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RESEARCH ARTICLE

Analysis of Three Main Error Sources in Traditional Bladder Volume Formula and Development of a Computer Bladder Volume Calculation Program

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This work involved human subjects in its research. Approval of all ethical and experimental procedures and protocols was granted by the Medical Ethics Committee of Dongying People's Hospital.

ABSTRACT This study analyzed three main sources of error in bladder volume calculation by traditional ultrasound bladder volume formula, which is most commonly used in clinic and built into most ultrasonic diagnostic apparatus. In order to solve these errors, we changed the traditional bladder volume formula to calculate bladder volume based on bladder axis to calculate volume based on bladder section area, and corrected this formula according to actual clinical data to obtain a new formula, which is called the modified ellipsoidal trend formula. This formula can easily calculate the bladder volume manually during ultrasound examination of the bladder. Based on this formula, OpenCV function is applied to build a program for calculating bladder volume through two ultrasound images of bladder. The method is to calculate the total number of pixels in the contour of the bladder image by the program, and convert the number of pixels to area, and calculate the bladder volume using the modified ellipsoidal trend formula. This algorithm can be implanted into Ultrasonic diagnostic apparatus or ultrasound workstation to replace the traditional bladder volume formula. In this study, 122 ultrasound cases were used to test the accuracy of the program, and the results showed that the program was more accurate than the traditional bladder volume formula.

INDEX TERMS Ultrasound, bladder volume, formula, computer program, urology, algorithms, image processing.

I. INTRODUCTION

The determination of bladder volume plays an important role in the diagnosis and treatment of many diseases, especially in urology [1], [2], [3], [4], [5], [6], [7], [8].

There are many methods for bladder volume measurement, among which catheter method is the most accurate method. However, this method makes patients uncomfortable and may lead to many complications such as injury and infection, so it is rarely used in clinical examination [6], [9], [10], [11], [12], [13], [14].

CT and MRI can also be used to determine bladder volume, but they are often expensive, and CT is radioactive, so they are also rarely used.

The most widely used method in clinical practice is the use of ultrasound to estimate bladder urine volume, because ultrasound is fast, convenient, non-invasive, reproducible and relatively accurate [2], [15], [16].

The basic method of ultrasound examination is to measure various diameter parameters of the bladder based on two-dimensional ultrasound, and then calculate bladder volume based on various calculation formulas [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27]. Since Holmes used ultrasound machine measurement to calculate the bladder

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volume in 1967 [5], [27], there have been many formulas for calculating the bladder volume using data measured by ultrasound [12], [15], [17], [20], [25].

After analyzing the literature of many years and combined with clinical practice, we found that the most commonly used methods to calculate bladder volume are using ultrasound to measure three axes of the bladder and using ellipsoid volume formula to calculate bladder volume.

The commonly formula is [5], [6], [27], [28]:

$$V = \frac{\pi \times \text{height} \times \text{depth} \times \text{width}}{6} = 0.52 \times \text{height} \times \text{depth} \times \text{width}.$$

In our study, this formula is called the traditional bladder volume formula (formula 1).

In the past few decades, the traditional bladder volume formula has gradually become the most widely used ultrasonic bladder volume calculation method, while most of the other methods have gradually faded out. To a certain extent, it can be said that the comprehensive performance of traditional bladder volume calculation formula is better than that of other ultrasonic bladder volume calculation methods. It also proves that the bladder volume has a good correlation with the volume calculated by this formula. The bladder has ellipsoidal characteristics to some extent. Although this formula is widely accepted, it has also been reported in the literature and been found by clinical practice to be inaccurate and often underestimates bladder volume [5], [15].

Three-dimensional ultrasound is also used to estimate bladder volume, but it is complicated and rarely used in clinic [5], [29], [30], [31].

The purpose of this study was to analyze the three main error sources of calculating bladder volume by traditional formula of bladder volume, and to derive a formula for calculating bladder volume mainly based on the maximum transverse and longitudinal area of the bladder according to the ellipsoid trend characteristics of the bladder. This formula was called the ellipsoidal trend formula in this study, which serves as the comparison formula and error analysis formula. Then, according to the above ellipsoidal trend formula, combined with the analysis of experimental data, we tried to get an easy-to-use and accurate correction formula of the ellipsoidal trend formula, which is called the modified ellipsoidal trend formula, and this formula is the bladder volume calculation formula in this study. Then, based on this formula, OpenCV function was used to build a computer program for calculating bladder urine volume, and the clinical application effect of this program was tested.

II. MATERIALS AND METHODS

A. PATIENTS SELECTION

In this work, a retrospective study was performed on the maximum longitudinal and transverse ultrasound image of bladder of 122 patients who received bladder ultrasonography in the department of ultrasound of Dongying People's Hospital between January 2021 and January 2023. The mean age of the patients was 51.84±16.21 years (range 8-90 years). All patients had urine volume records.

