

Received November 18, 2019, accepted November 30, 2019, date of publication December 10, 2019, date of current version December 31, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2958565

Identifying Benign Prostatic Hyperplasia Stages by Measuring the Length of the Proximal Prostatic Urethra: An Operator-Error-Free Early-Screening Ultrasonography Method With a Uniquely-Calibrated Standardized Plane

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The National Key Research and Development Plan Digital Diagnosis and Treatment Specificity Project (NO. 2017YFC0113800) was supported by Shanghai Municipal Health Commission, China.

ABSTRACT Recently, it has become a main consensus that early diagnosis of benign prostatic hyperplasia (BPH) is meaningful in delaying disease progression. Although ultrasound has been well recognized as the most useful early screening technique, the lack of a standard observation plane makes it difficult to determine the BPH stages in a way that is operator-independent and satisfies clinical expectations. Strong enthusiasm has fueled intense research on ultrasound coupled with artificial intelligence (AI) for automated or semiautomated classification of different clinical diseases. Therefore, it is crucial to formulate standard planes for ultrasound imaging with the implementation of AI to evaluate BPH. This study was a preliminary examination of AI-assisted ultrasound in the prostate disease diagnostic classification task, which aimed to define and assess the clinical value of the length of the proximal prostatic urethra (Lppu), detected via transrectal ultrasound within the uniquely calibrated standardized plane, in 643 patients suffering from BPH between January 2015 and December 2016. International Prostate Symptom Score (IPSS), quality of life (QoL) and PSA levels were also recorded. The mean (standard deviation) of Lppu was 28.54 mm (9.19 mm), and there were significant differences in the mean Lppu among men who were over 50 yrs old. Lppu was colinear with IPSS, voiding-IPSS, storage-IPSS and QoL with individual r values of 0.13, 0.09, 0.04, and 0.03, respectively ($P < 0.001$). Compared with the traditional ultrasound screening indicator represented by transitional zone index (TZI), the main advantage of measuring Lppu is that it is reasonable in terms of the pathophysiological characteristics of BPH, it is operator-error-free, it is based on the uniquely-calibrated observation plane, and it is effective in guiding personalized management of BPH, especially among men with severe LUTS but small prostates. Furthermore, this screening method is economical and improves the cost-efficiency of public health. After systematic evaluation, Lppu is believed to be an excellent quantitative measurement parameter and early screening tool for evaluating LUTS/BPH and BPH stages.

INDEX TERMS Transrectal ultrasound, benign prostatic hyperplasia, the length of the proximal prostatic urethra, early screening, ultrasound diagnostic criteria.

I. INTRODUCTION

As the most common prostate disease, benign prostatic hyperplasia (BPH) is found in almost every aging male. BPH

The associate editor coordinating the review of this manuscript and approving it for publication was Chua Chin Heng Matthew¹.

is the main reason for male lower urinary tract symptoms (LUTS) [1]. It is often first only a nuisance and can be easily overlooked. Men usually visit urologists after a significant LUTS event such as nocturia, frequency, urgency, hesitancy, and a sense of incomplete emptying of the bladder. LUTS suggestive of BPH (LUTS/BPH) has a significant impact

on quality of life. It is estimated that 90% of men between 45 and 80 yrs of age have LUTS/BPH, and the prevalence increases linearly with age [2]. In China, men below 50 yrs old seldom visit urologists for the presence of BPH. In the end stages of BPH, the obstruction of the urethra leads to bladder dysfunction and renal failure. Early intervention is recommended to improve patient outcomes and quality of life. Therefore, early screening for BPH is a high-priority target in the field of urology and radiography.

