Novel anatomical apical dissection utilizing puboprostatic "open-collar" technique: Impact on apical surgical margin and early continence recovery

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Abstract

Purpose
To evaluate the impact of modifications to anatomical apical dissection including a puboprostatic open-collar technique, which visualizes the lateral aspect of the apex and dorsal vein complex (DVC) covering the rhabdosphincter while preserving the puboprostatic collar, on positive surgical margin (PSM) and continence recovery.

Methods
One-hundred-and-sixty-seven patients underwent gasless single-port retroperitoneoscopic radical prostatectomy using a three-dimensional head-mounted display system. Sequentially modified surgical techniques comprised puboprostatic open-collar technique, sutureless transection of the DVC, retrograde urethral dissection, and anterior reconstruction. The associations of these modifications with PSM and continence recovery were assessed.

Results
The puboprostatic open-collar technique, sutureless DVC transection, and retrograde urethral dissection were significantly associated with lower apical PSM (P = 0.003, 0.003, and 0.010, respectively). The former two also showed similar associations in 84 patients with anterior apical tumor (P = 0.021 and 0.030, respectively). Among 92 patients undergoing all of these three procedures, overall and apical PSM rates were 13.0% and 3.3%, respectively. Retrograde urethral dissection (odds ratio [OR] 2.73, P = 0.004) together with nerve sparing (OR 2.77, P = 0.003) and anterior apical tumor (OR 0.45, P = 0.017) were independently associated with immediate continence recovery. A multivariable model for 3-month continence recovery included anterior apical tumor (OR 0.28, P = 0.003) and puboprostatic open-collar technique (OR 3.42, P = 0.062). Immediate and 3-month continence recovery
rates were 56.3% and 85.4%, respectively, in 103 patients undergoing both the puboprostatic open-collar technique and retrograde urethral dissection.

**Conclusion**

Novel anatomical apical dissection utilizing a puboprostatic open-collar technique may favorably impact on both apical surgical margin and continence recovery.

1. Introduction

Apical dissection is one of the most challenging procedures in radical prostatectomy (RP) given the competing goals of cancer control and maintenance of urinary continence and sexual function. The apex represents the most common anatomical site of positive surgical margins (PSMs) [1]. Visualization of the apical structures and dissection with adequate surgical margins, particularly in cases with apical tumor, contribute to reduction of apical PSM in laparoscopic RP including robot-assisted RP [2, 3]. At the same time, preservation of the rhabdosphincter, functional urethral length, bladder neck, levator ani muscles and their fascia is required for maintenance of urinary continence [4–7].

We have adopted a three-dimensional head-mounted display (3D-HMD) system for single-port retroperitoneoscopic RP without using CO\textsubscript{2} gas insufflation since October 2013. The general concept and techniques of gasless single-port retroperitoneoscopic RP using the 3D-HMD system (3D-RP) has been described in detail elsewhere [8–11]. Briefly, 3D-RP is carried out using a high-resolution stereovision in the wide extraperitoneal working space created along the anatomical plane through a single port of around 4 cm in diameter with affordable cost.

To improve cancer control and early continence recovery, we have modified the procedures for anatomical apical dissection in 3D-RP. The novelty of our modification is to better visualize lateral aspects of the apex and dorsal vein complex (DVC) covering the rhabdosphincter for better cancer control while preserving the structural continuity of the puboprosthetic ligament (PPL) and arcus tendinous (AT), the so called “puboprostatic collar”[12, 13] for maintaining continence, which we term a “puboprostatic open-collar technique”. This procedure facilitates sutureless DVC transection using a bipolar sealing device distally beyond the anterior apical tumor, if present, combined with retrograde urethral dissection to secure apical resection margins while maximizing the functional urethral length.

In this study, we explored the impact of modified surgical techniques for anatomical apical dissection and pelvic floor reconstruction on surgical margin status and early continence recovery in patients who underwent 3D-RP.

2. Patients and methods

2.1. Surgical techniques

The 3D-HMD system comprises a 3D deflectable endoscope (Endoeye flex 3D deflectable videoscope, Olympus, Tokyo, Japan) and a 3D-HMD (Sony, Tokyo, Japan; Fig 1A). To create and maintain the surgical field, PLES retractors (Innomedics, Tokyo, Japan) and Omni-Tract pediatric retractors (Integra LifeSciences, Princeton, NJ) were used, respectively [8].

S1 Video shows points of surgical procedures. Fig 2 summarizes our surgical techniques for anatomical apical dissection, pelvic floor reconstruction, and their sequential modifications during the study period. The surgical techniques described in this study were implemented as...
a standard-of-care at our institution. Patients were assigned to each surgical procedure for anatomical apical dissection and pelvic floor reconstruction on or after time points indicated in Fig 2. 3D-RP is approved by the Ministry of Health, Labour and Welfare, and is covered by the Japanese universal health insurance system.

2.1.1 Patient positioning and preparation of a single port

Patients were placed in the temperate Trendelenburg position. The extraperitoneal pelvic space was developed via a suprapubic midline incision of around 5 cm and a single port was prepared using an Alexis wound retractor S (Applied Medical, Rancho Santa Margarita, CA).

2.1.2 Pelvic Lymph Node Dissection (PLND). Standard or extended PLND was performed when the percentage risk of lymph node involvement, estimated using the Briganti
nomogram 2012, 2017, or 2018 [14–16], was 5–20% or >20%, respectively. A template of standard PLND includes inner external iliac, obturator, and outer internal iliac nodes. For extended PLND, the lymphatic chains of the external iliac artery, those medial to the internal iliac vessels, and distal common iliac area including Marcille’s fossa were removed in addition to the standard template. Fat tissues overlying the prostate were removed to expose the endopelvic fascia (EF) and PPL.

