British Journal of Urology (1996), 78, 219–223

Reproducibility of prostate volume measurements from transrectal ultrasonography by an automated and a manual technique

R.G. AARNINK, J.J.M.C.H. DE LA ROSETTE, F.M.J. DEBRUYNE and H. WIJKSTRA
Department of Urology, University Hospital Nijmegen, The Netherlands

Objective To assess the reproducibility of estimates of prostate volume determined by planimetry from transrectal ultrasonography (TRUS) images.

Materials and methods Two sequential sessions of images obtained by TRUS were obtained from 30 patients, with the ultrasound probe removed and inserted between the sessions. The stored images were outlined, both manually and by computer, and measurements of prostate volume obtained planimetrically. In addition, the ability of the urologist to accurately draw the contour was assessed by outlining predefined contours.

Results The mean (SD) variability of manual outlining between sessions was 3.5 (3.4)%, within one session was 1.7 (1.3)% and of computer outlining between sessions was 4.3 (3.8)%. Comparing the results of manual and computer outlining showed a mean (SD) variability of 7.5 (5.6)%, with larger values obtained from computer outlining. The mean (SD) variation in manually outlining predefined contours was 1.4 (1.4)%.

Conclusions The variability of computer outlining was slightly higher than expected theoretically. The within-session variability was higher than the variation caused by errors in outlining predefined contours, indicating that the interpretation of TRUS images differed with time. Automated determination of prostate volume can save time during clinical investigation and the variability is within the clinically acceptable range of 5%.

Keywords Step-section planimetry, reproducibility, prostate volume, ultrasonography

Introduction

The determination of prostate volume is routine during ultrasonographic examinations of patients with lower urinary tract symptoms. The volume can be calculated from appropriate formulae [1] or from step-section planimetry, the latter being more accurate [2]. In step-section planimetry, consecutive images of transverse sections are outlined to obtain the area of the prostate sections and the volume is then calculated by multiplying the sum of these areas by the inter-section distance [3]. Figure 1 illustrates the method with an *in vivo* example of prostate areas in a patient with lower urinary tract symptoms; a series of transverse cross-sectional images was obtained with TRUS at 4 mm intervals and the areas of the prostate obtained in the consecutive images are presented with different grey-scale values (represented in green).

The accuracy of step-section planimetry is dependent on several factors; as this method is a clinical implementation of numerical integration, the method is subject to the limitations of this integration. An important variable is the inter-section distance, which determines the number of samples taken from the object; previous authors have used inter-section distances between 2 and 5 mm [2,4]. Another important factor determining accuracy is the selection of the first step; Fig. 1 shows that a different first step will lead to different areas in the successive images, which may give a different computed volume. In theory, the first step is chosen randomly between zero and the inter-section distance; in clinical practice, this may more introduce more variation. An overview of the effect of step size and first-step selection on the accuracy of planimetry is presented in [5].

Besides accuracy, the reproducibility of the assessment of volume is important, especially for sequential determinations of prostatic volume. The results can be influenced not only by limitations of numerical integration, but also by the quality of outlining consecutive cross-sections. As ultrasonography is dependent on the skill of the operator, volume estimates may vary when the outlining is performed by different urologists; the results may even vary when obtained by one urologist. To overcome the time-consuming and subjective procedure of manually outlining prostate contours in consecutive images, an automated method for determining prostate volume has been

