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Anatomical study of the prostatic urethra using vinyl polysiloxane casts

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Abstract

Background: There are limited studies describing the detailed nonhistologic anatomy of the prostatic urethra. We studied radical prostatectomy specimens to describe the ex vivo anatomical details of its shape and size.

Methods: We conducted an observational study examining the prostatic urethra anatomy. Prostatic urethra casts (molds) were made using vinyl polysiloxane immediately after fresh specimens had been retrieved following prostatectomy for organ-confined prostate cancer. The following measurements were taken from the casts: anterior length, posterior length, maximal diameter, bladder neck to verumontanum, verumontanum to apex length, and prostate urethral angle (PUA). Prostate volume was calculated using the ellipsoid formula: ((p/6) × transverse × length × height).

Results: Thirty-three prostatic urethral casts were obtained. The mean prostate volume was 38.59 cc. The mean PUA was 127.6°. The mean transverse, apex, and length of the prostate were 4.65, 4.06, and 3.63 cm, respectively. The mean distance from the verumontanum to sphincter was 1.2 cm. The ratio between the anterior and posterior length of the prostatic urethra was 0.82 cm and did not correlate with prostatic size (Figure 8).

Conclusion: The distance from the verumontanum to the apex does not change with prostate size; it is uniform with a mean length of 1.2 cm. The anterior length, posterior length, and maximum diameter of the prostatic urethra increase with prostate size. The mean difference between the anterior and posterior length is 0.8 cm and did not correlate with prostate size. Urethral angulation decreased with prostate size but was not significant. Information obtained from this study is of value designing prostatic stents and devices for benign prostatic hyperplasia.

KEYWORDS
anatomy, prostatic urethra, prostatic urethra angulation

1 | INTRODUCTION

Although there are several reports on the anatomy of the prostate and prostatic urethra, descriptions of the actual prostatic urethral shape and measurements are limited. Lowsley et al performed the first reconstruction of the prostatic urethra using a wax model in the 1920s. By 1981, McNeal[1-5] further described the prostatic urethra as an angled tube based on step sections of radical prostatectomy specimens. Other anatomic studies have described the prostatic urethra as a cylindrical tube based on imaging to recreate the prostatic urethra anatomy.[4]

While histologic aspects of the prostatic urethra are known, the spatial and temporal measurements and their relationship to the prostate volume are not well described. With the advancement of medical therapies and minimally invasive treatments, a better understanding of the prostate urethral anatomy can be of value for diagnosis and management of benign prostatic hyperplasia (BPH) as well as help in the design of new devices.

The purpose of this study is to document measurements of the prostatic urethra in aging men and correlate with the size of the prostate using urethral casts obtained with vinyl polysiloxane impression material.

2 | MATERIAL AND METHODS

We conducted an observational study examining the prostatic urethral anatomy. This study was approved by the local institutional review board. Men (aged >50 years old) with clinical stage T1c prostate cancer who underwent radical robotic prostatectomies at Stanford from 2018 to 2019 were recruited for this study. Immediately after the specimen was retrieved, a urethral cast was obtained by injecting vinyl polysiloxane from the apical end of the prostatic urethra. The cast set within 2 minutes was then removed from the proximal (bladder neck) side. The specimens were sent for histology and the cast used for all measurements. The impression made by the verumontanum on the cast was marked (Figures 1 and 2). Prostatic urethra casts were digitally photographed, traced and measured using the ImageJ software. ImageJ was utilized to measure selected areas of interest after scaled calibration using the freehand selection tool[6] (Figure 3). The following measurements were obtained from the casts: prostate urethral angle (PUA), anterior length, posterior length, maximal diameter, bladder neck to verumontanum, and verumontanum to apex length. The PUA was defined as the vertex angle formed by two rays of both the proximal and distal prostatic urethra. Prostate volume was calculated using the ellipsoid formula: ((p/6) × transverse × length × height). Basic clinical demographics were recorded.