Unfortunately, convincing early screening radiography methods are very limited as present in identifying the BPH stages. Due to the invasiveness of many urological investigations, researchers have sought to discover noninvasive urodynamic and nonurodynamic methods, which mainly focus on ultrasound screening. For a long time, researchers tended to measure the prostate accurately and to determine clinical correlations for all prostate measurement values by comparing them with the symptoms of LUTS [3], [4]. More detailed prostate information can be detected via transrectal ultrasound (TRUS) than with abdominal ultrasound. A more precise length, width, and height of both the total and transitional zone of the prostate, prostatic urethral angle (PUA) [5], peripheral zone thickness (PZT) [6], and transitional zone index (TZI) have been measured with TRUS. TZI, the volume ratio of the transitional zone to the whole prostate, is more closely related to LUTS and peak urinary flow than to the size of the entire gland in patients with LUTS/BPH. Patients with a higher TZI may easily develop acute urinary retention [7], [8]. Despite these efforts, the application of a standardized plane for ultrasound inspection has always been a problem because the ultrasound images are highly operator-dependent. Consequently, the practical diagnostic value of ultrasound imaging is usually ignored by clinicians.

AI, known as machine learning and deep learning, is the ability of a machine to perform measured actions and maximize the chance of success for a specified goal. A classic example of AI in radiology is the automatic characterization of a lung nodule as benign or malignant using computed tomography (CT) [9]. High-quality standard images and large CT and magnetic resonance imaging (MRI) datasets enable AI to participate in the diagnosis, which is relevant to the development of a precise, personalized, and participative radiology practice characterized by improved preventive and predictive capabilities [10], [11]. In recent years, the use of ultrasonography coupled with AI techniques has become an important evaluation tool in prostate diseases given its ease of use, lack of contraindications, and improved resolution for soft tissue structures. However, the lack of standardization of ultrasound images has hampered its widespread use.

Given the goal of developing a confined and standardized early screening criterion for evaluating LUTS/BPH and the BPH stages, the physiological and anatomical structure of BPH should be fundamentally understood. Since the prostate has a strong anatomic relationship with the prostatic urethra, it was considered that the mechanisms of LUTS may be partly explained by urethral geometric changes.

The primary pathological characteristic of BPH is the enlargement of the mid-lobe, which extrudes into the prostatic urethra. One alternative surgery for BPH is called hemi-TURP [12], which involves resection of the middle lobe. This procedure removes prostate tissues to the point of verumontanum to relieve LUTS symptoms. Based on the above findings, this study aimed to use a new measurement, the length of the proximal prostatic urethra (Lppu), to identify the stages of BPH and to describe the changes in the urethra as the disease progresses.

In this study, we define and assess the clinical value of Lppu, detected via transrectal ultrasound within the uniquely-calibrated standardized plane in 643 patients suffering from BPH between January 2015 and December 2016. We hope that, by establishing a standardized plane to grade BPH, we will provide ideas for the diagnosis and treatment of BPH using ultrasound coupled with AI. International Prostate Symptom Score (IPSS), quality of life (QoL) and PSA levels were also recorded; the traditional clinical value of TZI was also calculated and used as a control to evaluate the diagnostic value of proposed Lppu. Regarding the common concerns in the fields of urology and radiology, we mainly focus on the methods of determining ultrasonography measurements and the ability to use these measurements to personalize medicine for management of BPH issues. Lppu performed with remarkable diagnostic accuracy and clinical practicability. Lppu is a simple value, but it makes great sense. The advantages, limitations and applicability of this new diagnostic criterion will also be systematically described in this paper.

II. PATIENTS AND METHODS

A. PATIENT SELECTION

From January 2015 to December 2016, consecutive patients who attended Shanghai Sixth Peoples Hospital with LUTS/BPH as the final diagnosis were enrolled in the study. Patients with LUTS/BPH were defined as those who had LUTS that were mainly caused by BPH. All patients were evaluated with TRUS and asked to complete an IPSS and QoL questionnaire. Informed consent was waived because of the retrospective nature of the study. The diagnostic criteria were based on the following points: 1) a history of LUTS, including voiding symptoms such as nocturia, frequency, urgency, and hesitancy, and storage symptoms, such as a sense of incomplete emptying of the bladder; and 2) TRUS showed an enlarged prostate, mainly in the inner gland. The exclusion criteria were: 1) a documented history of prostate cancer and/or bladder cancer; 2) PSA > 10.0 ng/ml; 3) PSA between 4.0 and 10.0 ng/ml with the requirement of a puncture and biopsy to exclude prostate cancer; 4) a history of lower urinary tract surgery; 5) use of medications affecting LUTS (e.g., phosphodiesterase type 5 inhibitor, α 1-acceptor blockers) over the prior three months; 6) a history of cerebrovascular events, diabetes mellitus and/or neurogenic diseases that can influence voiding symptoms; and 7) an inability to read, understand or complete IPSS and