Patients with bladder diverticulum, or a markedly enlarged prostate convex to the bladder, or inability to empty urine were excluded from this study.

All patients' information was stored in the medical records database of Dongying People's Hospital.

The ethical review and informed exemption of this study was approved by Medical Ethics Committee of Dongying People's Hospital.

B. EXAMINATION GUIDELINES AND PROCEDURE

Since the bladder volume calculation reported in literature is mostly based on ellipsoid shape, the measurement of each diameter of the bladder should be generally measured according to the ellipsoid measurement principle, and the measurement methods should be standardized to increase objectivity, repeatability, and accuracy in general, The measurement principle of bladder of in our department had been formulated as follows: 1. The patient is in the supine position; 2. The longitudinal and transverse sections of the bladder should be as perpendicular to each other as possible; 3. the measurement lines of the height, depth and width of the bladder should be perpendicular to each other as far as possible, and try to cross the Central point of the section. 4. Therefore, So the height line and width line should be as parallel as possible to the surface of the bed on which the patient is lying, and the depth line should be as perpendicular as possible to the bed. 5. The depth of the longitudinal and transverse sections should be as equal as possible.

Under those principle, all the bladder examinations of the patients selected in this work had performed by senior sonographers with PHILIPS IU Elite, GE-LOGIQ9 or PHILIPS IU Elite scanner with a 3.5-MHz transducer.

With the patient lying supine, the probe was passed over the suprapubic area to acquire the largest transverse section image. the image obtained from ultrasonic machine was stored into medical records database. the maximum width and depth diameters were taken in this section. the transducer was rotated through about 90 degrees to acquire the maximum longitudinal section, the image was also stored into medical records database, the maximum height were taken in this section, and the depth value of this section is also measured to compared with the depth in transverse section.

After the examination, the patient emptied the urine, and ultrasound had been used to determine that there was no residual urine in their bladder. The volume of urine was considered to be the true bladder volume.

C. THE AREA AND VOLUME CALCULATED BY THE TRADITIONAL FORMULA METHOD

The bladder longitudinal and transverse images are exported from medical records database for further analysis by the bladder volume calculation program.

The elliptic area formula area $= \pi ab$ (a and b are the semi-axes of the ellipse) was used to calculate the transverse and longitudinal area of the bladder.

formula 2:

$$\text{transverse area by elliptic formula (TABEF)} = \frac{\pi \times \text{width} \times \text{depth}}{4}.$$

formula 3:

$$\text{longitudinal area by elliptic formula (LABEF)} = \frac{\pi \times \text{width} \times \text{depth}}{4}.$$

The bladder volume was calculated by the traditional bladder volume formula (formula 1)

$V = 0.52 \times \text{height} \times \text{depth} \times \text{width}$.

D. BUILD COMPUTER PROGRAM FOR AREA AND VOLUME CALCULATIONS

In windows 7 system, visual studio 2013 community edition software and OpenCV3.0 were used to write and compile a bladder image processing and bladder volume calculating program.

In windows painting software, opened the longitudinal and transverse images of the bladder respectively, and used the red brush (RGB (255,0,0)) to outline the bladder contour along the inner edge of the bladder.

In the picture control of the main interface of the program, opened the transverse bladder image and longitudinal bladder image. the OpenCV function findContours was applied to identify the manually drawn red contours in the images, and the contours were marked in green.

These contours were drawn into memory images with black background of the same size as the bladder image, and the interior of the contours were filled with white.

The code is as follows:

drawContours(transversecontour, contours, largest_contour _index, cv::Scalar (255), CV_FILLED);

drawContours (longitudinalcontour, contours, largest_contour _index, cv::Scalar (255), CV_FILLED);

Count the number of pixels in the contours as bladder section areas with the countNonZero function.

The code is as follows:

transverse area(pixel) = countNonZero(transversecontours)

longitudinal area(pixel) = countNonZero(longitudinal-contours)

By clicking the start point and end point of the measurement line in the picture controls, the corresponding coordinate points were obtained, and the coordinate points were converted into the coordinate points in the original image, and the number of pixels between the two points in the original image were calculated, and then the number of pixels per centimeter of the original image were obtained.

