ASSESSMENT OF TESTICULAR VOLUME: HOW ACCURATE IS IT?

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Certificate

This is to certify that the work incorporated in this dissertation entitled "**ASSESSMENT OF TESTICULAR VOLUME: HOW ACCURATE IS IT?**" is a bonafide work done by **Dr. Rajiv Paul Mukha** in partial fulfillment of the rules and regulations of MCh Branch IV (Genitourinary Surgery) examination of the Tamil Nadu Dr. MGR Medical University, Chennai to be held in August 2009.

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Contents

INTRODUCTION

Introduction

The testicle (from Latin testicular, diminutive of testis, meaning "witness" [of virility]) is the male generative gland. The testis is a vital endocrine and reproductive organ. As well as semen and endocrinological analyses, the evaluation of testicular size is an initial and important method for estimating spermatogenesis and for monitoring the changes in pubertal status to optimize the treatment selection. Testicular volume has traditionally been assessed using orchidometers. The orchidometers over the years have been modified, refined and compared to each other. With the advent of Ultrasound, which is non invasive and patient friendly a new technique for the evaluation of testicular size came into being. We strive to look at the various techniques of testicular measurement and arrive at the most effective way of measurement of the human testes.

REVIEW OF LITERATURE

Review of literature

Testicular volume is the earliest indicator of puberty in adolescent boys [1]. According to Kaplan [1], boys' pubertal status can be accurately determined by testicular volume at a much earlier stage. Early assessment may be particularly important in a situation where "normal" pubertal staging may be changing due to environmental or other unknown factors. Testicular enlargement (diameter 2.5cm or greater) is the first indicator of puberty[1]. Hypogonadism has been associated with delayed puberty.

In conditions like varicocoele an arrest of testicular growth and reduced volume has been shown [2, 3, 4]. Reduced testicular volume means fewer tubules and thus also a lower number of germ cells [5]. According to a study by Kass et al the presence of a grade I varicocele in adolescence appeared to have no effect on normal testicular growth as compared to patients with a grade II varicocoele who were at risk of left testicular volume loss with time and need to have their testicular volume measured annually. Patients with grade III varicocoele were at risk of bilateral testicular volume loss; a careful evaluation and early surgical intervention was recommended in this group of patients [6]. Some authors suggested that a 20% to 25% volume differential is clinically significant [7]. It has also been demonstrated that there is clearly an increase in testicular size in adolescent subjects following surgical repair as a resumed growth of the testicle [8, 9, 10, 11].

Testicular volume is associated with the semen parameters. As the seminiferous tubules comprise 70–80% of the testicular mass, testicular size is a fair proxy for spermatogenesis [12]. Testicular volume strongly correlates with sperm counts. In Asian men, when the sum of bilateral testicular volume measurements was > 30 ml the testicular function was usually normal [13]. It has been showed that a decreased testicular volume is associated with altered semen parameters [9, 10] especially in cases with an associated varicocoele. There was an improvement in the semen parameters with the increase of testicular volume [14].

In a study by Handelsman et al testicular size was shown to be associated with body weight, age alcohol and malignancy [15]. Similarly treatment for childhood malignancies, with cytotoxic drugs like cyclophosphamide has been associated with a decrease in testicular size and altered semen parameters [16, 17].

Measurement

History of testicular measurements

There was very little in literature on the size of the normal testis, particularly in the living patient. In 1902, Spangaro [18] gave the measurement of the testes of ten corpses as length 40 to 50 mm, breadth 20 – 27mm, and thickness 25 to 35 mm. Roessle and Roulet (1932) [19] quoted Schultze's (1913) [20] measurements of adult testes to be 40 to 45 mm. length, 20 to 25 mm. breadth and 18 to 24 mm thickness. The same authors quoted Mita (1914) [21] as 38, 24, 23 mm. respectively. The majority of the workers who have examined living subjects have used models to indicate size, e.g. Engberg (1948) [22] divided the adult range into six sizes, ranging from a pea to normal adult size. Nordlander adopted the same principle (1948) [23]. Hurxthal (1948)[24] had eight models made for comparison, with volumes ranging from 2 ml to 18 ml and stated that the latter was normal from the age of 18 years. From Hansen (1949) [25] measured the length and breadth of the testis and calculated the volume on the assumption that the testis was the shape of an ellipsoid of revolution. He found the mean testicular volume of the normal adult to be 23.5 ml.

Lambert (1951) [26] compared the size of normal adult testes with subjects who had suffered from mumps. He showed that the formula for the rotation of an ellipsoid gave results that were inaccurate, and devised an empirical formula as follows: Testicular volume = 0. 71 x length x breadth x depth. From Hansen and With (1952) reported a series of testicular measurements of boys and men, the measurement here being the sum of the largest widths of the two testes. These authors give the mean total volume (corrected according to Lambert) as 34 +/- 7 ml. The figures reported by these authors on boys are in agreement with those of Reich (1924) [27] and also those of Quaade (1955) [28], who showed a relatively constant testicular volume until 12 years of age, followed by a rapid increase until the adult form is achieved at about 17 years.

Orchidometers

Prader orchidometer

In 1966 a pediatric endocrinologist Prof. Dr.Andrea Prader of the University of Zurich introduced an objective way of measuring the testicular volume [29]. This was the Prader orchidometer which consisted of a string of twelve numbered wooden or plastic beads of increasing size from about 1 to 25 milliliters.

The Prader orchidometer was the first universally accepted objective form of testicular measurement. These are sometimes informally referred to as "Prader's balls", "the medical worry beads", or the "endocrine rosary." The beads are available commercially and are made of plastic or wood.

The beads are compared with the testicles of the patient, and the volume is read off the bead which matches most closely in size. Prepubertal sizes are 1–3 ml, pubertal sizes are considered 4 ml and up and adult sizes are 12–25 ml. Professor Stephen Shalet, a leading endocrinologist who works for the Christie Hospital in Manchester, is reported to have told *The Observer*, "Every endocrinologist should have an orchidometer. It's his stethoscope." Since then this instrument has been used and compared to various different methods of volume assessment. The Prader orchidometer provides an easy and objective way of testicular measurent. However there are variations and subjectivity between individuals.

The Prader orchidometer testicular volumes are obtained after stretching the scrotal skin over the testis in a warm room, preferably over a heating pad, and comparing the testis to the 12 solid ellipsoid models constituting the orchidometer and ranging in volume from 1 to 25 cm^3 (1 to 6, 8, 10, 12,15,20, and 25 cm^3).

Rochester orchidometer

Takihara et al [30] devised a new orchidometer in 1983 called the Rochester orchidometer. The Rochester orchidometer consists of 15 punched-out elliptical rings with graded volumes 1 to 30 ml. (1 to 6, 8, 10, 12, 14, 16, 19, 22, 26 and 30 cc). Testicular volume is determined by snug placement of the ring up to the mid portion of the testis. Incidentally this was one of the first papers to note a difference in testicular size between races. The Japanese testicular volume being 14 ml and the Americans 17 ml respectively.

Schonfeld orchidometer

Another orchidometer that merits mention is the one described by Schonfield [31, 32]. He published two papers based on his measurements and discovered that his orchidometer tended to give overestimates of actual size at small volumes, and underestimates at large volumes.

The Schirren's circle was an orchidometer used in 1987 for a testicular assessment of 99 cadavers [33]. This showed a 52% increase in comparison to the volume by Archimedes principle. This is why this method did not come into extensive use.

Measurements using planometry

One of the simpler described methods to measure testicular volume has been using a simple ruler. In 1996 Tashkien et al [34] published a comparison of an ordinary ruler, orchidometer, and ultrasound for testicular measurements. The formula used for calculating the volume was the one proposed by Lambert (0.71 X longitudinal axis X transverse axis) [2]. The deduced that a simple method of measurement was by a ruler, provided it was done by an experienced clinician. However, this method according to them was not for an accurate measurement and could not be used for prognostication or follow up of developmental volumes as the degree of accuracy was low.

The calipers have been used to measure testicular volumes. There have been two calipers described – 'sliding; and 'pinch types [35]'. The sliding or the regular vernier calipers has been used as a simple aid for testicular. It is relatively inexpensive and commonly available. The length, width and depth of the testis can be calculated, volume calculated and then compared.

The pinch type of calipers that has been used is the one used to measure subcutaneous fat thickness. However, both these methods have been shown useful only for quantitative rather then qualitative assessment of testicular volume.

Ultrasonography and measurement

In 1987 Scott Rivkees et al [36] used the ultrasound on a pediatric population and compared the various methods after correlating with bovine and canine testes.

The first reports of ultrasound being used for testicular measurement in adults were in 1989 and 1990 by Behre [37] and Fuse et al [38]. They found ultrasound to be a reliable method of testicular measurement. In 1993 Lenz et al [39] published a report on the testicular volume and texture in 444 men and correlated it to the seminal profile. Ultrasound truly gained acceptance when the creator of the Rochester orchidometer Takihara [40] studied 282 testes and reported the limitations of his instrument and propagated the use of ultrasonography for accurate testicular measurements especially in cases needing finer measurements. In 2003 Schiffet al [41] reported the use of the ultrasound and found it complementary to the physical examination. The ultrasound provides additional information about intratesticular pathology and also allows an assessment of varicoceles. The current recommendations [42] for ultrasonic measurements involve the use of high frequency 7.5 MHz transducers with the use of light pressure to avoid distortion of the testicular shape. Gray-scale images of the testes are obtained in the transverse and longitudinal planes. At least three separate transverse and longitudinal images of each testis are needed.