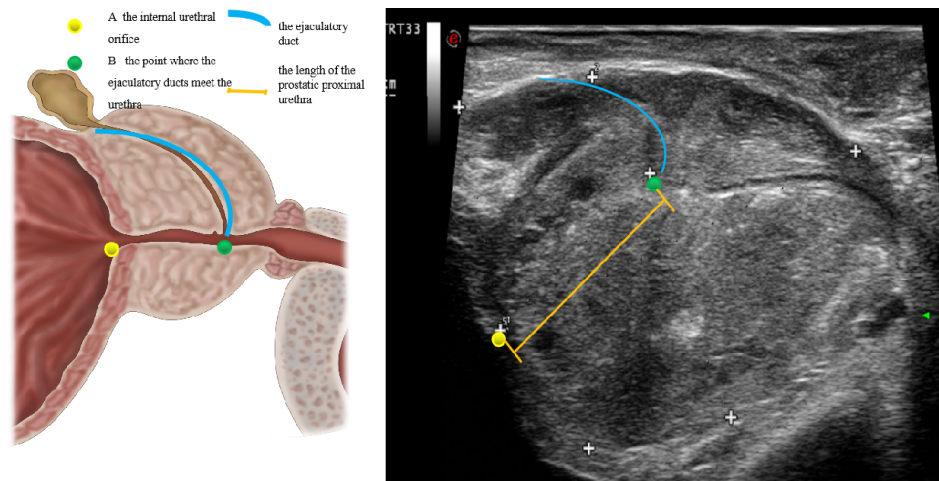


FIGURE 1. The uniquely-calibrated standardized measuring plane for Lppu. The uniquely-calibrated standardized plane was determined by three landmarks: the internal urethral orifice, the ejaculatory ducts and the point where the ejaculatory ducts meet the urethra. Lppu was defined as the distance from the beginning of the prostatic urethra to the point where the ejaculatory ducts meet the urethra in the mid-sagittal view (the distance between the points).

QoL questionnaire. All the results, including the test and questionnaire, were obtained within 1 month after the first visit. The study was approved by the Ethics Committee of the hospital. In total, 643 patients were enrolled in the study.

B. TREATMENT PROCESS

1) CONVENTIONAL CLINICAL SYMPTOMS ASSESSMENT

The questionnaire was completed by the patient at the time of the urologist consultation. The total IPSS score (tIPSS) was calculated as the sum of voiding symptom score (vIPSS) and storage symptom score (sIPSS).

2) CONVENTIONAL ULTRASOUND MEASUREMENT

All patients were assessed by two ultrasound doctors at two sessions via transrectal ultrasound (TRUS) using a MyLab Twice scanner (Esaote, Genoa, Italy) with a 4-13 MHz transverse sector probe (TRT33). Before the examinations, neither of the two doctors was informed of the basic information of the patients. The interval between the evaluation by the two doctors was no more than 30 minutes. The second doctor did not know the ultrasound results of the first doctor. The following parameters were assessed: the

length, width, and height of the prostate and the height, length, and width of the transitional zone (marked as TZH, TZL, and TZW, respectively).