Accepted for publication 26 March 1996

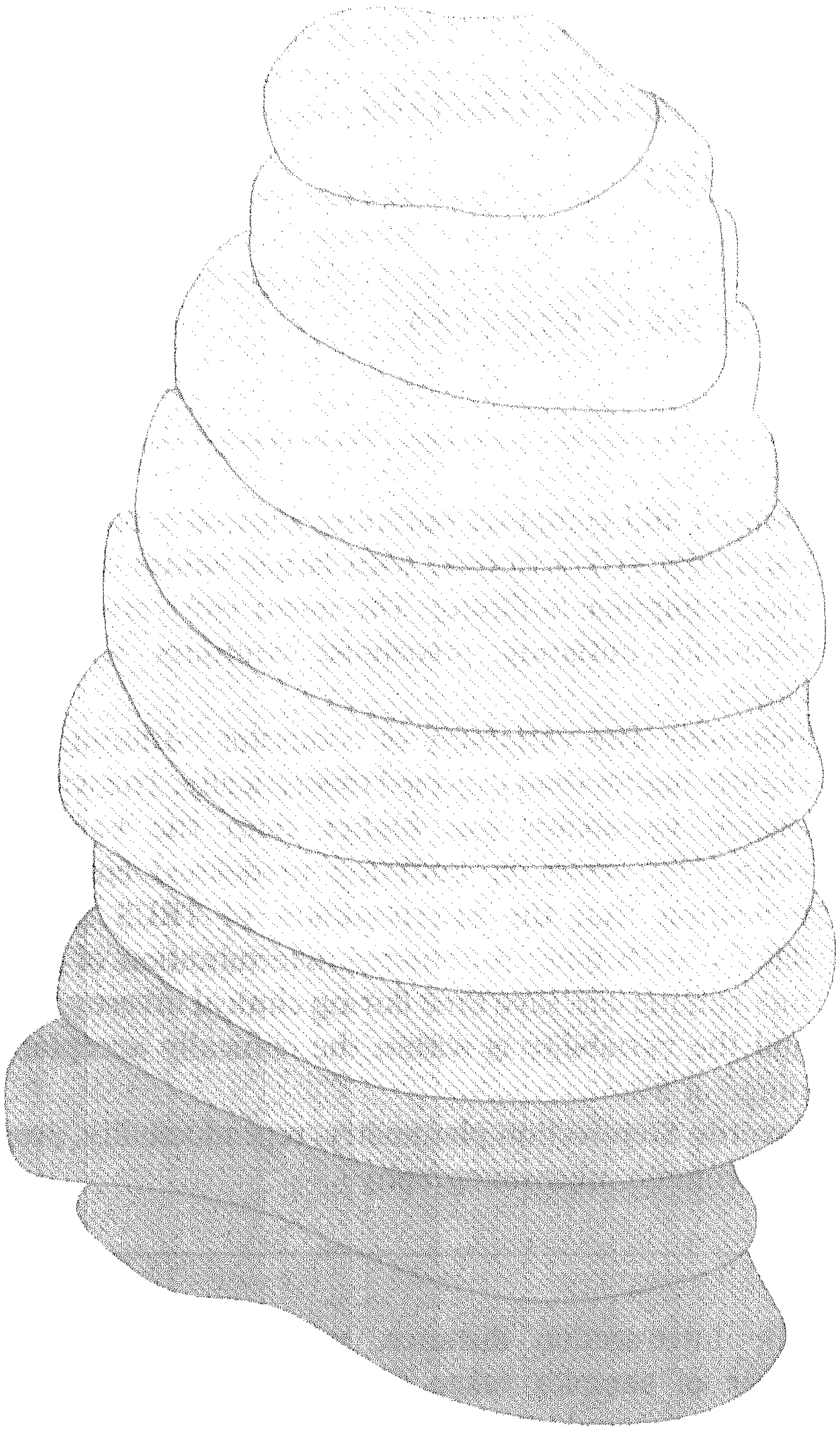

Fig. 1. Example of prostate volume measurement with step-section volumetry, showing the areas obtained from TRUS images taken at 4 mm intervals between sections.

developed, based on the detection of grey-level transitions in the ultrasonograms [6]. Using features which reflect specific information about the prostate in ultrasonograms, e.g. shape and grey-level appearance, the edges corresponding to the prostate boundary are selected and linked to form a closed prostate contour [3].

The present study assessed the reproducibility and errors when outlining consecutive images twice and the variability when two sequential sessions were recorded during one examination with the probe removed between the sessions.

