TURKISH JOURNAL OF UROLOGY
Turk J Urol 2020; 46(1): 50-6 • DOI: 10.5152/tud.2019.19148
ENDOUROLOGY
Original Article

Inter-imaging accuracy of computed tomography, magnetic resonance imaging, and transrectal ultrasound in measuring prostate volume compared to the anatomic prostatic weight

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Cite this article as: Narayanamurthy V, Mishra K, Mahran A, Bukavina L, Ponsky L, Gnessin E. Inter-imaging accuracy of computed tomography, magnetic resonance imaging, and transrectal ultrasound in measuring prostate volume compared to the anatomic prostatic weight. Turk J Urol 2020; 46(1): 50-6.

ABSTRACT

Objective: To evaluate the accuracy of transrectal ultrasound (TRUS), computed tomography (CT), and magnetic resonance imaging (MRI) compared to the reference standard of the post-surgical anatomic prostatic weight (APW).

Material and methods: A total of 349 patients from two institutions were included. The CT and MRI dimensions, and TRUS-reported prostate volumes (PV) were obtained. The prolate ellipsoid formula was used to calculate PV. Cross-sectional measurements were evaluated and compared to the reported post-surgical pathology measurements and calculated pathology volume (path PV). A basic statistical analysis was performed using the Pearson correlation, Bland–Altman analysis, and Passing–Bablok regression.

Results: A total of 198 patients were included in the MRI group, 118 in the CT group, 295 in the TRUS group, and 51 in the all-inclusive common cohort. The MRI PV demonstrated a good to excellent correlation with the APW (r=0.79). The CT PV demonstrated a good correlation with APW (r=0.78). The TRUS PV showed a correlation with APW (r=0.67). The correlations identified in each individual group held true in the common cohort as well. The path PV showed an excellent correlation with APW (r=0.87), followed by MRI PV (r=0.81), then CT PV (r=0.73), and lastly TRUS PV (r=0.71).

Conclusion: MRI and CT are equally effective in assessing the PV, and they can be readily utilized to guide the benign prostatic hyperplasia (BPH) management without repeating in-office TRUS. This is not only cost-effective, but also eliminates patient anxiety and discomfort.

Keywords: Benign prostatic hyperplasia; CT; MRI; prostate volume; transrectal ultrasound.

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Submitted:
31.07.2019

Accepted:
31.10.2019

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Available online at
turkishjournalofurology.com

Introduction

Benign prostatic hyperplasia (BPH) with lower urinary tract symptoms is a common condition affecting the aging men, which severely impacts the quality of life and incurs significant expenses.[1] In fact, a 2005 study found the economic burden of BPH to be 3.9 billion dollars attributable to both direct (medical) and indirect (lost earnings from employment) costs.[2] As a result, there has been an increasing emphasis on cost-efficiency of prescribed interventions. Clinicians use the prostate volume (PV) as an objective parameter to assess the anatomy, select appropriate treatments, predict outcomes, and manage complications.[3] In addition, with the advent of new modalities for the management of BPH, it is ideal to individualize treatments based on PV since certain surgical modalities are better suited for smaller prostates than others.

While PV can be measured in several ways, transrectal ultrasonography (TRUS) with the prolate ellipsoid formula remains the most readily available and cost-effective method for approximation.[4-6] However, hand-held TRUS is highly operator-dependent with the intra-operator variability estimated at –21% to +30% of total PV.[7] In addition, this technique has been shown to underestimate PVs for glands larger than 50 mL, and to overestimate for glands smaller than 30 mL.[8]

It is also important to consider that a growing percentage of American patients have prior computed tomography (CT) or magnetic resonance imaging (MRI) scans. Previous studies have compared TRUS volumes using various techniques and formulas, and correlated these with digital rectal examination (DRE), CT, and MRI measurements.[9-14] A recent review has analyzed 28 articles comparing different modalities.[15] Only two of these articles analyzed by the review looked at PV calculated from CT.[16,17] In fact, to the best of our knowledge, no group has compared all three imaging (TRUS, CT, MRI) techniques within the same analysis.

In this study, we correlated the inter-imaging variability among all three commonly used imaging techniques (TRUS, CT, MRI) to the anatomic prostatic weight (APW), derived from the pathology report. We hypothesize that the CT and/or MRI assessments of the PV are more accurate than TRUS; therefore, recent scans obtained by patients can be reutilized for a preoperative PV evaluation.

