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●*Original Contribution*

ERRORS IN TRANSRECTAL ULTRASONIC PLANIMETRY OF THE PROSTATE: COMPUTER SIMULATION OF VOLUMETRIC ERRORS APPLIED TO A SCREENING POPULATION

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Abstract—Three systemic errors in routine ultrasonic planimetric volume measurements of the prostate were assessed. A computer model using ellipsoids was used to simulate the step section technique and different forms of rotational movements of the prostate during planimetry. The planimetric volume was up to 12% smaller than the exact volume, depending on the degree of rotational movement, the shape, and the length of the ellipsoid. *In vivo* study of a screening population showed that it is worthwhile to compare caliper length with the number of planimetric steps, as the difference might be an indication of the difference between planimetric and caliper measured volume. In shorter prostates the planimetric volume was smaller than the prolate spheroid volume when compared to longer prostates, as was seen in the computer simulation.

Key Words: **Prostatic Ultrasound, Volume measurement, Tomographic scans, Ultrasonics.**

INTRODUCTION

The volume of the prostate is a useful parameter in clinical decisions. Various techniques are available to determine prostate volume *in vivo.* Digital rectal examination (DRE) and transrectal ultrasonography (TRUS) are widespread methods of volumetry. Estimation of prostate volume by TRUS mainly is done two different ways: by step-size planimetry, or by mathematical formulas using one or more ultrasonic calipers.

Terris and Stamey (1991) assessed the accuracy of ultrasonic volumetry comparing the volume of radical prostatectomy specimens with planimetric and caliper measured volumes *in vivo.* Planimetry underestimated the specimen volume in 86%, while caliper calculated volumes by prolate spheroid formula overestimated this volume in 26%, and elliptic formula in 90%. This suggests a systemic error in planimetry.

In our institution, Niemer et al. (1994) tested reproducibility of ultrasonic volumetry, and found prolate spheroid and planimetric measurements of the whole gland to be highly reproducible by both single and different observers. Measurements of the inner zone of the prostate gland were best reproducible using planimetry.

Variability in planimetry may be explained by various factors. Involuntary movements of the patient, and rotational movements of the prostate around the ultrasonic transducer during planimetry may disturb an optimal sequence of step-sections. The ultrasonographers may have variable interpretations of prostatic boundaries, which can be the result of ultrasonic disturbances, such as reverberation and deflection. The planimetric summation formula, like the caliper formulas, gives rise to geometrical simplification of the prostate, influencing the volumetry.

Longitudinal studies of ultrasonic volumetry are scarce due to its recent development and the ongoing changes of ultrasonic equipment. However, longitudinal studies of prostate specific antigen (PSA) are of growing interest. The combination of PSA and volumetry, reflected in volume adjusted PSA-values, is likely to remain important. Therefore, a continuing interest in volumetry of the prostate may be expected. Further improvement of volumetry, minimizing variability, is desirable.

We assessed three volumetric errors in planimetry, described as the salami effect, the capsizing effect, and the first step effect. The salami effect is the sectional effect of the planimetric method, which may leave small amounts at the extremes of the geometrical body unmeasured (Fig. 1).

Furthermore, when transverse sections are not perpendicular on the longitudinal axis of the geomet-

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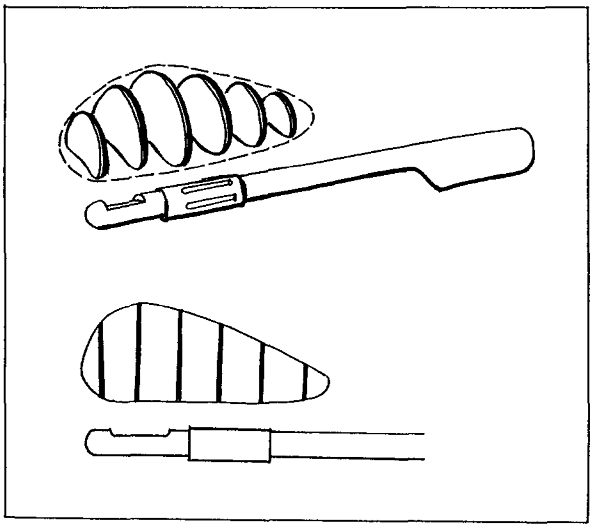

Fig. 1. Schematic representation of planimetry of the prostate, with the ultrasonic probe parallel to the cephalo-caudal axis.