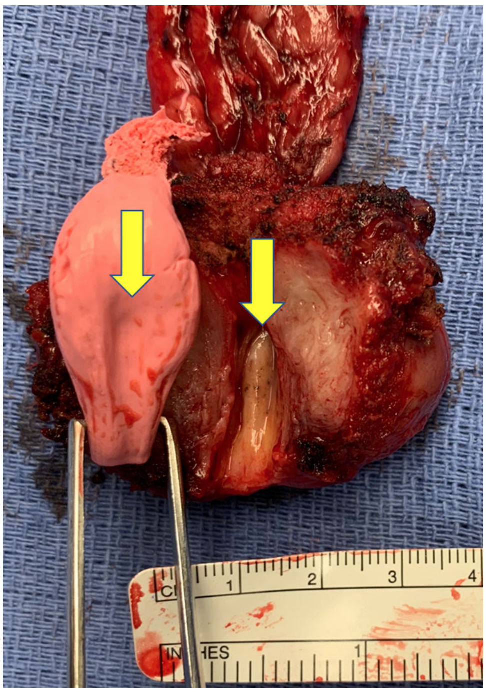

FIGURE 1 The verumontanum impression is seen on both the cast and specimen

FIGURE 2 Prostatic urethra cast and prostate specimen are shown

2.1 | Three-dimensional reconstruction

A three-dimensional (3D) model of the prostate urethral was generated from one of the prostatic urethral castings using Solidworks (Dassault Systems), a computer-aided design software. Using digital photographs of the prostate urethral casts, projections were scaled and created in three different planes and traces were stitched together. The 3D image of the prostatic urethra allowed for 360° rotation and cross-sectional observations to further study the anatomy (Figures 4-6).

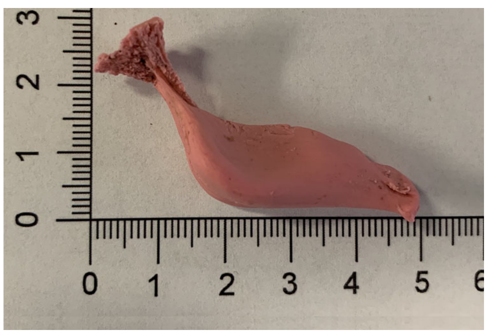

FIGURE 3 Prostatic urethra cast is measured using ImageJ

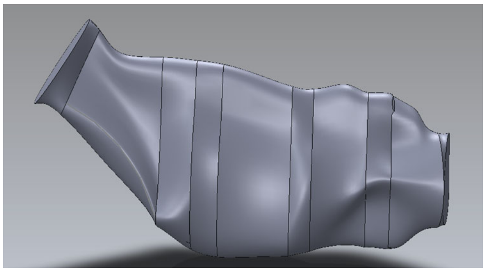

FIGURE 4 A three-dimensional view of the prostatic urethral was rendered using prostatic casts obtained [Color figure can be viewed at wileyonlinelibrary.com]

2.2 | Statistical methods

Continuous variables were examined for normality with the Kolmogorov-Smirnov univariate normality test. None met the criteria for transformation (D-statistics $P < .05$). Correlation of prostate volume, anterior/posterior length, verumontanum to the sphincter, angle, and maximum diameter of the urethra was assessed by the Pearson correlation test. Scatterplots of these variables were generated to illustrate the associations. All statistical tests were done at the two-sided P value .05 level of significance. Statistical analyses were performed using SAS, version 9.4 (SAS Institute Inc, Cary, NC).

3 | RESULTS

A total of 33 patients were included in the present study. Thirty-three prostatic urethra casts were created. The mean age of the cohort was 63 years. The mean prostate volume was 38.59 cc. The mean PUA was 127.57°. The mean transverse, apex, and length of the prostate were 4.65, 4.06, and 3.63 cm, respectively. The mean distance from the verumontanum to sphincter was 1.2 cm and this did not correlate with prostate size (Table 1). The maximal urethral diameter was the only measurement that correlated with prostate size (Figure 7).

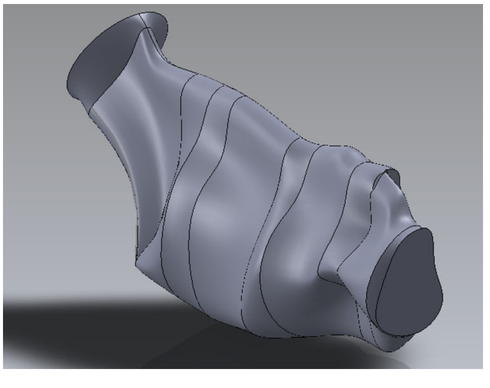

FIGURE 5 A side view of the three-dimensional rendition of the prostatic urethra [Color figure can be viewed at wileyonlinelibrary.com]

