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● *Clinical Note*

EVALUATION OF PROSTATE VOLUME BY TRANSABDOMINAL ULTRASONOGRAPHY WITH MODIFIED ELLIPSOID FORMULA AT DIFFERENT STAGES OF BENIGN PROSTATIC HYPERPLASIA

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Abstract—The aim of the study was to propose an eccentricity parameter (EP)-based correction to the ellipsoid formula to improve the evaluation of the prostate volume defined by transabdominal ultrasonography (TAUS) at different stages of benign prostatic hyperplasia (BPH). All 202 adult male volunteers underwent the prostate volume evaluations with TAUS and computerized tomography (CT). Based on the EP index, three clearly different stages of BPH were also deduced by analytical analysis. By applying the correction formula, the mean prostate volume differences of TAUS with CT were improved from 28.1%, –25.4% and –0.6% to 7.6%, –3.5% and –0.6% for EP $<$ 0.055, 0.055 $<$ EP $<$ 0.14 and EP $>$ 0.14, respectively. Hence, for EP $>$ 0.14, representing the advanced stage of BPH, TAUS with the ellipsoid formula can be regarded as an effective tool for computing volume, whereas for EP $<$ 0.14, the correction formula is recommended to improve the volume estimation based on TAUS. (E-mail: calin@pme.nthu.edu.tw) © 2011 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Prostate volume, Transabdominal ultrasonography, Ellipsoid formula, Computerized tomography, Analytical modeling.**

INTRODUCTION AND LITERATURE

An accurate and reproducible prostate volumetric measurement has a significant impact on the treatment regime for patients. Prostate volume (PV) is important for determining the appropriate brachytherapy program (Chenven et al. 2001), the calculation of serum prostate-specific antigen density (Bazinet et al. 1996) and other volume-based indices. Furthermore, the PV has been widely used to examine benign and malignant conditions of the prostate (van Venrooij et al. 2004) and bladder outlet obstruction (BOO) (Steele et al. 2000; Ockrim et al. 2001; Lim et al. 2006; Yang et al. 2007).

To provide measurements that accurately correlate with actual gland weight, 3-D imaging techniques have been adopted, such as magnetic resonance imaging (Roach et al. 1996; Smith et al. 2007), computerized tomography (CT) (Roach et al. 1996; Narayana et al. 1997; Badiozamani et al. 1999; Hoffelt et al. 2003; Kälkner et al. 2006; Smith et al. 2007; Yang et al. 2010), 3-D transabdominal ultrasound (Johnston et al. 2008) and transrectal ultrasound step-section planimetry (Narayana et al. 1997; Badiozamani et al. 1999; Chenven et al. 2001; Kälkner et al. 2006; Smith et al. 2007; Kim and Kim 2008). However, these methods are not only costly but are also time-consuming in practice. In addition, ultrasonography, which was first introduced for imaging the prostate by Watanabe et al. (1968), is routinely used in evaluating prostate size for patients with benign prostatic hyperplasia (BPH). Combined with the ellipsoid formula, it is widely used to estimate volume, and the benefits of this method include its low cost, its convenience and the ease of the procedure (Bazinet et al. 1996; Matthews et al. 1996; Nathan et al. 1996; Chenven et al. 2001; Yuen et al. 2002; Hoffelt et al. 2003; Huang Foen Chung et al. 2004; Kälkner et al. 2006; Sajadi et al. 2007; Kim and Kim 2008; Rodriguez et al. 2008). However, using the ellipsoid formula alone to estimate these variable prostate shapes may not be adequate. In addition, previous studies (Huang Foen Chung et al. 2004; Kim and Kim 2008) have reported a high degree of correlation between the

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transabdominal ultrasonography (TAUS) and transrectal ultrasonography (TRUS) methods in prostate volume estimation.

