Reconstruction of the Geometric Shape and Volume Measurement of the Prostate Utilizing Two Dimensional Transabdominal Ultrasonography

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ABSTRACT

Background: The prostate gland is a vital part of the reproductive system. As men age the prostate tends to enlarge (benign hypertrophy). Also, the incidence of prostate cancer increases. Management of cancer begins with early detection of disease, so prostatic volume measurement is a common clinical procedure.

Aims of the Study: To reconstruct computerized geometric shape of the prostate and to measure the volume of the prostate utilizing two- dimensional transabdominal ultrasonographic (2D-TAUS) images of the prostate, that can be used in diagnosing and prognosis of the patients with prostate disorders.

Patient and Method: Computer algorithms were applied on ellipsoidal images in 2010, at (Al-Mustansiriya University, Medical College, Department of Physiology), to reconstruct geometric shapes of these images (their volumes were calculated mathematically (computed). Then these computer algorithms were applied on the 2D-TAUS images in transverse and cephalocaudal views of the prostate of a patient with enlarged prostate in (National Diabetes Center / Division of Ultrasonography) to demonstrate the steps of the medical application of the present method to reconstruct geometric shape of the prostate.

Results: The shapes of the prolate ellipsoids were reconstructed using the present method. There is no significant difference between the computed volumes of the ellipsoidal images and the volumes of their reconstructed geometric shapes ($P < 0.0002$). Also this method was applied on 2D-TAUS images of a patient with enlarged prostate (reconstructed volume = 48.8 ml). Sequences of the geometric shapes of the enlarged prostate were displayed in different views.

Conclusion: Computerized geometric shape of the prostate was reconstructed, without using mathematical assumptions that can lead to misleading results, in order to obtain accurate reconstructed geometric shape and volume of the prostate. The present method can be applied to investigate and to follow the patients with enlarged prostate, as good guidance of the clinical or surgical management.

Introduction:

The prostate gland is a vital part of the male reproductive system. Benign prostatic hypertrophy (BPH) is the most common cause of prostate enlargement [1], and the management of prostate cancer begins with early detection of disease [2]. Accurate and reliable measurement of prostate volume is important not only for BPH, but also in planning non-surgical therapies of prostate cancers and follow ups [3].

Numerous imaging studies have been used to evaluate the prostate, such as two dimensional (2D) transrectal sonography (TRUS), transabdominal (TRUS), and three dimensional sonography (3DUS) [4-8]. Also, computed tomography (CT) and magnetic resonance imaging (MRI) have been used in evaluating the prostate gland [9-11]. Previous studies have reported high degree of correlations between TAUS and TRUS methods in prostate volume measurements [3,12].

Ultrasound examination is easy, fast, non-invasive and reasonably accurate.

The establishing of prostate volume represents a necessary stage in the method of solving a prostate adenoma. At the same time, the volume along with the shape of the prostate capsule is important in the diagnosis of prostate cancer [13]. In the present study the volume of the ellipsoidal shape images are computed in addition to the reconstruction of the geometric shape of the prolate ellipsoid images as a test for this method, then the steps of the present method is demonstrated by reconstruction of the geometric shape with the volume calculation of the prostate from the 2D TAUS images of a patient with enlarged prostate.

Patient and Method:

The geometric shape of (100) ellipsoidal images were reconstructed as demonstrated in flow chart one utilizing certain visual basic program (as a test for the present method). Also the present method was applied on the transabdominal ultrasonic examination of a patient (55 years) with enlarged prostate was performed using a real time ultrasound machine (FUKUDA UF-750XT) and utilizing 3.5 MHz convex phased array transducer.

Longitudinal (cephalocaudal) and three transverse images (upper third, mid-third, and lower third) of the prostate were obtained with the patient in supine position.

Longitudinal and transverse dimensions of the prostate were obtained from all of these images. Three dimensional volumes using (prolate ellipsoid method) and (prolate spheroid method) were also obtained.