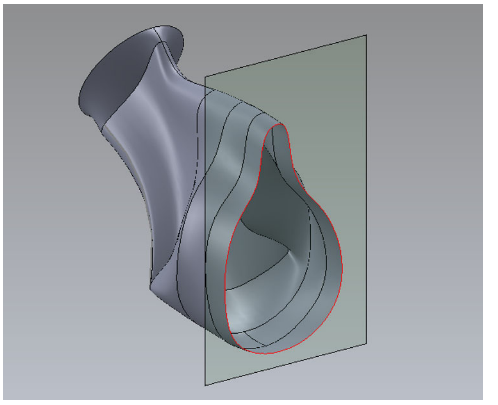

FIGURE 6 A cross-sectional view of the three-dimensional prostatic urethra [Color figure can be viewed at wileyonlinelibrary.com]

4 | DISCUSSION

Although there are a few studies on the anatomy of the prostate and prostate urethra, to our knowledge, this is the first study on the prostatic urethra examining casts on fresh radical prostatectomy specimens. These casts were used to obtain the size and shape of the prostatic urethra with a view to obtain data for designing prostatic urethral stents and devices (Figure 8).

Our study shows that the prostatic urethral cross-section is not a cylinder and there is consistent urethra angulation near the verumontanum. The cross-section of the bladder neck and apex of the prostate is circular but the rest is either a slit or triangular in cross-section, depending on the size of the prostate and presence of BPH. Previous studies have described the prostatic urethra in various shapes. McNeal first described the prostatic urethra as a nonlinear cylindrical tube.[5] By 1994, Ng et al[4] further describe the prostatic urethra, using transrectal ultrasound 3D imaging, as noncylindrical taking on crescentic or hourglass-shaped lumens. Cooney et al[1] described the cross-section of the prostatic urethra in canines was of "butterfly" shape.

The relevance of the PUA has been previously described and studied.[7] Our study showed that the angulation is consistently at the verumontanum, but we did not observe any correlation between the PUA and prostate size in our radical prostatectomy specimens (Table 2). Cho et al,[1,8,9] using a theoretical method, described the posterior urethral angle was inversely associated with urinary flow rate. Therefore, he hypothesized the urethra angulation may be involved in symptoms of BPH. He studied 65 healthy men without BPH, ages 50 to 59, and noted that the peak flow rate with significantly associated with PUA but not with the total prostate volume. Minagawa et al[10] similarly used sonourethrography with retrograde jelly in 43 patients showed that PUA is strongly correlated with urinary symptoms.

Our study was not designed to evaluate the functional correlation of the various anatomical measurements. In our study, most patients did not have symptomatic BPH and therefore we were unable to make any conclusions about

TABLE 1 Measurement of prostatic urethra characteristics from prostatic casts (n = 33)

Variable	Mean	Standard deviation	Median, (range)
Volume, cc	38.51	16.96	40.27, (10.04-78.29)
Posterior length, cm	4.86	0.96	4.66, (3.36-7.45)
Anterior length, cm	4.01	0.87	3.90, (1.90-5.81)
Verumontanum to apex, cm	1.2	0.37	1.17, (0.45-1.85)
Angle, °	127.57	13.69	126, (105-149)

the symptoms of BPH and PUA. However, urine flow dynamics of the prostatic urethra with tubular organ modeling have been previously described and speculated to have an impact on voiding functions.[11]

Although the anterior length, posterior length, and maximum diameter of the prostatic urethra increase with prostate size, the mean difference between the anterior and posterior length was 0.8 cm and did not correlate with prostate size (Table 2). Ko et al[2]