Material and methods

After the institutional review board approval, a total of 349 patients who underwent robotic-assisted laparoscopic prostatectomy from two institutions were included (258 and 91 patients). Due to the retrospective nature of the study, no informed consent was necessary. All guidelines by the ethics approval committee were followed.

The APW was derived from the post-surgical pathology report, without the seminal vesicles, along with three prostatic dimensions (length, width, and height). The measurements of the pathology specimen and the size were performed prior to the introduction to formalin. The APW was determined by weighing the prostate on a scale. The correlation of 1 cm^3 of prostatic tissue is approximately 1 g; therefore, the volume was used as a surrogate for prostate weight.[18]

The MRI dimensions were provided in 198 out of 349 patients, 118 patients had CT dimensions, and 295 patients had the TRUS-reported PV (TRUS PV). PV were calculated using the prolate ellipsoid formula (height x length x width x p/6) from the dimensions obtained in the pathology report (path PV), CT scan (CT PV), and MRI (MRI PV). The path PV was compared to the APW. Additionally, the calculated PV from CT, MRI, and TRUS were compared to the APW.

Continuous variables were presented as the mean±standard deviation (SD). A paired student's two-tailed t-test and Pearson correlation were used to compare the calculated volumes from different imaging modalities to the APW. The Pearson correlation coefficients were categorized into poor (0), slight (0.01-0.20), fair (0.21-0.40), moderate (0.41-0.60), good (0.61-0.80), and strong (0.81-1.0). A Bland-Altman analysis and Passing-Bablok regression were performed to test the agreements between the different methods of imaging.

Statistical analysis

Statistical software (r.3.4.1) was used for statistical analysis. A p-value <0.05 was considered statistically significant.

Results

Overall, the study patients had a mean age of 64±6.6 years and a mean prostate specific antigen (PSA) of 10.4±7.5 ng/mL (Supplementary Table 1: Demographics-See https://doi.org/10.5152/tud.2019.19148). A strong correlation was identified (r=0.84) between the path PV and the APW. The upper and lower limits of agreement between the path PV and APW were 7 and –30 (Figure 1a).

MRI group

A total of 198 patients were included in this group. The MRI PV demonstrated a good to excellent correlation with the APW (r=0.79). The width and length showed a moderate correlation with the pathology width and length (r=0.47 and r=0.45, respectively), while the height showed fair correlation with the pathology height (r=0.33, Table 1). The upper and lower limits of agreement between the MRI PV and APW were 11 and –34 (Figure 1b).

CT group

A total of 118 patients were included in this group. The CT PV demonstrated a good to excellent correlation with APW (r=0.78). The width and length showed a moderate correlation with the pathology width and length (r=0.45 and r=0.47, respectively), while height showed a fair correlation with the path height (r=0.38; Table 1). The upper and lower limits of agreement between the CT PV and APW were 16 and –30 (Figure 1c).

TRUS group

A total of 295 patients were included in this group. The TRUS PV showed a good correlation with APW (r=0.67; Table 1). The upper and lower limits of agreement between the TRUS PV and APW were 13 and –38 (Figure 1d).

Common cohort

A total of 51 patients had all three imaging modalities. The correlations and the limits of agreements identified in each individual group listed above held true in this cohort as well (Figure 2). The path PV showed an excellent correlation with APW (r=0.87), followed by MRI PV (r=0.81), then CT PV (r=0.73), and lastly TRUS PV (r=0.71; Supplementary Table 2-See https://doi.org/10.5152/tud.2019.19148).

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DOI:10.5152/tud.2019.19148

Table 1. Correlation of pathology-reported prostate measurements compared to MRI, CT, and TRUS

Correlation between MRI and pathology measurements (n=198)

Variable	Path (mean±SD)	MRI (mean±SD)	Mean Diff (95% CI)	Paired T-test, p	r (95% CI)	Pearson corre-lation, p
Prostate height	3.98 (0.68)	4.33 (0.88)	0.35 (0.22, 0.48)	<0.001	0.33 (0.20–0.45)	<0.001
Prostate width	4.74 (0.69)	4.55 (0.78)	–0.14 (–0.25, –0.03)	0.001	0.47 (0.35–0.57)	<0.001
Prostate length	3.97 (0.60)	3.79 (0.75)	–0.19 (–0.30, –0.08)	0.001	0.45 (0.34–0.56)	<0.001
APW/MRI PV	52.17 (16.10)	40.52 (18.49)	–11.6 (–13.3, –10.03)	<0.001	0.79 (0.73–0.83)	<0.001