Material and methods

Regular ultrasonographic examinations were performed using a Kretz Combison 330 ultrasound scanner with a 7.5 MHz transrectal multiplane 3D transducer. A computer system (80486DX2, 50 MHz, with an additional image-processing card) was connected to the video output signal of the echo scanner. The prostate was imaged transversally starting at the base and cross-sectional images were stored every 4 mm by retracting the probe with a mechanical indexer until the apex of the prostate was reached.

Two sequential series of TRUS sections were obtained from 30 patients (mean age 65.7 years, range 38–83) with lower urinary tract symptoms, during their visit to the out-patient clinic, with the probe removed and re-inserted between the sessions. Both series of sections were outlined twice during different drawing sessions (with a week between the sessions) to obtain the intra-session variability. During the outlining of the images from the second session, the urologist was unaware of the results of the first. Furthermore, the reproducibility of different measurements was assessed by comparing the values of the first session to those of the second. The images were outlined manually and then automatically by the computer.

The reproducibility of manual outlining is determined not only by whether the urologist can see what must be drawn but also by whether the urologist can draw what is seen. To evaluate the second point, the outlining of the second session was interrupted by a manual test of outlining after every fifth series of images; two images were selected randomly from a set of five with a predefined contour, as outlined in the first session. The urologist was instructed to follow the indicated contour, at about the same drawing speed; the area within this contour was obtained and correlated with the area within the predefined contour.

Results

For manual outlining, the results of the second series (mean volume 47.5 mL, SD 30.5) are given as a function of the results of the first (mean volume 46.7 mL, SD 27.7) (Fig. 2). The Pearson correlation coefficient between the manual series was 0.977, with no significant difference between them. The variation between the measurements is presented in Fig. 3; the mean (SD) variation was 3.5 (3.4)%, with a maximum of 11.1%, while the absolute mean volume difference was 3.6 mL with a maximum of 30 mL. For the second session, the mean (SD) variation was 3.4 (3.0)%, with a maximum of 10.0%, while the absolute mean difference was 3.2 mL with a maximum of 21 mL.

The results of the second automated measurement (mean 50.9 mL, SD 27.5) as a function of the first automated measurement (mean 51.4 mL, SD 27.7) is given in Fig. 4, with the line of equality for the first and second series. The Pearson correlation coefficient for