In transverse image:

$$\text{pixels per centimeter} = \frac{\text{pixels in depth}}{\text{depth(cm)}}.$$

In longitudinal image:

$$\text{pixels per centimeter} = \frac{\text{pixels in height}}{\text{height(cm)}}.$$

The areas of the transverse image and the longitudinal image is obtained by the following formula

$$\text{transverse area by program}\left(\text{cm}^2\right) = \frac{\text{transversearea (pixel)}}{\text{pixels per centimeter}^2}.$$

$$\text{longitudinal area by program(cm}^2) = \frac{\text{longitudinal area(pixel)}}{\text{pixels per centimeter}^2}.$$

The traditional bladder volume formula is the ellipsoid volume formula, which can be further derived. The process is as follows:

Formula 1:

$$V = \frac{\pi \times \text{height} \times \text{depth} \times \text{width}}{6}.$$

Formula 2:

$$\text{transverse area by elliptic formula (TABEF)} = \frac{\pi \times \text{depth} \times \text{width}}{4}.$$

formula 3:

$$\text{longitudinal area by elliptic formula (LABEF)} = \frac{\pi \times \text{depth} \times \text{height}}{4}.$$

then:

$$\text{TABEF} \times \text{LABEF} = \frac{\pi \times \pi \times \text{depth} \times \text{width} \times \text{heigh} \times \text{depth}}{16}.$$

$$\text{depth} \times \text{width} \times \text{height} = \frac{16 \times \text{TABEF} \times \text{LABEF}}{\pi \times \pi \times \text{depth}}$$

Let's substitute the above expression "depth × width× height" into formula 1, then:

$$V = \frac{\pi \times \text{height} \times \text{depth} \times \text{width}}{6} = \frac{\pi \times 16 \times \text{TABEF} \times \text{LABEF}}{\pi \times \pi \times \text{depth} \times 6} = \frac{16 \times \text{TABEF} \times \text{LABEF}}{6 \times \pi \times \text{depth}} = \frac{0.85 \times \text{TABEF} \times \text{LABEF}}{\text{depth}}.$$

Then we get the new formulas for estimating bladder volume, formula 4:

$$V = \frac{0.85 \times \text{TABEF} \times \text{LABEF}}{\text{depth}}.$$

We retrieved a formula for bladder volume calculation in the literatures [12], [20], as shown at the bottom of the next page.

Formula 4 is essentially consistent with this formula, both of which are variations of the ellipsoidal volume formula. Since Formula 4 is convenient to analyze the source of bladder error, it was used in this study for error analysis and comparison of calculation results.

In the computer program of this study, TABEF and LABEF in formula 4 are replaced by the transverse area by program and longitudinal area by program to obtain a new formula (formula 5), as shown at the bottom of the page.

This formula is called the ellipsoidal trend formula in this paper.

According to the preliminary analysis of the experimental data, there is a linear relationship between the volume calculated by ellipsoidal trend formula and the true bladder volume, but the volume calculated by the ellipsoidal trend formula is still smaller than the true bladder volume, so the ellipsoidal trend formula needs to be corrected. By dividing the actual bladder volume of each patient by the bladder volume calculated by the ellipsoidal trend formula, the quotient is obtained. The mean of these quotients of all patients is 1.19, and the ellipsoidal trend formula is corrected by multiplying the mean of these quotients.

The process is as follows:

$$V = \frac{1.19 \times 0.85 \times \text{ transverse area by program} \times \text{longitudinal area by program}}{\text{depth}}$$
$$= \frac{1.01 \times \text{ transverse area by program} \times \text{longitudinal area by program}}{\text{depth}}$$
$$\approx \frac{\text{transverse area by program} \times \text{longitudinal area by program}}{\text{depth}}.$$

Then we obtain a new formula for calculating bladder volume (formula 6):

$$V = \frac{\text{transverse area by program} \times \text{longitudinal area by program}}{\text{depth}}$$

This formula is called the modified ellipsoidal trend formula in this paper.

Formula 5 and formula 6 were applied in the program, and the bladder volume of the ellipsoidal trend formula and the bladder volume of the modified ellipsoidal trend formula were obtained respectively, Figure 1 is a screenshot of the program in action.

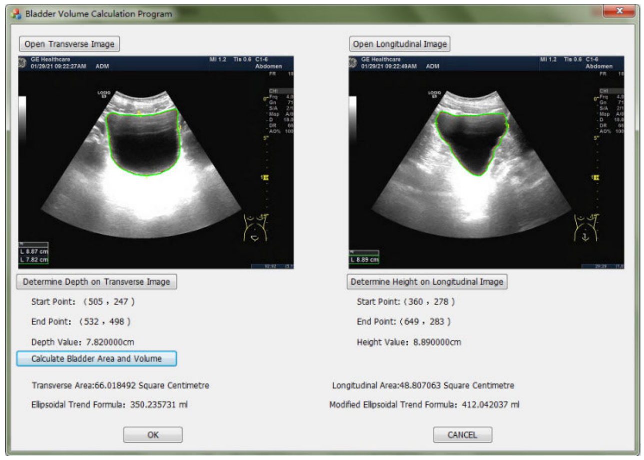

FIGURE 1. **The screenshot of the program.**

E. STATISTICAL ANALYSIS

Due to the preliminary data test, most groups of area and volume data in this experiment do not conform to normal distribution, so the data were presented by the median. Percent error was determined by the formula:

$$\text{percentage error} = \frac{\text{volume calculated} - \text{true volume}}{\text{true volume}}.$$

Absolute percentage error was determined by the formula:

$$\text{absolute percentage error} = \frac{|\text{volume calculated} - \text{true volume}|}{\text{true volume}}.$$

Data were compared using Wilcoxon Signed Rank test. When $p<0.05$, the differences were considered statistically significant. Correlation analysis between the data was performed using the person's correlation and spearman's correlation. All the statistical analyses were performed using computer software, i.e., IBM SPSS Statistics (version 21.0), Microsoft Excel 2010.

