A Proposed Method for Measuring the Volume of the Expanded Bladder by Ultrasonography

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短　報

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超音波による拡張した膀胱容量測定に関する提案

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Abstract

In the present study, upon a perceived urinary urgency, the bladder volume (BV) of six male university students was measured using ultrasonography (US). Immediately after imaging, each subject discharged all urine present in his bladder and the discharged urine volume (UV) was measured. The BV was calculated using US images with the conventional method and compared with the actual discharged UV. The regression coefficient of the relationship between the discharged UV and US-calculated BV differed relative to the amount of urine in the bladder. We hypothesized that this difference existed because the conventional method assumes that the shape of the bladder is ellipsoid. To prove this hypothesis, 12 US images of a fully expanded bladder were obtained from various angles using US. The shape of the bladder model created from the 12 US images resembled a rectangle or a quadrangular pyramid. For these reasons, the shape of the bladder should not be assumed to be ellipsoid when calculating the volume of a fully expanded bladder with a sufficient UV by US. Therefore, it is necessary to develop a new method to calculate the BV with a sufficient UV by US.

Keywords：ultrasonography, urine volume, dysuria, male subject, bladder shape

Introduction

There are several methods for the non-invasive measurement of bladder volume (BV), most of which use ultrasonic waves[1)–6)]. However, ultrasonography (US)-based measurement of urine volume (UV) may significantly differ from the actual discharged UV[7),8)]. When the BV is measured by US, we assume that the shape of the bladder is ellipsoid. However, the actual shape of the bladder is not perfectly ellipsoid; thus, we hypothesized that this assumption regarding the shape of the bladder results in a difference between the US-calculated BV and the actual discharged UV. One reason for using US is to measure the UV that remains in the bladder after urination in patients with dysuria. Because the residual UV is relatively small, accurate measurement is important. Thus, we examined the ability of the conventional US method to accurately measure a large UV[5),8)]. However, during US of organs in the pelvic cavity, a sufficient UV usually exists in the subject's bladder. A large UV in the bladder makes it easier to detect lesions on the bladder wall and to observe the organs that exist on the dorsal side of the bladder; specifically, the uterus in females and the prostate in males. When there is a sufficient UV in the bladder, volumetric information has no clinical significance. However, accurate measurement of BV can provide useful information about patients with medical conditions, such as disordered urination, which enables

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analysis of the relationship between the actual discharged UV and urinary urgency.

We examined how the shape of the fully expanded bladder should be approximated with a large UV in the bladder. To accurately measure BV using US, it is necessary to approximate the actual shape of the bladder as accurately as possible.

Subjects and Methods

1. Subjects

The study cohort included six healthy male university students, aged 21–22 years. Written informed consent was obtained from all subjects prior to participation in the study, in accordance with the ethical standards of the Declaration of Helsinki.

2. Measurements

In this study, all measurements were acquired with the subjects in the standard supine position. Median tomographic images and horizontal cross-sectional images of the bladder were obtained using a ProSound Alpha6 ultrasound system (Hitachi Ltd., Tokyo, Japan) equipped with a 2- to 5-MHz convex transducer. US images were recorded 8 to 12 times per subject at various times. Immediately after each measurement, all urine in the bladder was discharged and the discharged UV was measured.

3. Calculation of BV and UV

1) Calculation of BV by ultrasound

Figure 1 shows a representative horizontal cross-sectional image (A) and a median tomographic image (B) of the bladder. The maximal diameter (W, cm) from the left end to the right end of the bladder was measured on a horizontal cross-sectional image. Then, the maximal diameter (D, cm) from the ventral end to the dorsal end and the maximal diameter (H, cm) from the cranial end to the caudal end was measured on the median tomographic image of the bladder. If the shape of the bladder is assumed to be ellipsoid, the volume (V, mL) of the ellipsoid is represented by equation (1) [6].