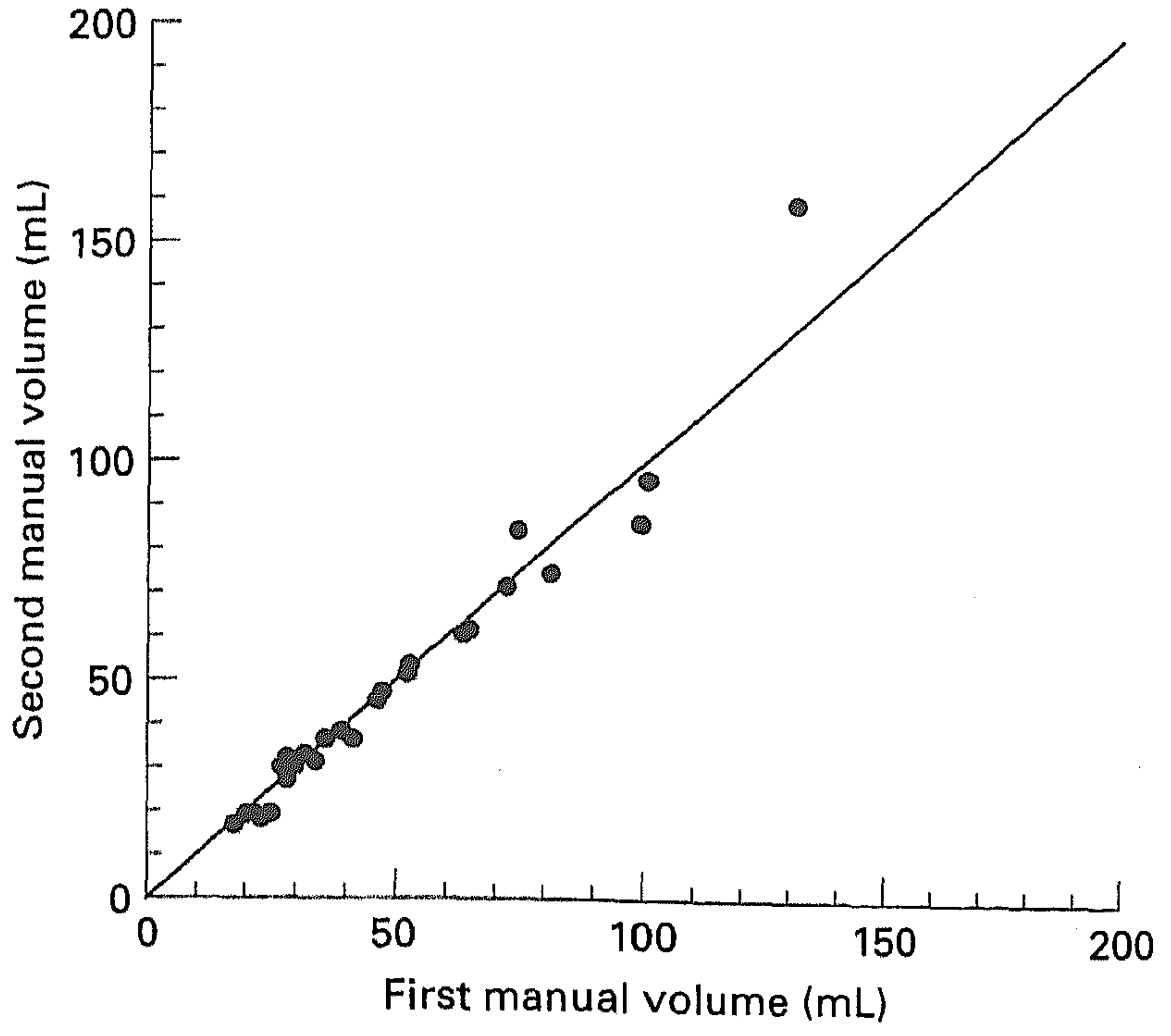

Fig. 2. The results of the second series of manual outlining as a function of the results of the first.