FLOW CHART ONE

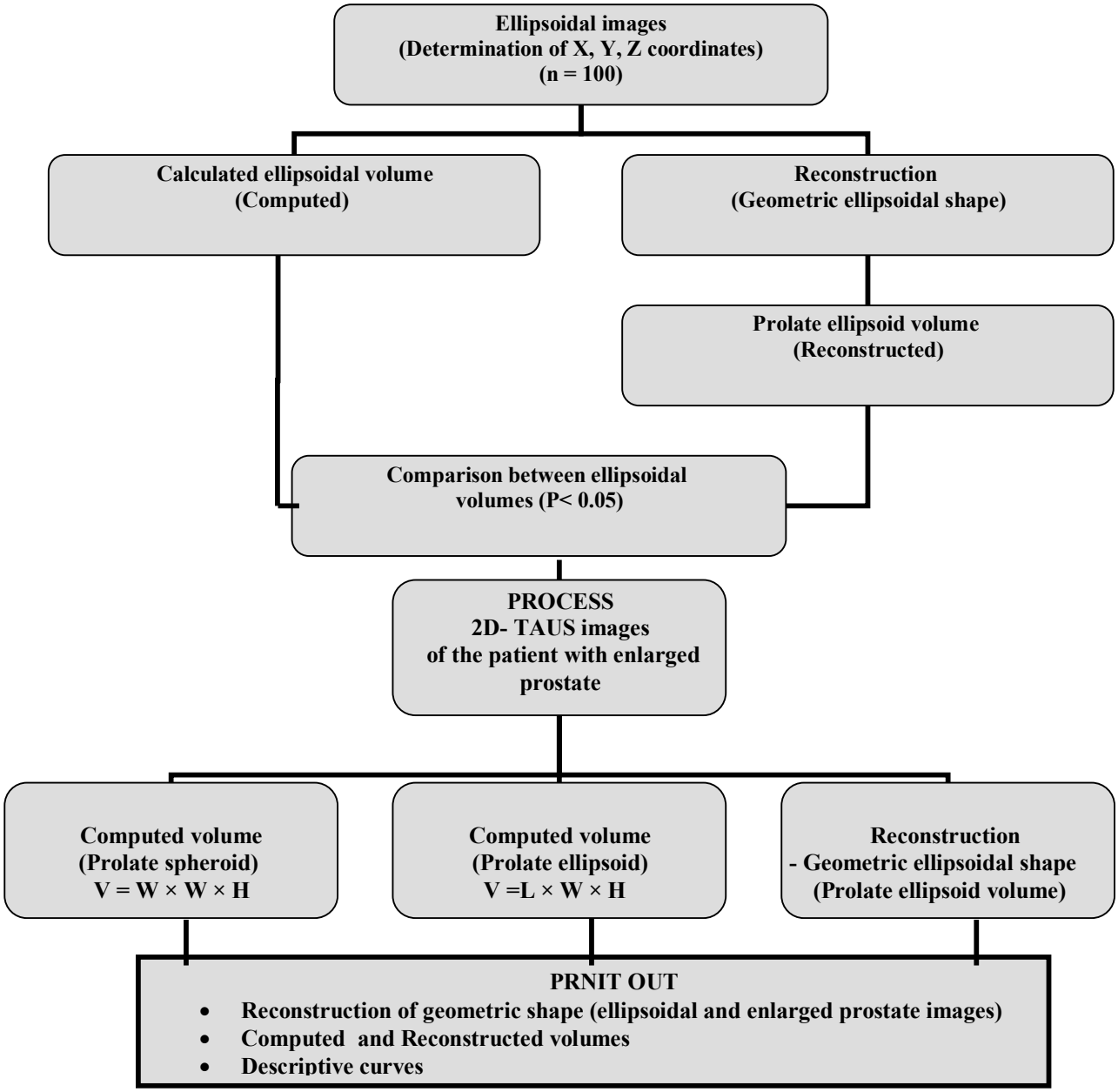

Fig. 1: Flow diagram for reconstruction of geometric shape and volume measurements of the prolate ellipsoid from ellipsoidal images and 2D-TAUS images of the prostate studied.

Estimation of the prostate volume:

A- The common methods of estimating prostate volume utilizing TAUS and TRUS are:

1. Prolate ellipsoid shape: Three diameters are used, the largest antero-posterior (Height = H), transverse (width=W), and cephalocaudal (length = L) of the prostate images.
   $V_{PE} = H \times W \times L \times 0.524$-1 [14,15]
   Where V_{PE} = prolate ellipsoid volume, 0.524 = $\pi / 6$, and $\pi = 3.1415$
2. Prolate sp heroid shape:Three diameters are used (images in the transversal plane).
   $V_{PS} = W \times W \times L \times 0.524$ ------- 2 [16]
   Where V_{PS} = prolate spheroid volume

B- Three-Dimensional shape: This method actually measures volumes even in irregularly shaped prostate. The volume measurement methods introduced by 3DUS are: The tracing of the perimeter of the prostate in multiple parallel planes [17].