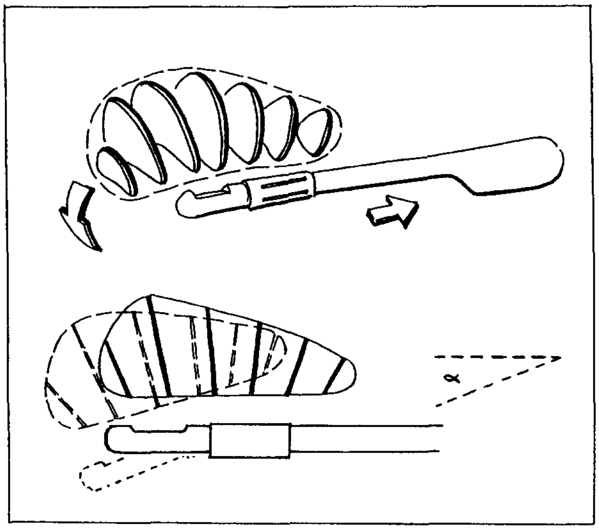

Fig. 3. Schematic representation of the capsizing effect during step section planimetry with a continuously changing rotation angle α.

rical body, the angulation gives rise to slices of different surface and thickness, and might even influence the number of step sections. The angle between the longitudinal axis of the prostate, and the longitudinal axis of the ultrasonic transducer was defined as α (Fig. 2).

During a pilot study, the capsizing effect was also observed, which occurs during planimetry when the cephalo-caudal or longitudinal axis of the prostate continuously changes (Fig. 3), which results in measurements of nonparallel transverse cross-sections. The first step is an observer-dependent error, which was described as the reduction of number of step sections due to recognizing the first step section too far into the prostate (Fig. 4).

In a computer simulation, the maximal volumetric differences between real (caliper measured) volume and planimetry of several ellipsoids were determined. Also, the shape of the ellipsoids was analyzed. The results were compared with volumetric data of 59 randomly chosen participants of a screening population for prostate cancer in Rotterdam, obtained by TRUS with a 7 MHz biplanar rectal probe on a Bruel and Kjaer 1846 ultrasound machine.

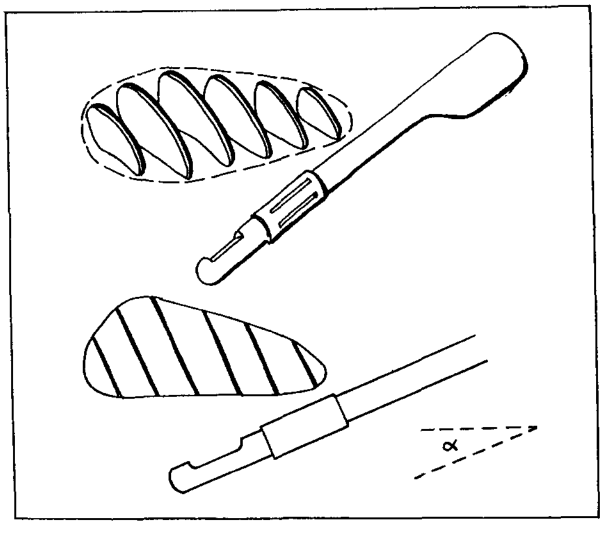

Fig. 2. Schematic representation of the salami effect during planimetry with a fixed angle α.

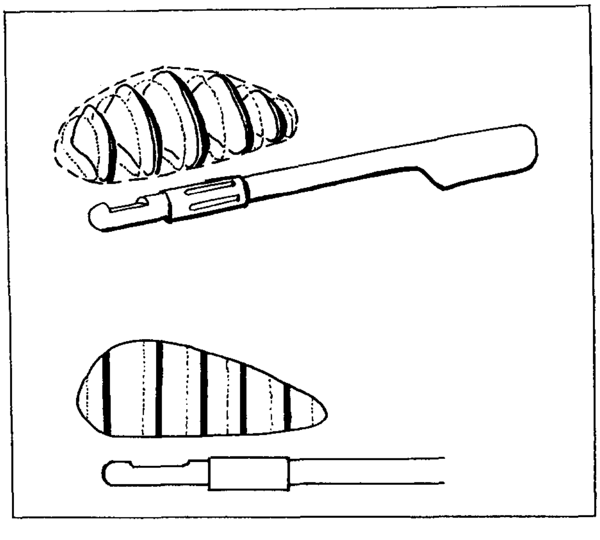

Fig. 4. Schematic representation of the first step effect during step section planimetry.