Autopsy studies and water displacement methods (Archimedes principle)

The first study on cadavers was in 1902 by Spangarro [14]. He used linear measurements using a linear scale. Subsequently the first indexed report of autopsy studies was in 1955 by Quaade F [43]. He however only measured testicular length in a few cadavers. In 1987 Dörnberger V, Dörnberge G [32] and published their report on the use of the Archimedes principle for the measurement of testicular volume in 99 corpses. They compared the results of testicular sonography, Prader's orchidometer, Schirren's' circle and the sliding calipers. They found the sonographic measurements to be the most accurate.

Density of the testis

Handelsman et al [14] studied the autopsies of 1056 consecutive complete necropsies on males ranging in age from 18 to 96 years conducted over a period of 3 years in Sydney, Australia, where the population was predominantly (>97%) Caucasian. The measurements of both testes were taken during the necropsy after removal of the epididymis and prior to histologic fixation. Testicular weight was determined to the nearest 0.1 g on a balance, volume to the nearest 1 ml by water displacement, and dimensions (length and width defined as the maximal and minimal dimensions) to the nearest 0.1 cm by a ruler. They found the mean testicular density to be 1.038 ± 0.001 g/ml which was not altered over age, body weight or illnesses.

Rivkees [35] et al in 1987 studied bovine and canine testes and found their density to be 1.04 +/- 0.03g/dl.

In 2002 Paltiel et al [44] studied 18 canine testes and found their weights and volumes. They used Handelsman's density values in their study and found the ultrasound measurements to be most accurate.

Comparison and limitations of various methods

The first attempt to compare the different methods of testicular volume assessment was by Dorberger et al [32] in 1986. They studied 99 testes of corpses and compared sonography, Archimedes principle, Prader's orchidometer and Schirren's circle. There was a mean error of 7% for the Archimedes principle and 15% for sonographic determination. The error was greatest at volumes below 4 ml. The Prader and Schirren's circle were measured without skin and so were not compatible with real life measurements.

In the same year Scott A. Rivkees [35] presented a paper in the Annual meeting of the society for Pediatric research and American Pediatric Society, Washington. He compared estimates of testicular volume by Prader orchidometer and real time ultrasonography in 12 boys with central precocious puberty. He then determined the accuracy of these techniques by measuring bovine and canine testicular volumes by the above methods and comparing them with the actual testicular volumes. To simulate the human scrotum these testes were placed in an artificial scrotum with a thickness of 2.7 mm.

There was correlation between the ultrasound and orchidometer volumes. However, orchidometer volumes uniformly exceeded ultrasound volumes over the range of testes examined. Ultrasound volumes very closely matched the actual testicular volumes from 1.0 to 23 ml with a coefficient of variation of 4.6% +/- 1.6%. However the mean orchidometer measurements actual testicular volumes by nearly 30% when testicles ranged from 1.0 to 15 ml, and approximated actual volumes in testes 20 ml or more. The also measured length and width and calculated volume of the testes. These too exceeded the actual volumes and closely matched orchidometer measurements. They concluded that the clinical estimates of testicular volume using the Prader orchidometer are neither accurate nor reproducible. In contrast, ultrasound measurements of testicular volume have a high degree of accuracy and excellent reproducibility, and should be the preferred modality when accurate assessment of testicular volume is important.

Later, Behre et al [35] compared autopsy studies on 14 testes and clinical measurements of 256 patients using the Prader orchidometer and ultrasound. The orchidometer measurements correlated highly with sonographic measurement and ultrasound to be both accurate and reproducible.

In 1996 there two papers on testicular measurements both with very different conclusions. Seppo Taskinen et al [33] from the Department of Urology, Helsinki, Finland measured 76 adults with 151 testes. One had undergone unilateral orchidectomy for testicular atrophy. Each testis was measured with a plastic rule (with a centimeter scale), an ellipsoid orchidometer, a flat projection of the Prader orchidometer with ellipsoid apertures of different sizes equivalent to testicular volumes of 1, 2, 3, 4, 5,6 8, 10, 12, 15, 20, 25, 30 and 35 ml, and ultrasonography. The ruler and orchidometer measurements were performed by a urologist, and the ultrasonography was done by a radiologist. Each measurement was performed independently without any previous knowledge of the results obtained by the other methods. They deduced that the testicular volumes obtained by the three different methods were similar overall. The mean testicular volume was 15 +/- 8 ml. (standard deviation) by the ruler method, 16 +/- 7 ml. with an orchidometer and 17 +/- 2.8 ml. by ultrasonography with the Lambert formula[2] but only 9 +/- 2.5 ml. when measured planimetrically. The correlation between the different methods was similar. Mean orchidometry and ultrasonography values were 1.2 +/- 0.5 and 1.3 +/- 0.7 times greater, respectively, than those obtained with an ordinary ruler. Mean ultrasonography values, in turn, were 1.1 +/- 0.3 times greater than those determined with the orchidometer. The planimetric method resulted in a mean of only 0.6 +/- 0.2 time's greater volume obtained by the ultrasonographic method directly applying the Lambert formula. There appeared to be an especially great variation in the volumes of the small testes when results obtained with the orchidometer and ruler were compared. They concluded no clinical method is completely accurate or ideal. For simple qualitative measurements they concluded that a simple ruler is adequate for measurements.

Chipkevitch et al [45] from Brazil compared the measurements of 42 adolescent testes. They enrolled patients who had an ultrasound to rule out scrotal pathology.

Five methods were used:

1) Ultrasound performed by one of the authors using a high resolution, real-time scanner with a 7.5 MHz. transducer. The largest length (L), width (W) and depth (D) were measured and volume was calculated using the formula, V = pi/6 X L X W X D.

2) For the graphic method the testicle was held in 1 hand and visually compared to a graphic model consisting of 6 drawings of elliptical rings representing volumes of 2 ml. (length 2, and width and depth 1.4 cm.), 5 ml. (length 2.9, and width and depth 1.8 cm.), 10 ml. (length 3.6, and width and depth 2.3 cm.), 15 ml. (length 4, and width and depth 2.7 cm.), 20 ml. (length 4.5, and width and depth 2.9 cm.) and 25 ml. (length 4.7, and width and depth 3.2 cm.).

3) For the dimensional measurement method length and width of the testis were measured with a caliper and volume was calculated using the formula, V = pi/6 X L X W2.

4) For the Prader orchidometer method the testis was compared to 12 ellipsoid models (1 to 6, 8, 10, 12, 15, 20 and 25 ml.), as proposed by Prader.

5) For the ring orchidometer method the testis was fitted into 1 of the 15 punched out elliptical ring models, representing volumes of 1 to 6, 8, 10, 12, 14, 16, 20, 22, 26 and 30 ml, as proposed by Takihara et al.

They concluded after a statistical analysis of their data that all 4 clinical methods as well as ultrasound are equally reliable for measuring testicular volume. Therefore, the graphic method proposed by them was as reliable as the 4 traditional methods. The graphic method also dispensed with the use of ultrasonography, orchidometers and calipers, which are not always available in all clinical settings. They also created an equation of the linear structural model which enabled one to calculate without bias and equal reliability.

Diamond et al [46] in the year 2000 compared the assessment of pediatric testicular volumes using orchidometers and ultrasound. A total of 65 males were studied. Not all their patients were pediatric in contrast to the title of their paper, since the age range was 7 to 24 years. There were 58 patients diagnosed with varicocele, including 6 after unilateral orchiopexy and 1 after correction of unilateral testicular torsion. Each patient was examined by the attending urologist and had testicular volumes measured with the Prader and Rochester (Takihara) orchidometers. The urology nurse then repeated testicular volume measurements using both orchidometers blinded to measurements obtained by the attending urologist. Patients then underwent testicular volume measurements by a radiology attending physician. Testes were scanned in axial and longitudinal planes, and at least 2 measurements of length, width and thickness were obtained. Scans were reviewed by board certified radiologists experienced in scrotal sonography. Both orchidometers had a strong linear relationship to the ultrasound measurements. However, both orchidometers relative to ultrasound significantly overestimated testicular volume by approximately 6 cc (mean difference Prader 5.8 cc, Rochester 6.1 cc, p = 0.0001). The absolute testicular volume measurements by physician and nurse correlated strongly with each other using both orchidometers. However, measurements by the nurse were higher than those of the physician by approximately 2 cc on average. The Prader orchidometer was more specific in detecting differential measurements between the two testes than the Rochester orchidometer. They concluded that the ultrasound assessment was important in detecting testicular volume differential when assessing the patient with varicocele. Although the orchidometer was valuable in serially following the size of the individual testis, it was too insensitive to volume differentials to be used routinely to determine growth impairment secondary to varicocele. For this reason they recommended annual ultrasound of testicular volume for an adolescent with varicocele.

A canine study [44] was done by the same group in 2002. They sought to compare the accuracy and precision of orchidometer and US measurements in a canine model by using the two most commonly employed orchidometers, the Prader and the Rochester, and (b) to compute testicular volume from US-derived measurements by using three of the most commonly quoted formulas in the literature and to compare the accuracy and precision of these formulas with respect to true volume. This was one of the first studies to address the issue of the mathematical formulas to assess testicular volumes.