The rotational tracing method, in which the 360º surrounding a prostate is divided into precise increments by software (this technique is known as virtual organ computer–aided analysis (VOCAL), and has been reported to be reproducible [6,7,8].

Reconstruction of the Geometric Shape of the Prostate:

In the present study the reconstruction of the geometric shape and the quantification of the volume of the prolate ellipsoid from the ellipsoidal images or the reconstruction of the geometric shape of the prostate from Transabdominal 2DUS images of the prostate are done by the computerized analysis of the semi-manual tracing of the circumferences of cross-sections of the structures (ellipsoidal or 2DUS images) at three levels (upper,mid, and lower parts) to find (b and c dimensions or X and Y coordinates) , and the tracing of the circumferences of longitudinal planes of the ellipsoids or 2DUS images of the prostate in cephalo-caudal view to find (a, or Z coordinates).

The computer used combines between these coordinates (X, Y, and Z) to reconstruct the geometric shapes of the ellipsoidal images and 2DUS images of the prostate studied. Generally (Z) coordinate is represented as a function of the (X, Y) coordinates.

The results obtained are used to reconstruct the initial shape (wire frames) and the final shapes of the prolate ellipsoids or the geometric shape of the prostate and then to calculate their volumes from the summation of the volumes of all transverse slices (the computer used divides the main three transverse parts of the reconstructed prolate ellipsoid or the geometric shape of the prostate to multiple transverse slices) as demonstrated in Fig.2.A and B.

The coordinates of the 2D-TAUS of the prostate images in cephalo-caudal view (L = Z) is represented as a function (f) of circumference coordinates (W=X, and H=Y) of each transverse planes**.**

Z = f (X, Y) ------ (3)

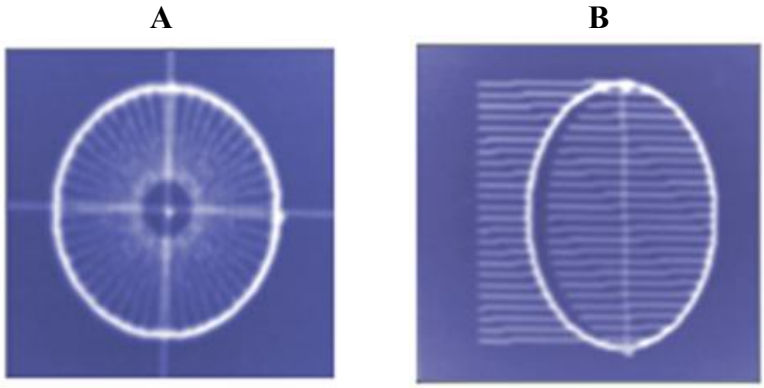

Fig.2: The analysis of the circular and ellipsoidal images to reconstruct prolate ellipsoid using certain computer program.

Results:

The following results were obtained from the application of the present study:

1. Determination of the main dimensions of the ellipsoidal images, as in Fig.3.A (a= [major axis/2] = 4 cm), with circular cross-section (c= b, and they equal to radius = 1.5 cm). The volumes of the reconstructed prolate ellipsoid (fig.3.B) in the range (18.84 cm³ – 129.39 cm³). The present method was applied 100 times, to reconstruct new prolate ellipsoid for each 1 cm³ of increasing in their volumes.

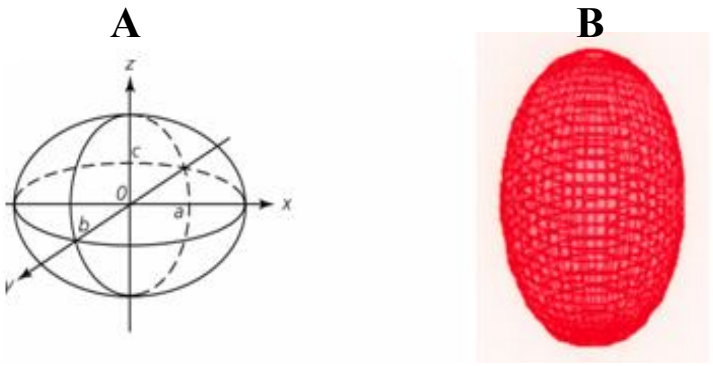

Fig.3: The geometric shape of the prolate spheroid, A: Major axis (a), and minor axes (b and c), B: The reconstructed prolate spheroid utilizing the present method.

Ten readings of the two volumes which include the range of the volumes of the prolate ellipsoids, as mentioned above (table 1) to determine the differences, and the percent deviations between the computed and the reconstructed volumes.