MATERIALS AND METHODS

Pilot study

In a pilot study, five prostates between 26 and 91 mL (planimetric volume) were analyzed. Step section planimetry with 5 mm steps was completed within 8 to 12 steps. Mean stepsize was calculated by the ratio of cephalocaudal length and number of steps, and varied between 3.5 to 5.0 mm. At each step, the angle of rotation of the prostate in the longitudinal direction around the ultrasound probe was determined from videophotographs, and was between 0 and 7 degrees for each step. The total capsizing rotation was between 12 and 32 degrees, independent of the prostatic volume or step size. It was not possible to determine whether the rotation was gradual or during a specific part of the procedure, for example at the end when the probe is almost completely retracted from the rectum.

Computer simulation

A computer model was created to simulate the salami effect, the capsizing effect, and the first step effect. The prostate was geometrically simplified into an ellipsoid. Ellipsoids were chosen with varying length, width, and height within physiological ranges as obtained in the Rotterdam feasibility study for screening of prostate cancer. Width or height was chosen never to exceed length. Seventy-four 244 different ellipsoids were analyzed, arranged according to length, as length theoretically correlates best with the number of planimetric steps. Twenty-four classes of 2 mm steps were created, containing 234 to 7634 ellipsoids of different shapes and sizes. During planimetry, the salami effect and capsizing effect were analyzed while the cephalocaudal axis of the ellipsoid was varied gradually over an angle α between 0 to 45 degrees with 5 degrees steps, compared with the axis of the planimetric probe. The difference between planimetric volume and exact calculated ellipsoid volume, defined as delta-volume, was classified in relative values (the percentage of the exact ellipsoid volume).

During the simulation described above, the first section was made exactly at the edge of the ellipsoid, simulating the perfect observer. When starting a planimetric measurement of a geometrical body *in vivo,* the first section is made through one end of this body with an ultrasonic appearance just recognizable as part of this body. Usually the surface area of this first section is between 1 and 2 cm^2. By recognizing the first section area too late, that is, too far into the ellipsoid, a reduction of the number of step sections may occur, diminishing the measured total volume. This was referred to as the first step effect. The effect may be dependent on the shape of the ellipsoid. In our computer simulation model, we created a series of ellipsoids with identical volume (31.4 mL, approximating the median volume in our screening population) but seven different shapes. This was done by varying systematically one of the parameters length, width, or height by a chosen factor 1.5, and correcting one of the other parameters. While gradually capsizing these different ellipsoids over 30°, we were able to determine a critical surface area above which the first-step effect occurred and which was the cause of an increased volumetric error. An additional error occurs if the last step area is also not recognized, when equal or less than the first step area.

Comparison to in vivo data

To detect missing or extra steps during planimetry, we noted in 59 randomly chosen participants of the Rotterdam feasibility study for prostate cancer the number of steps during measurement of total volume. Also, caliper measured volumes were calculated. The product of number of steps times the standard step size was calculated to predict the length of the prostate. The absolute difference between predicted length and caliper measured length was supposed to be insignificant when smaller than 5 mm, as this would not induce extra or missing planimetric steps. All larger differences were divided in classes. The differences between planimetric volume and caliper measured volumes were also ordered in classes of percentage of the caliper measured volume. This volumetric difference was correlated to the number of steps and the caliper length. The prolate spheroid volume was chosen as reference.

