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Ultrasound measurements of testicular volume: Comparing the three common formulas with the true testicular volume determined by water displacement

T.U. Mbaeri*, J.C. Orakwe, A.M.E. Nwofor, C.K. Oranusi, O.O. Mbonu

Department of Surgery, Nnamdi Azikiwe University Teaching Hospital Nnewi, Anambra State, Nigeria

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Abstract

Objective: To determine the accuracy of various ultrasound formulas for measuring the testicular volume in humans by comparing the resultant measurements with the actual testicular volume.

Subjects and methods: The testicular volume of 121 testes from 62 patients with prostate cancer (mean age 72.7 ± 9.4) was measured using ultrasonography before therapeutic bilateral orchidectomy. The ultrasound measurements of the testicular volume were calculated using the following three formulas: (a) length (L) \times width (W) \times height (H) \times 0.52; (b) $L \times W^2 \times 0.52$ and (c) $L \times W \times H \times 0.71$. The actual testicular volume was determined by water displacement of the testis.

Results: The mean actual testicular volume was 10.6 ± 3.5 ml. A strong correlation was found between the actual testicular volume and the volume calculated by the three-ultrasound formulas ($r = 0.853$ – 0.871 , $p = 0.0001$). The smallest mean difference from the actual testicular volume was observed with the formula $L \times W \times H \times 0.71$, which underestimated the actual volume by 0.4 ml (3.9%).

Conclusion: The results of this study show that ultrasonography and the formula $L \times W \times H \times 0.71$ are the most accurate method for the calculation of the testicular volume.

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* Corresponding author. Tel.: +234 8034041865.

E-mail addresses: duzo2001@yahoo.com, uzomambaeri@yahoo.com

(T.U. Mbaeri), jayceeorakwe@yahoo.com (J.C. Orakwe),

xnwofor@yahoo.com (A.M.E. Nwofor), chidex30@yahoo.co.uk

(C.K. Oranusi), mbonuora@yahoo.com (O.O. Mbonu).

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Introduction

The testes are responsible for the production of spermatozoa and testosterone in the man. Approximately 80–90% of the testicular volume are made up of seminiferous tubules and germ cells [1,2]. Thus, a reduction in the number of these cells is manifested in a reduction in testicular volume [3].

Reliable and accurate determination of the testicular volume is of great benefit in the evaluation of patients with disorders affecting testicular growth, development and function. Studies in infertile men have shown that the testicular volume has a direct correlation to seminal fluid and sex hormone assay, just like the simple measurement of testicular length, width and depth [4–6]. A total testicular volume (i.e. summation of right and left) of 20 ml and more, as determined by ultrasound, is indicative of normal testicular function [4]. These findings underscore the importance of testicular volume measurement in the management of male infertility. In line with this, one of the components of a minimum full evaluation of male infertility is palpation of the testes and measurement of their size [7].

In the management of adolescent varicocele, testicular volume measurement aids in deciding when to operate in cases where seminal fluid analysis could be seen to be psychologically or ethically incorrect [8–10].

Another important application of testicular volume measurement is the monitoring of patients following varicocele ablation in children and adults, and orchidopexy for undescended testes [11,12]. It is also a vital tool in staging puberty, as the testicular volume is the first clinical evidence of puberty [13], and in diagnosing idiopathic hypogonadotropic hypogonadism and Klinefelter's syndrome [14–17].

Over the years, many instruments have been used in an attempt to accurately, reliably and conveniently measure the testicular volume in vivo. These include rulers, tapes, vernier calipers, orchidometers, graphic models and ultrasound scan [18–24]. Earlier studies using these tools showed conflicting results, especially with regard to ultrasound-scan measurement where different formulas were used in various studies [4,19,22–24].

The present study, therefore, attempts to critically assess the accuracy of ultrasonography in measuring the testicular volume and to assess the best formula for calculating the ultrasound-determined testicular volume in patients with advanced prostate cancer who opted for orchidectomy after counseling in our center.

Subjects and methods

This hospital-based cross-sectional prospective study was carried out over a period of 19 months from June 2009 to December 2010. The aim of the study was the assessment of the testicular volume of patients with advanced prostate cancer who were offered bilateral total orchidectomy as a form of hormone ablation therapy. Bilateral total orchidectomy is one of the standard methods of surgical castration, and at our center special care is taken not to risk leaving any testicular tissue remnant.