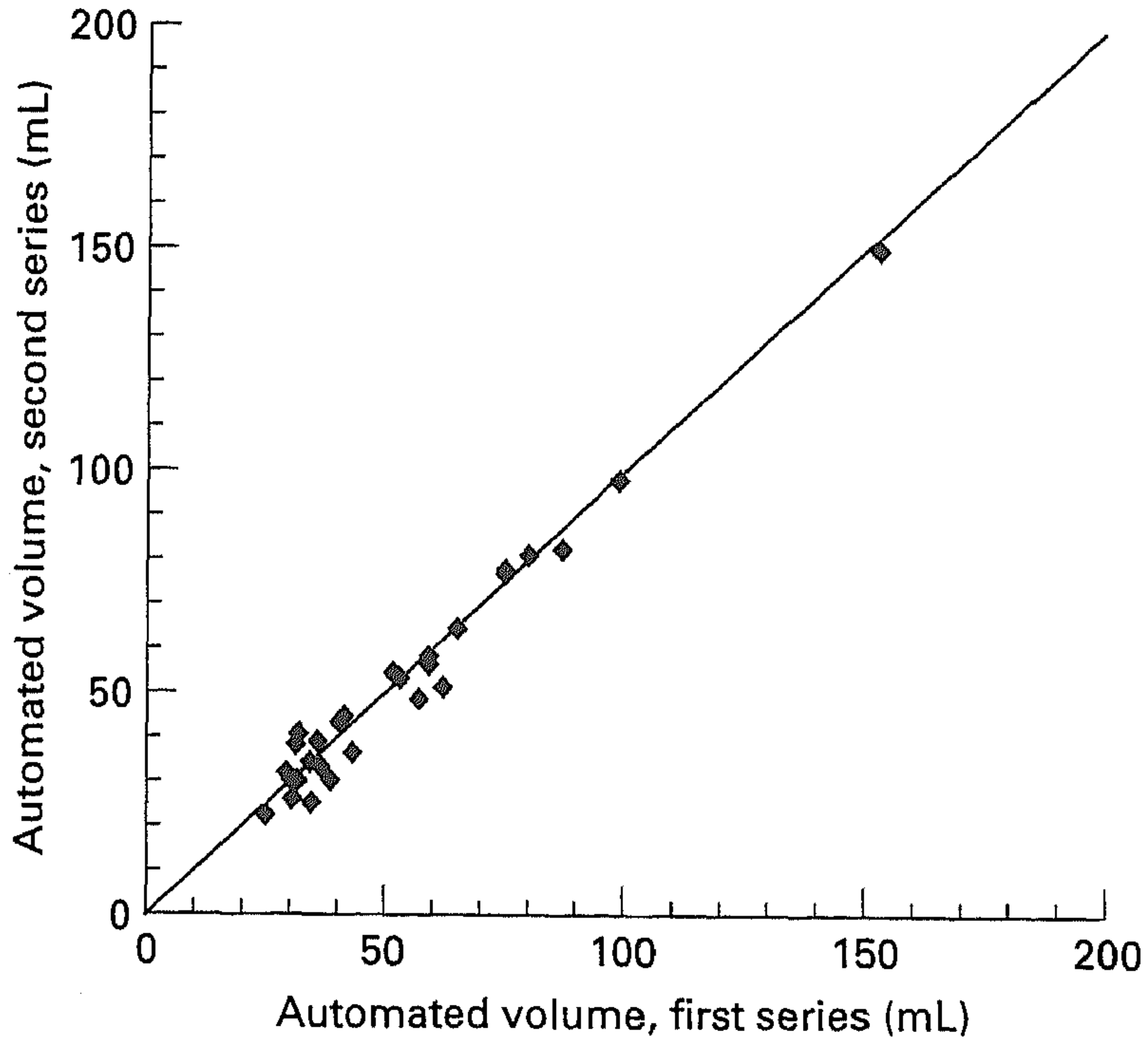

Fig. 4. The results of the second series of automated outlining as a function of the results of the first.