Correlation between CT and pathology measurements (n=118)

Variable	Path (mean±SD)	CT (mean±SD)	Mean Diff (95% CI)	Paired T-test, p	r (95% CI)	Pearson corre-lation, p
Prostate height	3.98 (0.75)	4.40 (0.73)	0.42 (0.27, 0.57)	<0.001	0.38 (0.21–0.52)	<0.001
Prostate width	4.76 (0.75)	5.07 (0.74)	0.31 (0.17, 0.45)	<0.001	0.45 (0.30–0.59)	<0.001
Prostate length	3.95 (0.61)	3.81 (0.63)	–0.14 (–0.26, -0.02)	0.02	0.47 (0.32–0.60)	<0.001
APW/CT PV	52.72 (18.53)	45.74 (17.48)	–7 (–9.1, –4.8)	<0.001	0.78 (0.70–0.84)	<0.001

Correlation between TRUS and pathology measurements (n=295)

Variable	Path (mean±SD)	TRUS (mean±SD)	Mean Diff (95% CI)	Paired T-test, p	r (95% CI)	Pearson corre-lation, p
APW/TRUS PV	51.20 (15.95)	38.66 (16.37)	–12.5 (–14.04, –11.03)	<0.001	0.67 (0.60–0.73)	<0.001

MRI: magnetic resonance imaging; CT: computed tomography; TRUS: transrectal ultrasound; APW: anatomic prostatic weight; PV: prostate volume calculated using prolate ellipsoid formula; Diff: difference; Path: pathology

Discussion

The diagnosis and treatment of BPH is becoming increasingly sophisticated, and estimating the PV is an important step in guiding treatment. Knowing the PV prior to surgical intervention may help determine the ideal surgical modality, as larger prostates may require more invasive procedures, while smaller prostates may be amenable to medical treatment, or minimally invasive surgical therapies. The AUA guidelines suggest that clinicians should consider assessing the shape and size of the prostate either by transrectal or abdominal ultrasound, cystoscopy, or by pre-existing cross-sectional imaging (i.e., CT/MRI) prior to intervention for BPH.[19] In our experience, clinicians often repeat the volume evaluation prior to surgical intervention using in-office TRUS. Since the reported prostatic growth rate is only 1.6% per year on average, recent cross-sectional imaging (CT, MRI) may be reutilized for volume estimation during presurgical evaluation.[20]

Previous studies have compared TRUS volumes using various techniques and formulas, and correlated these with DRE, CT, and MRI measurements.[9-14] However, none of these studies have correlated the inter-imaging variability between TRUS, CT, and MRI to the post-surgical APW.[6,11,12] While planimetry has been assumed to be the most accurate method for the PV assessment in previous studies, this technique is expensive and time-consuming, and it is not often employed in clinical practice.[4-6,21,22] In our study, we employed the widely used prolate ellipsoid formula for all calculations of PV. We compared the volumes calculated with TRUS, CT, and MRI to the APW obtained from pathology reports.

The MRI PV demonstrated the best agreement to the APW, followed by CT, and then TRUS; however, the absolute differences between these three groups were minimal (Figure 3). This pattern was consistent with the correlation as well, with TRUS showing the lowest correlation with APW (r=0.67; Table 1). Our results indicate that both MRI and CT scans are more accurate than TRUS for calculating PV, with MRI being the most accurate imaging modality.

In addition to the higher accuracy, there are also patient comfort and cost-efficiency considerations that support the reutilization