2.1.3 Puboprostatic open-collar technique (Fig 1B–1K). The lateral surface of the prostate was exposed unless intrafascial nerve sparing (NS) was attempted. Following the original technique of puboprostatic collar preservation [12, 13], the parietal pelvic fascia (PF) and visceral PF were bluntly separated antegrade toward the apex, where the PF were fused at the attachment site of the pubococcygeus muscle (Fig 1B and 1E). Similarly, the parietal and visceral PF were bluntly separated medial to the PPL in an attempt to preserve the parietal PF overlaying the pubococcygeus muscle (Fig 1C and 1F). Then, the EF covering apical attachment of the pubococcygeus muscle was sharply incised to preserve the puboprostatic collar (Fig 1D and 1G). Finally, apical attachment of the pubococcygeus muscle (Fig 1H) was transected using a bipolar sealing device (Fig 1I). Only the anterior part of the muscular attachment was released when intrafascial NS was attempted. These procedures visualized the lateral aspect of the apex and DVC covering the rhabdosphincter while preserving the puboprostatic collar (Fig 1J). After completing these procedures, open collar-shaped PPL-AT complexes
were preserved (Fig 1K). Until March 2014, we used to transect the muscular attachment lateral to the PPL and thus the PPL-AT complex was divided (Fig 2).

**2.1.4 Sutureless transection of the DVC (Fig 1L and 1M).** The DVC was transected without suture ligation using a bipolar sealing device and scissors. The DVC was transected distally for adequate resection margins in cases of anterior apical tumor on MRI (Fig 1L), and the rhabdosphincter was exposed (Fig 1M). Until January 2016, DVC was clamped distally with long straight Pean forceps and suture-ligated, which had limited adequate resection margins in cases of anterior apical tumor (Fig 2).

**2.1.5 Dissection and reconstruction of the bladder neck.** The bladder neck was incised and reconstructed in a tennis racket shape with mucosal eversion at three sites.

**2.1.6 Dissection of the vas deferens and seminal vesicles.** The vas deferens were isolated and divided followed by seminal vesicle dissection.

**2.1.7 Lateral pedicle control.** When planning intrafascial NS, the neurovascular bundle (NVB) was peeled off from the prostatic capsule. A plane was subsequently developed between the prostatic capsule and Denonvillier’s fascia posteriorly, proceeding distally and laterally. Otherwise, the Denonvillier’s fascia was separated or incised posteriorly to carry out interfascial/extrafascial NS or wide resection of the NVB.

**2.1.8 Retrograde urethral dissection (Fig 1N).** Overlying DVC tissues were retrogradely dissected from the rhabdosphincter and urethra toward the apex to secure apical margins and to preserve the functional urethral length (Fig 1N). Modest retrograde urethral dissection was attempted in cases of anterior apical tumor on MRI. The urethra was sharply divided and the prostate was freed. Until September 2015, the most proximal site of the urethra exposed after DVC transection was transected without retrograde urethral dissection (Fig 2).

**2.1.9 Pelvic floor reconstruction and anastomosis (Fig 1O and 1P).** Posterior reconstruction was done in two layers using continuous and mattress 3–0 Vicryl sutures. Following vesico-urethral anastomosis with six 3–0 Vicryl stitches, the detrusor muscle was anchored to the PPL-AT complex at its original apical attachment site using a 3–0 Vicryl stitch (Fig 1O and 1P). Anterior reconstruction has been performed since July 2014.

**2.2. Surgical outcomes**

**2.2.1 Study population.** A prospectively maintained RP database in which all data were fully anonymized was reviewed to retrieve the records of consecutive patients who underwent 3D-RP from October 2013 to June 2020 at a single cancer center. To maintain the database, patients’ medical records at Komagome Hospital were accessed between October 2013 and March 2021. Since the introduction of robotic RP in 2017, 3D-RP has been mainly performed for patients with locally advanced disease. Nine surgeons including six novices of <20 RP experiences performed 3D-RP, all of which were supervised by a senior surgeon (FK). All patients underwent mpMRI preoperatively. Risk classification was defined according to the European Association of Urology guidelines, in which clinical tumor stage (cT) 3–4 or clinical node stage (cN) 1 disease was classified as locally advanced disease [17]. Preoperative androgen deprivation therapy (ADT) was offered as a part of multimodal therapy to the majority of patients with locally advanced disease. A small subset of patients received preoperative ADT because of a change in treatment plan from radiation to RP. This study was approved by the Institutional Review Board of Komagome Hospital (#2400) and was conducted in accordance with the principles of the Declaration of Helsinki and Good Clinical Practice Guidelines. A written informed consent was obtained from all patients included in this study. The individuals in this manuscript (Fig 1 and S1 Video) have given written informed consent to publish these case details.
2.2.2 Outcomes measurement and statistical analysis. Primary endpoints were overall PSM, apical PSM, continence recovery immediately (within a week) after catheter removal and at 3-months after RP. A urethral catheter was removed on postoperative day 5. Continence recovery was defined as no pad or 1 security liner per day by self-report, which was obtained at the outpatient visit at 1-month and 3-months after RP. Patients documented the time of pad exchange and weight of urine loss in bladder diary for 1-month after the catheter removal and the duration to achieve continence recovery was recorded in medical chart by reference to the bladder diary. Biochemical recurrence (BCR), defined as PSA elevation above 0.2 ng/mL, was also assessed.