Ethical approval was sought and obtained from the ethical committee of the hospital. Patients who did not give their consent to the study

and patients with hydrocele, painful testes and/or an edematous scrotum were excluded.

All the patients were subjected to scrotal ultrasound scans in order to check for any scrotal pathology and to measure the length (longitudinal diameter), width (transverse diameter) and height (anterior posterior diameter) of the testes. These scans were carried out by a consultant radiologist, using a 7.5 MHz probe. The testicular volume was calculated using (a) the formula for an ellipsoid (formula 1): length (L) \times width (W) \times height (H) \times 0.52; (b) the formula for a prolate spheroid (formula 2): $L \times W^2 \times 0.52$; and (c) the empiric formula of Lambert (formula 3): $L \times W \times H \times 0.71$.

Orchidectomies were then performed, tagging the right testis for identification, and the epididymis was removed by sharp dissection. The actual testicular volumes were measured by the water displacement method using a measuring cylinder. All the results were recorded in the study proforma.

Data analysis

Statistical analysis was done using the Statistical Package for Social Sciences (SPSS) version 17.0. Simple frequencies were determined for the age, while descriptive statistics were used for the testicular volume measurements. The paired sample t -test was used for evaluating the significance of testicular volumes, while the correlation was determined using the Pearson correlation coefficient.

Results

Of the 62 patients studied, 59 had bilateral testes, two had only the right testis and one had only the left testis, amounting to a total of 121 testes evaluated in this study. The patients' age ranged from 55 to 92 years with a mean age of 72.7 ± 9.4 years. The peak age group patients were aged between 71 and 75 years ($n = 18$; 29%).

The mean volume calculated with ultrasound formulas 1, 2 and 3 was 7.6 ± 3.4 ml (range 2.9–16.1), 6.5 ± 3.0 ml (range 2.2–14.8) and 10.2 ± 4.4 ml (range 3.9–21.2), respectively. The mean actual testicular volume as measured by water displacement was 10.6 ± 3.5 ml (range 4.4–20.0) (Table 1).

Ultrasound formulas 1, 2 and 3 underestimated the actual volume by 3.0 ± 1.9 ml, 4.1 ± 1.8 ml and 0.4 ± 2.2 ml, respectively. These results show that ultrasound formula 3 was the most accurate one, as it underestimated the actual volume by only 3.9%, compared to underestimations by ultrasound formulas 1 and 2 of 28.0% and 38.5%, respectively (Table 1). The mean difference between the actual testicular volume and the volume calculated with ultrasound formulas 1, 2 and 3 was found to be statistically significant ($p < 0.0001$, $p < 0.0001$, $p < 0.05$, respectively) (Table 1).

Table 1 also shows the correlation between the measuring methods. Although the mean difference between the actual testicular volume and the volume calculated with the ultrasound formulas was statistically significant, all three ultrasound-determined volumes correlated strongly with the actual testicular volume (Pearson correlation coefficient $r = 0.853$, $p < 0.0001$; $r = 0.858$, $p < 0.0001$ and $r = 0.871$, $p < 0.0001$ for ultrasound formulas 1, 2 and 3, respectively) (Table 1; Figs. 1–3).

Table 1 Comparison of the mean value of each of the ultrasound formulas with that of water displacement.

	Ultrasound formula 1	Ultrasound formula 2	Ultrasound formula 3	Water displacement
Descriptive statistics				
<i>n</i>	121	121	121	121
Mean volume	7.6228	6.5107	10.1816	10.5934
Minimum volume	2.85	2.21	3.87	4.40
Maximum volume	16.10	14.80	21.18	20.00
Std. deviation of mean	3.36671	2.99507	4.41072	3.50178
Paired difference				
Paired difference with water (mean)	-2.97058 (-28.04%)	-4.08273 (-38.54%)	-0.41182 (-3.89%)	0 (0%)
Std. dev.	1.86854	1.79755	2.19305	
Std. error mean	0.16987	0.16341	0.19937	
<i>t</i>	-17.488	-24.984	-2.066	
Sig. (2-tailed)	0.0001	0.0001	0.041	
Correlation				
Pearson correlation	0.853	0.858	0.871	
Sig. (2-tailed)	0.0001	0.0001	0.0001	

n, total number of testes; *t* = *t* value; Sig. (2 tailed) = 2 tailed significance.

