Three-Dimensional Ultrasonographic Bladder Volume Measurement

Reliability of the Virtual Organ Computer-Aided Analysis Technique Using Different Rotation Steps

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Objective. The purpose of this study was to investigate the reliability of Virtual Organ Computer-Aided Analysis (VOCAL; GE Healthcare, Kretztechnik, Zipf, Austria) using the 4 standard rotation steps to measure the bladder volume with 3-dimensional (3D) ultrasonography.

Methods. Using the 4 standard rotation steps of VOCAL, 2 independent observers made 3D volume measurement data sets from the urinary bladder (n = 180). Sets of 30, 20, 12, and 6 planes were obtained from the sequential rotations of 6°, 9°, 15°, and 30°, respectively. The internal contours of the bladders were determined manually. Reliability was evaluated with the intraclass correlation coefficient (ICC), and Bland-Altman plots were generated to examine bias and agreement. One-way analysis of variance was used to compare bladder volume measurements between the angles. P < .05 was considered statistically significant.

Results. A high degree of reliability was observed between pairs of different rotation angles (ICC, 0.994–0.999). There was good agreement between all pairs of different rotation angles, with percentages of the mean difference ranging from –0.9% to 1.8%. No significant difference was found for bladder volume measurements by the VOCAL technique with varying rotation steps. Intraobserver and interobserver reliabilities were high (ICC, 0.994–0.998).

Conclusions. Urinary bladder volume measurement by the VOCAL technique using different rotation steps is highly reliable. A plane rotation of 30° produces the fastest result.

Key words: reliability; rotation angle; 3-dimensional ultrasonography; Virtual Organ Computer-Aided Analysis.

Postvoid residual urine measurement is indicated for patients with incomplete bladder emptying. Measurement of the true residual urine volume is done by urethral catheterization, but this does cause the patient discomfort and trauma, and there is an increased risk of urinary tract infection. Ultrasound equipment has been used to measure the bladder volume and has proved to be simple to use, noninvasive, painless, and accurate. Compared with 2-dimensional ultrasonography, 3-dimensional ultrasonography (3DUS) gives better validity and reliability for volume measurement. It allows the examiner to better visualize some planes of the structure of interest that cannot be so readily obtained with 2-dimensional ultrasonography.
Currently, the Virtual Organ Computer-Aided Analysis (VOCAL; GE Healthcare, Kretztechnik, Zipf, Austria) technique is the most popular method used to obtain volume measurements and has been previously evaluated with high reliability and good intraobserver and interobserver agreement. There are 4 standard rotational angles that can be selected by the observer for each contour plane of 6°, 9°, 15°, and 30°. However, most studies have arbitrarily tended to select the 30° rotation angle because it saves time and also requires only 6 steps to complete a volume measurement. In an in vitro study using the different rotation angles, Raine-Fenning et al16 found that measurements made with the 6° rotation step were significantly more reliable than those made by all other angles with the exception of the 9° rotation step and significantly more valid than those made with the 30° rotation step. An in vivo study of fetal urinary bladder volume measurement using 3DUS and VOCAL compared the 15° and 30° rotation steps and found a good correlation between the angles.17 However, another in vivo study focusing on the reliability of the VOCAL technique using the 4 different rotation angles was limited in scope. To select the appropriate rotational angle that will be reliable, feasible, and less time-consuming, we conducted an in vivo study to evaluate the reliability of the various rotation angles. The aim was to evaluate the reliability of 3DUS for bladder volume measurement using VOCAL with all 4 standard angles of rotation.

Materials and Methods

The study protocols were reviewed and approved by the Ethics Committee of the Faculty of Medicine, Prince of Songkla University, before the research was conducted at Songklanagarind Hospital. Between May and December 2006, 90 patients gave their written informed consent before participating in the study and were subsequently enrolled. Among the study group, 20 were inpatients who had indications for residual urine volume measurement, and 70 were volunteers recruited from outpatients who had come for gynecologic scans at the maternal-fetal medicine unit.

Two observers, identified only as observers 1 and 2, were used in the study and had been trained in the use of the VOCAL software. They both performed bladder volume measurement independently using the same images. The observers were blinded to each other’s measurements.

Volume Acquisition

The volume data sets were acquired with 3-dimensional (3D) ultrasound equipment (Voluson 730 Expert; GE Healthcare, Kretztechnik) and a motorized curved array transducer (2-5 MHz). The urinary bladder scan was performed by observer 2. Each patient was subjected to 2 separate scans, and these separate images from the first and second scans were used to evaluate the intraobserver reliability.