3) DETERMINATION OF THE STANDARDIZED PLANE AND MEASUREMENT OF LPPU

The uniquely-calibrated standardized plane for measuring Lppu was determined by three landmarks: the internal urethral orifice, the ejaculatory ducts and the point where the ejaculatory ducts meet the urethra, which is known as verumontanum. Lppu was defined as the distance from the beginning of the prostatic urethra to the point where the ejaculatory ducts meet the urethra in the mid-sagittal view

(Fig. 1). All values were the average from the two doctors' measurements.

C. DATA PROCESSING

1) STATISTICAL ANALYSIS

All analyses were performed using R 3.2.5 (R foundation for statistical computing, Vienna, Austria). Continuous variables were expressed as the mean \pm standard deviation or median (first-third quartile). Categorical variables were expressed as numbers (percentages). The descriptive analysis of all measurements and variables was followed by fitting a linear regression model to the measurement data and regressed against age. The collinearity of the measurements was also assessed.

2) ULTRASONOGRAPHY DATA PROCESSING

TZI was calculated and used as a control value. The calculation was relatively complicated because it requires the measurement of many original values. The total prostate volume (TPV) and transitional zone volume (TZV) were calculated according to formula (1), and TZI was the value of TZV/TPV.

$$V = a * b * c * 0.52 \quad (1)$$

a: height; b: width; c: length

However, Lppu was directly recorded after the uniquely-calibrated standardized plane was defined, which was very concise and accurate.

III. RESULTS

A. DESCRIPTIVE ANALYSIS

Table 1 showed the baseline characteristics of the 643 patients. The mean age of the subjects was 65.64 yrs old (95% CI, 64.48, 66.80), and 9% (57/643) of them were under 40 yrs old. The youngest patient was 18 yrs old and

TABLE 1. Characteristics of participants in this study.

Variables	n	Mean (95% CI)	Range
Age (yrs)	643	65.64 (64.48, 66.80)	18-89
Prostate size (ml)			
TPV	643	62.71 (59.75, 65.66)	5.99-249.54
TZV	643	32.15 (30.15, 34.15)	1.40-146.77
TZI	643	0.4615(0.45, 0.47)	0.054-0.949
Lppu (mm)	643	28.54 (27.83, 29.25)	11-69
PSA (ng/ml)	643	7.28 (6.83, 7.73)	1.40-9.01
tIPSS	643	12.91 (12.55, 13.28)	0-24
vIPSS	643	6.77 (6.55, 6.99)	0-13
sIPSS	643	6.14 (5.94, 6.35)	0-13
QoL	643	3.31 (3.21, 3.40)	0-6

Demographic characteristics were summarized descriptively. total prostate volume, TPV; transitional zone volume, TZV; transitional zone index, TZI; length of proximal prostatic urethra, Lppu; prostate specific antigen, PSA; International Prostate Symptom Score, IPSS; voiding scores of IPSS, vIPSS; storage scores of IPSS, sIPSS; quality of life, QoL.

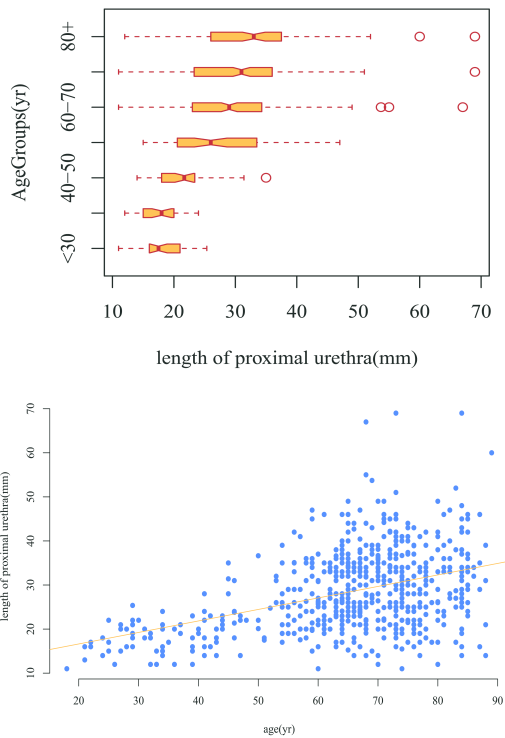


FIGURE 2. Length of the proximal prostatic urethra of all age groups; Scatterplot of Lppu (mm) and age groups.