Variables included in this study are listed in Table 1. Statistical analysis was performed using JMP software version 14 (SAS Institute, Cary, NC). The differences in frequency were evaluated using a chi-square test or Fisher’s exact probability test. Logistic regression analyses were used to evaluate variables associated with continence recovery. Cox proportional hazard model was used to assess variables associated with BCR. A reduced multivariable model was developed using the stepwise backward method, in which the variable with the highest P value was eliminated from each iteration of the multivariable analysis. A two-tailed P < 0.05 was considered significant.

3. Results

Table 1 summarizes the clinicopathological and operative demographics of 167 consecutive men included in the study. Median (range) age at the time of 3D-RP and PSA at the initiation of treatment was 68 years (45–78) and 9.9 ng/mL (1.9–271), respectively. The numbers of patients with low-risk, intermediate-risk, high-risk, and locally advanced disease were 2 (1.2%), 65 (38.9%), 53 (31.7%), and 47 (28.1%), respectively. Preoperative mpMRI showed anterior apical tumor in 84 (50.3%) patients. Preoperative ADT was given to 52 (31.1%) patients, of whom 38 (73.1%), 6 (11.5%), and 8 (15.4%) had locally advanced, high-risk, and intermediate-risk disease, respectively.

Puboprostatic open-collar technique, sutureless DVC transection, retrograde urethral dissection, and anterior reconstruction were performed in 153 (91.6%), 93 (55.7%), 103 (61.7%), and 144 (86.2%) patients, respectively. Standard and extended PLND was performed in 91 (54.5%) and 50 (29.9%) patients, respectively. Intra- or interfascial NS was performed in 68 (40.7%) patients. Median (range) operation time and blood loss including urine were 338 minutes (233–457) and 580 mL (20–2548), respectively. Intra- or post-operative blood transfusion was required in 4 (2.4%) patients. There was no significant association between the modified surgical techniques and operation time or blood loss. A surgical complication of Clavien-Dindo grade 3 or more was grade 3a deep venous thrombosis in a patient (0.6%).

Pathological (p) T stage was yT0, T2 or yT2, T3a or yT3a, and T3b or yT3b in 3 (1.8%), 110 (66.9%), 32 (19.2%), and 22 (13.2%), respectively. Fifteen (9.0%) patients had pN1.

3.1 Surgical margin outcomes

Overall and apical PSM were reported in 27 (16.2%) and 14 (8.4%) patients, respectively. The precise location of the apical PSM was as follows: the anterior apex alone in 9, the anterior and posterior apex in 2, the lateral apex in 2, and the posterior apex alone in 1. None had positive urethral margin. In cases of PSM, median (range) extent of PSM (a sum of PSM length, mm) was 4 (0.4–33). Higher pT stage (P < 0.001) and pN1 (P = 0.030) were significantly associated with overall PSM (Table 2). Of note, apical PSM rates were significantly lower for a puboprostatic open-collar technique (P = 0.003), retrograde urethral dissection (P = 0.003), and sutureless DVC transection (P = 0.010) along with lower pT stage (P < 0.001). Overall and apical
| Variables                          | N (%)  |
|-----------------------------------|--------|
| **Age (years)**                   | 68 (45–78) |
| **PSA (ng/mL)**                   | 9.9 (1.9–271) |
| **Clinical T stage**              |        |
| T1c                               | 6 (3.6) |
| T2a                               | 79 (47.3) |
| T2b or 2c                         | 36 (21.5) |
| T3a                               | 28 (16.8) |
| T3b                               | 15 (9.0) |
| T4                                | 3 (1.8) |
| **Clinical N stage**              |        |
| N0                                | 159 (95.2) |
| N1                                | 8 (4.8) |
| **Biopsy Gleason score**          |        |
| 3+3                               | 14 (8.4) |
| 3+4                               | 28 (16.8) |
| 4+3                               | 41 (24.6) |
| 8                                 | 52 (31.1) |
| 9 or 10                           | 32 (19.2) |
| **Risk classification**           |        |
| Low                               | 2 (1.2) |
| Intermediate                      | 65 (38.9) |
| High                              | 53 (31.7) |
| Locally advanced                  | 47 (28.1) |
| **Anterior apical tumor**         |        |
| Yes                               | 84 (50.3) |
| No                                | 83 (49.7) |
| **Preoperative ADT**              |        |
| No                                | 115 (68.9) |
| Yes                               | 52 (31.1) |
| **Nerve-sparing surgery**         |        |
| Intra- or interfascial            | 68 (40.7) |
| Extrafascial or none              | 99 (59.3) |
| **Operation time (min)**          | 338 (233–457) |
| **Blood loss (including urine, mL)** | 580 (20–2548) |
| **Blood transfusion**             |        |
| No                                | 163 (97.6) |
| Yes                               | 4 (2.4) |
| **Puboprostatic open-collar technique** |        |
| Yes                               | 153 (91.6) |
| No                                | 14 (8.4) |
| **Anterior reconstruction**       |        |
| Yes                               | 144 (86.2) |
| No                                | 23 (13.8) |
| **Retrograde urethral dissection** |        |
| Yes                               | 103 (61.7) |
| No                                | 64 (38.3) |
| **Sutureless DVC transection**    |        |

(Continued)
PSM rates were 13.0% and 3.3%, respectively, in 92 patients who underwent all of the three modified techniques.

Similar results were obtained in a subgroup of 115 ADT-naïve patients (Table 2); puboprostatic open-collar technique (P = 0.003), retrograde urethral dissection (P = 0.005), and sutureless DVC transection (P = 0.031) were significantly associated with negative apical surgical margins.

Among 84 patients with an anterior apical tumor, the puboprostatic open-collar technique (P = 0.021) and retrograde urethral dissection (P = 0.030) were significantly associated with negative apical surgical margins (Table 3). The former was also associated with a lower overall PSM rate (P = 0.045).