III. RESULT

The transverse areas of bladder calculated by elliptic area formula ranged between 8.24 and 95.39 Square centimeter (median 39.99 Square centimeter); The longitudinal areas of

$$\left(\frac{3.14 \times \text{transverse width} \times \text{sagittal depth} \times \text{sagittal height}}{6} + \frac{8 \times \text{longitudinal area} \times \text{transverse area}}{3 \times 3.14 \times \text{transverse depth}}\right) \div 2.$$

$$V = \frac{0.85 \times \text{ transverse area by program} \times \text{ longitudinal area by program}}{\text{depth}}.$$

TABLE 1. The differences and percentage errors of the formulas compared to the true bladder volume.

	Median Volume(ml) And Range	Median Percentage Error (%)	Median Absolute Percentage Error (%)	Wilcoxon Signed Rank Test, p-Value
True Bladder Volume	305.00 (25-1130)			
Traditional Bladder Volume Formula	212.47 (11.47-778.46)	-32.22	32.31	p<0.001
Ellipsoidal Trend Formula	246.60 (46.47-901.42)	-14.25	17.42	p<0.001
Modified Ellipsoidal Trend Formula	290.12 (54.99-1060.49)	0.88	14.36	P=0.669

TABLE 2. Pearson's correlation coefficient and Spearman's rank correlation coefficient between true blader volume and volume calculated by each formula.

		Traditional Bladder Volume Formula	Ellipsoidal Trend Formula	Modified Ellipsoidal Trend Formula
Pearson's correlation	r	0.927	0.915	0.915
	p	0.000	0.000	0.000
spearman's correlation	r	0.919	0.920	0.920
	p	0.000	0.000	0.000

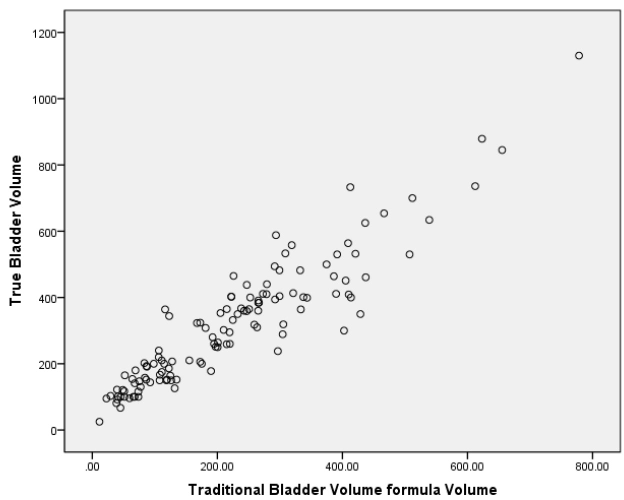

FIGURE 2. Scatter plot of true bladder volume against volume calculated by traditional bladder volume formula.

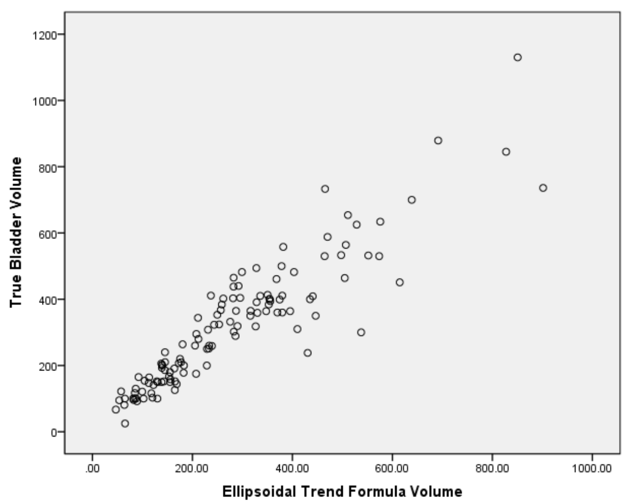

FIGURE 3. Scatter plot of true bladder volume against volume calculated by ellipsoidal trend formula.

bladder calculated by elliptic area formula ranged between 3.46 and 97.10 Square centimeter (median 36.62 Square centimeter); The transverse areas of bladder calculated by the program ranged between 12.06 and 89.49 Square centimeter (median 48.00 Square centimeter); The longitudinal areas of bladder calculated by the program ranged between 8.57 and 108.33 Square centimeter (median 37.63 Square centimeter).