Table 1: The differences between certain volumes of the reconstructed and computed prolate ellipsoids

Prolate ellipsoid (NUMBERS)	Prolate ellipsoid volumes (cm^3) (RECONSTRUCTED)	Ellipsoidal volumes (cm^3) (COMPUTED)	Volumes (cm^3) (Reconstructed – Computed)
1	19.84	18.84	1
2	26.42	25.08	1.34
3	34.3	32.57	1.73
4	43.61	41.41	2.2
5	54.46	51.72	2.74
6	66.99	63.62	3.37
7	81.3	77.2	4.1
8	97.52	92.6	4.92
9	115.76	109.92	5.84
10	136.14	129.29	6.85

There is no significant difference between the two volumes ($P < 0.0002$), as plotted in Fig.5 using the statistical method (paired t-test, two tails).

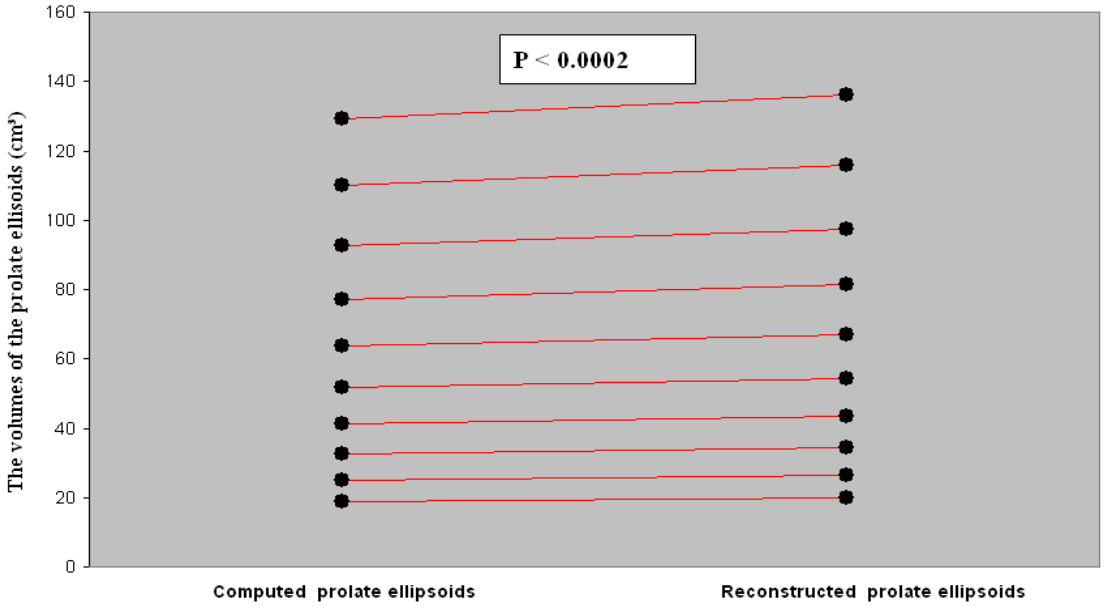

Fig. 5: The volumes of the reconstructed and computed prolate ellipsoids

2. To explain the medical application of the present method, it was applied on 2D images of the TAUS in **two** views (transverse views at upper, mid, and lower levels) and (cephalocaudal view) of the prostate of a patient (fig. 6).

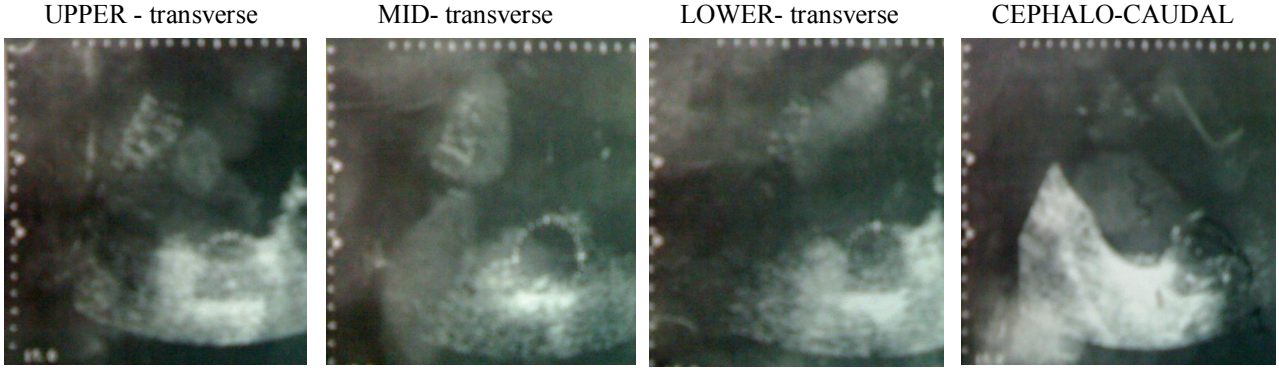

Fig. 6: 2D images of the prostate studied in two views (transverse and cephalo-caudal views) using TAUS.