RESULTS

With the salami effect delta-volume appeared to be larger in shorter ellipsoids, and generally increased with increasing angle α (Fig. 5). Volumetry was optimal when planimetric slices exactly fitted with the ellipsoid length, as illustrated by the dips in the graphical representation. For the curve with sections perpendicular to the longitudinal axis ($\alpha = 0$), the volumetric error was predominantly seen to be less than in case of angulation. The number of planimetric steps was always equal or one less than expected from the ellipsoid length.

With the capsizing effect delta-volume was larger in shorter ellipsoids, and increasing rotation angle α (Fig. 6), as was seen for the salami effect. The number of planimetric steps was always equal or one less than expected from the ellipsoid length. Volumetric difference between exact and planimetric volumes of various ellipsoids of the same length showed a progressive increase after a critical rotation angle which was smaller for longer ellipsoids (Fig. 5). This means that the influence of capsizing of the ellipsoid during pla-

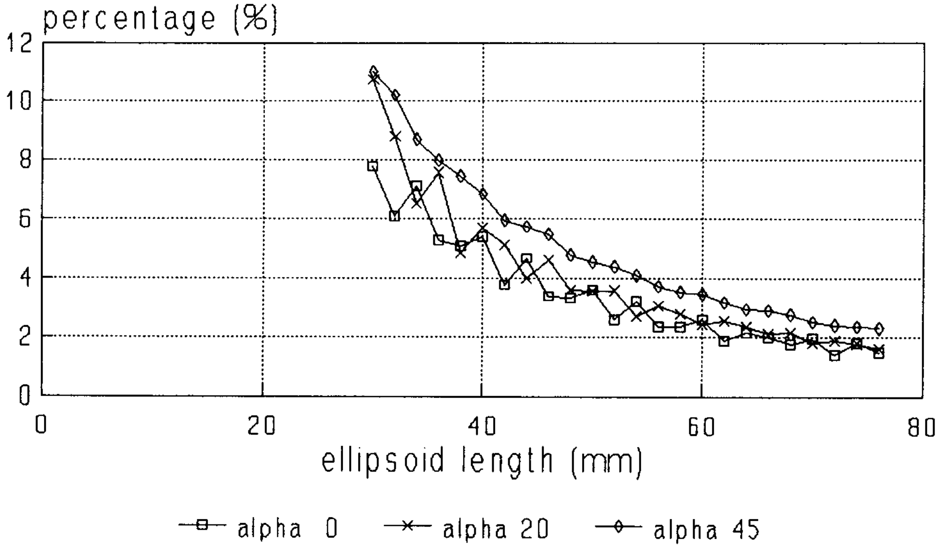

Fig. 5. Volumetric difference between exact volume and planimetric volume of ellipsoids in percentage of the exact volume as a function of increasing ellipsoid length for the salami effect with angles α of 0, 20, and 45°.

nimetry is relatively constant in shorter ellipsoids, although the difference in volume is relatively larger than in longer ellipsoids (Fig. 6: upper curve). As the critical angle of rotation is smaller in longer ellipsoids, effects of capsizing will be seen more early, only the relative volumetric difference will be smaller than in shorter ellipsoids (Fig. 6: lower curve). For each length class, the mean minimal volumetric difference was 0.4 mL, and this was seen to occur in the ellipsoids of low volume. The salami effect was responsible for 0.3 mL of this volumetric difference.

The volumetric error due to the first step effect in the computer simulation was especially seen in ellipsoids whose shape is low and broad (Table 1: numbers 2 and 6), resembling a usual configuration of a prostate. The total volume may be diminished up to 11% in a ellipsoids of 31.4 mL.

Missing or extra steps during planimetry *in vivo* were calculated in 59 prostates (Table 2). Missing steps were noticed in 13 prostates (22%). In 10 of these prostates, the planimetric volume was less than the prolate spheroid volume, in 8 of them even more than