had been suffering from frequency for 1 month. With an enlargement of the prostate observed on TRUS, he was diagnosed as LUTS/BPH. After 3 months of treatment and follow-up, the volume of the prostate remained greater than the normal size. Among younger patients (<40 yrs), most of them suffered acute inflammatory conditions and most commonly had symptoms such as frequency, urgency and dysuria; occasionally, these patients also had urinary incontinence and urinary retention. Patients over 40 yrs old had higher IPSS, especially for vIPSS.

TABLE 2. Correlation coefficient between LUTS parameters and age.

Measurements	Estimated r	Multiple r-squared	Adjusted r-squared	P value
QoL	0.046	0.314	0.313	<0.001
IPSS	0.190	0.368	0.367	<0.001
sIPSS	0.074	0.174	0.173	<0.001
vIPSS	0.116	0.387	0.386	<0.001
length	0.447	0.256	0.255	<0.001
width	0.203	0.145	0.143	<0.001
height	0.261	0.160	0.158	<0.001
TZL	0.381	0.216	0.215	<0.001
TZW	0.420	0.265	0.264	<0.001
TZH	0.259	0.166	0.165	<0.001
TZV	0.694	0.163	0.162	<0.001
TPV	0.478	0.164	0.163	<0.001
TZI	0.452	0.186	0.185	<0.001
Lppu	0.261	0.182	0.180	<0.001

Parameters of the prostate were measured via transrectal ultrasound. Quality of life, QoL; International Prostatic Symptom Score, IPSS; length of transitional zone, TZL; width of transitional zone TZW; height of transitional zone, TZH; length of proximal prostate urethra, Lppu.

TABLE 3. Correlation coefficient between Lppu and age groups.

Age Groups	Estimated r	Multiple R-squared	Adjusted R-squared	P value
30 to 40 (n=25)	0.260			0.789
40 to 50 (n=32)	3.860			0.064
50 to 60 (n=59)	9.520			<0.001
60 to 70 (n=190)	11.940	0.204	0.195	<0.001
70 to 80 (n=210)	12.516			<0.001
>=80 (n=96)	14.507			<0.001

B. LINER REGRESSION MODELS OF THE MEASUREMENTS AND AGE

For LUTS in men, the occurrence of symptoms increased with age (Table 2). Anatomical measures of the prostate were also significantly and positively correlated with age. TZV was also highly correlated with age (r=0.694). The length, width and height of the prostate were moderately

TABLE 4. Correlation coefficient between the prostate parameters and LUTS scores.

	IPSS						QoL	
	Total		Voiding symptoms		Storage symptoms		Estimated r	Adjusted
	Estimated r	Adjusted r-squared	Estimated r	Adjusted r-squared	Estimated r	Adjusted r-squared		
TZV	0.045 ***	0.060***	0.029 ***	0.071**	0.016 ***	0.023 ***	0.009***	0.034***
TPV	0.031 ***	0.061***	0.020 **	0.069***	0.011 ***	0.025 **	0.006***	0.039***
TZI	0.080 ***	0.070* **	0.050 ***	0.078***	0.030 ***	0.030 ***	0.018***	0.049***
Lppu	0.133***	0.066***	0.088 ***	0.082***	0.045 ***	0.023 ***	0.030***	0.048***

*** P<0.001

International Prostatic Symptom Score, IPSS; Quality of life, QoL; transitional zone volume, TZV; total prostate volume, TPV; transitional zone index, TZI; length of proximal prostate urethra, Lppu.

correlated with age ($r = 0.447, 0.203,$ and 0.260 , respectively), indicating that the prostate may grow much longer as men age. Similar to a previous study in our department [13], TZI was closely correlated with age ($r=0.45, p<0.001$). Lppu was increased in older men, which was consistent with the hypothesis that the whole prostate, especially the inner gland, was increasingly longer in elderly men (Fig. 2). A comparison of the percentage increase in Lppu in seven age groups revealed that the growth rate of Lppu was accelerated in groups of men over 50 yrs. There was no difference in Lppu among the under 30, 30-40 and 40-50 yrs old age groups (Table 3).