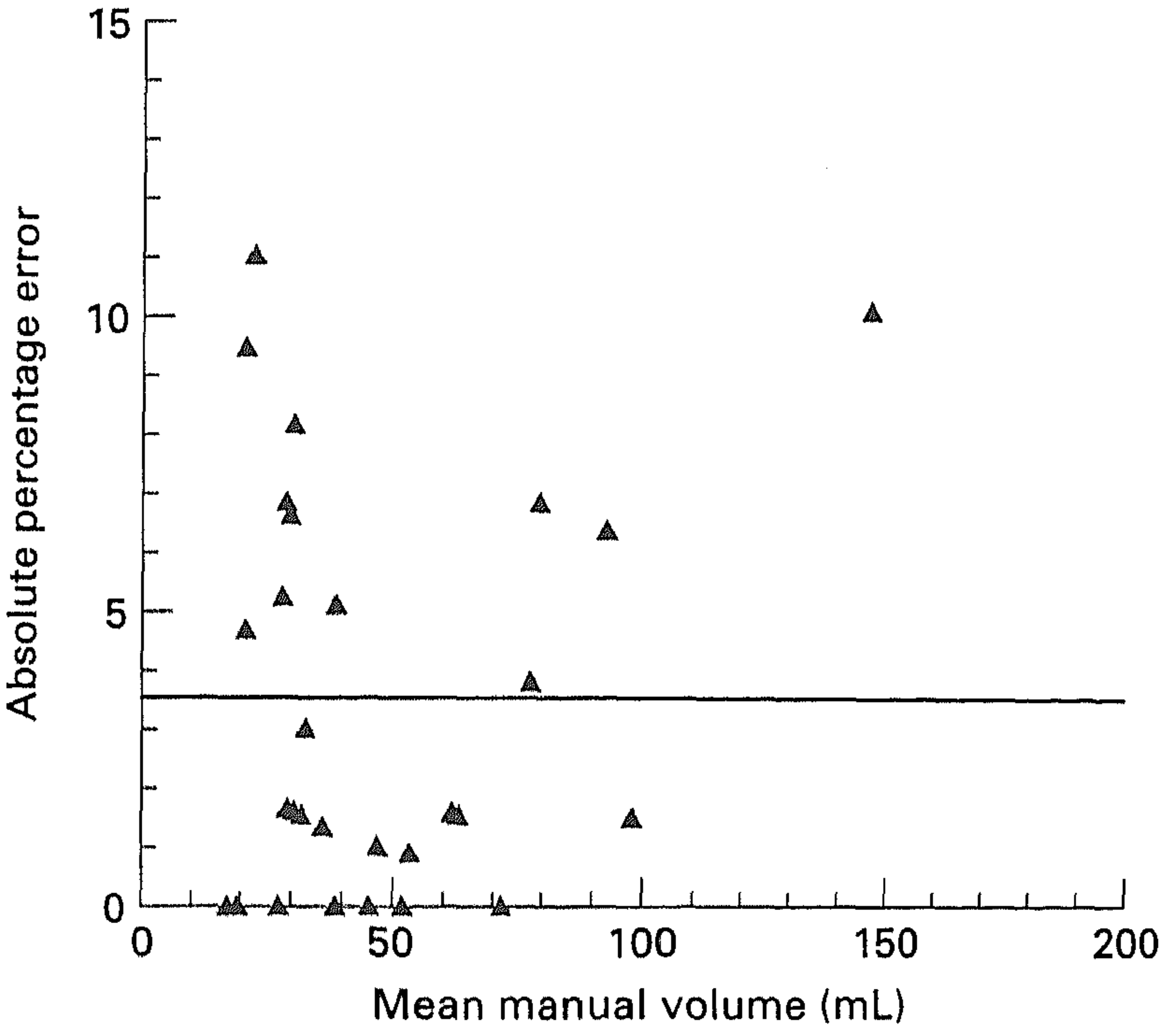

Fig. 3. The absolute percentage error between manual outlining of the two series as a function of the mean manual volume.