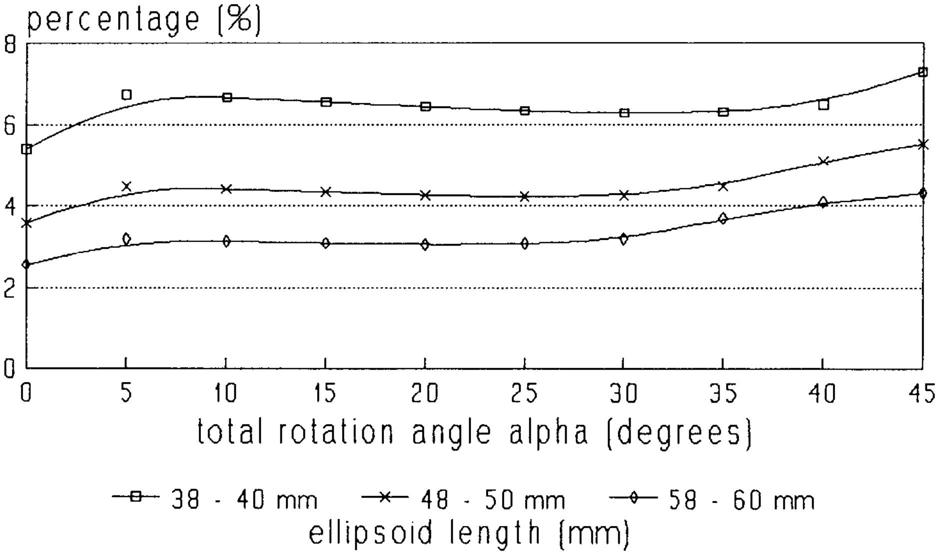

Fig. 6. Volumetric difference between exact volume and planimetric volume of ellipsoids in percentage of the exact volume as a function of initial rotation angle α for ellipsoids during the capsizing effect rotating 5° each planimetric step section, in three different length classes of ellipsoids.

Table 1. Volumetric difference between exact volume and planimetric volume in percentage of the exact volume of different ellipsoids of 31.4 mL, while planimetry started at a first section area of 1.0 or 2.0 cm^2. Critical first section area for occurrence of first step effect noted in cm^2.

Ellipse	Width (cm)	Height (cm)	Length (cm)	Percentage of volumetric error		Critical area (cm*2)
				(1.0 cm*2)	(2.0 cm*2)	
1	4	4	4	5	4	—
2	6	2.7	4	4	11	1.6
3	2.7	6	4	7	5	—
4	4	6	2.7	2	8	1.2
5	6	4	2.7	6	5	—
6	4	2.7	6	4	8	1.6
7	2.7	4	6	4	8	1.2

10%. In 22 prostates, too many steps for planimetry had been taken (37%). In 25 patients the prostates were in the range of equal length; in 8 out of 25 prostates the volumetric difference between prolate spheroid and planimetric volume exceeded 10%. The number of missing steps correlated with the loss of planimetric volume compared to the prolate spheroid volume (r = 0.52).

In 60% the planimetric volume was smaller than the prolate spheroid volume. In shorter prostates (as in the computer simulation) the planimetric volume was smaller compared to the prolate spheroid volume (r = 0.29), but this was very weakly correlated to missing steps (r = 0.18). The number of planimetric steps was well correlated with caliper measured length (r = 0.65) and the planimetric volume (r = 0.80), as might be expected.

DISCUSSION

Step-section planimetry is a well-accepted method of volumetry of the prostate. It was described by Basset et al. (1991) as an accurate technique *in vitro.* In our institution it is the method of choice due to its reproducibility of total and inner zone volume measurements (Niemer et al. 1994).

Table 2. Number of volumetric differences (prolate spheroid volume minus planimetric volume) in percentage of prolate spheroid volume (%) in 59 prostates, and differences between predicted and real length (mm) (step section size = 5 mm).

Percentage volumetric difference	Missing steps		Equal	Extra steps		
	2	1	0	1	2	3
< −10	—	3	3	6	1	2
−10 − 0	—	—	6	3	2	1
> 0 − 10	—	2	11	—	—	—
> 10	1	7	8	4	2	—
Total number	13		25	21		

Terris and Stamey (1991) compared the various ultrasonic volumetric methods *in vivo* with the weight of the radical prostatectomy specimens, unfortunately without performing ultrasonography of the post-operative specimen. Prolate spheroid measurements correlated best with the prostatic weight (r = 0.94), only slightly better than planimetry did (r = 0.93). The mean difference, as an index for accuracy, in 2 mm step section planimetry was as high as in prolate spheroid volumetry.