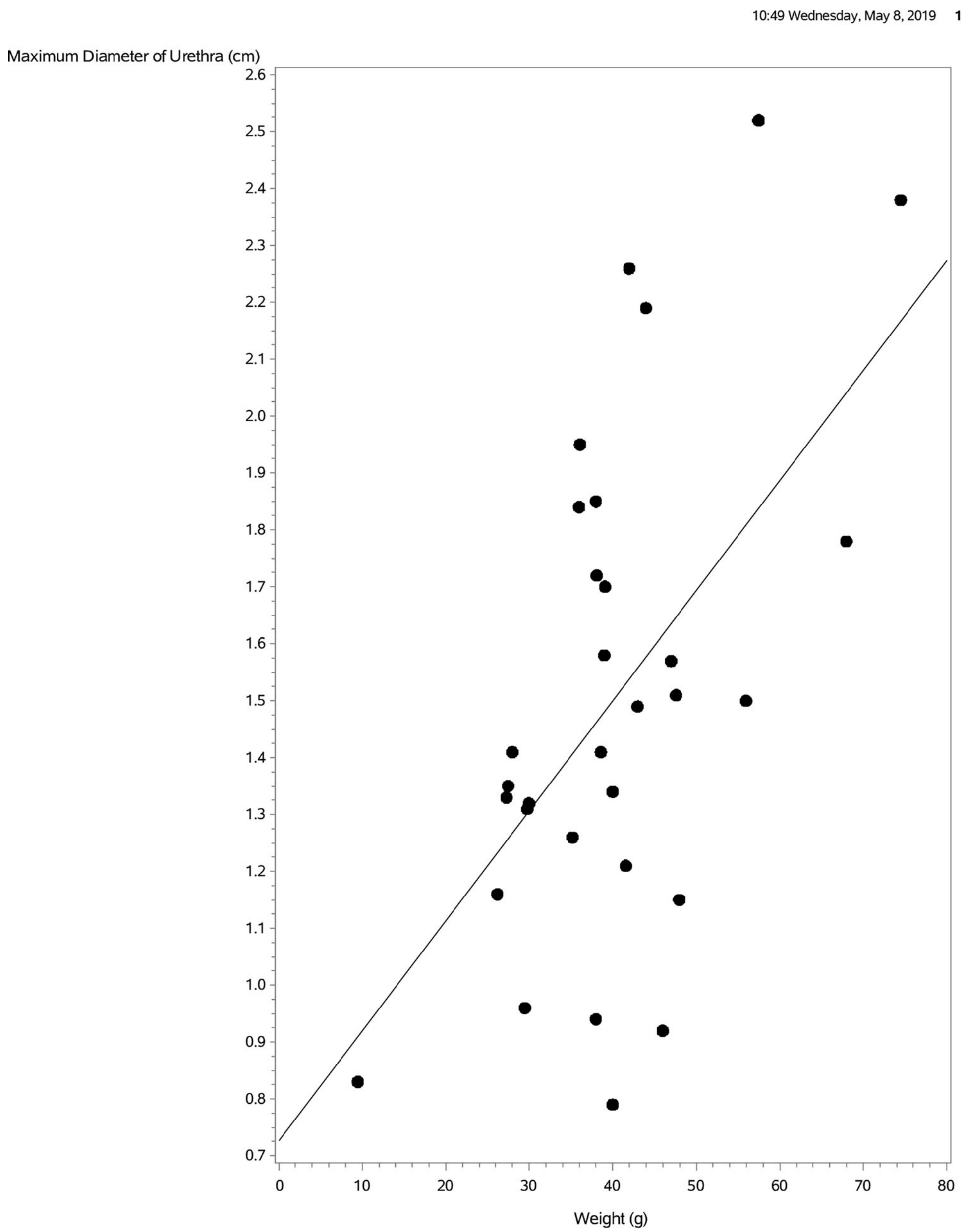

FIGURE 7 Scatterplot displaying regression line of maximum prostatic urethral diameter and prostate weight ($R = 0.46$, $P = .007$)