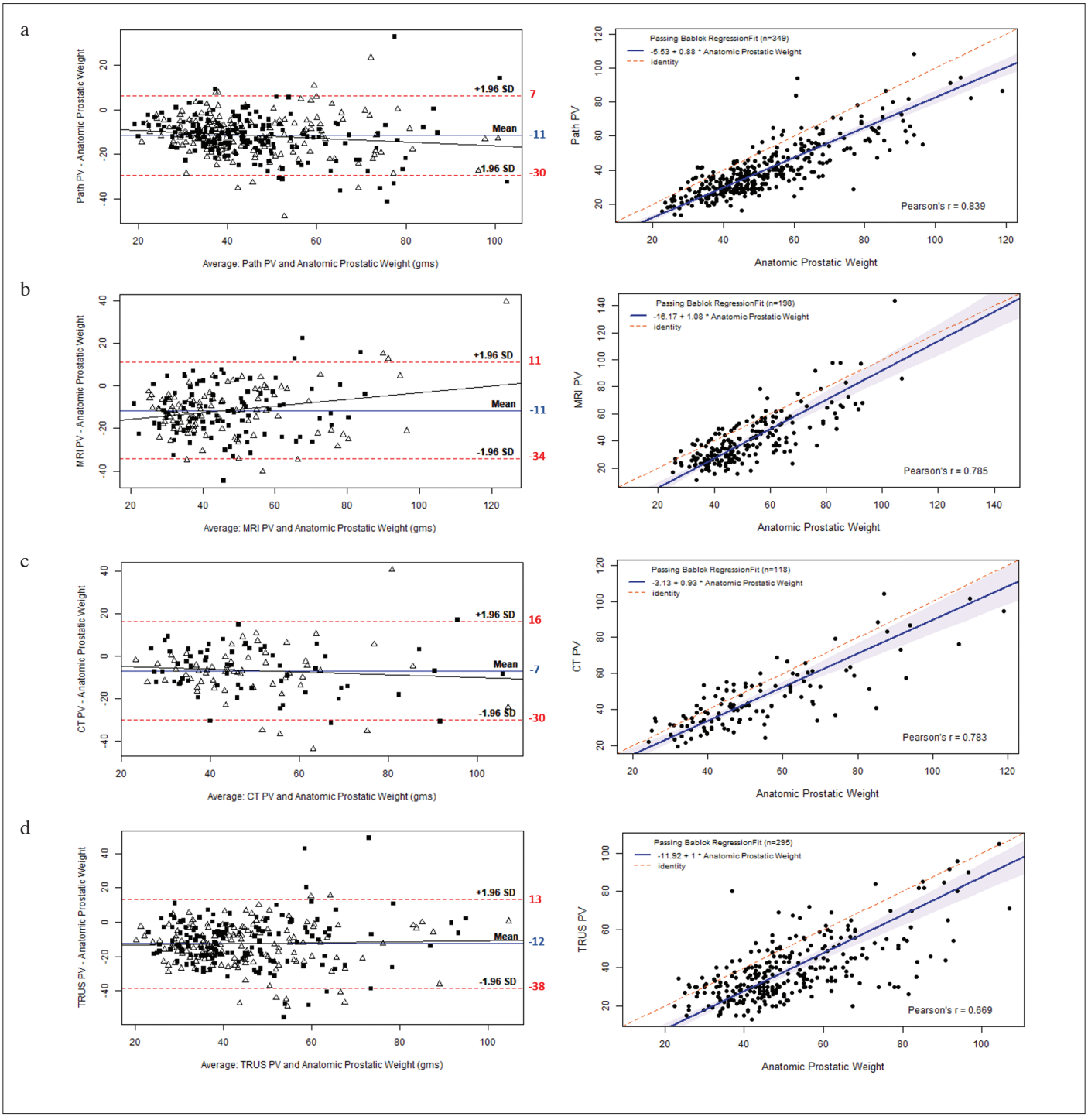

Figure 1. a-d. MRI, CT, and TRUS groups compared to pathology-reported measurements. (a) Path PV (n= 349), (b) MRI PV (n=198), (c) CT ellipsoid PV (n=118), and (d) TRUS ellipsoid PV (n=295): the Bland–Altman plot (left) and the Passing–Bablok regression (right)
MRI: magnetic resonance imaging; CT: computed tomography; TRUS: transrectal ultrasound; Path: pathology; PV: prostate volume; SD: standard deviation. Prostate volumes were calculated using the prolate ellipsoid formula

of existing CT and MRI scans. TRUS is an invasive technique that induces anxiety and pain for the patient. This is particularly exacerbated in patients with a history of sexual abuse, external hemorrhoids, previous anal surgery, or stool in the rectum during the procedure.[23] While some pain may be alleviated with strategies such as using a local anesthetic, a microconvex transducer, or with distraction interventions (i.e., breathing, music), reutilizing existing scans completely avoids these issues.[23,24]