### 3.2 Continence outcomes

In total, immediate and 3-month continence recovery were achieved in 78 (46.7%) and 137 (82.0%) patients, respectively. In multivariable analysis (Table 4), anterior apical tumor was independently associated with adverse immediate and 3-month continence recovery (odds ratio [OR] 0.45, 95% confidence interval [CI] 0.23–0.87, P = 0.017; and OR 0.28, 95% CI 0.11–0.66, P = 0.003, respectively). NS was independently associated with favorable immediate continence recovery (OR 2.77, 95% CI 1.43–5.47, P = 0.003). Among surgical procedures modified, retrograde urethral dissection was independently associated with favorable immediate continence recovery (OR 2.73, 95% CI 1.37–5.57, P = 0.004). Puboprostatic open-collar technique remained in the final multivariable model for 3-month continence recovery but did not reach statistical significance (P = 0.062). Sutureless DVC transection was not associated with adverse continence recovery. Immediate and 3-month continence recovery rates were 56.3% and 85.4%, respectively, in 103 patients who underwent both puboprostatic open-collar technique and retrograde urethral dissection.
Table 2. Associations of clinicopathologic variables with surgical margin status.

| Variables                  | Surgical margin, N (%) | P value | Apical surgical margin, N (%) | P value |
|----------------------------|------------------------|---------|-------------------------------|---------|
|                            | Positive | Negative |                  | Positive | Negative |                  |
| Total                      | 27 (16.2) | 140 (83.8) |                 | 14 (8.4) | 153 (91.6) |                 |
| Age (years)*               | 68 (45–78) | 68 (54–76) | 0.93 | 68 (45–78) | 67 (59–74) | 0.68 |
| PSA (ng/mL)*               | 9.9 (1.9–271) | 10.6 (5–192) | 0.24 | 10.0 (1.9–271) | 9.7 (5.0–28.0) | 0.80 |
| Clinical T stage           | 0.76 | 0.77 |
| T1c or 2a                  | 12 (14.1) | 73 (85.9) | | 8 (9.4) | 77 (90.6) | |
| T2b or 2c                  | 4 (11.1) | 32 (88.9) | | 1 (2.8) | 35 (97.2) | |
| T3a                       | 6 (21.4) | 22 (78.6) | | 3 (10.7) | 25 (89.3) | |
| T3b or 4                   | 5 (27.8) | 13 (72.2) | | 2 (11.1) | 16 (88.9) | |
| Clinical N stage           | 1.00 | 1.00 |
| N0                         | 26 (16.4) | 133 (83.7) | | 14 (8.8) | 145 (91.2) | |
| N1                         | 1 (12.5) | 7 (87.5) | | 0 (0) | 8 (100) | |
| Biopsy Gleason score       | 0.64 | 0.89 |
| 3+3                        | 2 (14.3) | 12 (85.7) | | 2 (14.3) | 12 (85.7) | |
| 3+4                        | 4 (14.3) | 24 (85.7) | | 3 (10.7) | 25 (89.3) | |
| 4+3                        | 5 (12.2) | 36 (87.8) | | 3 (7.3) | 38 (92.7) | |
| 8                          | 8 (15.4) | 44 (84.6) | | 4 (7.7) | 48 (92.3) | |
| 9 or 10                    | 8 (25.0) | 24 (75.0) | | 2 (6.3) | 30 (93.8) | |
| Risk classification        | 0.34 | 0.77 |
| Low or intermediate        | 7 (10.4) | 60 (89.6) | | 7 (10.4) | 60 (89.6) | |
| High                       | 10 (18.9) | 43 (81.1) | | 4 (7.6) | 49 (92.5) | |
| Locally advanced           | 10 (21.3) | 37 (78.7) | | 3 (6.4) | 44 (93.6) | |
| Anterior apical tumor      | 0.40 | 0.16 |
| Yes                        | 16 (19.1) | 68 (81.0) | | 10 (11.9) | 79 (88.1) | |
| No                         | 11 (13.3) | 72 (86.8) | | 4 (4.8) | 74 (95.2) | |
| Preoperative ADT           | 0.37 | 0.23 |
| No                         | 21 (18.3) | 94 (81.7) | | 12 (10.4) | 103 (89.6) | |
| Yes                        | 6 (11.5) | 46 (88.5) | | 2 (3.9) | 50 (96.2) | |
| Nerve-sparing surgery      | 0.52 | 0.40 |
| Intra- or interfascial     | 9 (13.2) | 59 (86.8) | | 4 (5.9) | 64 (94.1) | |
| Exterofascial or none      | 18 (18.2) | 81 (81.8) | | 10 (10.1) | 89 (89.9) | |
| Blood loss (including urine, mL)* | 595 (90–2050) | 550 (20–2548) | 0.67 | 590 (110–1740) | 550 (20–2548) | 0.61 |
| Puboprostatic open-collar technique | 0.054 | 0.003 |
| Yes                        | 22 (14.4) | 131 (85.6) | | 9 (5.9) | 144 (94.1) | |
| No                         | 5 (35.7) | 9 (64.3) | | 5 (35.7) | 9 (64.3) | |
| Retrograde urethral dissection | 0.053 | 0.003 |
| Yes                        | 12 (11.7) | 91 (88.4) | | 3 (2.9) | 100 (97.1) | |
| No                         | 15 (23.4) | 49 (76.6) | | 11 (17.2) | 53 (82.8) | |
| Sutureless DVC transection | 0.41 | 0.010 |
| Yes                        | 13 (14.0) | 80 (86.0) | | 3 (3.2) | 90 (96.8) | |
| No                         | 14 (18.9) | 60 (81.1) | | 11 (14.9) | 63 (85.1) | |
| Pathological T stage       | <0.001 | <0.001 |
| yT0                        | 0 (0) | 3 (100) | | 0 (0) | 3 (100) | |
| T2 or yT2                  | 4 (3.6) | 106 (96.4) | | 3 (2.7) | 107 (97.3) | |
| T3a or yT3a                | 11 (34.4) | 21 (65.6) | | 8 (25.0) | 24 (75.0) | |
| T3b or yT3b                | 12 (54.6) | 10 (45.5) | | 3 (13.6) | 19 (86.4) | |

(Continued)
Among surgical procedures modified, retrograde urethral dissection was significantly associated with better immediate (P = 0.018) and 3-month (P = 0.041) continence recovery in the 84 patients with anterior apical tumor (S1 Table).