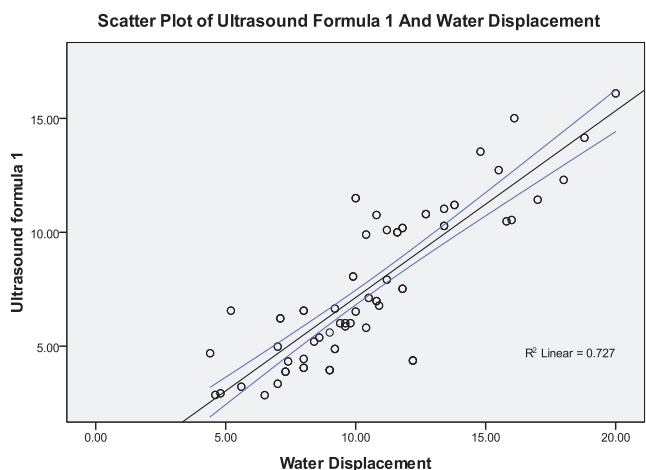


Figure 1 Correlation between ultrasound formula 1 and water displacement in a scatter plot. The blue lines represent the 95% confidence interval; *r* = Pearson correlation coefficient.

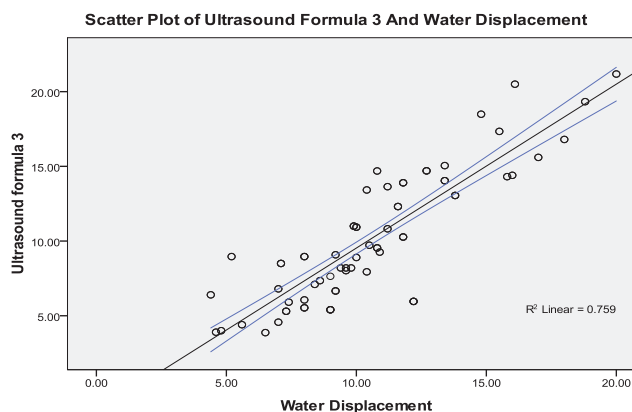


Figure 3 Correlation between ultrasound formula 3 and water displacement in a scatter plot. The blue lines represent the 95% confidence interval; *r* = Pearson correlation coefficient.

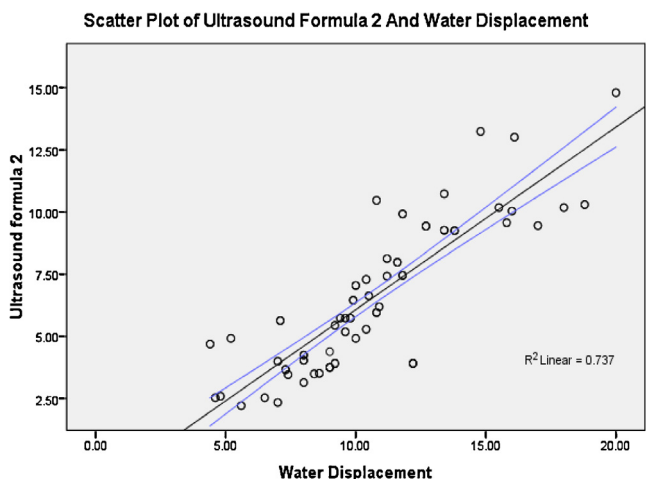


Figure 2 Correlation between ultrasound formula 2 and water displacement in a scatter plot. The blue lines represent the 95% confidence interval; *r* = Pearson correlation coefficient.

Discussion

The mean age of the patients included in this study was 72.7 ± 9.4 years. This is similar to the mean age of 74.5 ± 7.5 years reported by Sakamoto et al. [23] who studied the testicular volume of 40 testes in 20 patients. In a study by Ogunbiyi and Shittu [25] in Ibadan, Nigeria, on the incidence of prostate cancer in Nigeria, the mean age of the patients included was 71.4 ± 14.3 years which is comparable to the mean age of the prostate cancer patients evaluated in the present study.