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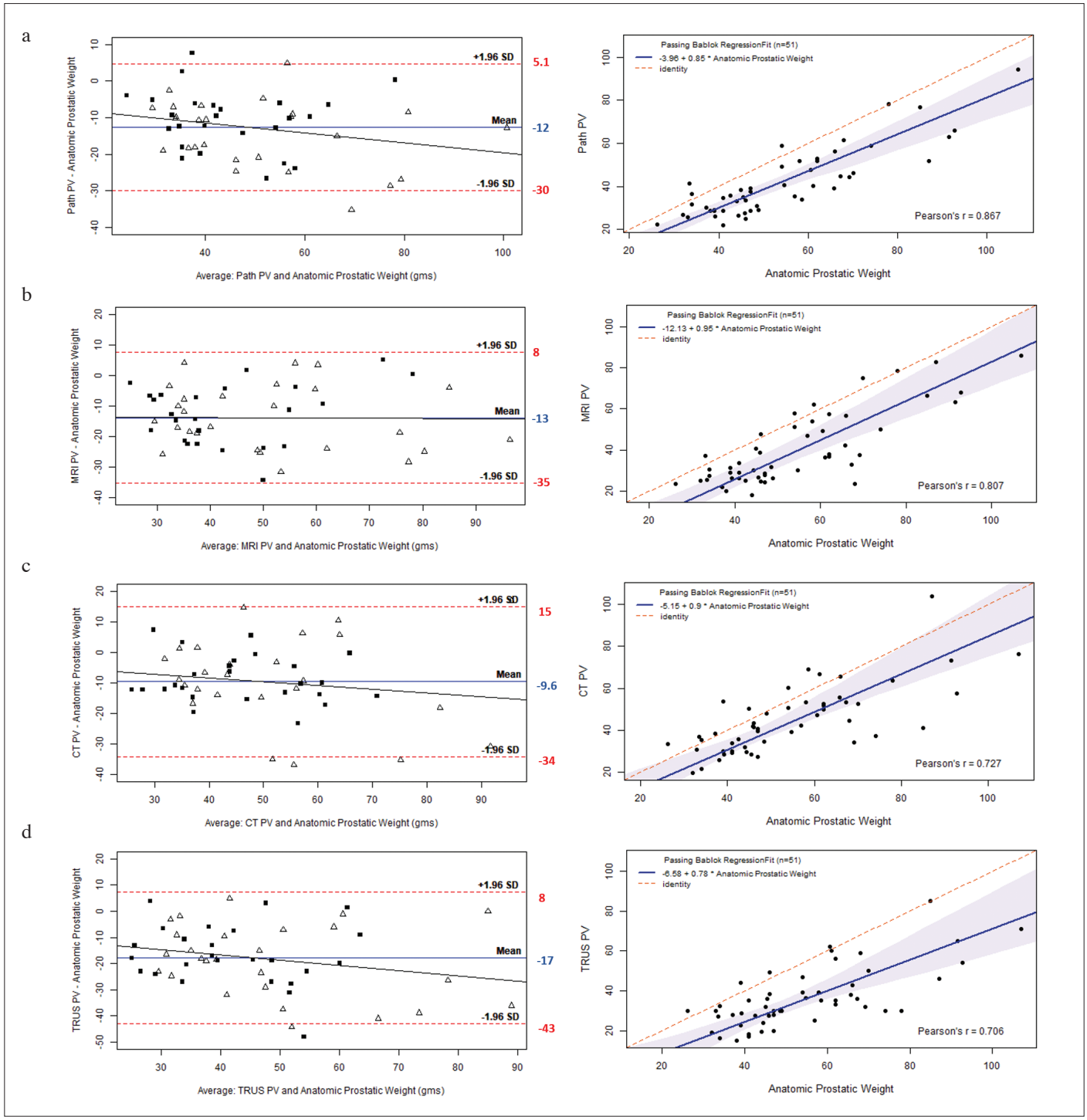

Figure 2. a-d. Common cohort. (a) Path PV (n=51), (b) MRI PV (n=51), (c) CT PV (n=51), and (d) TRUS PV (n= 51): the Bland–Altman plot (left) and the Passing–Bablok regression (right)
MRI: magnetic resonance imaging; CT: computed tomography; TRUS: transrectal ultrasound; Path: pathology; PV: prostate volume; SD: standard deviation. Prostate volumes were calculated using the prolate ellipsoid formula.