Testicular volumes were calculated by using three formulas:

(a). The formula for an ellipsoid: length (L) X width (W) X height (H) X 0.52;

(b). The formula for a prolate spheroid: L X W^2 X 0.52; and

(c). The empiric formula of Lambert: L X W X H X 0.71.

This was the first study in which the water displacement measurements were done after removal of the epididymis. True testicular volume was calculated by using the formula volume = weight / density, where density equaled 1.038 gm/ml [15]. They obtained nine volume measurements for each of the 18 testes: two orchidometer assessments (Prader and Rochester), six ultrasound calculations (three formulas for each of the two US transducers), and weight determination followed by calculation of true volume, as described earlier. Their results showed The Prader orchidometer and four of the six US techniques produced testicular volume measurements that were significantly different from true volume ($P < .05$ in all cases). The SD's were much higher for the orchidometers (Prader SD = 2.5 ml; Rochester SD = 2.2 ml) than for any of the US methods (SD = 0.6–1.0 ml). Ultrasound formula (c) had the smallest mean difference from true volume. They concluded ultrasound methods of testicular volume measurement were more accurate and more precise than orchidometry. The formula L X W X H X 0.71 was the most accurate for determining testicular volume.

In 2003 Schiff [41] reported his assessment of testicular volumes on a set of older men (mean age being 36.6 years). He examined 314 testes in 159 men who presented for evaluation for infertility. He compared the orchidometer with ultrasound. The mean (SD, 95% CI) estimates of testis volume for orchidometry and US were not significantly different. He concluded orchidometer is an accurate method to assess testicular volume when the scrotum is warm and the dartos muscle is relaxed. Ultrasound provided additional information about intratesticular pathology and allowed an assessment of varicoceles. He was however assessing an older group and was not doing any quantitative follow up.

The creator of the Rochester orchidometer [40] Takihara compared his orchidometer to the ultrasound in 2005. He assessed 281 testes from 142 patients. Three cases had unilateral orchidectomy because of testicular tumor. The mean testicular volumes in 281 testes measured by orchidometer and USG were 15.0 ml and 11.7 ml, respectively. The orchidometer overestimated testicular volume by 3.3 ml compared to USG. There was a strong linear relationship between orchidometer and USG ($r = 0.94$, $P < 0.0001$). To calculate testicular volume he used the formula length × width × thickness × 0.71. The mean O/U ratio in 281 testes was 1.37. The O/U ratio was high in the application of the orchidometer for adolescent boys or small testes. There were high U/O ratios for patients Klinefelter's syndrome (2.24 ± 0.82), ipsilateral detorted testes with mean 6.7 months follow-up periods (2.06 ± 0.34) and hypogonadtropic hypogonadism (1.74 ± 0.43). He concluded that the orchidometer was able to accurately evaluate testicular volume precisely except when the testicular volume is low in conditions such as Klinefelter's syndrome, detorted testes and hypogonadism. He recommended the use of his orchidometer for patients who did not have small testes.

A study from Turkey in 2005 compared the interobserver variability in cases of testicular measurement with the Prader orchidometer. Karaman [47] and his colleagues studied 100 testes from 50 boys (mean ages 6.4 years), who were examined by three experienced urologists. The testicular volumes measured with orchidometer by the first investigator were between 2 ml to 18 ml with a mean volume of 4.01 +/- 3.79 ml (SE). The second investigator measured the volumes between 1 ml to 18 ml with a mean testicular volume of 3.66 +/- 3.46 ml (SE). Finally, the measurements by the last one were also between 1 ml to 18 ml with a mean of 3.86 +/- 3.54 (SE). Mean testicular volumes measured by three examiners A, B and C were 4.01 + /- 3.79 ml (SD) (2–18 ml), 3.66 +/- 3.46 ml (SD) (1–18 ml) and 3.86 +/- 3.54 ml (SD) (1–18 ml), respectively. The statistical correlation between the measurements of investigator A and B, A and C, and B and C showed a high correlation {(r= 0.954 (P<0.01), r = 0.964 (P<0.01), and r= 0.979 (P<0.01)}, respectively. They concluded the Prader orchidometer measurements correlated highly among experienced examiners using this orchidometer.

There have been two recent studies by Hideo Sakamoto from Showa University School of Medicine, Tokyo, Japan. They have assessed in situ and ex vivo testicular volumes. The first [48] of these was a study on 40 testes from 20 patients with prostate cancer scheduled for bilateral orchiectomy. The mean age of the subjects was mean age +/- SD 74.5 +/- 7.5 years. The testicular volumes were measured preoperatively using a Prader orchidometer. They performed high-frequency ultrasound by one experienced examiner using 5-MHz and 7.5-MHz transducers (ALOKA SSD 2000, Tokyo, Japan) with subjects in the supine position. The testicular volumes were calculated using three formulas: (a) the formula for a prolate ellipsoid: length (L) X width (W) X height (H) X 0.52, (LWH 0.52); (b) the formula for a prolate spheroid: L X W^2 X 0.52 (LW^2 0.52); and (c) the empiric formula of Lambert: L X W X H X 0.71 (LWH 0.71). Following bilateral orchidectomy for androgen ablation therapy the epididymis was removed and each testis was weighed, and the actual testicular volume was measured by water displacement. The testicular volumes measured using a Prader orchidometer and calculated using each of the three US formulas were compared with the actual testicular volume and with each other, and the correlation coefficients were calculated. The mean actual testicular volume and weight was 9.3 +/- 4.5 cm^3 (range 2.5 to 23.0) and 9.5 +/- 4.6 g (range 2.4 to 23.6). The mean difference was - 8.58 cm^3 (- 54.43%) for the formula LWH0.52, - 10.03 cm^3 (- 64.1%) for the formula LW^2 0.52, and - 5.89 cm^3 (- 37.78%) for LWH 0.71. However, the testicular volume measurements obtained using each of the three formulas correlated strongly with the Prader orchidometer volume. The testicular volume measured using the Prader orchidometer and each of the three US formulas differed from the actual testicular volume. The largest mean difference from the actual testicular volume was with the Prader orchidometer, which overestimated the actual volume by 6.68 cm^3 (81.7%). The US volume measurements using each of the three formulas showed a stronger correlation with the actual volume than did the Prader orchidometer. The testicular volumes calculated using the formulas LWH X 0.52 and LWH X 0.71 had stronger correlations with the actual volumes than did those calculated using LW^2 X 0.52. However, the Prader orchidometer measurements also correlated strongly with the actual testicular volume. They concluded that testicular volume measurement by US is more accurate than by Prader orchidometry. The US formula L X W X H X 0.71 generated the most accurate testicular volume.

They extended their findings to a study on infertile men which included 938 testes in 469 men with abnormal semen [42] over seven years. The mean age of the subjects +/- SD 35.8 +/- 5.4 years, range was 22 to 56 years. The testicular volumes were obtained after stretching the scrotal skin over the testis in a warm room by two experienced urologists by comparing the testes with 12 the solid ellipsoid models constituting the Prader orchidometer and ranging in volume from 1 to 25 cm^3 (1 to 6, 8, 10, 12, 15, 20, and 25 cm^3). This was followed by high-frequency US was performed by one experienced examiner using 5-MHz and 7.5-MHz transducers with subjects in the supine position. The Prader orchidometer overestimated US testicular volume by 5.1 +/- 3.9 cm^3 (range +/- 10.8 to 16.2 cm^3) for the right testis and 5.5 +/- 3.5 cm^3 (range +/- 6.4 to 16.0 cm^3) for the left testis. The largest mean absolute difference between methods was observed for testicular volumes of 10 to 15 cm^3 in the right testis and 5 to 10 cm3 in the left testis, and the mean percentage difference between the two methods was greatest for testicular volumes less than 5 cm^3, on the right and left.

The absolute and percentage of differences between the two methods decreased with an increasing US testicular volume. However, for US volumes of 25 cm^3 or more, the mean and percentage of difference in testicular volume on each side was underestimated using orchidometry, by 3.07 cm^3 and 9.8% on the right and 2.55 cm3 and 7.6% on the left, respectively. Nonetheless, the testicular volume measurements obtained using the US formula showed a strong correlation with the Prader orchidometric measurements.

They concluded based on this study that testicular volumes obtained with a Prader orchidometer correlated closely with US testicular volume measurements, considered the standard method. However, Prader orchidometry overestimated the testicular volume, especially in small testes, and underestimated the volume of testes larger than the largest model provided in the Prader orchidometer.

There are several different factors causing bias when measuring testicular volume. The experience of the examiner undoubtedly affects the result. The shape of the testis is neither uniform nor necessarily ellipsoid, as has been proposed when applying the different formulas in use. The generally accepted ellipsoid formula is definitely not accurate and an ellipsoid orchidometer can, in fact, only be used as a relatively rough estimate of testicular volume. Particularly in the case of small testes, the thickness of the skin and subcutaneous tissue may strongly influence the result. The testis is an elastic organ and its elasticity may vary, particularly in a cryptorchid gonad with different grades of dysplastic changes of the parenchyma. During measurement the testis easily becomes compressed, resulting in distortion of shape and dimensions. In addition, especially with ultrasonography, the axis of the testis may become oblique instead of perpendicular as required for the ellipsoid formula.