The true bladder volume ranged between 25 and 1130 ml (median 305 ml); The traditional bladder volume formula volume ranged between 11.47 and 778.46 ml (median 212.47 ml); The ellipsoidal trend formula volume ranged between 46.74 and 901.42 ml (median 246.60 ml); The modified ellipsoidal trend formula volume ranged between 54.99 and 1060.49 ml (median 290.12 ml).

Wilcoxon signed rank test results showed:

The transverse areas of bladder calculated by elliptic area formula was less than the transverse areas of bladder calculated by program ($p<0.001$); The longitudinal areas of bladder calculated by elliptic area formula was less than the longitudinal areas of bladder calculated by program($p<0.01$).

The volume calculated by traditional bladder volume formula was less than the true bladder volume ($p<0.001$); The volume calculated by ellipsoidal trend formula in the program was less than the true bladder volume ($p<0.001$); There were no significant difference between the volume calculated by modified ellipsoidal trend formula in the program and the true bladder volume ($p=0.669$).

The percentage error of the bladder volume calculated by each formula is shown in Table 1.

There was a high correlation between the true bladder volume and the calculated bladder volumes of each formula, person correlation coefficient and spearman correlation coefficient were shown in Table 2.

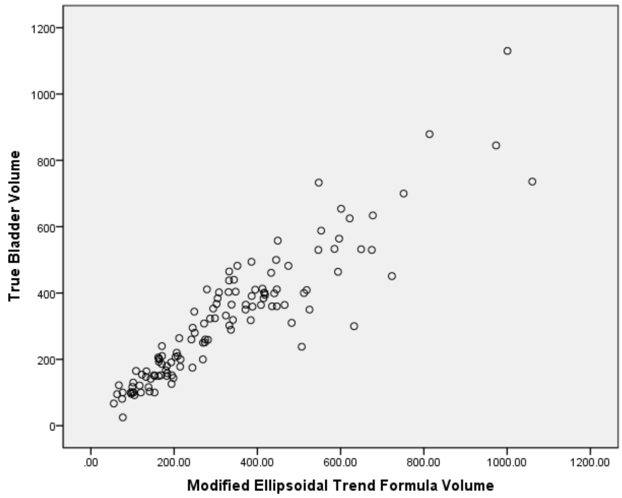

FIGURE 4. Scatter plot of true bladder volume against volume calculated by modified ellipsoidal trend formula.

IV. DISCUSSION

According to the literature reports of bladder volume calculation by ultrasound of many years, the use of ellipsoid volume formula to calculate bladder volume is more recognized and applied.

This proved that there is a correlation between bladder morphology and ellipsoid morphology.

However, it was also pointed out in many literatures that the bladder volume calculated by this method is smaller than the true bladder volume. We have also identified this problem ourselves in clinical practice.

The reason is that there is a correlation between the bladder volume and the ellipsoid volume, but the two volumes are not equal. Thus, calculations of bladder volume using the ellipsoidal volume formula are not very accurate and often underestimate the true bladder volume.

Accuracy is the primary requirement for bladder urine volume calculation methods, it is of great significance in the diagnosis and treatment of urinary tract diseases, such as the diagnosis of urinary retention or the detection of bladder function, which requires a method to accurately calculate bladder volume, and especially an accurate assessment of whether the bladder volume is near or below than 100ml is imperative for determining the type of lower urinary tract symptoms [6], [7], [8].

In addition, simplicity and ease of memorization are also beneficial criteria for evaluating a bladder volume method. As ultrasound doctors are usually very busy at work, therefore, a bladder volume calculation method that is easy to remember, easy to use, and widely applicable will benefit the work of ultrasound doctors.

Therefore, it is necessary to analyze the causes of error of the traditional bladder volume formula and find out the corrected method to calculate the bladder volume according to the causes of the error. The method needs to be more accurate, while being as easy to remember and easy to use as possible.

According to mathematical knowledge, if the shape of the bladder is similar to ellipsoid, the shape of the maximum transverse section and the maximum longitudinal section of the bladder is similar to ellipse or circle.

On the same bladder, if the ellipsoidal volume formula can be used to accurately calculate the volume of the bladder, then the elliptic area formula can be used to accurately calculate the maximum transverse area and the maximum longitudinal area, If the maximum transverse area and the maximum longitudinal area cannot be accurately calculated, then the volume of the bladder cannot be accurately calculated, and there is a direct relationship between the volume and the area of the ellipsoidal body. The difference between the volume of the ellipsoid and the volume of the bladder can be analyzed by analyzing the difference between the maximum transverse area and the maximum longitudinal area of the ellipsoid and that of the bladder.