### 3.3 BCR

During followup (median 56 months, range 7 to 88), 46 patients experienced BCR and two patients died of the disease. The modified surgical techniques were not associated with BCR while extracapsular extension, seminal vesicle involvement, and intra- or interfascial NS were independently associated with BCR (S2 Table).

### 4. Discussion

Our modifications of anatomical apical dissection including the puboprostatic open-collar technique, retrograde urethral dissection, and sutureless DVC transection were associated

### Table 2. (Continued)

| Variables | Surgical margin, N (%) | P value | Apical surgical margin, N (%) | P value |
|-----------|------------------------|---------|-------------------------------|---------|
|           | Positive | Negative | Positive | Negative |           | Positive | Negative |           |
| Pathological N stage |  |  |  |  |  |  |  |  |
| Nx | 3 (11.5) | 23 (88.5) | 2 (7.7) | 24 (92.3) | 0.030 |  |  |  |
| N0 | 18 (14.3) | 108 (85.7) | 11 (8.7) | 115 (91.3) | 0.95 |  |  |  |
| N1 | 6 (40.0) | 9 (60.0) | 1 (6.7) | 14 (93.3) |  |  |  |  |

*Median (range). ADT, androgen deprivation therapy. DVC, dorsal vein complex.

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### Table 3. Associations of clinicopathologic variables with surgical margin status in subsets of 115 ADT-naïve patients and 84 patients with anterior apical tumor on mpMRI.

| Variables | ADT-naïve patients | P value | Patients with anterior apical tumor | P value |
|-----------|---------------------|---------|-----------------------------------|---------|
|           | Surgical margin, N (%) |  | Apical surgical margin, N (%) |  |
|           | Positive | Negative | Positive | Negative | Surgical margin, N (%) | Positive | Negative | Surgical margin, N (%) | Positive | Negative |
| Total | 21 (18.3) | 94 (81.7) | 12 (10.4) | 103 (89.6) | 16 (19.0) | 68 (81.0) | 10 (11.9) | 74 (88.1) | 0.021 |
| Anterior apical tumor | 0.63 | 0.064 | 0.045 | 0.031 |
| Yes | 11 (20.4) | 43 (79.6) | 9 (16.7) | 45 (83.3) | 16 (19.0) | 68 (81.0) | 10 (11.9) | 74 (88.1) |
| No | 10 (16.4) | 51 (83.6) | 3 (4.9) | 58 (95.1) | 0 | 0 | 0 | 0 |
| Puboprostatic open-collar technique | 0.028 | 0.003 | 0.057 | 0.030 |
| Yes | 16 (15.4) | 88 (84.6) | 7 (6.7) | 97 (93.3) | 13 (16.7) | 65 (83.3) | 7 (9.0) | 71 (91.0) |
| No | 5 (45.5) | 6 (54.6) | 5 (45.5) | 6 (54.6) | 3 (50.0) | 3 (50.0) | 3 (50.0) | 3 (50.0) |
| Retrograde urethral dissection | 0.23 | 0.005 | 0.057 | 0.030 |
| Yes | 9 (14.1) | 55 (85.9) | 2 (3.1) | 62 (96.9) | 7 (13.0) | 47 (87.0) | 3 (5.6) | 51 (94.4) |
| No | 12 (23.5) | 39 (76.5) | 10 (19.6) | 41 (80.4) | 9 (30.0) | 21 (70.0) | 7 (23.3) | 23 (76.7) |
| Sutureless DVC transection | 0.64 | 0.031 | 0.45 | 0.085 |
| Yes | 9 (16.4) | 46 (83.6) | 2 (3.6) | 53 (96.4) | 8 (16.3) | 41 (83.7) | 3 (6.1) | 46 (93.9) |
| No | 12 (20.0) | 48 (80.0) | 10 (16.7) | 50 (83.3) | 8 (22.9) | 27 (77.1) | 7 (20.0) | 28 (80.0) |
| Pathological T stage | <0.001 | 0.003 | <0.001 | 0.043 |
| T2 | 3 (3.9) | 73 (96.1) | 3 (3.9) | 73 (96.1) | 4 (6.9) | 54 (93.1) | 3 (5.2) | 55 (94.8) |
| T3a | 10 (40.0) | 15 (60.0) | 7 (28.0) | 18 (72.0) | 6 (33.3) | 12 (66.7) | 5 (27.8) | 13 (72.2) |
| T3b | 8 (57.1) | 6 (42.9) | 2 (14.3) | 12 (85.7) | 6 (75.0) | 2 (25.0) | 2 (25.0) | 6 (75.0) |

ADT, androgen deprivation therapy. mpMRI, multiparametric magnetic resonance image. ADT, androgen deprivation therapy. DVC, dorsal vein complex.