Once the image of the first scan of the urinary bladder had been saved, a second scan was immediately performed following the same procedure. This gave a total of 180 volume data sets from the 90 patients. Once a transverse view of the urinary bladder had been obtained, the volume acquisition was made with automated sweeps. The data images were all stored on the hard drive of an ultrasound machine (SonoView; GE Healthcare, Kretztechnik) for subsequent analysis and calculation.

Volume Measurements

Urinary bladder volume measurements were made from the stored 3D volume data sets by the standard VOCAL method. This software creates slices of the bladder for each selected standard angle around the main axis of the bladder outline. Within the software algorithms, there are 4 standard rotation angles set at 6°, 9°, 15°, and 30°, which allow for distinct sets of 30, 20, 12, and 6 planes, respectively.

After 3 simultaneous perpendicular planes were displayed on the monitor, the central organ slice with the largest dimension in 1 of the 3 orthogonal planes was selected and defined as the reference plane. Next, the limits on the upper and lower borders of the reference plane image were set, and the bladder contours were manually traced. Then the reference plane was rotated around the vertical axis, and the new surface contour was determined on the rotated...
reference plane. A rotation step for each contour plane was selected with all 4 standard angles. This procedure of rotating the reference plane and determining the surface contour on a rotated reference plane was done repeatedly until a full rotation of 180° was achieved. At each step, the bladder surface contours were manually traced by the examiner. The bladder volume was calculated after all contours had been traced. The VOCAL software automatically calculates the bladder volume, which is expressed in cubic centimeters.

Each individual image was measured independently by each observer for each of the 4 angular rotation steps, ie, 6°, 9°, 15°, and 30°. Figure 1 shows the surface geometry of the bladder and its calculated volume.

Two data sets were created from the first and second scans of each patient’s urinary bladder. These were used to calculate the intraobserver agreement. The interobserver agreement for each rotation angle was calculated from a comparison of the first set of measurements obtained by observers 1 and 2. Comparisons between the different rotational angles for volume measurements and the time required to perform these measurements were also obtained from the first data set of measurements made by both observers.

**Statistical Analysis**

Reliability analyses were performed for all the rotation angles, and intraclass correlation coefficients (ICCs) were calculated. On the basis of the method proposed by Bland and Altman, the agreement between any different rotation angle, the intraobserver and interobserver agreement, and the 95% limits of agreement were calculated using the percentage difference $[100 \times (\text{first measurement} - \text{second measurement})/\text{average}]$ versus the average. One-way analysis of variance (ANOVA) was used to compare the bladder volume measurements and the time required to perform measurements among all rotation angles. Statistical analysis was performed with SPSS version 15.0 software (SPSS Inc, Chicago, IL) and MedCalc version 9.6.4.0 software (MedCalc Software, Mariakerke, Belgium).

**Results**

A total of 720 urinary bladder volume measurements from the 180 volume data sets with varying rotation steps were performed by each observer. Both observers were able to obtain volume measurements using the VOCAL technique for all rotation angles. Urinary bladder volume measurements ranged from 2.62 to 1189.11 cm³.

**Intraobserver Agreement**

The percentage of the mean difference and 95% limits of agreement for the measurements using all rotation angles obtained by the 2 observers are shown in Table 1. Bland-Altman plots of the percentage of the mean difference and 95% limits of agreement for the intraobserver measurements obtained by the 2 observers using VOCAL with the rotation angle of 30° are shown in Figures 2 and 3. A high degree of reliability was observed for the intraobserver measurements using all rotation angles obtained by both observers, as follows: observer 1: 6°, ICC, 0.997; 95% confidence interval (CI), 0.996–0.998; 9°, ICC, 0.997; 95% CI, 0.995–0.998; 15°, ICC, 0.996; 95% CI, 0.994–0.997; and 30°, ICC, 0.996; 95% CI, 0.994–0.997; observer 2: 6°, ICC, 0.998; 95% CI, 0.996–0.998; 9°, ICC, 0.998; 95% CI, 0.998–0.999; 15°, ICC, 0.997; 95% CI, 0.996–0.998; and 30°, ICC, 0.998; 95% CI, 0.997–0.999.