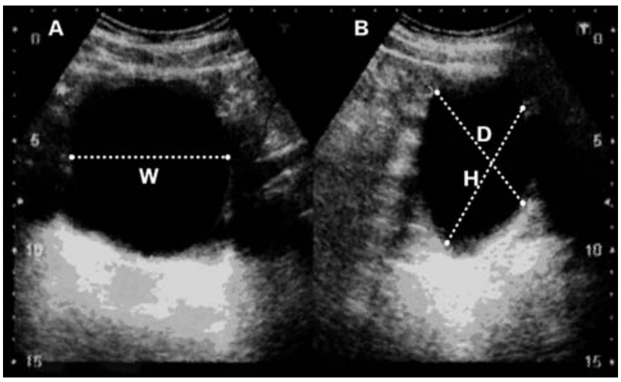

Fig. 1: Dimensions used to calculate the BV. A, horizontal section of bladder; B, midline section of bladder; W, transverse diameter of the bladder; D, anteroposterior diameter of the bladder; H, vertical diameter of bladder.

$$V = \frac{4}{3}\pi \times \frac{W}{2} \times \frac{D}{2} \times \frac{H}{2} \fallingdotseq \frac{W \times D \times H}{2} \qquad (1)$$

2) Discharged UV

The discharged UV was calculated from the urine weight, assuming a specific gravity of urine of 1.

4. Analysis of the relationship between BV and UV

We plotted a graph with the discharged UV on the Y-axis and the US-calculated BV on the X-axis. In this study, pairs of measurements of the discharged UV and BV were obtained. Of a total of 63 pairs of measurements, 60 were used for analysis, as two pairs with extremely small discharged UVs and one with an extremely large discharged UV were excluded. We calculated 12 regression coefficients using five pairs of measurements in a descending order of the discharged UV. We determined six regression coefficients, calculated from 30 pairs of measurements, suggesting a low discharged UV, as the regression coefficient of the low-urination group. We further determined six regression coefficients, calculated from 30 pairs of measurements, suggesting a high discharged UV, as the regression coefficient of the high-urination group. In this analysis, a discharged UV of <214 mL was classified into the low-urination group and a discharged UV of ≥214 mL was classified as the high-urination group. Significant differences in the regression coefficients between the low- and high-urination groups were identified using the unpaired t-test.

Results

Figure 2 depicts the plot of discharged UV on the Y-axis and the US-calculated BV on the X-axis using 63 pairs of measurements. The solid line represents the regression line of discharged UV and the US-calculated BV, and this straight line was required to pass the origin. The equation of this regression line is y = 1.16x. The correlation coefficient between the discharged UV and

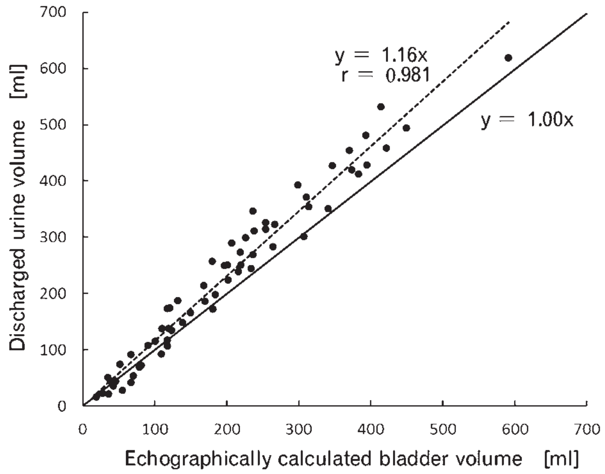

Fig. 2: Relationship between the actual discharged UV and the US-calculated BV. The dotted line shows the regression line calculated from the data points. The solid line represents the actual discharged UV merged with the US-calculated BV.

the US-calculated BV was r = 0.981 ($p < 0.05$), indicating a strong and positive correlation.

Figure 3 shows the regression coefficient for converting the US-calculated BV into the discharged UV in the analyzed 12 groups. The regression coefficient on Y-axis and the average UV of each group on X-axis were plotted. The regression coefficient increased up to the mean UV of 240 mL, but when the mean UV exceeded 240 mL, the regression coefficient became flat at about 1.2.

Figure 4 shows the regression coefficient between the discharged UV and the US-calculated BV of the low- and high-urination groups. In the low-urination group, the regression coefficient between the discharged UV and

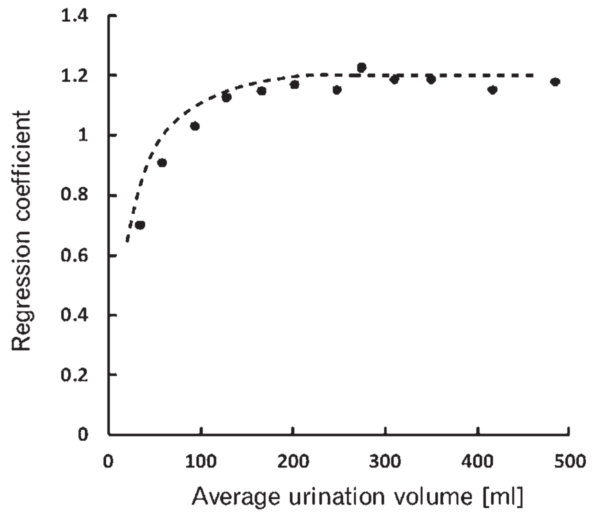

Fig. 3: Regression coefficient for converting the US-calculated BV into a UV. The regression coefficient was plotted on the Y-axis and the average UV of each group on the X-axis. The dotted line shows the regression curve subtracted by eye measurement.