The Prader orchidometer correlates with the ultrasound. However, there is an overestimation at lower volumes and underestimation at higher volumes. There is an interobserver variability in cases of the examiners being inexperienced. Ultrasound provides an accurate and objective method of testicular measurement. The most accurate formula for calculating the testicular volume is length (L) X weight (W) X height (H) X 0.71.

Difference between ethnic races and Indian data

There has been a difference in different races with respect to testicular size. Seppo Taskinen et al [33] from Finland found the mean testicular volume to be 17 +/- 2.8 ml. by ultrasonography. In another publication by Schiff [41] et al from New York USA the mean testicular volume as assessed by ultrasonography was 18.4 ml and 17.1ml for the right and left side respectively.

The Asian data is mainly from Japan. Koji Shiraishi [40] et al found the mean testicular volume in Japanese men to be 11.7 ml by ultrasound. The measurements from Hideo Sakamoto et al [42] from Japan are similar to Shiraishi' measurements. The mean testicular volume was by US was 13.7 ml for the right testis and 12.5 ml for the left respectively.

These studies seem to suggest that there is a difference between Caucasians and Asian men, with the Asian size being lesser.

The only Indian data on this subject is by K. B. Lall [49] et al in 1980. They did a cross sectional study on 1000 school children in Ajmer, between the ages of 8 – 16 years to find out the normal testicular volume. At 8 years the testicular volume averaged 1.4 ml. This increased at the rate of 0.5 ml per year, till it reached 2.9ml at the age of 11 years. A spurt of testicular growth (increment of 1.6 ml) was recorded between 11 and 12 years. This accelerated growth continued at a rate of about 2.5 ml to 4.0 ml / year, so as to attain a mean testicular volume of 15.6 ml by 16 years of age. There is no data on adult testicular volumes from our country.

AIMS

Aims

The aim of this study was to assess the accuracy of orchidometer and sonographic testicular volume assessment in comparison to true volume assessment in the Indian population.

Determine the average testicular volume in the Indian adult male.

Objectives

1. Comparison of testicular volumes as calculated using
2. Ultrasound
3. Prader orchidometer
4. Water displacement method.
5. To arrive at an appropriate correction factor to be applied to sonographic measurement to improve the accuracy of in situ assessment of testicular volume.
6. To calculate the density of the human testes.
7. Determine the average testicular volume in the Indian adult male in the population studied.

Materials and methods

Materials and methods

This study was conducted on patients with advanced carcinoma prostate who were scheduled to have bilateral orchidectomy as part of hormone ablation. All men who opted for bilateral orchidectomy instead of medical castration were part of this study. Men with conditions like hydrocoeles, filarial scrotums, prior scrotal surgery, hernias, varicoceles and any other condition altering the anatomy of the scrotum or the testis were excluded from the study.

All patients were explained the nature of the study and an informed consent in the patients own language was obtained. The study design and methodology was approved by the Ethics Committee and the Institutional Review Board.

The patients underwent a preoperative assessment by the Prader orchidometer by a single urologist. In a warm room with adequate privacy after explaining the procedure, the scrotal skin was stretched and size of the testis determined by comparison to the Prader orchidometer. The ellipsoid best matching the actual testicular volume was taken as the correct measurement.

Subsequently, sonographic assessment of testicular volume was performed by a single radiologist, who was blinded to the earlier measurements. The testis was scanned with an ultrasound imaging machine (Siemens Antares, Germany) using both high and low frequency linear array transducers (7.5 – 10 MHz). Scanning was performed by using light pressure to avoid distortion of the testicular shape. At least three separate transverse and longitudinal images of each testicle were obtained with both transducers. The three largest volumes were averaged and used for calculation and comparison.

Immediately after the orchidectomy, the epididymis was surgically removed and each testicle weighed separately on an electronic balance. Each testicle was then immersed in a calibrated beaker containing a previously known volume of normal saline. The amount of fluid displaced by the testicle was indicated by an increase in height of the water level. This method, in keeping with Archimedes principle, allowed us to calculate the true volume of each testicle. The density (Weight / Volume) of each testicle was also calculated.

Calculations

Testicular volumes can be calculated using these three formulas: the formula for a prolate ellipsoid: length (L) X width (W) X height (H) X 0.52 (LWH 0.52), the formula for a prolate spheroid: L X W^2 X 0.52 (LW^2 0.52), and the empiric formula of Lambert: L X W X H X 0.71 (LWH 0.71).According to previous study by Hideo Sakamoto et al [48] the ultrasound formula LW^2 0.52 underestimated the actual volume by 3.35 cm3 (37.6%), LWH0.52 underestimated the actual volume by 1.90 cm^3 (21.3%), and LWH0.71 overestimated the actual volume by 0.80 cm^3 (7.42%).

The empiric formula of Lambert: L X W X H X 0.71 (LWH0.71) was the closest to the actual volume and was the formula used by us to calculate the true volume.

Statistical analysis

We used paired t tests to determine whether the orchidometer and ultrasound volume measurements differed significantly from the true volume.

The relationship between each measurement technique and true testicular volume was evaluated by using linear regression analysis, with true volume as the independent variable and the orchidometer or ultrasound measurement as the dependent variable. For each regression, 95% confidence bands and a 45 degree line (equivalence) was included to provide a comparison with the no-intercept regression. The R^2 statistic provided a measure of the strength of the linear association.

A one-sample Student t test was performed to see whether the difference of each method as compared to true testicular volume was consistent over the range of volumes measured or whether it varied with the magnitude of the volume.

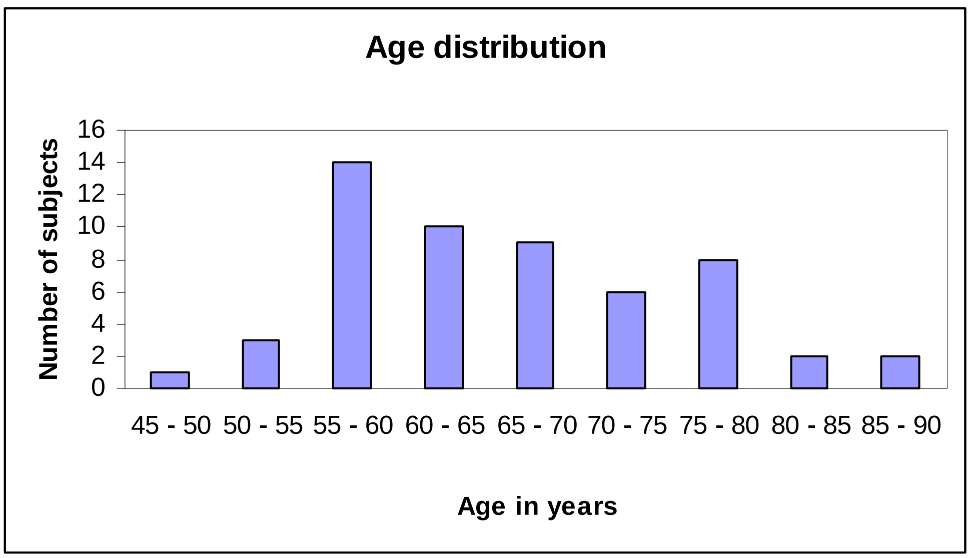
RESULTS

Results

General demographics

There were a total of fifty five patients with patients with 110 testes. The mean age of the patients was 65. 6 years, the range being ninety to forty eight years. The maximum number of subjects was between the age group 55 – 60 years.

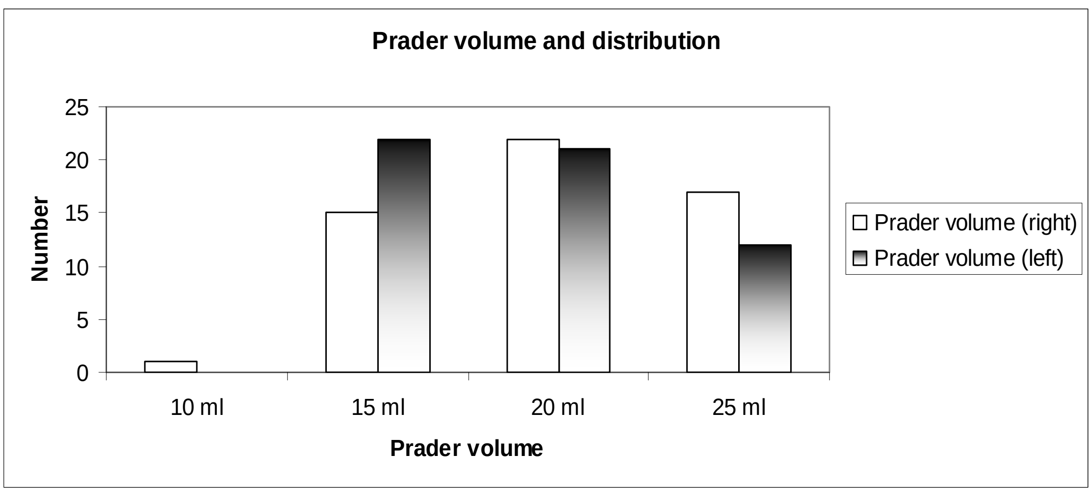
Chart showing the distribution of the subjects according to the age



Testicular volumes as measured by the Prader orchidometer

The mean testicular volume on the left side with the Prader orchidometer was 19.09 ml, the range being 15 – 25 ml. On the right side the mean volume according to the Prader orchidometer was 20 ml the range being 10 - 25 ml. The mean testicular volume combining both sides by the Prader orchidometer was 19.5 ml (range 10 – 25 ml).