The second consideration is the cost associated with repeat imaging in an already financially cumbersome condition. Studies focusing on the economics of BPH reveal that 12.2 million men are actively managed for the condition each year in the United States. Of these, 54.8% are treated with medication, 1.1% with surgical interventions, and 35.0% are under watchful observa-

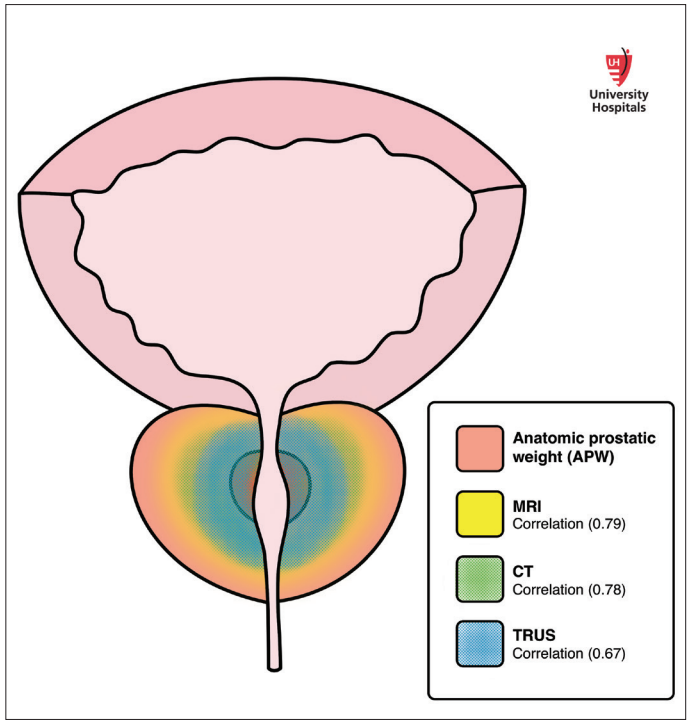

Figure 3. Schematic representation of prostate volumes calculated from MRI, CT, and TRUS and compared with the anatomic prostatic weight.
MRI: magnetic resonance imaging; CT: computed tomography; TRUS: transrectal ultrasound

tion.[25] The overall BPH cost of care has been estimated to be between 2.3 to 4 billion dollars per year.[26] With the prevalence of BPH and the aging population, these costs are only expected to increase in the future. Clearly this condition incurs significant financial burden, and it is imperative that cost-effective approaches be examined and optimized. The cost of each in-office TRUS performed at our institution is 190 dollars. This superfluous expense may be avoided by reutilizing existing patient scans.

Our retrospective study has some limitations. We included CT, MRI, and TRUS imaging scans from within 2.5 years of the surgical intervention; hence, there may be some degree of prostatic growth during that time interval. Therefore, clinicians should be judicious in reutilizing imaging that may be too far removed from the planned surgery. In addition, we were only able to obtain the PV from TRUS without the individual dimensions. Therefore, comparisons of the TRUS length, width, and height could be not performed in relation to the pathology measurements. Finally, there are inherent flaws to the prolate ellipsoid formula. Previous studies utilizing this formula have demonstrated the intra-observer variability and sensitivity to artifact (i.e., stool burden in the rectal vault), in addition to under- or overestimating PV depending on the gland size.[7,8,12] We find these shortcomings to hold true in our study as well, where we observed a significant difference between the APW and the calculated path PV. The volume measured from pathology should correlate perfectly with the APW; however, we found a difference (r=0.84). Both CT (r=0.78) and MRI (r=0.79) achieved good correlation to APW, which was very close to the path PV (our "gold standard" in this study).

In conclusion, several studies that have compared volume measurements from different imaging techniques. However, very few studies have looked at PVs calculated from CT. Here we expanded the available literature by correlating the inter-imaging variability among all three commonly used imaging techniques to the prostatic weight derived from the pathology report. Our results suggest that PVs calculated using CT and MRI scans are more accurate when compared to TRUS. Hence, recent imaging may be utilized to guide therapy in patients presenting with BPH. Patients and practitioners may be able to avoid the anxiety, discomfort, and superfluous cost associated with repeating in-office TRUS by reutilizing existing scans.

You can reach the questionnaire of this article at https://doi.org/10.5152/tud.2019.19148.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of University Hospitals Cleveland Medical Center IRB Study (20180322).