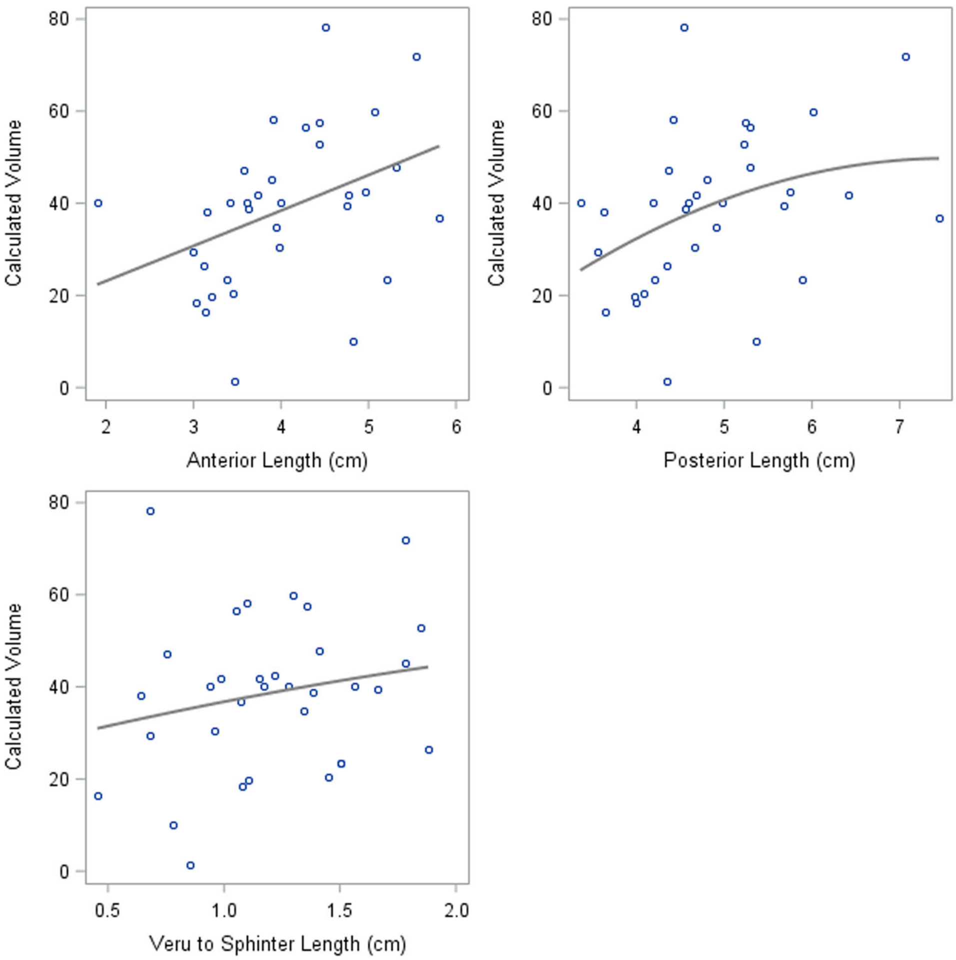

FIGURE 8 Scatterplot displaying regression line of anterior length (*P* = .02), posterior length (*P* = .04) and verumontanum to sphincter length (*P* = .26) in relation to prostate volume [Color figure can be viewed at wileyonlinelibrary.com]

described the ratio of the prostate urethra length to the prostatic volume in 293 patients with BPH using ultrasound and demonstrated that the ratio is significantly correlated with the severity of voiding symptoms. Kim et al[12] studied the clinical relevance of the total prostatic urethra length and transition zone urethra length. In 679 men studied at five different institutions, he found that prostatic urethra length and transitional zone urethra length were independently associated with BPH related surgery.

The distance from the verumontanum to the apex does not change with prostate size with a mean of 1.2 cm (Table 1). This provides a significant safety margin during transurethral prostate surgery in the prostate between the verumontanum and external sphincter. Shah et al[13] studied the anatomy of cadaver prostates and described the prostate tissue distal to the verumontanum varied from 10% to 50% of the total prostate volume but the size of prostates was not reported. Our study provides a further detailed measurement of this distance.

TABLE 2 *P* values according to Pearson's correlation between prostatic urethra characteristics to prostate weight

Variable	*R*	*P* value
Anterior length, cm	0.4	.02*
Posterior length, cm	0.36	.04*
Verumontanum to apex, cm	0.2	.26
Angle, °	−0.13	.5
Maximal diameter, cm	0.46	.007*

**P* < .05.

There were several limitations to this study. First, all patients had early-stage prostate cancer and not necessarily BPH. We did not have any data on urinary symptoms to correlate with prostatic anatomy. Thus functional relevance of these measurements cannot be speculated. Despite these limitations, this study has provided further insight into the actual morphology and anatomy of the prostatic urethra.

5 | CONCLUSION

The results of our study have demonstrated that the prostate volume is significantly associated with the following variables: anterior length, posterior length, angle, and maximal diameter. The detailed anatomic features from this study can help inform the design in the length and shape of prostatic stents and devices for BPH.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

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