**Figure 1.** Calculation of urinary bladder volume using VOCAL with the 30° rotation step. The images show the bladder volume measurement obtained with 3DUS using VOCAL: top left, bladder contours in the reference plane; top right and bottom left, bladder contours perpendicular to the reference plane; bottom right, 3D reconstruction of the bladder.
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Table 1. Percentage of Mean Difference and 95% Limits of Agreement for Intraobserver Measurements

<table>
<thead>
<tr>
<th>Rotation Angle, °</th>
<th>% of Mean Difference</th>
<th>95% Limits of Agreement</th>
<th>% of Mean Difference</th>
<th>95% Limits of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>-2.1</td>
<td>-25.5, 21.2</td>
<td>-3.4</td>
<td>-27.1, 20.4</td>
</tr>
<tr>
<td>9</td>
<td>-2.2</td>
<td>-26.4, 22</td>
<td>-1.9</td>
<td>-30.1, 26.4</td>
</tr>
<tr>
<td>15</td>
<td>-2.1</td>
<td>-23.4, 19.3</td>
<td>-2.2</td>
<td>-29.9, 25.4</td>
</tr>
<tr>
<td>30</td>
<td>-1.7</td>
<td>-31.2, 27.7</td>
<td>-2.0</td>
<td>-21.7, 17.7</td>
</tr>
</tbody>
</table>

Figure 2. Bland-Altman plot for observer 1 showing the percentage of the mean difference and 95% limits of agreement for the intraobserver measurements (first measurement – second measurement) using the 30° rotation angle against the mean volume (cubic centimeters).

Figure 3. Bland-Altman plot for observer 2 showing the percentage of the mean difference and 95% limits of agreement for the intraobserver measurements (first measurement – second measurement) using the 30° rotation angle against the mean volume (cubic centimeters).

Table 2. Percentage of Mean Difference and 95% Limits of Agreement for Interobserver Measurements

<table>
<thead>
<tr>
<th>Rotation Angle, °</th>
<th>% of Mean Difference</th>
<th>95% Limits of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>4.9</td>
<td>-14.8, 24.6</td>
</tr>
<tr>
<td>9</td>
<td>3.4</td>
<td>-18.8, 25.6</td>
</tr>
<tr>
<td>15</td>
<td>4.3</td>
<td>-16.5, 25.2</td>
</tr>
<tr>
<td>30</td>
<td>5.6</td>
<td>-17.6, 28.8</td>
</tr>
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</table>

Interobserver Agreement

There was good interobserver agreement. The percentage of the mean difference and 95% limits of agreement for the interobserver measurements using different rotation steps are shown in Table 2. Figure 4 shows a Bland-Altman plot for the percentage of the mean difference and 95% limits of the agreement for the interobserver measurements using the rotation angle of 30°. The reliability of the interobserver volume measurements was high, as follows: 6°, ICC, 0.996; 95% CI, 0.993–0.997; 9°, ICC, 0.994; 95% CI, 0.991–0.996; 15°, ICC, 0.996; 95% CI, 0.993–0.997; and 30°, ICC, 0.994; 95% CI, 0.991–0.996.

Agreement Between Different Rotation Angles

A high degree of reliability was observed between any pair of different rotation angles (ICC, 0.994–0.999), as shown in Table 3. The percentage of the mean difference and 95% limits of agreement between any pair of different rotation angles for both observers are shown in Table 4. Bland-Altman plots for the percentage of the mean difference and 95% limits of agreement between rotation angles of 6° and 30° for the 2 observers are shown in Figures 5 and 6. No significant difference was seen in the urinary bladder volume measurements made by each observer across any of the rotation angles (Table 5).
Time Taken to Perform Volume Measurements

Table 6 shows the time taken to perform volume measurements for the 4 different rotation angles. The measurement using the 6° rotation angle required 5 to 6 times longer to complete than the one using the 30° angle.

Discussion

This study attempted to evaluate the reliability of the 4 different rotation angles when estimating urinary bladder volume using 3DUS with VOCAL. The results showed a high degree of reliability for bladder volume measurements across all 4 rotation angles, as shown by both the excellent ICCs and good agreement between all pairs of different angles, as well as good intraobserver and interobserver agreement. Volume calculations made from the 4 different rotation angles were not significantly different.

The traditional method used to evaluate bladder volume by ultrasonography is the ellipsoid formula measurement. However, this method is not as accurate as the VOCAL technique because the bladder is not exactly in an ellipsoid shape. The VOCAL technique is currently the most frequently used method to obtain volume measurements from 3D volume data sets. It has been tested in vitro and shown to be more reliable and valid when calculating volumes than manual planimetry. It has also been studied in vivo to measure volumes of solid organs and fetal structures such as the bladder, stomach, and lungs and also for the assessment of hourly fetal urine production. Most of the