Informed Consent: Due to the retrospective design of the study, informed consent was not taken.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - V.N., K.M., A.M., L.B., L.P., E.G.; Design - V.N., K.M., A.M., L.B., L.P., E.G.; Supervision - L.P., E.G.; Resources - V.N., K.M., A.M., L.B., L.P., E.G.; Materials - V.N., K.M., A.M., L.B., L.P., E.G.; Data Collection and/or Processing - V.N., K.M., A.M., L.B., L.P., E.G.; Analysis and/or Interpretation - V.N., K.M., A.M., L.B., L.P., E.G.; Literature Search - V.N., K.M., A.M., L.B., L.P., E.G.; Writing Manuscript - V.N., K.M., A.M., L.B., L.P., E.G.; Critical Review - V.N., K.M., A.M., L.B., L.P., E.G.

Acknowledgements: We thank Christina Antonopoulos for her assistance in providing us with the cost of the TRUS procedure in our hospital.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

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Supplementary Table 1A. Demographics by institution

	Total (n=349)	First institution (n=258)	Second institution (n=91)	p
Age: mean (SD)	64 (6.6)	63.6 (6.7)	65.3 (6.4)	0.032
BMI: mean (SD)	29.29 (5.10)	29.53 (5.30)	28.61 (4.44)	0.142
PSA: mean (SD)	10.35 (7.47)	10.59 (8.16)	9.69 (5.03)	0.324
Anatomic Prostatic Weight: mean (SD)	51.58 (16.73)	50.82 (16.57)	53.71 (17.08)	0.158

Student T-test. BMI: body mass index; PSA: prostate specific antigen; SD: standard deviation

Supplementary Table 1B. Demographics by cross-sectional imaging

	MRI (n=198)	CT (n=118)	TRUS (n=295)	p
Age: mean (SD)	63.9 (6.6)	64.4 (6.9)	64.3 (6.3)	0.75
BMI: mean (SD)	29.44 (5.29)	28.86 (5.21)	29.23 (4.97)	0.622
PSA: mean (SD)	10.78 (9)	11.70 (10.38)	10.43 (7.67)	0.411

Analysis of variance. BMI: body mass index; PSA: prostate specific antigen; SD: standard deviation

Supplementary Table 2. Correlation of pathology-reported prostate measurements compared to imaging in the common cohort

Correlation between MRI, CT, and TRUS, and pathology measurements in the common cohort (n= 51)

Variable	Path (mean±SD)	MRI (mean±SD)	Mean Diff (95% CI)	Paired T-test, p	r (95% CI)	Pearson cor-relation, p
Prostate height	3.96 (0.78)	4.26 (0.85)	0.31 (0.09, 0.52)	0.007	0.55 (0.33–0.72)	<0.001
Prostate width	4.90 (0.72)	4.59 (0.72)	–0.31 (–0.50, –0.12)	0.002	0.55 (0.32–0.72)	<0.001
Prostate length	4.01 (0.56)	3.82 (0.79)	–0.19 (–0.40, 0.02)	0.07	0.44 (0.18–0.64)	<0.001
APW/MRI PV	54.33 (17.73)	40.43 (17.60)	–13.9 (–16.99, –10.8)	<0.001	0.81 (0.68–0.86)	<0.001
Variable	**Path (mean±SD)**	**CT (mean±SD)**	**Mean Diff (95% CI)**	**Paired T-test, p**	**r (95% CI)**	**Pearson cor-relation, p**
Prostate height	3.96 (0.78)	4.33 (0.65)	0.37 (0.14, 0.61)	0.002	0.34 (0.08–0.56)	0.02
Prostate width	4.90 (0.72)	5.08 (0.65)	0.18 (–0.01, 0.38)	0.07	0.48 (0.24–0.67)	<0.001
Prostate length	4.01 (0.56)	3.78 (0.58)	–0.23 (–0.41, –0.05)	0.01	0.38 (0.11–0.59)	0.007
APW/CT volume	54.33 (17.73)	44.78 (15.95)	–9.6 (–13.08, –6.02)	<0.001	0.73 (0.57–0.84)	<0.001
Variable	**Path (mean±SD)**	**TRUS (mean±SD)**	**Mean Diff (95% CI)**	**Paired T-test, p**	**r (95% CI)**	**Pearson cor-relation, p**
APW/TRUS Volume	54.33 (17.73)	36.47 (14.97)	–17.9 (–21.5, –14.3)	<0.001	0.71 (0.53–0.82)	<0.001

MRI: magnetic resonance imaging; CT: computed tomography; TRUS: transrectal ultrasound; APW: anatomic prostatic weight; PV: prostate volume calculated using prolate ellipsoid formula; Diff: difference; Path: pathology