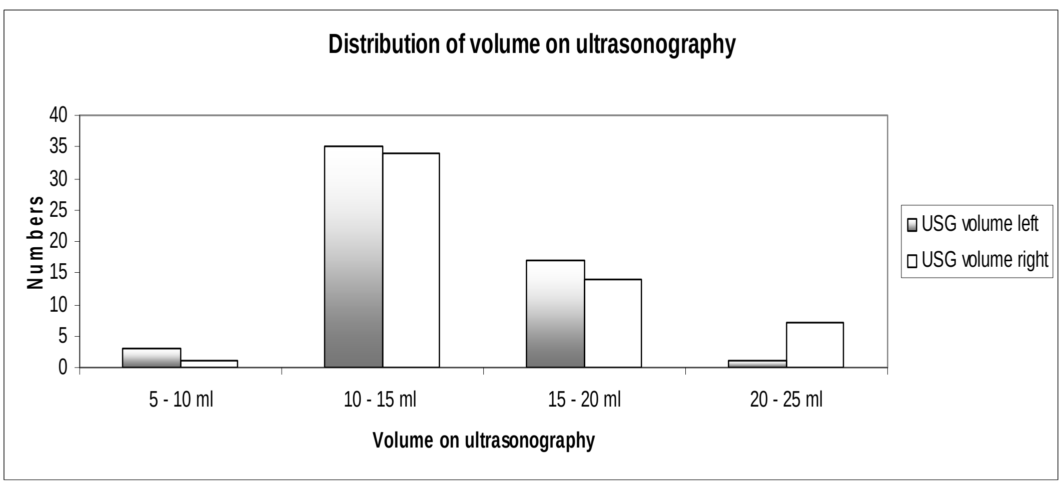
Figure showing the distribution of the testicular volumes as measured by the Prader orchidometer



Testicular volumes as measured by ultrasonography

The mean testicular volume measured on ultrasonography on the left side was 13.7 ml, the range being 7.3 – 21.8 ml. On the right side the mean testicular volume was 15.1 with the range being 7.3 – 23.0 ml. The average testicular volume combining both sides was 14.6 ml with a range of 7.3 – 23.0 ml. The maximum number of subjects had a volume of 10 - 15 ml.

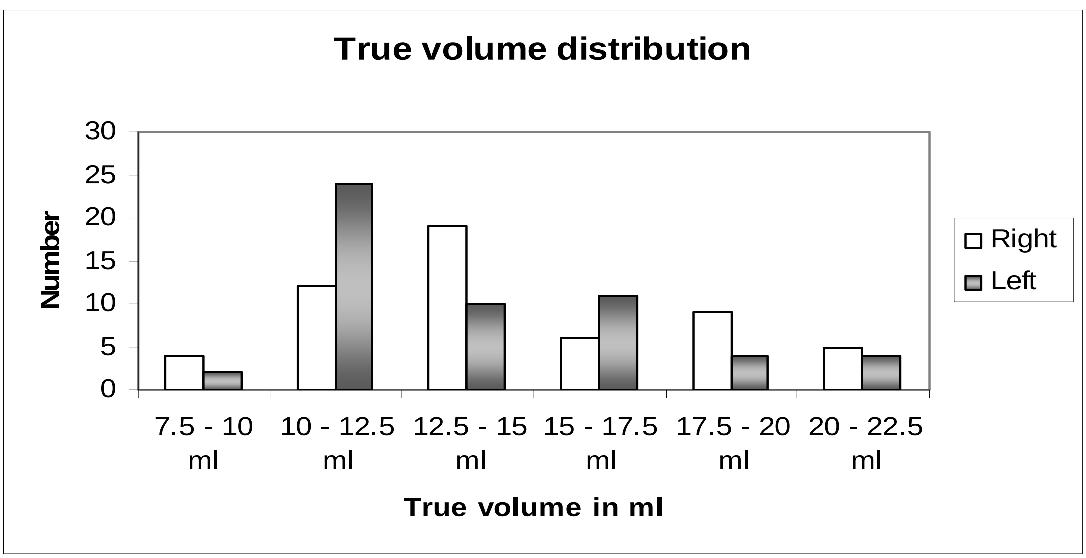
Figure depicting the distribution of testicular volume as measured by ultrasonography



Testicular volumes as measured by the water displacement method (Archimedes's principle)

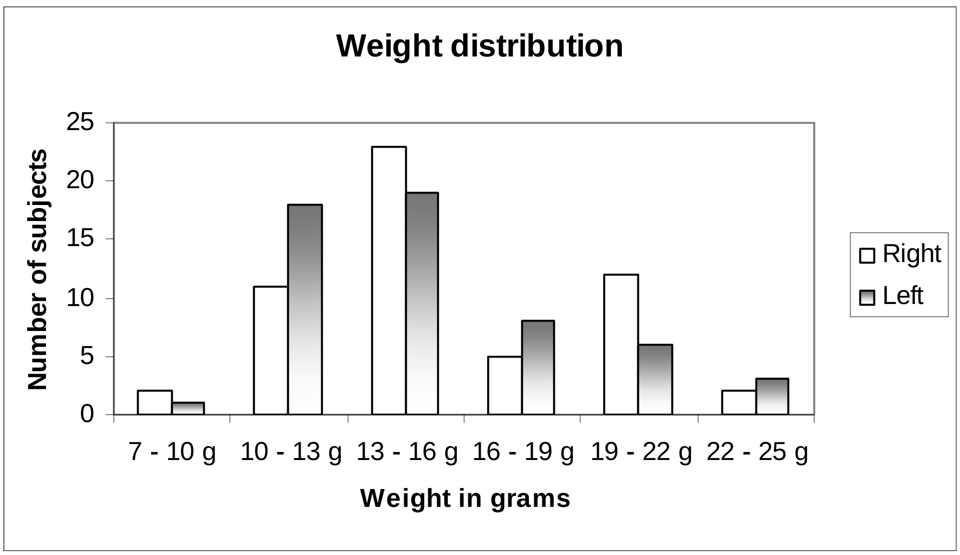
The mean testicular volume by the water displacement method, after the removal of the epididymis on the left side was 14.3 ml. The range was 8.0 – 20.6 ml. The results on the right side were mean 14.6 ml, range 7.6 – 22.0 ml. The average volume combining both sides was 14.45 ml, range 7.6 – 22.0 ml. The maximum number of subjects had testicular volumes ranging from 10 – 15 ml.

Figure depicting the distribution of testicular volume as measured by the water displacement method



Testicular weight

The mean testicular weights after the surgical removal of the epididymis were 14.6 g and 15.5 g on the left and right side respectively. The ranges were 9.5 – 23.1 g for the left side and 8.2 – 22.7 g on the right side. The mean testicular weight combining both sides was 15 g, range 8.2 – 23.1 g.



Density

The mean testicular density on the left side was 1.08 and on the right side 1.06 respectively. The average testicular density for both sides was 1.07.

Differences between the three methods

Prader and ultrasound

The mean difference in volumes between the Prader orchidometer and ultrasound volume on the left side was 5.33 ml. The range was 11.36 to 0.6 ml.

On the right side the mean difference in the volumes was 4.85 ml, with a range of 9.33 to - 0 .036 ml.

The mean difference combining both the sides was 5.09 (range 11.36 to - 0 .036ml).

This was a mean difference of 34.17 % (range 87.44 to – 0.234%) of the ultrasound volume on the right side. On the left side the mean percentage volume difference of the ultrasound volume was 41.56% (range 104.63 to 4.16%). The percentage difference combining both sides was 37.85% (range 104.63 to – 0.234%).

Prader and true volume

The mean difference in volumes between the Prader orchidometer and the true volume by ultrasound volume on the left side was 5.53 ml. The range was 10.0 to 1.1 ml.

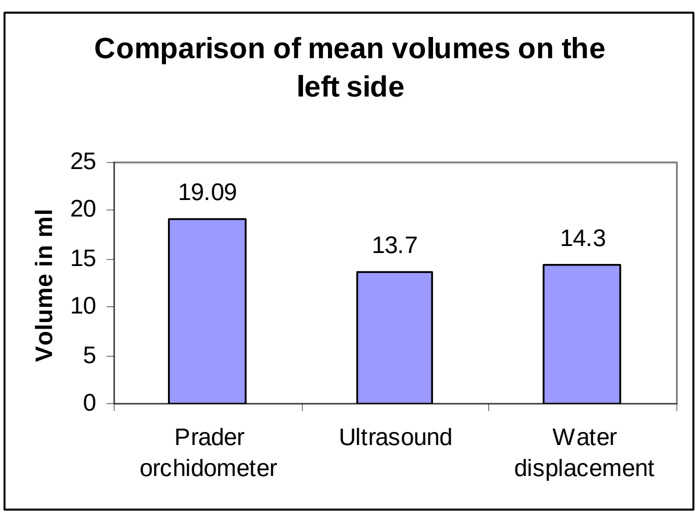
On the right side the mean difference in the volumes was 5.36 ml, with the range being 8.8 to 0.5 ml. On the left side the mean percentage difference of the true volume was 43.05% with a range of 100 to 7.9%. On the right side the mean percentage volume difference of the true volume was 38.35% (range 66.66 to 3.44%). The percentage difference combining both sides was 40.7% (range 100 to 3.44%).