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with reduced apical PSM rates. In addition, the former two were associated with better continence recovery. Sutureless DVC transection using a bipolar sealing device was unlikely to compromise continence recovery even in cases of anterior apical tumor, an independent risk

| Variables                              | Immediate recovery | 3-month recovery |
|----------------------------------------|--------------------|------------------|
|                                        | Univariable OR (95% CI) | P value | Multivariable OR (95% CI) | P value | Univariable OR (95% CI) | P value | Multivariable OR (95% CI) | P value |
| Age (years)                            | 0.98 (0.93–1.03)   | 0.50            | 1.01 (0.95–1.09)         | 0.78    |
| PSA (ng/mL)                            | 1.00 (0.99–1.01)   | 0.96            | 1.00 (0.99–1.01)         | 0.53    |
| Risk classification                     |                    |                 |                    |
| Low or intermediate                    | Reference          |                  | Reference          | 0.70    |
| High                                   | 0.75 (0.36–1.56)   | 0.45            | 0.69 (0.27–1.80)      | 0.45    |
| Locally advanced                       | 0.57 (0.26–1.21)   | 0.14            | 0.77 (0.28–2.10)      | 0.60    |
| Anterior apical tumor                  |                    | 0.025           | 0.017               | 0.005   |
| No                                     | Reference          |                 | Reference          | 0.003   |
| Yes                                    | 0.49 (0.27–0.91)   | 0.45 (0.23–0.87) | 0.30 (0.12–0.70)     | 0.28 (0.11–0.66) |
| Preoperative ADT                       | 0.67               |                 |                    |
| No                                     | Reference          | 0.45 (0.23–0.87) | 0.30 (0.12–0.70)     | 0.28 (0.11–0.66) |
| Yes                                    | 1.30 (0.55–3.32)   |                 |                    |
| Nerve-sparing surgery                  | 3.15 (1.67–6.05)   | 0.14            | 1.76 (0.77–4.32)     | 0.18    |
| Extrafascial or none                   | Reference          |                 | Reference          |         |
| Blood loss (including urine, mL)       |                    | 1.00 (1.00–1.00) | 1.00 (1.00–1.00)     | 0.31    |
| Puboprostatic open-collar technique    | 0.041              |                 |                    |
| Yes                                    | 3.53 (1.05–16.0)   | 2.84 (0.82–8.98) | 3.42 (0.93–11.7)     |         |
| No                                     | Reference          |                 |                    |
| Anterior reconstruction                | 0.21               |                 |                    |
| Yes                                    | 1.77 (0.72–4.65)   | 1.76 (0.59–4.75) | 0.29               |
| No                                     | Reference          |                 |                    |
| Retrograde urethral dissection         | 0.001              | 0.004           | 0.15               |
| Yes                                    | 2.84 (1.49–5.55)   | 2.73 (1.37–5.57) | 1.80 (0.81–4.01)     |         |
| No                                     | Reference          |                 |                    |
| Sutureless DVC transection             | 0.040              |                 | 0.77               |
| Yes                                    | 1.91 (1.03–3.58)   | 1.12 (0.50–2.48) |                    |
| No                                     | Reference          |                 |                    |
| PLND                                   | 0.14               |                 |                    |
| No                                     | Reference          |                 |                    |
| Standard                               | 0.40 (0.16–0.99)   | 0.046           | 0.54 (0.12–1.81)     | 0.34    |
| Extended                               | 0.42 (0.15–1.09)   | 0.075           | 0.51 (0.11–1.87)     | 0.32    |
| Pathological T stage                   | 0.58               |                 | 0.37               |
| yT0                                    | 0.53 (0.02–5.77)   | 0.61            | 7.32×10^0 (0.19–∞)   | 0.32    |
| T2 or yT2                              | Reference          |                 |                    |
| T3a or yT3a                            | 0.65 (0.28–1.43)   | 0.28            | 0.65 (0.25–1.84)     | 0.41    |
| T3b or yT3b                            | 1.29 (0.51–3.30)   | 0.59            | 0.49 (0.17–1.51)     | 0.20    |

ADT, androgen deprivation therapy. DVC, dorsal vein complex. PLND, pelvic lymph node dissection. OR, odds ratio. 95% CI, 95% confidence interval.

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factor of persisting urinary incontinence. Novel anatomical apical dissection utilizing a puboprostatic open-collar technique may contribute to both reducing PSM and early continence recovery among men undergoing 3D-RP.

In the original techniques for puboprostatic collar preservation, the DVC is divided proximal to the PPL [12, 13]. In our puboprostatic open-collar technique, exposure of the lateral aspects of the apex and DVC covering the rhabdosphincter allows for transecting the DVC distally beyond the tumor in cases of anterior apical tumor, which potentially secures safer resection margins and may reduce apical PSM. At the same time, preservation of the parietal PF, including the puboprostatic collar, plays a pivotal role in maintenance of urinary continence because the levator ani muscles support actions of the rhabdosphincter in continence mechanisms [18] and autonomic nerve branches of pelvic plexus to the rhabdosphincter run underneath the parietal PF [19]. Indeed, our puboprostatic open-collar technique appears to have contributed to reducing apical PSM and improving 3-month continence recovery, although the latter did not reach a statistical significance in multivariable analysis. Because of the significant reduction in apical PSM while maintaining early continence recovery, the puboprostatic open-collar technique may be considered in cases with anterior apical tumor.

Retrograde urethral dissection and NS were associated with better immediate continence recovery, which corroborated the importance of preservation of the functional urethral length [5, 7, 20] and NS [21] in maintaining urinary continence. Of note, these surgical procedures were not associated with better 3-months continence recovery. Given that the puboprostatic open-collar technique was applied to all and most (64/68) cases of retrograde urethral dissection and NS, respectively, these surgical procedures may contribute to immediate continence recovery on the background of preserved fascial structures of the pelvic floor.