the US-calculated BV was 1.0 ± 0.18 (mean ± standard deviation), which was very close to 1.0. In the high-urination group, the regression coefficient between the discharged UV and the US-calculated BV was 1.2 ± 0.026 (mean ± standard deviation), which was greater than 1.0. Although the regression coefficient in the high-urination group was larger than that of the low-urination group, this difference was not statistically significant ($p = 0.077$).

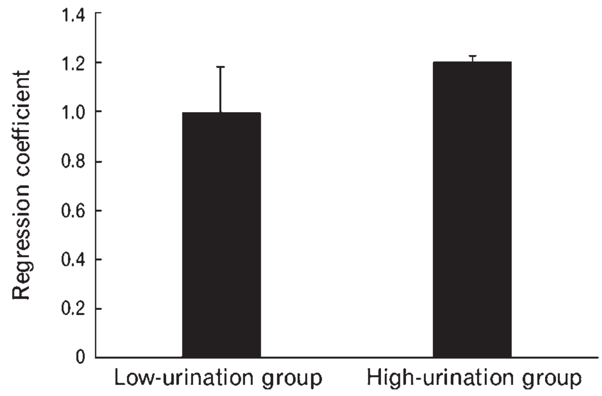

Fig. 4: Regression coefficient between the actual discharged UV and the US-calculated BV in the low- and high-urination groups.

Discussion

When pairs of measurements were used to calculate, the correlation coefficient between the discharged UV and the US-calculated BV was very high, indicating a strong and positive correlation. However, the regression coefficient between these measurements was greater than 1.0. Therefore, although the BV could be calculated from the vertical, anteroposterior, and lateral diameters of the bladder, approximating the shape of the bladder as an ellipsoid was not necessarily appropriate. In addition, the US-calculated BV was often less than the actual discharged UV, in accordance with the findings of previous studies that the US-calculated BV was often less than the actual discharged UV in many cases[6),9)]. Previous studies have attributed this effect to the blurry bladder wall boundaries on US images[6),9)]. However, there may be other potential reasons for this difference. There was a relatively large difference in regression coefficients between the actual discharged UV and the US-calculated BV between the low- and high-urination groups, which could indicate that the bladder does not expand in its original form as urine accumulates. In other words, the shape of the bladder changes according to the BV, which may be a natural phenomenon that occurs because the

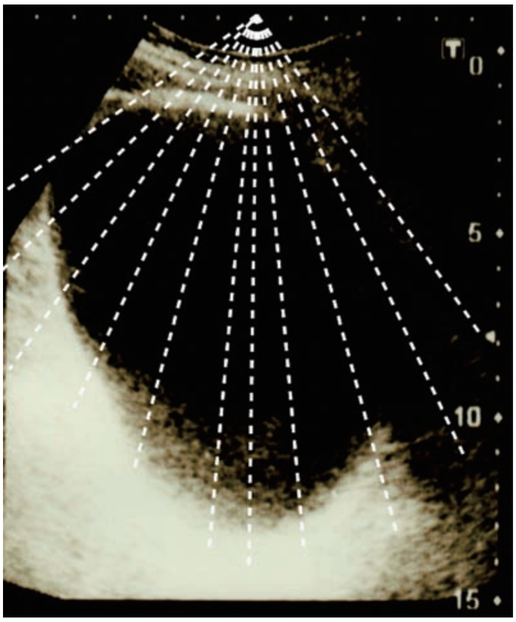

Fig. 5: A midline US image that was used to measure the shape of the fully expanded bladder. This image, and 11 others sliced at the plane represented by the dotted line, were used to construct a model of the bladder.