Ultrasound and true volume

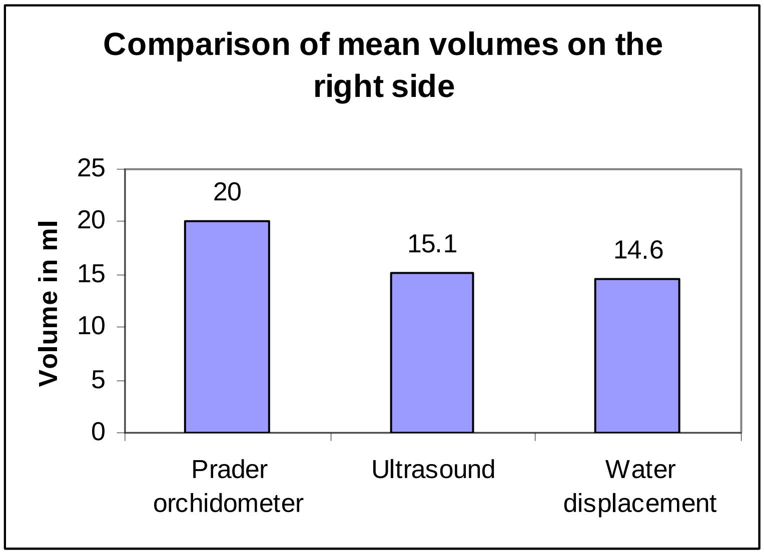
The mean difference between the true volume and the ultrasound volume on the left side was – 0.19ml (range 4.66 to -2.6 ml). On the right side the mean difference was – 0.51ml (range 2.83 to – 3.76). This difference expressed as a percentage of the true volume was – 3.76 % and – 1.70 % on the right and left side respectively. The mean difference as a percentage of the true volume combining both sides was 1.03 %. This result showed that the ultrasound overestimated the volume of the testes by about 1% of the true volume. In milliliters this amounted to 0.35 ml.

Comparison of the means of the three methods

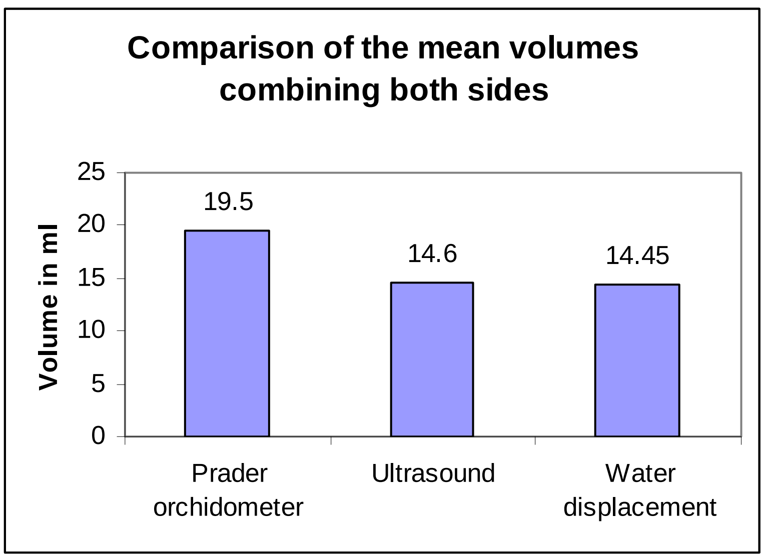
Left side



Right side



Mean of both the sides



As is fairly evident there was a marginal difference in the volumes measured by ultrasonography and water displacement as compared to the volume measured by the Prader orchidometer.

Statistical analysis

We used paired t tests to determine whether the orchidometer and ultrasound volume measurements differed significantly from the true volume. The relationship between each measurement technique and true testicular volume was evaluated by using linear regression analysis, with true volume as the independent variable and the orchidometer or ultrasound measurement as the dependent variable. For each regression, 95% confidence bands and a 45 degree line (equivalence) was included to provide a comparison with the no-intercept regression. The R^2 statistic provided a measure of the strength of the linear association. A one-sample Student t test was performed to see whether the difference of each method as compared to true testicular volume was consistent over the range of volumes measured or whether it varied with the magnitude of the volume.

Paired samples test (T tests)

Left side

The difference in the means with t tests on the left side comparing Prader volume and the true volume showed a significant difference (P = <0.05).

Paired Samples Test[a]

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 True vol; - Prader vol	-5.531	2.193	.296	-6.124	-4.938	-18.702	54	.000

a. side = Left

The difference in means between the true volume and the volumes on ultrasound on the left was not significant (p = < 0.05).

Paired Samples Test[a]

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 True vol; - USG vol	-.19636	1.23742	.16685	-.53088	.13816	-1.177	54	.244

a. side = Left

Right side

On the right side the difference between the true volume and the Prader volume was significant (p = <0.05).

Paired Samples Test[a]

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 True vol; - Prader vol	-5.365	2.092	.282	-5.930	-4.799	-19.022	54	.000

a. side = Right

The difference in means between the true volume and the ultrasound was significant though not as much as the difference when compared to the Prader volume.

Paired Samples Test[a]

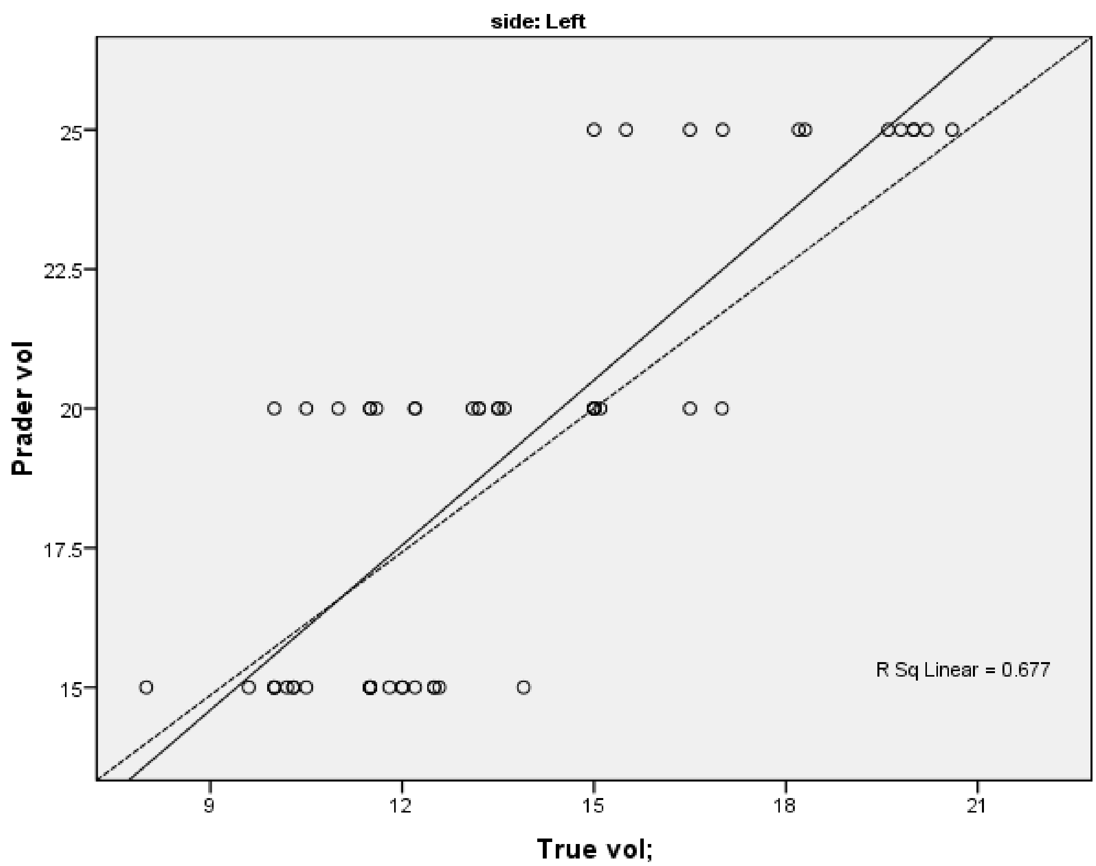
	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 True vol; - USG vol	-.51455	1.41466	.19075	-.89698	-.13211	-2.697	54	.009