C. LINEAR REGRESSION MODELS OF THE PROSTATE ANATOMICAL FACTORS AND IPSS/QOL

The changes in the prostate anatomical factors did affect the symptoms of LUTS and the QoL scores (Table 4). Among all parameters evaluated, TZI and Lppu were better correlated with IPSS ($r=0.080$ and 0.133 , respectively). Lppu, as a new measurement, was significantly and positively correlated with IPSS, vIPSS, sIPSS and QoL ($r=0.133, 0.088, 0.045, 0.030$, respectively).

D. LINEAR REGRESSION MODELS OF THE PROSTATE ANATOMICAL FACTORS AND IPSS/QoL IN PATIENTS WITH SMALL PROSTATES

For patients with small prostates, whose prostate volume was less than 30 mm^3 (133/643), Lppu was still better correlated with IPSS than with TZI (0.336 and 0.205 , respectively) (Table 5).

IV. DISCUSSION

It is meaningful to grade BPH before treatment. Men will receive watchful waiting and then behavioral modification when they have BPH. Only after the annoying LUTS appear will they need pharmacological therapy or even surgery. Male LUTS could be troublesome with a broad range of other etiologies, but the main cause is BPH. Early diagnosis of BPH in patients with LUTS primarily lies in the understanding of the relationship between LUTS and BPH [1]. Therefore, this paper included cases with 'LUTS suggestive of BPH (LUTS/BPH)' with the aim of defining and testing the severity of LUTS and its transformation through the grades of BPH with the new Lppu value.

The above results from assessments of the BPH stages of patients with LUTS/BPH clearly revealed that the Lppu value was superior to the TZI value. The reasons are as follows:

- 1) First, our data are reasonable from a pathological and anatomical point of view. This single-center retrospective study aimed to describe the natural growth trend of the prostate using real-world data extracted directly from records at Shanghai Sixth Peoples Hospital. We also conducted research to evaluate the new Lppu measurement to find its clinical value in assessing LUTS/BPH. We found that the length of the prostate (compared with the height and width) and TZW (compared with TZL and TZH) were more closely related to age. This may indicate that, as men are aging, the total prostate lengthens; however, the transitional zone, which is the area where hyperplasia occurs, grows more in width than in length. In other words,

TABLE 5. Correlation coefficient between TZI/Lppu and LUTS scores in patients with small prostate.

	IPSS						QoL	
	Total		Voiding symptoms		Storage symptoms		Estimated r	Adjusted r-squared
Estimated r			Estimated r		Estimated r			
Adjusted r-squared			Adjusted r-squared		Adjusted r-squared		Adjusted r-squared	
TZI	0.205	0.144***	0.116	0.132***	0.090	0.108***	0.041	0.061**
Lppu	0.336	0.055**	0.187	0.049**	0.149	0.041*	0.124	0.090***

*** P<0.001

International Prostatic Symptom Score, IPSS; Quality of life, QoL; transitional zone index, TZI; length of proximal prostate urethra, Lppu.