Retrograde urethral dissection was also associated with reduced apical PSM in the overall patient group and those with anterior apical tumor. More importantly, retrograde urethral dissection appears to have contributed to reducing apical PSM in cases with anterior apical tumor (Table 3), which may be ascribed to the puboprostatic open-collar technique that visualizes the apical anatomy and sutureless distal DVC transection in such cases. Because sutureless DVC transection did not worsen early continence recovery in patients with anterior apical tumor, thermal injury to the rhabdosphincter using a sealing device seemed to be minimal.

The presence of anterior apical tumor on MRI negatively influenced early continence recovery but not apical PSM. In cases of anterior apical tumor, apical dissection was performed with an attempt of more distal transection of the DVC and modest retrograde urethral dissection. Such individualized modifications of apical dissection may account for poorer continence recovery while maintaining a relatively low apical PSM rate in such cases.

Despite their associations with reduced PSM, our modified surgical techniques were not associated with reduced risk of BCR. Unexpectedly, NS but not PSM was independently associated with BCR. In our practice, intra- or interfascial NS was carried out unless MRI-positive lesions contacted the prostatic capsule even in patients with high-risk disease when they desired NS. Indeed, about a half of patients undergoing NS procedures had high-risk disease. Although NS did not compromise PSM rates (13% vs. 18% in non-NS patients) in our cohort, applying stricter criteria of NS might reduce the risk of BCR following NS procedures.

Several limitations exist in the present study. First, this study of a small patient cohort has possible selection bias due to the retrospective nature. Second, this study involved multiple surgeons including residents and lacked consideration of their learning curves in 3D-RP. Our surgical team had been familiar with gasless single-port retroperitoneoscopic RP using a conventional 2D endoscope. Because use of the 3D-HMD system facilitated surgical procedures compared with a 2D endoscope, we feel that learning curve effects were minimal for 3D-RP performed under supervision by experienced surgeons in terms of oncological and functional
outcomes. Third, we did not evaluate the generalizability of our techniques in other minimally invasive modalities. In our experience, favorable oncological and functional outcomes have been obtained when applied to robotic RP. Reproducibility of our surgical techniques also needs to be evaluated. Fourth, we did not compare outcomes between the original puboprostatic collar preservation and open-collar technique. The original technique may yield better functional outcomes without compromising oncological outcomes in patients without apical tumor. Fifth, we did not preoperatively measure membranous urethral length, which reportedly influenced continence recovery [22]. Given that apical dissection was modified according to the tumor location, postoperative urethral length may also be important in our study cohort. Lastly, we did not assess postoperative sexual function.

5. Conclusions
Novel anatomical apical dissection utilizing a puboprostatic open-collar technique may favorably impact both the apical surgical margin and early continence recovery. These techniques warrant further studies to evaluate the generalizability and reproducibility of oncological and functional efficiency in minimally invasive RP other than 3D-RP.

Supporting information
S1 Video. Novel anatomical apical dissection including the puboprostatic open-collar technique, sutureless transection of the Dorsal Vein Complex (DVC), and retrograde urethral dissection. Surgical procedures are described in details.
(DOCX)

S1 Table. Associations of surgical procedures with postoperative continence recovery in patients with anterior apical tumor.
(DOCX)

S2 Table. Uni- and multivariable analysis for biochemical failure.
(DOCX)

S1 Data.
(XLSX)

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References

1. Smith JA Jr., Chan RC, Chang SS, Herrell SD, Clark PE, Baumgartner R, et al. A comparison of the incidence and location of positive surgical margins in robotic assisted laparoscopic radical prostatectomy and open retropubic radical prostatectomy. J Urol. 2007; 178(6):2385–9; discussion 9–90. https://doi.org/10.1016/j.juro.2007.08.008 PMID: 17936849

2. Sasaki H, Miki J, Kinuma T, Sanuki K, Miki K, Takahashi H, et al. Lateral view dissection of the prostaticurethral junction to reduce positive apical margin in laparoscopic radical prostatectomy. Int J Urol. 2009; 16(8):664–9. https://doi.org/10.1111/j.1442-2042.2009.02328.x PMID: 19862106

3. Tewari AK, Srivastava A, Mudaliar K, Tan GY, Grover S, El Douaihy Y, et al. Anatomical retro-apical technique of synchronous (posterior and anterior) urethral transection: a novel approach for ameliorating apical margin positivity during robotic radical prostatectomy. BJU Int. 2010; 106(9):1364–73. https://doi.org/10.1111/j.1464-410X.2010.02318.x PMID: 20377582

4. Kojima Y, Takahashi N, Haga N, Nomiya M, Yanagida T, Ishibashi K, et al. Urinary incontinence after robot-assisted radical prostatectomy: pathophysiology and intraoperative techniques to improve surgical outcome. Int J Urol. 2013; 20(1):1052–63. https://doi.org/10.1111/iju.12214 PMID: 23841851

5. van Randenborg H, Paul R, Kubler H, Breul J, Hartung R. Improved urinary continence after radical retropubic prostatectomy with preparation of a long, partially intraprostatic portion of the membranous urethra: an analysis of 1013 consecutive cases. Prostate Cancer Prostatic Dis. 2004; 7(3):253–7. https://doi.org/10.1038/sj.pcan.4500726 PMID: 15184863

6. Nyarangi-Dix JN, Radtke JP, Hadaschik B, Pahernik S, Hohenfellner M. Impact of complete bladder neck preservation on urinary continence, quality of life and surgical margins after radical prostatectomy: a randomized, controlled, single blind trial. J Urol. 2013; 189(3):891–8. https://doi.org/10.1016/j.juro.2012.09.082 PMID: 23017512

7. Schlomm T, Heinzner H, Steuber T, Salomon G, Engel O, Michl U, et al. Full functional-length urethral sphincter preservation during radical prostatectomy. Eur Urol. 2011; 60(2):320–9. https://doi.org/10.1016/j.eururo.2010.09.0318.x PMID: 20377582

8. Kihara K. Fundamentals of gasless single-port RoboSurgeon surgery. In: Kihara K, editor. Gasless single-port RoboSurgeon Surgery in Urology. Tokyo: Springer; 2015. p. 1–22.