a. side = Right

Analysis of variants

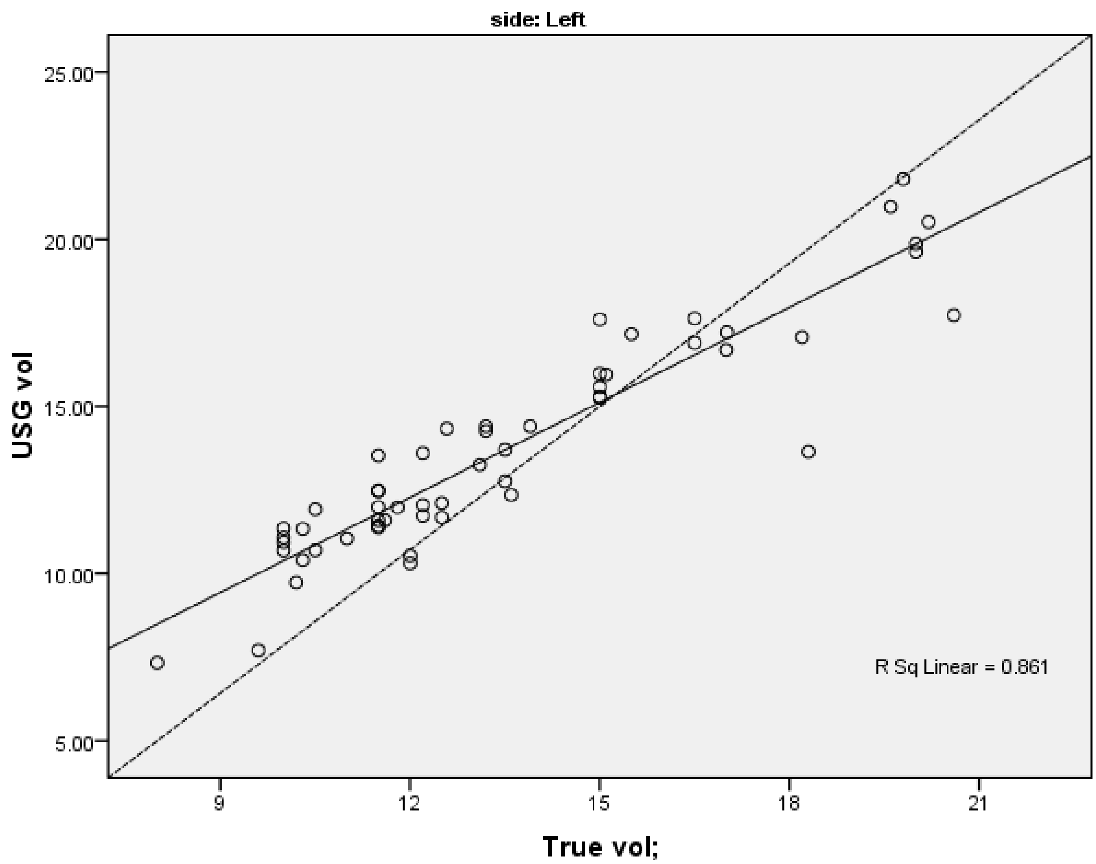
There was a linear relationship between the volumes measured by the orchidometer, ultrasound and the water displacement method. However this was strongest between the water displacement method and ultrasound.

Left Side

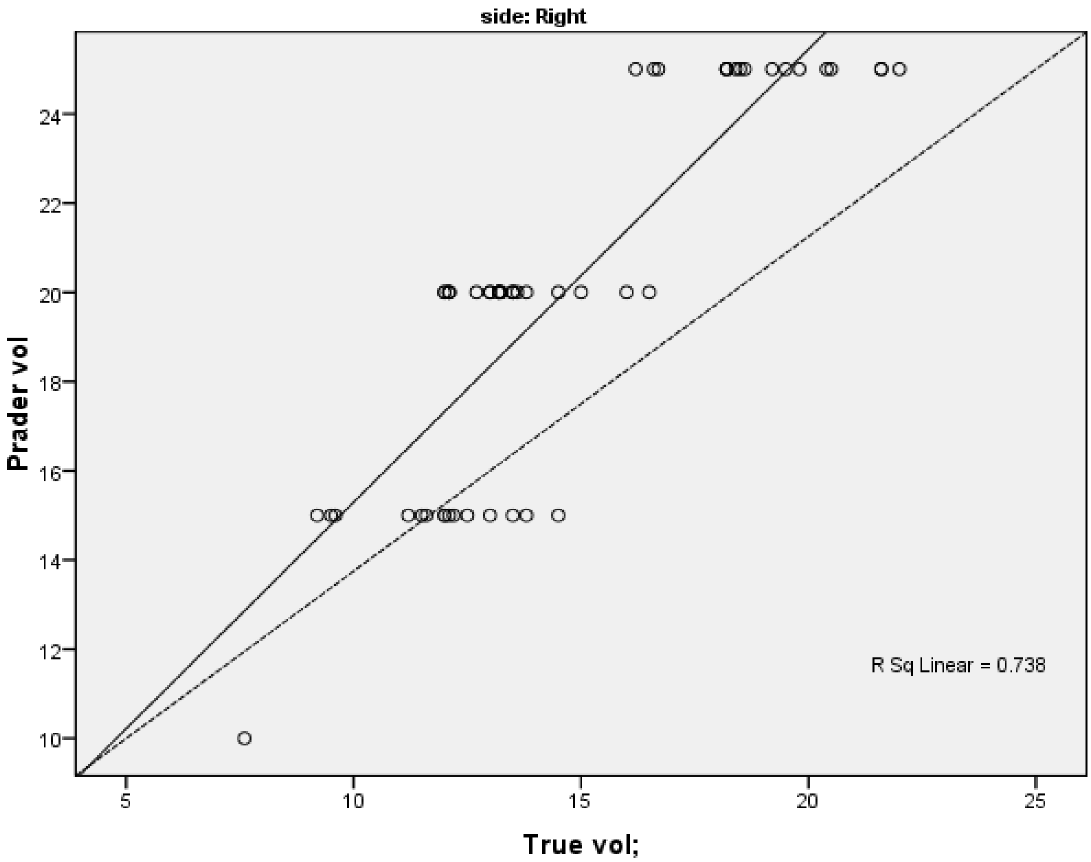


This graph shows a scatter diagram of the testicular volumes on the left side, comparing Prader with the true volume. The ‘r’ value is 0.823 with a p value of < 0.001.

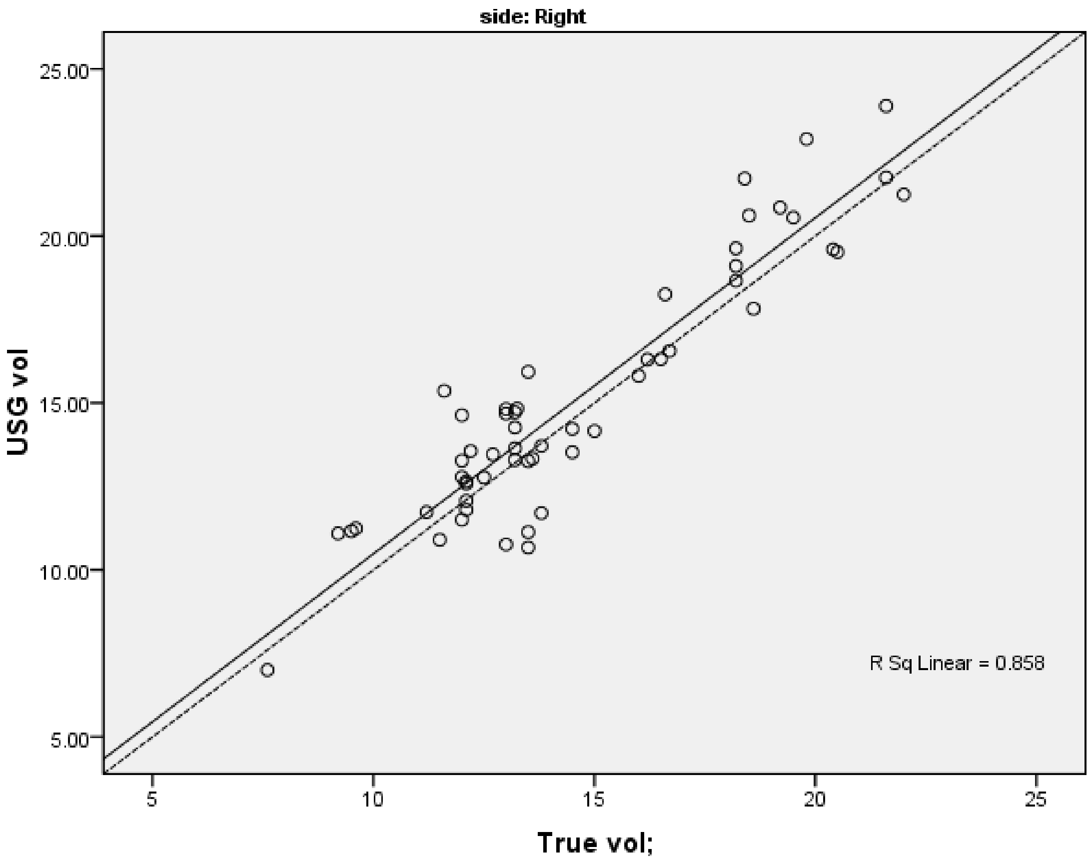
The linear relationship between the ultrasound and the true volume is plotted here (r = 0.823, p <0.001). This graph shows a stronger relationship between the ultrasound and the volume by the water displacement method.



Right Side



This is scatter representative of the right side comparing Prader and the true volumes (r = 0.859, < p = <0.001). There is a strong linear relationship, though not as strong as the one between the true volume and the volume on ultrasonography.



This graph is the scatter representation of the true volume and the volume by ultrasonography (r = 0.926, p = < 0.001). The relationship here is stronger than that between Prader and true volume.