Table 3. Reliability of VOCAL With Different Steps of Rotation

<table>
<thead>
<tr>
<th>Pair of Rotation Angles, °</th>
<th>Observer 1</th>
<th>Observer 2</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ICC 95% CI</td>
<td>ICC 95% CI</td>
</tr>
<tr>
<td>6 vs 9</td>
<td>0.999 0.998–0.999</td>
<td>0.999 0.998–0.999</td>
</tr>
<tr>
<td>6 vs 15</td>
<td>0.998 0.997–0.999</td>
<td>0.999 0.998–0.999</td>
</tr>
<tr>
<td>6 vs 30</td>
<td>0.996 0.995–0.998</td>
<td>0.996 0.994–0.997</td>
</tr>
<tr>
<td>9 vs 15</td>
<td>0.999 0.998–0.999</td>
<td>0.999 0.998–0.999</td>
</tr>
<tr>
<td>9 vs 30</td>
<td>0.996 0.994–0.998</td>
<td>0.994 0.992–0.996</td>
</tr>
<tr>
<td>15 vs 30</td>
<td>0.997 0.995–0.998</td>
<td>0.997 0.995–0.998</td>
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</tbody>
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Table 4. Percentage of Mean Difference and 95% Limits of Agreement Between Rotation Angles

<table>
<thead>
<tr>
<th>Pair of Rotation Angles, °</th>
<th>Observer 1 % of Mean Difference 95% Limits of Agreement</th>
<th>Observer 2 % of Mean Difference 95% Limits of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Mean Difference 95% Limits of Agreement</td>
<td>% Mean Difference 95% Limits of Agreement</td>
</tr>
<tr>
<td>6 vs 9</td>
<td>0.5 –10.2, 11.3</td>
<td>–0.9 –13, 11.1</td>
</tr>
<tr>
<td>6 vs 15</td>
<td>0.6 –15, 16.2</td>
<td>0.1 –9.5, 9.6</td>
</tr>
<tr>
<td>6 vs 30</td>
<td>0.2 –15.5, 15.9</td>
<td>0.9 –16.9, 18.7</td>
</tr>
<tr>
<td>9 vs 15</td>
<td>0.1 –13.3, 13.5</td>
<td>1 –10.8, 12.7</td>
</tr>
<tr>
<td>9 vs 30</td>
<td>–0.3 –18, 17.4</td>
<td>1.8 –15.7, 19.4</td>
</tr>
<tr>
<td>15 vs 30</td>
<td>–0.4 –14.1, 13.3</td>
<td>0.9 –15.1, 16.8</td>
</tr>
</tbody>
</table>

Figure 4. Bland-Altman plot of interobserver agreement showing the percentage of the mean difference and 95% limits of agreement for the interobserver measurements using the 30° rotation angle (observer 1 versus 2 measurements) against the mean volume (cubic centimeters).
available studies have evaluated the intraobserver and interobserver agreement of volume measurements and have found excellent results, as indicated by the high ICC values. Our study also estimated the intraobserver and interobserver agreement for all 4 rotation angles and found that the percentage of the mean difference for each rotation angle was small, ranging from −3.4% to 5.6%, indicating good agreement, consistent with other studies and confirmed clearly by the Bland-Altman plots showing only a small number of outliers. The ICC, a measure of the proportion of variance attributable to the objects of measurement, has emerged as the universal and widely accepted reliability test. The ICC values in our study were high in all reliability analyses. It was noted that the volume measurements from both observers from the first data set were a little smaller than those from the second data set, which might be explained by urine filling in the bladder as the recording time was passing. However, the mean differences were still quite small, ranging from −3.4% to −1.7%, because we performed the second scan immediately after the first one.

Regarding the time required to perform the bladder volume measurements, our results showed that the 30° rotation angle took less than 1 minute,
whereas at 6°, it took approximately 2 to 3 minutes to complete the measurements. The range of time taken to perform volume calculations in many studies varied according to the target structure, the difficulty in identifying the target organ boundaries, and the operator's skill. Most of the images in this study showed clear boundaries of the urinary bladder, which were easily distinguishable from the surrounding structures.

An advantage of our study was that the range of bladder volumes was wide, varying from 2.62 to 1189.11 cm³. Therefore, the applicability of the limits of agreement for the different angles was not restricted. Additionally, all rotation angles were evaluated. Difficulty in identifying the boundaries of the urinary bladder with only a very small volume, eg, versus shadows from a bowel loop, did pose a problem and placed some minor limitations on the study. However, because this affected only a few volume data sets, we think that this did not affect the main outcome measures because a high degree of reliability and agreement was still observed.

In conclusion, use of 3DUS with the VOCAL technique and the different rotation angles is a highly reliable and effective method for bladder volume measurement because there seems to be no significant difference found in the volume calculations of the 4 standard rotation angles. The 30° rotation angle yields the fastest measurements.

References

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