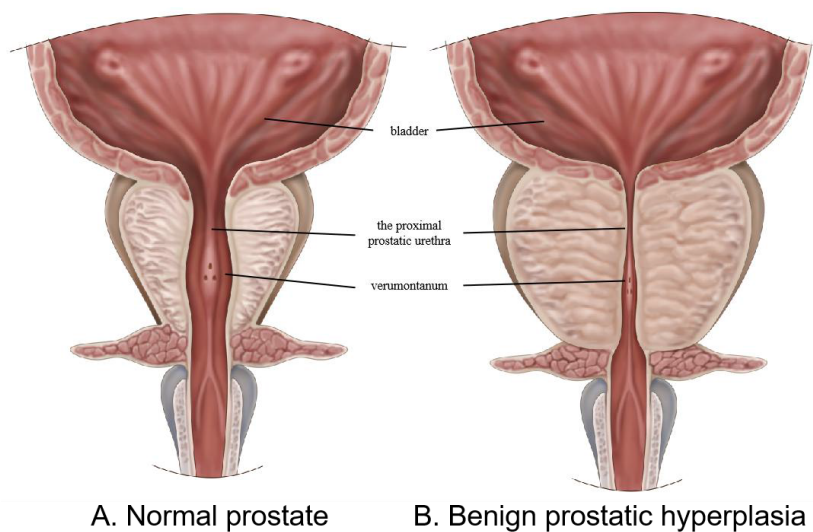


FIGURE 3. The proximal prostatic urethra grows longer while men age. The total prostate is elongated while the transitional zone, the part where hyperplasia occurs, and grows more in width than in length, which results in the proximal prostatic urethra being severely squeezed by the inner gland.

while the prostatic urethra is growing longer, it is more severely compressed by the inner gland (Fig. 3), which can explain the more significant correlation with vIPSS than with sIPSS ($r = 0.116, 0.074$, respectively, Table 4). Moreover, Lppu is also colinear with age. Lppu growth rate was increased in men over the age of 50 yrs, which affected the growth characteristics of the entire prostate (the total prostate tended to grow longer). These results are consistent with those from our previous study [13]. When compared with symptom scores, TZI and Lppu were the variables most closely correlated with IPSS ($r=0.080$ and 0.133 , respectively). Both Lppu and TZI supports the fact that BPH is secondary to hyperplasia of the transitional zone with a minor contribution from hyperplasia of the central zone. The age-related relevance of Lppu and its correlation with symptom scores was superior to that of TZI.

2) Lppu can be directly and precisely measured on a calibrated standardized plane. In a typical ultrasound

for measuring Lppu, the internal urethral orifice, ejaculatory ducts and verumontanum need to be visible on the same ultrasound plane (Fig. 1). Applying the standardized plane has always been a problem for ultrasound inspection. As a result, the other values of the prostate are generally measured according to their so-called maximum diameters [14]. TZI, as the ratio of TZV to TPV, requires six measurements that may each have errors. Young doctors with less experience in examining the prostate can determine the standardized plane after several hours of training. When compared with symptom scores, Lppu showed a closer correlation with IPSS than TZI ($r = 0.133$, and 0.080 , respectively). In general, Lppu reduced operator error and was fairly clinically adaptable.

3) Lppu was a better predictor for assessing LUTS symptoms compared with TZI. We separated symptom scores into vIPSS and sIPSS. Both TZI and Lppu showed a closer correlation with vIPSS. Lppu, which travels in the same direction as the prostatic urethra,

could be one of the factors that affects voiding symptoms in men with LUTS/BPH. The model examining differences between age groups showed that there was no significant difference in Lppu between age groups for patients under 50 yrs old (Table 2). For participants over 50 yrs old, Lppu differences among different age groups were statistically significant. In previous studies, TZI was accepted as being associated with IPSS, especially in some patients with severe LUTS but small prostates, and it may also be useful for determining the need for surgical intervention [15]. A study in our department proved that TZI was closely associated with increasing age and could be one of the explanations for the symptoms of LUTS in a cohort of Chinese men [13]. Patients with a higher TZI may develop acute urinary retention more easily [7], [8]. A report showed a correlation between IPSS, prostate volumes (TV, TZV) and TZI [3]. In a cohort study, Kwon *et al.* [6] explored whether PZT, which was similar to TZI, was related to IPSS when compared with volume. TZI was applied clinically to evaluate the effect of brachytherapy and was proven to be correlated with the time to IPSS normalization [16]. All of these studies further demonstrated that Lppu could identify BPH stages by predicting the severity of the patients' symptoms, especially voiding symptoms. Therefore, BPH patients with a longer Lppu are at higher risk with watchful waiting and may be better served with medical therapy.