DISCUSSION

Discussion

Our study showed the mean testicular volume by the Prader orchidometer to be 19.5 ml (range 10 – 25 ml). The average testicular volume on sonography was 14.6 ml with a range of 7.3 – 23.0 ml. The average volume by the water displacement method was 14.45 ml, (range 7.6 – 22.0 ml).

There was little difference in the mean volume between the two sides when measured by the Prader orchidometer – right being 20 ml and left being 19.09 ml. This difference in sides was more pronounced in the case of the mean volume measured on sonography, right - 15.1 ml and left - 13.7 ml. The least difference between the two sides was by the water displacement method, right - 14.6 ml and left 14.3 ml.

According to our study the density of the human testes was 1.07. As is evident, there was a very minor difference between the volumes measured by ultrasound as compared to the volume measured by the water displacement method (1.03 %). The correction factor to be applied to the ultrasound volume to get the true volume was 1.01 which is a negligible difference.

Our results also showed a significant difference between the measurements by the Prader orchidometer and the other two methods. These were in keeping with the results of Hideo Sakamoto et al [42, 48], where they too found the ultrasound to be the most accurate comparison to the true volume. The Prader orchidometer overestimated the volume by almost 41%, similar to the results by Hideo Sakamoto et al. According to our study the density of the human testes was 1.07, which was marginally different from the one reported by Handelsman et al [14] 1.038.

This anthropological study addressed an oft repeated question as to the accuracy of the different non invasive methods of testicular measurements. A rough estimate of testicular size may suffice in cases that do not need any active intervention; however, where a surgical intervention or accurate prognostication as in a varicocele or oligospermia is needed a more accurate assessment of the volume is necessary.

There have been doubts as to the accuracy of the measurement of testicular volumes by conventional methods since 1990 when Fuse et al [38] found the ultrasound to be a valuable tool for testicular measurement. Since then there have been further refinements in the technique, ultrasonic probes and experience with this craft. The ultrasound today is probably the most acceptable method to measure testicular volume. We did this study since there was no Indian data on this subject. All the figures quoted for various studies have been from the western literature. Our mean testicular volume by the ultrasound was 14.6 ml. The Caucasian data on testicular volumes is from two studies from Finland [33] and USA [41] where the volumes by sonography have been 17 +/- 2.8 ml and 17.15 ml respectively. The most recent data on the Japanese measurent by the ultrasound was 11.7 ml [40] and 13.1 ml [42]. These measurements are different from our data, highlighting the fact that a discrepancy does exist between races.

Our main modality of treatment for advanced carcinoma prostate is orchidectomy, giving us access to a greater number of subjects as compared to the west. We wanted to establish a standard for our population and have been able, to a certain extent. Of course, a larger number would have helped us to establish better standards.

STRENGTHS AND LIMITATIONS OF THIS STUDY

Strengths and limitations of this study

This study is the first of its kind in our country, there have been reports from Japan on Asian data but these may not be applicable to our population since there is a marked difference in the body habitus.

Diamond et al [46] reported an inter observer variability in the volumes measured by different individuals and different methods. We did not have the problems of inter observer variability since there was a dedicated urologist and radiologist doing the study. The team undertook a pilot study to familiarize themselves with the different methods of measurements.

One of the limitations of our study was that we did not use the punched out Rochester orchidometer. In 2005 Shiraishi et al [40] showed that the punched out orchidometer overestimated the testicular volume when compared with the US formula L x W x H x 0.71. As mentioned earlier our population was that of elderly men though Handelsman et al published data stating that testicular size does not change with age, it may still be useful to have a study with a younger population. Of course the question of determining the volume by Archimedes principle does not arise since there are no indications for orchidectomy in normal young individuals. Another issue which was not addressed was that testicular volume and blood supply. The testis being a small organ has a limited volume of blood supply, but this nonetheless contributes to the volume. Discrepancies in the timing of clamping of the testicular artery and the veins could have resulted in minor artifacts as to volume measured by the water displacement method.

CONCLUSIONS

Future prospects

In the near future the orchidometers may be phased out and replaced with more objective forms of measurements. The MRI too has a role in the measurement though at present the costs are too prohibitive. With the advent of newer more accurate ultrasonic probes the accuracy of the ultrasound will improve.

Summary

Testicular enlargement is the earliest sign of pubertal gonadotropin elevation in boys, and a testicular volume of 4 ml or greater is used as a clinical marker for the onset of puberty [1]. In adolescents with varicoceles a difference in size is an indicator of need for treatment [18]. A difference in volume of 20 -25 % has been found to be significant [19, 51]. Results of a study in infertile men have shown that testicular volume has a direct correlation with semen profile. This same study showed that a testicular volume of 30 ml with the Rochester orchidometer was associated with a lesser than normal sperm density in infertile men. Men with volumes less than 20 cm^3 were severely oligospermic and those with a volume less than 10 cm3 were azoospermic [25].

This study was in compliance with the published data so far and revealed ultrasonography to be the most accurate and objective in vitro method of assessment of testicular volume when compared to a more accurate ex vivo measurement post orchidectomy.

Conclusions

This study shows that the ultrasound is more reliable than the Prader orchidometer. The testicular measurements on ultrasound are nearly as accurate as those by the water displacement method. The Prader orchidometer appears to overestimate the size of the testis. We recommend that the ultrasound be used to measure testicular volume in all cases with abnormalities of testicular function.

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Annexure

Informed consent document

I, Mr. ____, aged ____years, son of ____, resident of____, have already consented to undergo bilateral orchidectomy as part of the treatment for a diagnosed medical condition understanding that the findings will not benefit me in my treatment.

I am willing to have my testes examined manually and by ultrasound prior to the operation. Furthermore, I am willing to donate the excised testes for research purposes.

I hereby state that I am in no way coerced into participating in this study and am participating of my own free will.

I have read this document or someone has explained the contents of this document to me in a language I understand.

Signed :

Name :

Date :

Place :

Master Data Sheet

Prader vol Right	USG vol	True vol	True wt	Prader vol Left	USG vol	True vol;	True wt
15	11.7	13.8	14.1	15	10.31	12	12.5
20	11.8	12.1	12.5	15	11.08	10	10
20	14.68	13	13.5	20	15.29	15	14.5
15	13.26	13.5	15.2	15	12.11	12.5	13
25	19.6	20.4	19.7	20	15.58	15	16
20	10.67	13.5	14.6	15	7.33	8	10
20	14.26	13.2	14.3	15	11.35	10	12
25	21.72	18.4	20.5	20	13.7	13.5	14
25	17.82	18.6	20.5	25	19.87	20	20
15	11.24	9.6	11.2	20	13.25	13.1	15.2
20	14.82	13	14	20	10.69	10	12
25	18.66	18.2	20.5	25	17.21	17.01	17.4
20	14.63	12	13.5	20	14.26	13.2	14.1
25	22.9	19.8	21.2	25	20.97	19.6	21.1
20	13.71	13.8	15.1	25	17.73	20.6	23.1
25	23.89	21.6	22.7	25	17.07	18.2	20
25	20.55	19.5	21.7	25	16.9	16.5	19.8
25	16.3	16.2	18.5	20	11.59	11.6	12.5
15	11.09	9.2	11.1	15	12.47	11.5	13.5
25	18.25	16.6	18.5	25	15.98	15	17
25	20.61	18.5	20.8	20	17.6	15	16.5
25	20.85	19.2	21	20	17.63	16.5	17.5
25	21.75	21.6	22.4	25	21.8	19.8	22
25	21.24	22	20	25	19.62	20	22
20	15.81	16	18	20	16.69	17	18
20	14.22	14.5	15	15	11.38	11.5	13
20	16.31	16.5	18	25	13.64	18.3	20
15	11.5	12	11.5	20	11.73	12.2	13
15	12.77	12.5	13	20	14.4	13.2	14.5
20	12.78	12	13.08	15	10.93	10	10.5
15	10.9	11.5	9.2	15	10.4	10.3	9.5
15	12.58	12.1	10.6	20	11.59	11.5	13.3
20	13.46	12.7	14.7	20	10.7	10.5	12.6
15	13.27	12	12	20	13.53	11.5	13.1
10	7	7.6	8.2	15	9.73	10.2	12
20	15.93	13.5	15.2	20	13.6	12.2	14.5
15	13.56	12.2	12	15	11.98	11.8	13
20	13.33	13.6	15	15	14.4	13.9	12
20	13.64	13.2	14	15	11.43	11.5	12
15	15.36	11.6	12	20	12.35	13.6	14
20	12.65	12.1	13.2	15	11.99	11.5	12.1
15	11.73	11.2	12	20	11.05	11	13
15	10.76	13	13.5	15	10.53	12	12.25
20	12.07	12.1	12.5	15	11.92	10.5	10.5
20	14.83	13.25	13	20	15.26	15	14.5
15	13.52	14.5	15.4	15	11.68	12.5	13
25	19.52	20.5	19.2	20	15.95	15.1	16.8
20	11.13	13.5	14.4	15	7.7	9.6	10.5
20	14.72	13.2	14.5	15	11.34	10.3	12.5
25	19.63	18.2	20.1	20	12.76	13.5	14
25	19.1	18.2	20.6	25	20.52	20.2	20.8
15	11.16	9.5	11	15	12.48	11.5	12
25	16.56	16.7	17.6	25	17.16	15.5	17
20	14.16	15	13.6	15	14.33	12.58	13.9
20	13.29	13.2	14.8	15	12.05	12.2	12.8