The results obtained(X, Y, and Z coordinates) from the analysis of the circumferences of all views of the prostate are utilized by the computer used to establish multiple transverse slices to reconstruct the initial geometric shape (wire frame) and the final shape of the prostate studied with eight sites (fig. 7.A and B). All images of the reconstructed geometric shape are displayed on the screen of the computer used in accordance with the sequence of rotation (clockwise) to visualize all sites of the prostate (MP= mid – posterior zone, MA= mid – anterior zone; P1= posterior zone before MP, A1= anterior zone before MA; A= end of the anterior zone, P= end of the posterior zone; A2= anterior zone after MA, P2= posterior zone after MP). Fig. 8 shows the anterior site of reconstructed colored geometric shape of the prostate studied with clear.

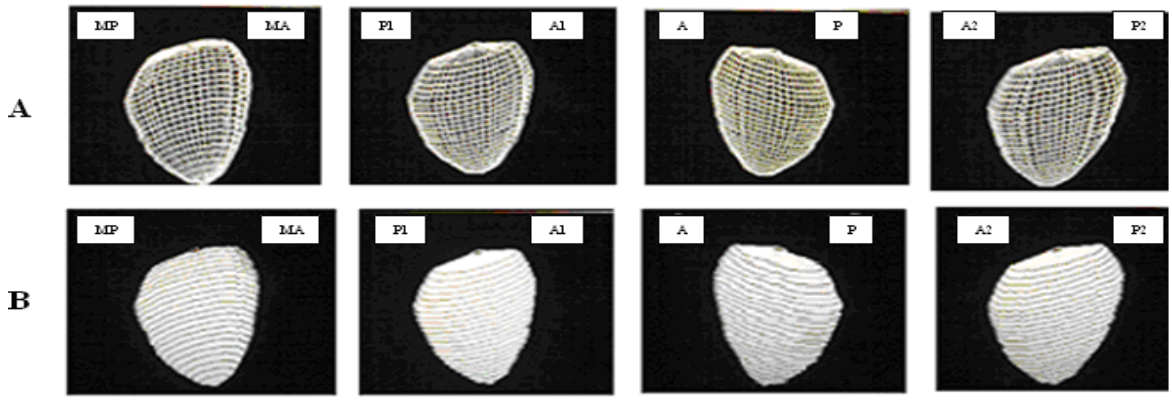

Fig. 7: The reconstructed prostate of the patient studied in four different views (anterior and posterior sites), A: Initial structure and, B: final structure of the reconstructed prostate.

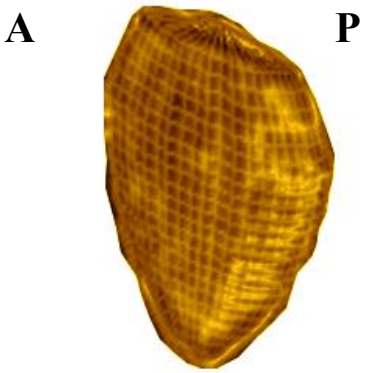

Fig. 8: Shows the anterior site of the final geometric shape of the reconstructed prostate of the patient studied (colored and rotated).

The volume of the reconstructed prostate was determined and compared with the calculated volumes of the same prostate studied by the sonographic system used (depending on the common equations (1 and 2) of the prolate ellipsoid and prolate spheroid respectively), these equations were applied at the mid-level of the prostate images. The readings of all dimensions and volumes of the images of the prostate studied are listed in Table (2 and 3) respectively.

Table 2: The dimensions of the 2D-TAUS views of the prostate studied at upper (U), mid (M), and lower (L) levels.

2D- TAUS VIEWS (of the prostate studied)	DIMENSIONS (cm)		
	U	M	L
Antero-posterior (W)	3.8	4.1	3.7
Transverse (H)	3.8	4.4	4
Cephalo-caudal (L)	4.5		

Table 3: Determination of the prostate volumes utilizing TAUS methods at the mid-level (computed) and the reconstructed geometric shape (the present method).