Both Niemer et al. (1994) and Terris and Stamey (1991) mentioned the variability of caliper measurements of prostatic length. Collins et al. (1993), however, described a reproducible technique of cephalocaudal length measurements.

Though accuracy and reproducibility of planimetry is as good as prolate spheroid caliper measurements, it is remarkable that planimetric volumetry results in smaller prostatic volumes compared to caliper measurements. We showed the effect of three potential errors, all of them giving rise to smaller planimetric volumes compared to optimal caliper measurements.

The salami effect was mentioned by Dahnert (1992) as a methodological weakness. In the salami effect, the angulation causes a mathematical error during the summation of step sections slightly larger compared to perpendicular slices. The combined error of salami effect with the step-section technique is in our study 12% at maximum, and relatively larger in shorter ellipsoids.

The angulation which occurs during the salami effect might also occur during caliper measurements. Considering the same angle α, the decrease of caliper length will be related to sin α. Ten degrees will diminish the calculated prolate spheroid volume by 1.5%, 20° by 6%, and 30° by 13%. In calculating the volume of ellipsoids with three caliper measurements, the error is the product of three measurements, and only needs

5% error in every caliper measurement ($\alpha = 20°$) to produce a total decrease of 13%. As a result, we might say that in planimetry the salami effect is mainly dependent on the length of the ellipsoid (Fig. 5), while in caliper measurements this angulation effect depends on the angle α. *In vivo,* it is impossible to avoid the salami technique completely, as the longitudinal axis of the prostate is hard to define objectively, in contrast to an ellipsoid in a geometrical model. In caliper measurements, the angle α can be avoided by measuring the height perpendicular to the length in the sagittal plane.

Capsizing occurred in the pilot study in up to 30°. In the computer simulation, the capsizing effect caused only 2 to 7% loss of volume. Longer ellipsoids were influenced to a larger extent than ellipsoids shorter than 45 mm. The capsizing effect is obviously of less importance than the salami effect. Missing a step section due to the first step effect is of considerable interest, as this may induce a volumetric loss up to 11% in prostates of median volume. Starting the planimetric series of step sections, we usually check the position of our first section by taking the ultrasonic longitudinal view, which indicates the position of the ultrasonic transverse section (Bruel and Kjaer 1846 multiplanar probe).

The *in vivo* study showed that only in 9 out of 59 prostates the planimetric volume was smaller than the prolate spheroid volume, while the number of planimetric steps was also smaller than the expected number. Accepting the caliper measurement of length as a standard parameter in this study, the computer simulation predicting a smaller volume by a reduced number of steps was applicable only in 15% of our *in vivo* population.

In contrast to missing a step section by the first step effect, an extra step may be induced, as illustrated in our *in vivo* study. Our computer model, with the point of rotation in the center of the prostate, cannot account for these observations. They may be caused by other movements of the prostate resulting in a series of fan-like overlapping slices. If during planimetry the amount of step sections exceeds the amount of steps as expected by the length of the prostate, the total planimetric volume might exceed the real volume, as too many planimetric slices are added into the planimetric summation formula.

Testing the relation between length and volumetric difference, it was seen that in shorter prostates the planimetric volume was smaller than the prolate spheroid volume when compared to longer prostates. This was also seen in the computer model.

CONCLUSION

Planimetric measurements are influenced by nonparallel or oblique slices, described as the salami effect and the capsizing effect. These effects may diminish the total volume *in vitro* up to 12%, especially in shorter ellipsoids. The shape of ellipsoids may cause small additional errors (the first step effect).

To minimize these errors *in vivo* it is worthwhile to compare caliper length with the number of planimetric steps. Also, pressure of the ultrasonic probe against the prostate should be avoided, as this might promote capsizing and deformation of shape.

The intraobserver variation found in our institution to be 12%, and the standard deviation of the difference in interobserver variation in planimetry (Niemer et al. 1994) might be partly explained by the described effects.

Increasing the number of steps by diminishing step-sizes theoretically improves accuracy and reproducibility of planimetric volumetry of the prostate. This, however, lengthens the procedure considerably in daily practice. Simultaneous representation of the prostate in a sagittal and a transverse plane, as used in three-dimensional planigraphy, can be of additional value.

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