As discussed in Section II-C, if the shape of the bladder is similar to that of an ellipsoid, the maximum transverse area and longitudinal area of the bladder can be calculated by the following formula:

formula 2:

$$\text{transverse area by elliptic formula (TABEF)} = \frac{\pi \times \text{depth} \times \text{width}}{4}.$$

formula 3:

$$\text{longitudinal area by elliptic formula (LABEF)} = \frac{\pi \times \text{depth} \times \text{height}}{4}.$$

However, although the true bladder shape has some ellipsoidal trends, it is inconsistent with the ellipsoidal shape. Therefore, the true maximum transverse area and the maximum longitudinal area of the bladder are different from the maximum transverse area and the maximum longitudinal area calculated by elliptic area formula. As a result, the bladder volume calculated by ellipsoidal area formula is not equal to the true bladder volume. In order to analyze the source of error, the true transverse area and longitudinal area of the bladder need to be obtained first.

At the same time, most of the current ultrasonic diagnostic instruments are equipped with the method of calculating the area by tracing the contour of the area, so this problem is easy to solve.

In this study, we need to establish a general method for bladder volume estimating that can be used alone or transplanted into ultrasonic diagnostic instruments and ultrasound workstations. Therefore, a method for calculating true transverse and longitudinal area of bladder by using OpenCV function is designed in the program.

In Section II-D of this paper, we have designed a computer algorithm based on OpenCV function to calculate the transverse area and longitudinal area of the bladder.

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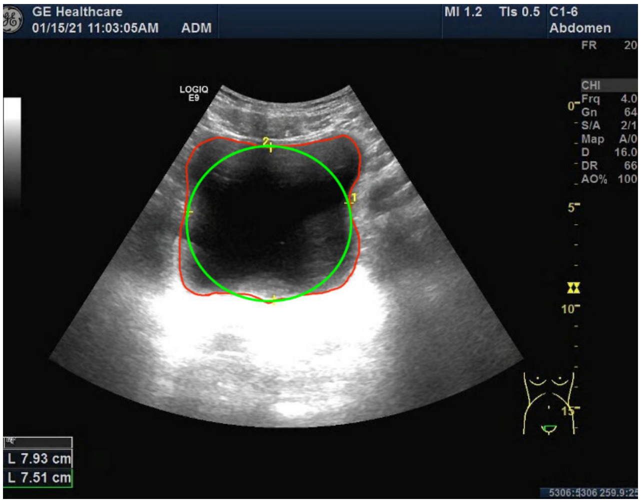

FIGURE 5. **Comparison of true transverse area and elliptic area.**

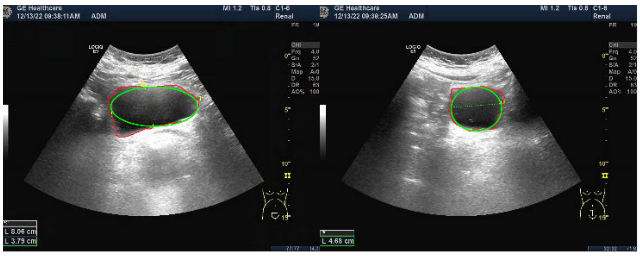

FIGURE 6. **Transverse and longitudinal images of the bladder of a patient with small bladder volume.**

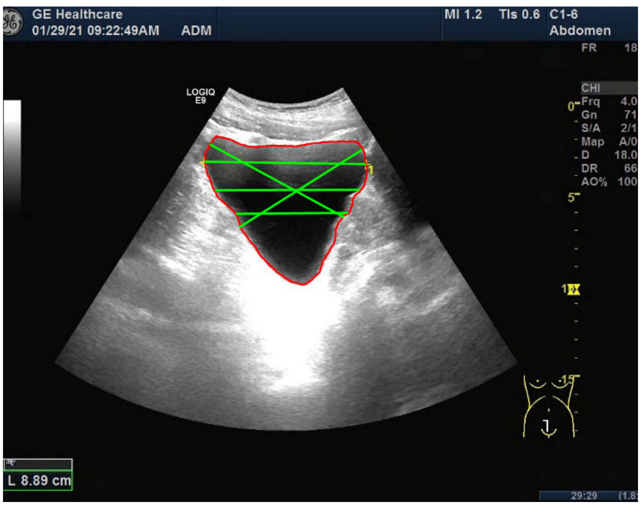

FIGURE 7. **Illustration of the uncertainty in bladder axes measurement.**

OpenCV is Intel's open source computer vision library. In this study, OpenCV function was used to calculate the area of the bladder section according to the most basic mathematical knowledge, and we can assume that those areas calculated by the program were the true areas of the bladder section.

