imaging. 2021;48(5):1626–38.
47. Bahler CD, Tachibana I, Tann M, Collins K, Swensson JK, Green MA, et al. Comparing magnetic resonance imaging and prostate-specific membrane antigen-positron emission tomography for prediction of extraprostatic extension of prostate cancer and surgical guidance: a prospective nonrandomized clinical trial. J Urol. 2024;212(2):290–8.