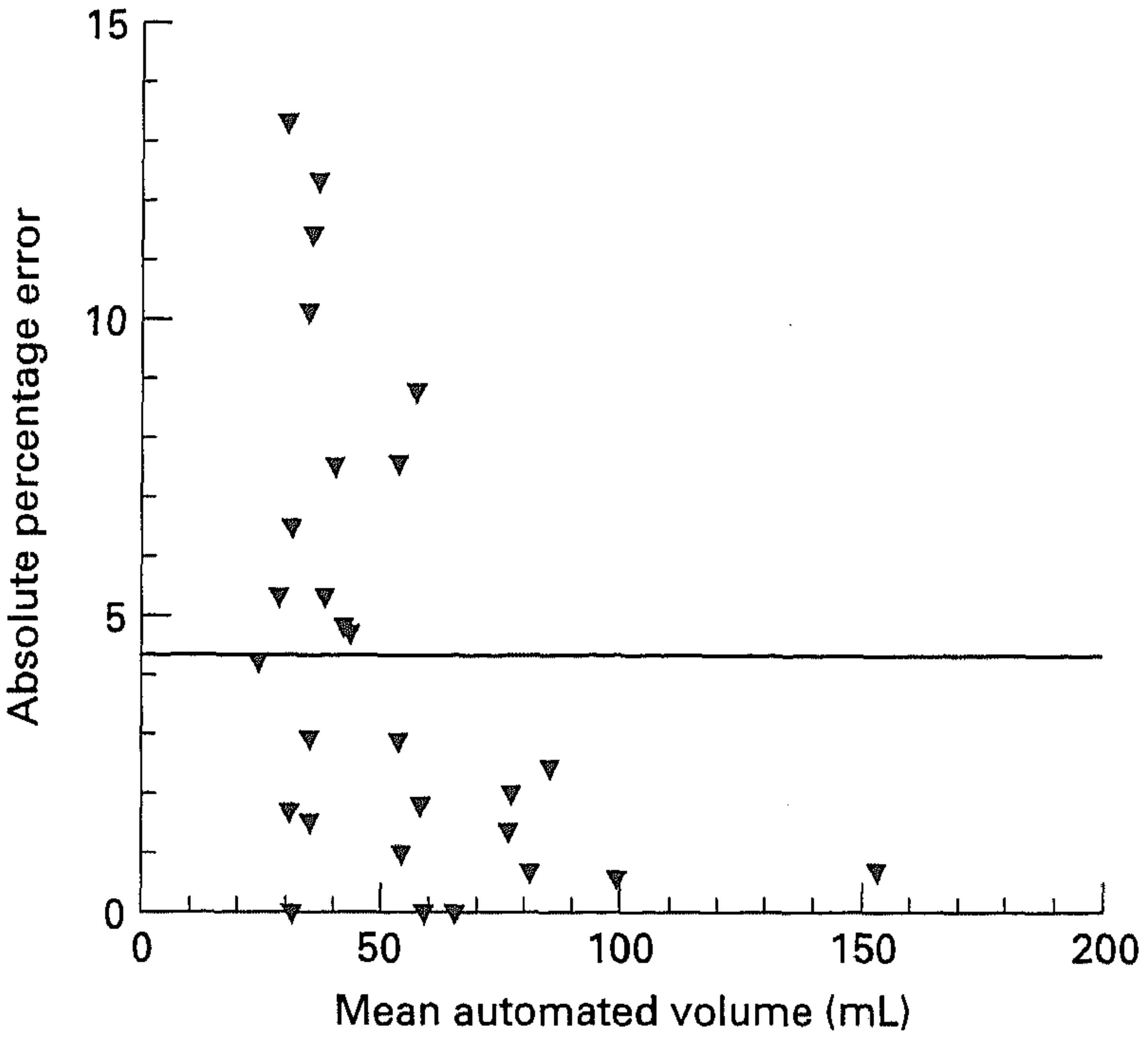

Fig. 5. The absolute percentage error between automated outlining of the two series as a function of the mean automated volume.

both series was 0.987, with no significant difference between them. The variation was defined as the absolute difference between the measurements divided by the sum of the two measurements, and is presented as a function of the mean of the two measurements (Fig. 5); the mean (SD) variation was 4.3 (3.9)%, with a maximum variation of 13.3%. The mean absolute difference between the measurements was 3.5 mL, with a maximum deviation of 10 mL.

The automated measurements are presented as a function of the corresponding manual measurement in Fig. 6 ($n=60$); the correlation coefficient was 0.971, with the results of the automated measurements being significantly larger. The mean (SD) difference was 7.6 (5.6)%, with a maximum of 20% and the absolute mean difference was 6.4 mL, with a maximum of 22 mL. This difference was also reflected in the linear regression analysis, with the best fit given by:

$$\text{automated} = 0.92 \times \text{manual} + 7.8.$$

The difference obtained when outlining a series of images twice is presented in Fig. 7 which shows the results of the second drawing session (mean 46.3 mL, SD 28.3) as a function of the results of the corresponding series of the first drawing session (mean 47.1 mL, SD 28.9; $n=60$). The mean (SD) variation was 1.7 (1.3), with a maximum