Historically, PV estimation by ultrasound with the ellipsoid formula has been reported to underestimate the actual prostate weight, particularly in larger glands (Matthews et al. 1996; Nathan et al. 1996; Rodriguez et al. 2008). Furthermore, several studies have demonstrated that the methodology overestimates the actual prostate weight in smaller glands (Matthews et al. 1996; Kälkner et al. 2006; Sajadi et al. 2007). One of the key reasons for these inadequate estimations is the collocation between the shape of the prostate gland and the assessment formulas (Bazinet et al. 1996; Kim and Kim 2008). That is, the shape of the prostate does not always resemble a sphere or an ellipsoid. In fact, the transverse image of the normal prostate shows a triangular shape, whereas that of a prostate with BPH has a semilunar shape with squared shoulders in the early stage and a circular shape in the advanced stage (Watanabe 1998). The changes in the prostate shape are shown in Fig. 1a and are described by Watanabe (1998). Clearly, the ellipsoid formula would not provide appropriate prostate volume estimation in all cases.

TAUS is noninvasive, easy to operate and inexpensive. In this study, to make a significant contribution to improve the accuracy of PV measurements by TAUS (PV_{TAUS}) with the ellipsoid formula, a new parameter called the *eccentricity parameter* (EP) was designed to determine which kinds of prostate shapes could be accurately estimated. In addition, an analytical analysis and the CT-estimated PV (PV_{CT}) were used to judge whether the ellipsoid formula is able to estimate the prostate size from the TAUS. Finally, an EP index–based correction to the ellipsoid formula was proposed to improve the evaluation of the prostate volume defined by TAUS.

MATERIALS AND METHODS

Two-hundred and two adult male volunteers with lower urinary tract symptoms were admitted to Taipei Veterans General Hospital and Tri-Service General Hospital. Written, informed consent was obtained from all volunteers. The study was approved by the Institutional Review Board of Taipei Veterans General Hospital (VGHIRB No: 95-10-04A).

Prostate volume estimation with TAUS and CT

All of the volunteers underwent the PV_{CT} and PV_{TAUS} measurements. For ultrasonography measurement, ultrasound scanners (GE Logiq 9, USA and Philips HDI 5000, Philips Corp., Bothell, WA, USA) were used. Furthermore, PV_{TAUS} was based on the ellipsoid formula ($PV = \pi \div 6 \times [\text{width} \times \text{height} \times \text{length}]$), where width (right-left) and height (anterior-posterior) were measured on the transverse plane, and length (cranial-caudal) was measured on the sagittal plane.

CT examinations were performed with conventional CT scanners (Toshiba Aquilion 64, Toshiba American Medical System, Inc., Irvine, CA, USA; and Picker Marconi PQ6000, Picker International Corp., Cleveland, OH, USA). Computed axial tomography images of the pelvis and prostate were obtained with men placed in a supine position. The CT images were analyzed using a software package (AMIRA 3.1, Visage Imaging GmbH, Berlin, Germany), which included contour segmentation, volume calculation and length measurement. The 3-D rebuilt images are shown in Fig. 1c.

Eccentricity parameter

The EP index was created to differentiate the prostate shapes at different stages of BPH. These phenomena would be clearly reflected and displayed on images of the transverse plane of the gland, but not on the sagittal plane. In addition, on the sagittal plane, a poor sonic window for transabdominal ultrasonography limits the view of the caudal part of the prostate. Thus, the parametric formula is:

$$(\text{radius\_min}/\text{width}) \times (\text{radius\_min}/\text{height}),$$

where radius_min is measured from the intersecting point of the width and height to the posterior or anterior side, choosing the shorter one, on the transverse plane (Fig. 1b). The two ratios are multiplied to distinguish a triangular or chestnut shape from a circular shape. If the shape of the gland is circular, the EP is 0.25. However, if the gland resembles a chestnut shape, or even a triangular shape, the EP will be less than 0.25.

Analytical analysis

As previously indicated, as BPH progresses, the prostate shape gradually shifts from a triangular shape to a circular shape in the advanced stage (Watanabe 1998). It is possible to reconstruct analytically the prostate shape at different stages of BPH. This can be used as a complementary evaluation to verify the accuracy of the commonly adopted ellipsoid formula. In the present study, the following equation was used to mimic the variation of the cross-sectional prostate at different stages of BPH:

$$\underbrace{\left[\frac{x^2}{a^2} \times \left(\frac{1+cy}{1-cy}\right) + \frac{y^2}{b^2}\right]}_{\text{Ellipsoid}} \times w + \underbrace{\left[\frac{x^4}{a^4} + \frac{y^4}{b^4}\right]}_{\text{Rounded Rectangular}} \times (1-w) = 1, \tag{1}$$