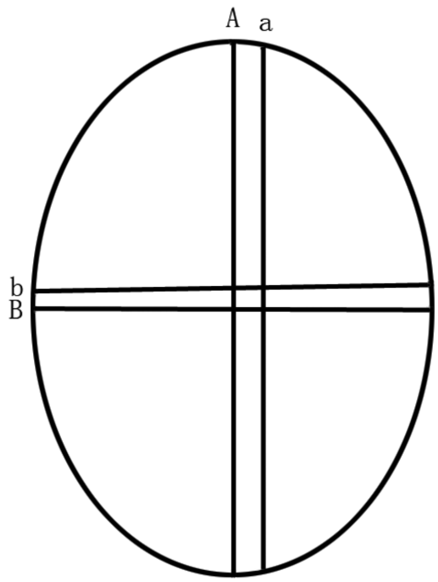

FIGURE 8. **Comparison of the true bladder axes with the actual measured axes.**

That is, the true maximum transverse area of bladder is equal to the transverse area by program, and the true maximum longitudinal area of bladder is equal to the longitudinal area by program.

This formula 6 from Section II-D can also be written in the following formula form (formula 7), as shown at the bottom of the page.

In this study, formula 6 and formula 7 are equivalent and considered to be the same formula.

On the basis of analysis of the true maximum transverse and longitudinal area of the bladder and the clinical practice and experimental result, we found that there are three main sources of error in the calculation of bladder volume using the traditional bladder volume formula which is essentially ellipsoidal volume formula.

Error 1: The area of bladder section calculated by elliptic area formula is smaller than the true area.

Although the traditional bladder volume formula considers that the shape of the bladder is similar to an ellipsoid, and the transverse and longitudinal sections of the bladder are similar to ellipses, in fact, the transverse section of the bladder is almost rectangular in most cases, and the transverse section area is larger than the ellipse area calculated by the bladder depth and width as axes. Figure 5 illustrates this situation. Figure 5. Comparison of true transverse area and elliptic area.

$$V = \frac{\text{true transverse area} \times \text{ true longitudinal area}}{\text{depth}}.$$

In this study, the true bladder transverse image area calculated by the program is larger than area calculated by elliptic area formula ($p<0.001$).

The shape of the longitudinal section of the bladder varies greatly, and it is difficult to compare the true area of the longitudinal section of the bladder with the ellipse area calculated according to the height and depth of the longitudinal image as axes by naked eye. However, through our experiment, the true bladder longitudinal image area calculated by the program is larger than that calculated by elliptic area formula ($p<0.01$).

The transverse area calculated by depth and width measured by ultrasound is smaller than the true transverse area of the bladder, and the longitudinal area calculated by height and depth is smaller than the true longitudinal area of the bladder, and the depth values of the two are consistent, then according to the formula 4

$$V = \frac{0.85 \times \text{TABEF} \times \text{LABEF}}{\text{depth}}.$$

and formula 5, as shown at the bottom of the page.

The bladder volume calculated by the traditional formula must be smaller than the true bladder volume. This situation is more obvious in the state of small bladder volume (shown in Figure 6), and the accurate estimation of small volume of the bladder, especially near or below than 100ml is imperative for determining the type of lower urinary tract symptoms [6], [7], [8], however, in the state of small bladder volume, there is often a large gap between the shape of bladder and ellipsoid, resulting in a large gap between the volume calculated by the ellipsoid volume formula and the actual bladder volume.

Figure 6 Transverse and longitudinal images of the bladder of a patient with small bladder volume.

Error 2: the uncertainty in bladder axes measurement (Figure 7)

When calculating the volume of the ellipsoid, the depth, height and width of the ellipsoid should be the three axes of the ellipsoid, which pass through the center of the bladder and are perpendicular to each other. If the shape of the bladder is similar to the shape of the ellipsoid, the measurement of the bladder diameter should also comply with the above principles, that is, through the center, perpendicular to each other. However, because the shape of the bladder is different from that of the ellipsoid to some extent, the above principles cannot be truly realized, Subjective interpretation of bladder dimensions of different operator may introduce errors in volume calculation by tradition bladder volume formula. Meanwhile, potential variability in measurements taken by different operators or the same operator on different occasions may also introduce errors in volume calculation. This situation is more obvious in the longitudinal section of the bladder, for example, most longitudinal sections of the bladder actually like figure 7.

Figure 7. Illustration of the uncertainty in bladder axes measurement.

In this longitudinal image of the bladder, we can say that the five straight lines on the image all fit some characteristic of the axis of the ellipse in some way, and we can say that all the lengths of these lines are the height of the bladder, but their lengths are so different that the difference will inevitably cause a large error in the volume calculation.

Error 3: the bladder section measured by ultrasound is usually smaller than the true maximum section of the bladder

Although the bladder is inconsistent with the ellipsoid, it generally has an ellipsoid trend. In terms of the shape of the ellipsoid, the maximum section of the bladder measured by ultrasound is smaller than the actual maximum section to varying degrees in most cases, which results in the bladder volume calculated by the bladder parameters measured by ultrasound being smaller than the actual bladder volume. As shown in Figure 8:

Figure 8 is a coronal view of the human bladder. Line A is the line passed by the maximum longitudinal section of the bladder, but the line passed by the maximum longitudinal section measured in the actual measurement is similar to line a in more cases, and the length of line a must be less than line A. Line B is the line passed by the maximum transverse section of the bladder, but the line passed by the maximum longitudinal section measured in the actual measurement is similar to line b in more cases, and the length of line b must be less than line B. The bladder volume calculated by the length of lines a and b is necessarily smaller than that calculated by the length of lines A and B.