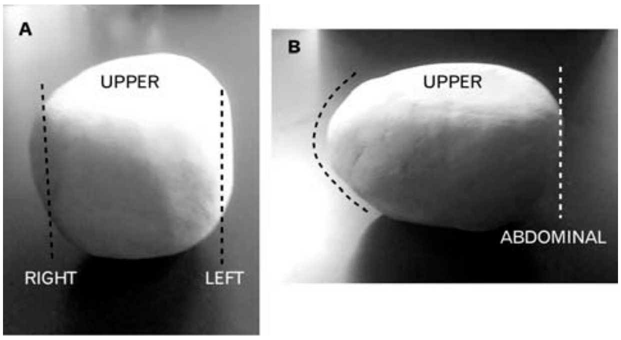

Fig. 6: A bladder model constructed from 12 US images. A, front view; B, right side view. The upper surface, the left and right surfaces, and the abdominal surface were flat.

bladder exists in the relatively tight confines of the pelvic cavity. To confirm the validity of this hypothesis, we recorded US images of a fully expanded bladder to create a three-dimensional model. The recorded US images consisted of a midline cross-section of the bladder and 11 cross-sections, sliced according to the dotted line in Figure 5. As clearly shown in Figure 6, in the fully expanded bladder, the upper, left, right, and abdominal surfaces were flat; therefore, the shape of the bladder was closer to a rectangular parallelepiped or a truncated pyramid. The volume of the ellipsoid inscribed in this rectangular parallelepiped was calculated in accordance with the conventional method, which showed that the calculated BV was smaller than the actual BV.

However, in this study, it was very difficult to determine any form to approximate the shape of the fully expanded bladder because considerable labor and time are needed to create a three-dimensional shape model of the bladder from two sectional views. Hence, future studies are warranted to characterize the shape of the fully expanded bladder.

Conclusions

The conventional calculation method that assumes that the shape of a fully expanded bladder is ellipsoid should not be used to calculate the bladder UV based on US.

References

1) Hakenberg OW, Ryall RL, Langlois SL, et al (1983): The estimation of bladder volume by sonocystography. J Urol. 130, 249-251.
2) Griffiths CJ, Murray A, Ramsden PD (1986): Accuracy and repeatability of bladder volume measurement using ultrasonic imaging. J Urol. 136, 808-812.
3) Haylen BT, Frazer MI, Sutherst JR, et al (1989): Transvaginal ultrasound in the assessment of bladder volumes in women; Preliminary report. Brit J Urol. 63, 149-151.
4) Coombes GM, Millard RJ (1994): The accuracy of portable ultrasound scanning in the measurement of residual urine volume. J Urol. 152, 2083-2085.
5) Oh-oka H, Nose R (2005): Efficacy and problems of bladder volume measurement using portable three dimensional ultrasound scanning device; in particular, on measuring bladder volume lower than 100 ml. Jpn J Urol. 96, 601-609. (in Japanese)
6) Yabunaka K, Yotsuya J, Nakagami G (2016): Comparison of validity of bladder volume measurement by four different kinds of ultrasound devices. J Jpn WOCM. 20, 420-425. (in Japanese)
7) Kiely EA, Hartnell GG, Gibson RN, et al (1987): Measurement of bladder volume by real-time ultrasound. Br J Urol. 60, 33-35.
8) Simforoosh N, Dadkhah F, Hosseini SY, et al (1997): Accuracy of residual urine measurement in men: comparison between real-time ultrasonography and catheterization. J Urol. 158, 59-61.
9) Watanabe H, Azuma Y, Nagai K, et al (2014): Periodical measurement of bladder capacity by

abdominal three-dimensional ultrasound. Jpn J Med Ultrasonics. 41, 367-373.

Conflicts of Interest

The authors have no conflict of interest directly relevant to the content of this article.

要　　旨

本研究は，男子大学生６名を対象とした。被験者が様々な尿意を感じているとき，膀胱を超音波検査装置で描出し，エコー像を記録した。膀胱のエコー像を記録した直後に，被験者に全排尿させ，その尿量を測定した。従来の計算法でエコー像から，算出した膀胱内容積と排尿量を比較した。膀胱の拡張の程度に応じて，排尿量とエコー像から算出される膀胱内容積の回帰係数が変化した。我々は，この結果の原因は従来の計算法では，膀胱の形状を楕円体として近似することによるものであると推測した。この仮説を証明するために，十分に拡張した膀胱を様々な角度から，超音波検査装置で，12枚のエコー像を記録した。 記録した12枚のエコー像を使用して，膀胱モデルを作製した。作製した膀胱モデルの形状は，楕円体より直方体，または，四角錐台に近いものであった。

これらの理由から，エコー像を用いて膀胱内の容積を計算する場合，膀胱が大きく拡張しているとき，膀胱の形状を楕円体として近似することは不適切であろう。我々は，大きく拡張している膀胱の容積を計算するための新たな近似法を検討する必要があると考えている。