9. Kihara K, Fujii Y, Masuda H, Saito K, Koga F, Matsuoka Y, et al. New three-dimensional head-mounted display system, TMDU-S-3D system, for minimally invasive surgery application: procedures for gasless single-port radical nephrectomy. Int J Urol. 2012; 19(9):886–9. https://doi.org/10.1111/j.1442-2042.2012.03044.x PMID: 22587397

10. Kihara K, Kawakami S, Fujiy, Masuda H, Koga F. Gasless single-port access endoscopic surgery in urology: minimum incision endoscopic surgery, MIES. Int J Urol. 2009; 16(10):791–800. https://doi.org/10.1016/j.juro.2009.02.040 PMID: 19694839

11. Matsuoka Y, Kihara K, Kawashima K, Fujiy. Integrated image navigation system using head-mounted display in "RoboSurgeon" endoscopic radical prostatectomy. Videoochir Inne Tech Maloinwazyny. 2014; 9(4):613–8. https://doi.org/10.5114/witm.2014.44135 PMID: 25562001

12. Takenaka A, Tewari AK, Leung RA, Bigelow K, El-Tabey N, Murakami G, et al. Preservation of the puboprostatic collar and pubоперineoplasty for early recovery of urinary continence after robotic prostatectomy: anatomic basis and preliminary outcomes. Eur Urol. 2007; 51(2):433–40; discussion 40. https://doi.org/10.1016/j.eururo.2006.07.007 PMID: 16904817

13. Tewari AK, Bigelow K, Rao S, Takenaka A, El-Tabi N, Te A, et al. Anatomic restoration technique of continence mechanism and preservation of puboprostatic collar: a novel modification to achieve early urinary continence in men undergoing robotic prostatectomy. Urology. 2007; 69(4):726–31. https://doi.org/10.1016/j.urology.2006.12.026 PMID: 17445659
14. Briganti A, Larcher A, Abdollah F, Capitanio U, Gallina A, Suardi N, et al. Updated nomogram predicting lymph node invasion in patients with prostate cancer undergoing extended pelvic lymph node dissection: the essential importance of percentage of positive cores. Eur Urol. 2012; 61(3):480–7. https://doi.org/10.1016/j.eururo.2011.10.044 PMID: 22078338

15. Gandaglia G, Fossati N, Zaffuto E, Bandini M, Dell'Oglio P, Bravi CA, et al. Development and Internal Validation of a Novel Model to Identify the Candidates for Extended Pelvic Lymph Node Dissection in Prostate Cancer. Eur Urol. 2017; 72(4):632–40. https://doi.org/10.1016/j.eururo.2017.03.049 PMID: 28412062

16. Gandaglia G, Ploussard G, Valerio M, Mattei A, Fiori C, Fossati N, et al. A Novel Nomogram to Identify Candidates for Extended Pelvic Lymph Node Dissection Among Patients with Clinically Localized Prostate Cancer Diagnosed with Magnetic Resonance Imaging-targeted and Systematic Biopsies. Eur Urol. 2019; 75(3):506–14. https://doi.org/10.1016/j.eururo.2018.10.012 PMID: 30342844

17. Mottet N, Comford P, van den Bergh RCN, Briers E, De Santis M, Fanti S, et al. EAU-EANM-ESTRO-ESUR-SIOG Guidelines on Prostate Cancer 2020 [Available from: https://uroweb.org/wp-content/uploads/EAU-EANM-ESTRO-ESUR-SIOG-Guidelines-on-Prostate-Cancer-2020v4.pdf.

18. Murakami G, Nakajima F, Sato TJ, Tsugane MH, Taguchi K, Tsukamoto T. Individual variations in aging of the male urethral rhabdosphincter in Japanese. Clin Anat. 2002; 15(4):241–52. https://doi.org/10.1002/ca.10015 PMID: 12112350

19. Akita K, Sakamoto H, Sato T. Origins and courses of the nervous branches to the male urethral sphincter. Surg Radiol Anat. 2003; 25(5–6):387–92. https://doi.org/10.1007/s00276-003-0151-9 PMID: 13680183

20. Hamada A, Razdan S, Etafy MH, Fagin R, Razdan S. Early return of continence in patients undergoing robot-assisted laparoscopic prostatectomy using modified maximal urethral length preservation technique. J Endourol. 2014; 28(8):930–8. https://doi.org/10.1089/end.2013.0794 PMID: 24739066

21. Takenaka A, Soga H, Sakai I, Nakano Y, Miyake H, Tanaka K, et al. Influence of nerve-sparing procedure on early recovery of urinary continence after laparoscopic radical prostatectomy. J Endourol. 2009; 23(7):1115–9. https://doi.org/10.1089/end.2008.0512 PMID: 19614811

22. Mungovan SF, Sandhu JS, Akin O, Smart NA, Graham PL, Patel MI. Preoperative Membranous Urethral Length Measurement and Continence Recovery Following Radical Prostatectomy: A Systematic Review and Meta-analysis. Eur Urol. 2017; 71(3):368–78. https://doi.org/10.1016/j.eururo.2016.06.023 PMID: 27394644