Mainly because of the above three errors, the bladder volume calculated according to the traditional bladder volume formula is less than the true bladder volume.

There are other sources of error in bladder volume calculation, such as the difficulty of fully reflecting all features of the shape of the bladder by two ultrasound images, and the quality of ultrasound images affecting doctors' judgment, etc. However, in this study, we mainly analyzed the source of error in calculating bladder volume with this traditional bladder volume formula. The main errors in the calculation of bladder volume by this formula are mainly the above three errors. Because the traditional bladder volume calculation formula method is the most commonly used method for bladder volume calculation, the error caused by this formula is also the important error in bladder volume calculation.

One solution to solve these errors is to use formula 5 to calculate the bladder volume. By substituting the true maximum transverse area and maximum longitudinal area of the bladder

$$V = \frac{0.85 \times \text{transverse area by program} \times \text{longitudinal area by program}}{\text{depth}}.$$

calculated by the program into Formula 5 to calculate the bladder volume, we can get the bladder volume closer to the real one. The true transverse area and longitudinal area of the bladder were obtained by the computer program of this study.

Because the true transverse and longitudinal area of the bladder is used in the formula, the error 1 caused by the area calculated by the elliptic area formula being smaller than the true area is avoided. Because the area is a relatively fixed value, for the same bladder section image, the difference of areas measured by different operators is small, and the difference can be ignored. In this way, the error in the volume calculation caused by subjective interpretation of bladder dimensions of different operator is also avoided.

The formulas 5 need to be divided by the depth value of the transverse section. From the previous analysis, we know that the actual transverse area is larger than the ellipse area calculated by depth and width, so the measured depth is less than the depth of a virtual ellipse whose area is equal to the actual bladder transverse area and whose shape is similar to the ellipse with the bladder width and depth as the axis. Dividing by this smaller depth will result in the increase of the calculated bladder volume. However, in fact, due to error 3, the maximum transverse and longitudinal area of the bladder measured by ultrasound is generally smaller than the true maximum transverse and longitudinal of the bladder. Therefore, even if the actual transverse and longitudinal area of the bladder measured by ultrasound are used, the calculated volume is still smaller than the true volume. However, the increase of the calculated result caused by dividing by this depth can offset the volume reduction caused by error 3 to some extent.

In addition, the larger the error in measurement process, the smaller the actual area of the bladder, the smaller the depth, and the greater the error offset effect will be, In this way, the formula reduces the influence of error 3 in the above analysis to some extent by dividing the product of the transverse area and longitudinal area by depth.

It can be seen from the experiment that the volume calculated by formula 5 is closer to the true bladder volume than that calculated by the traditional bladder volume formula, but it is still smaller than the true bladder volume. There are some sources of error that cannot be explained by the above analysis, which need to be further experimental analysis in the future, but this result still needs to be corrected.

Based on the principle of combining accuracy and convenience, through preliminary data analysis, this study removed the coefficient 0.85 from formula 5 to get formula 6, and calculated the bladder volume with formula 6. It was found that the calculated volume was very close to the true bladder volume, and the mean values of the two groups of data were almost equal, and there was no significant difference in statistical analysis.

It can be seen from the experimental results that the modified ellipsoidal trend formula is accurate, and is easy to use and remember. It can be used manually or by computer, which meets the actual requirements of ultrasound doctors for bladder calculation in their busy work. In this study, this formula is used as the formula for bladder volume calculation.

V. CONCLUSION

This study proved that the traditional bladder volume formula had large errors, while the modified ellipsoidal trend formula was more accurate, simple and practical, and can easily calculate the bladder volume manually during ultrasound examination of the bladder. This modified ellipsoidal trend formula was worthy of clinical promotion. Based on this formula, this study developed a program for calculating bladder volume by using two section images of the bladder. The bladder volume can be accurately calculated, and this program is also worthy of clinical promotion. Meanwhile, the algorithm of this program can also be implanted in ultrasonic diagnostic apparatus or ultrasound workstation, which is more convenient for clinical application.

VI. OUTLOOK

Just like the ellipsoidal trend of the bladder, many organs and shapes in human body or parts of these shapes have a certain degree of ellipsoidal trend, but affected by various factors, the volume of each organ has its own different characteristics. By referring to mature biomedical modeling theory [32] and combining with the ellipsoidal trend method of this study, it is expected to help design more ultrasonic calculation methods for human organ volume, and find better solutions for human organ volume calculation.

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