The Methods Applied (at the mid-level of the prostate)	Prostate volumes (cm^3)	Differences (cm^3) (reconstructed – computed)
Prolate ellipsoid (computed)	42.5	6.3
Prolate spheroid (computed)	38.7	9.3
Reconstructed geometric shape	48.8	-

The differences percentage between the volumes of the reconstructed prostate and the calculated volumes using the prolate ellipsoid and prolate spheroid methods at the mid-level of the transverse view of the prostate studied were 6.3 ml (12.9%) and 9.3 ml (20.7%) respectively. The volumes of the prostate studied using the different methods are (reconstructed = 48.8 ml, V_{EP}= 42.5, and V_{ES}= 38.7 ml).

Discussion:

Accurate and reliable measurement of prostate volume is crucial for the management of prostate disease [18]. Direct measurement of prostate volume can be performed on radical prostatectomy specimens, and the prostate volume might be underestimated due to shrinkage [16] or overestimated because adjacent periprostatic tissue [19]. CT has not proven to be of much value in evaluating the benign enlarged, prostate. MRI is useful in evaluating prostate size [1].

Ultrasonography is reliable prior to surgery for estimating prostate size [20]. The accuracy of estimated prostate was found to be high by TAUS and TRUS, but the accuracy of TRUS was more reliable [21]. Since TRUS methods can produce great discomfort to the patient, TAUS was demonstrated to be equivalent to TRUS for measuring the prostate when bladder volume is over 100 ml [22,23].

Previous study showed that there were no significant differences between TAUS and TRUS [24]. In another study, the comparison of TAUS and TRUS methods, the mean difference was 8.4 ± 10.5 ml and correlation coefficient (r) was 0.775 ($p < 0.01$). The experienced examiner for the TRUS method had the highest correlation (r = 0.967) and the significantly smallest difference (5.4 ± 3.9 ml) compared to the other examiners (the beginner and the trained; $p < 0.05$). The experience in TRUS is important in the correlation with TAUS but not with the three-dimensional ultrasonography (3DUS) [18].

The prolate spheroid formula requires measurements in the transverse plane only, while the prolate ellipsoid formula needs cephalocaudal (length) prostate diameter. Both methods are almost equivalent and simpler to perform [17].

The ellipsoidal volume calculation is used in both TAUS and TRUS volume measurements, but the method is only an estimation of real volume. Volume measurement by 3DUS is not a process of estimation, but requires additional time and needs additional high priced equipment and software [25,18].

In the present study ellipsoid images was used to reconstruct prolate ellipsoids.

There is no significant difference between the reconstructed and computed prolate ellipsoid volumes ($P< 0.0002$) using the statistical method (paired t-test, two tails).

The difference between the two volumes is 4.92 ml (5%, overestimation), when the volumes of the reconstructed and computed prolate ellipsoid are 97.52 ml and 92.6 ml respectively.

Geometric shape of the prostate studied was reconstructed in different views with the ability of rotation during display on the screen of the computer used to see the posterior and anterior parts (divided to six zones).

This method analogous to 3DUS, but without using special three- dimensional transducer and depends on the 2D TAUS images of the prostate studied at (the upper, mid-, and lower levels to find the transverse dimensions H and W), in addition to longitudinal (cephalocaudal) view to find (L). 2D TAUS images were Auto analyzed after manual tracing of the perimeters of these images to determine all dimensions (W, H, and L) and X, Y, Z coordinates to reconstruct the geometric shape and to determine the volume of the prostate studied.

The reconstructed volume was compared with the volumes determined by the sonographic system used (reconstructed = 48.8 ml, V_{EP} = 42.5, and V_{ES} = 38.7 ml) and reveals that the prostate studied is enlarged (the differences between these volumes and the maximal normal prostate volume (20 to 30ml) [17] are 38.5%, 29.4%, and 22.5% respectively.

Future study is to apply the present method on benign and malignant tumors of the prostate to establish new model of the enlarged prostate.

In conclusion the method used for the computerized reconstruction of the geometric shape of the prostate is easy, fast and non-invasive because it depends on 2D TAUS images and does not need high priced equipment or complex software. It measures the volume of the prostate with irregular shape without estimation.

The reconstructed geometric shape of the prostate can be rotated in order to see all its sides, so the present method is of a diagnostic importance and surgical management.

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