4) Lppu could also be a better indicator to evaluate LUTS even in men with small prostates. Early studies attempted to associate LUTS with the total prostate volume only [5]. It was observed that Asian men generally had smaller prostate gland sizes than Western men, but the prevalence of LUTS was similar [17]. The mean TZI was significantly higher in Korean men ($r=0.45$) than in Caucasian and Hispanic men ($r=0.39$ and 0.38 , respectively) [17]. In our study, we examined the correlation coefficient between TZI/Lppu and LUTS scores in patients with small prostates (<30 ml). Lppu showed a better correlation with IPSS than TZI ($r=0.336$ and 0.205 , respectively). In summary, the new indicator, Lppu, can better evaluate the prostatic urethra during the period of BPH progression. This value is consistent with the nature of LUTS induced by BPH. Additionally, the above results can better explain the age group with the higher prevalence of male BPH (>50 yrs old). Overall, the Lppu value is a good variable for early screening by precisely describing anatomical changes in the prostate, particularly in patients who have a smaller prostate volume but severe symptoms.

Overall, Lppu performed with better diagnostic accuracy and more clinical practicability. First, Lppu was reasonable in terms of the pathophysiology of BPH, and it was collinear with age ($r=0.26$, $p<0.001$). Second, Lppu can be directly and precisely measured. Even young doctors with

less experience can determine the calibrated standardized plane by recognizing the three landmarks after a few hours of training. The computer deep-learning network can also better acquire this standard aspect and make a one-step diagnosis. Third, Lppu can be a better indicator for assessing LUTS than the former value, TZI. Lppu was more closely correlated with clinical symptom scores, and therefore, it can help us reach the goal of personalized medicine for the management of BPH. Furthermore, Lppu can be widely used among patients with LUTS/BPH, especially among men with severe LUTS but small prostates. Last but not least, ultrasound is truly economical, and its use contributes to reducing the financial burden on the global health care system.

Although it is valuable, Lppu is still imperfect because it cannot be used as a single indication for surgery. The pathological processes are probably varied between patients, with younger patients more likely to suffer acute prostatitis and older patients more likely to have BPH and chronic prostatitis [18]. For younger patients, even when we undertook transrectal ultrasound after the acute phase of inflammation, the prostate might still have been edematous; thus, we could not obtain healthy normal prostate measurements in younger patients. Despite these limitations, our work has clearly indicated that the Lppu value, with its sound pathological and anatomical basis, can greatly reduce operator error in the identification of BPH stages. This value has significant advantages for early screening of BPH, especially in men less than 50 yrs old with no obvious symptoms.

V. CONCLUSION

BPH can significantly detract from the quality of life of aging males. The core strategy of diagnosis and treatment is not merely to alleviate bothersome symptoms but also to prevent disease progression in the early stage. In this study, our newly proposed Lppu measurement value, which was based on measuring the distance from the beginning of the prostatic urethra to the point where the ejaculatory ducts meet the urethra on a uniquely-calibrated standardized plane, had the closest correlation with symptom scores, especially with the vIPSS ($r = 0.116$, $p<0.001$). The length of the total prostate and the width of the transitional zone grew faster as men ageing ($r=0.447$ and 0.420 , respectively, $p<0.001$). The critical pathophysiological change caused by the prostatic urethra being squeezed by the middle lobe as BPH progresses can be sensitively reflected by the Lppu value. Compared with the traditional ultrasound diagnostic criteria (TZI), Lppu is superior both in diagnostic accuracy and clinical adaptability with many unique advantages, such as being operator-error-free based on the plane defined by three special physiological points. Lppu is also able to be directly measured by young inexperienced doctors within a few hours of training. Finally, ultrasound is economical, and the use of Lppu can contribute to improving the cost-efficiency of public health. Lppu is particularly suitable for the early screening of LUTS/BPH, especially for patients with small prostates but severe LUTS.

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