The mean actual testicular volume measured by water displacement was 10.6 ± 3.5 ml (range 4.4–20.0) in this study. The same actual testicular volume (10.6 ml) was found by Hsieh et al. [26] in a similar study carried out in China, while Sakamoto et al. [23] reported on a mean actual testicular volume of 9.3 ± 4.5 ml. This difference may be said to have arisen from the fact that his study included a smaller number of testes (40) compared to the 121 testes evaluated in the present study. But Hsieh et al. [26] who found a similar mean volume like ours studied only 30 testes, i.e. even a smaller number than the one of Sakamoto et al. This implies that the sample size alone cannot explain the difference.

In the study by Sakamoto et al., the patients' mean age was 74.5 ± 7.5 years with no range indicated. Since his study population was small, this may mean that the presence of a few extremely low age groups could bring down the mean age of his perhaps older patient population. If this is true, it could explain why his mean actual testicular volume is smaller, since the testicular volume (though relatively constant after puberty) has been found to start decreasing from the eighth decade of life [27,28]. Also the fact that we studied a different population group (Japanese vs. Nigerian patients) could account for the difference, since environment and race have also been found to influence the testicular volume [22,29,30].

All the ultrasound formulas in this study underestimated the actual testicular volume. Formula 1 ($LWH \times 0.52$) underestimated the actual testicular volume by 2.97 ml (28.04%), formula 2 ($LW^2 \times 0.52$) by 4.08 ml (38.54%) and formula 3 ($LWH \times 0.71$) by 0.41 (3.89%), with formula 3 being the most accurate of the three ultrasound formulas in this study. Sakamoto et al. [23], in their work, found that ultrasound formula 1 underestimated the actual testicular volume by 1.9 ml (21.3%), formula 2 by 3.35 ml (37.6%) and formula 3 by 0.8 ml (7.46%). Though slightly different from this study, they also noted the most accurate formula to be formula 3. The slight difference in the level of underestimation by ultrasound scan in these two studies may be due to the difference in the actual testicular volume measured by water displacement (10.6 ml in this study and 9.27 ml by Sakamoto et al. [23]). In addition, it is noteworthy that the results of the three formulas in the two studies vary by a range of 0.39 ml to 1.07 ml (1.07 ml for formula 1, 0.73 ml for formula 2 and 0.39 ml for formula 3), which is within the confines of the mean difference in actual testicular volume between the two studies, thus presenting a minimal difference.

The difference in sample size (40 vs. 121 testes) may also have played a role. Hsieh et al. [26] found a mean value of 3.3 ml (31.4%), 1.8 ml (17.2%) and 0.6 ml (6.3%) for formulas 1, 2 and 3, respectively. Their mean actual testicular volume is the same with that of the present study (10.6 ml), the difference thus being 0.33 ml for formula 1, 2.28 ml for formula 2 and 0.2 ml for formula 3.

Except for formula 2, the difference in the two studies is less than 0.5 ml, i.e. approximately 3%, which may also depend on the person carrying out ultrasonography.

Paltiel et al. [22], in their work on canine testes, also noted that the most accurate ultrasound formula was formula 3. In their work, formula 1 underestimated the actual volume by 1.9 ml (31%) and formula 2 by 1.1 ml (11%). They noted that formula 3 caused the least mean bias, but they did not indicate the value calculated with formula 3.

Rivkees et al. [20] in their earlier work performed in 1987 when the choice of the best formula was not an issue, used only formula 2 on 10 calves and 9 dogs with a simulated scrotum. They found that this formula had an accuracy of $4.6 \pm 1.6\%$. This is, however, not consistent with any of the studies mentioned earlier, which may be due to the fact that they worked on a scrotum that was simulated by double sheepskin.

In the present study, it was also found that the ultrasound results correlated strongly with the actual testicular volume, which is in accordance with other reports.

Thus, all the previous works using the three formulas unanimously agreed on the superiority of formula 3 and confirmed the strong correlation of all ultrasound formulas with the actual testicular volume.

In conclusion, ultrasound measurement of the testicular volume correlates strongly with the actual testicular volume measured by water displacement, but formula 3, i.e. $LWH \times 0.71$, proved to be the most accurate of the three ultrasound formulas. Currently, most ultrasound machines indicate the testicular volume automatically, using the formula length \times width \times height \times 0.52 (formula 1). We recommend to use the formula length \times width \times height \times 0.71 as the accepted norm instead and to incorporate it into the ultrasound software.

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