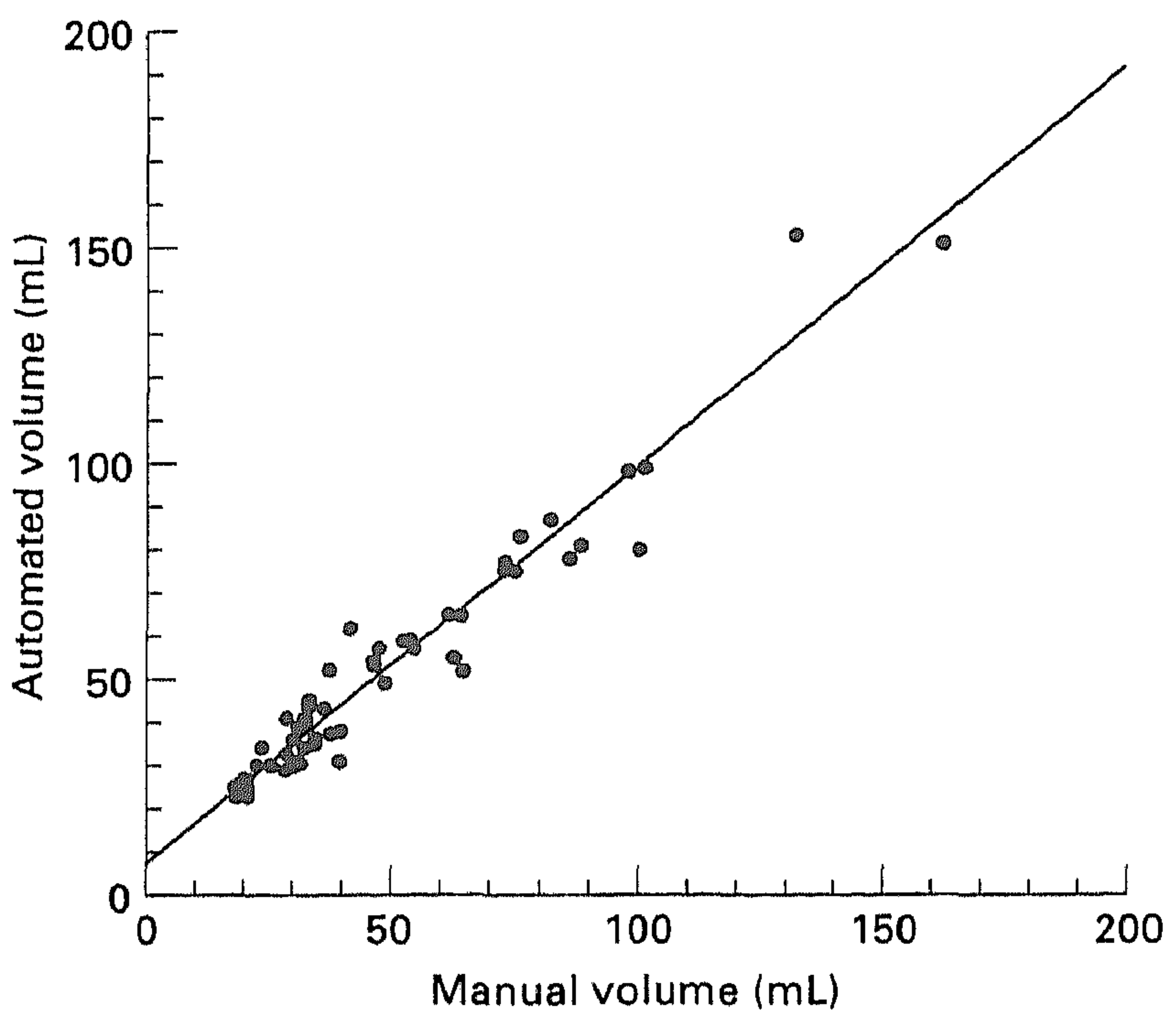

Fig. 6. The results of automated outlining as a function of the corresponding results of manual outlining.

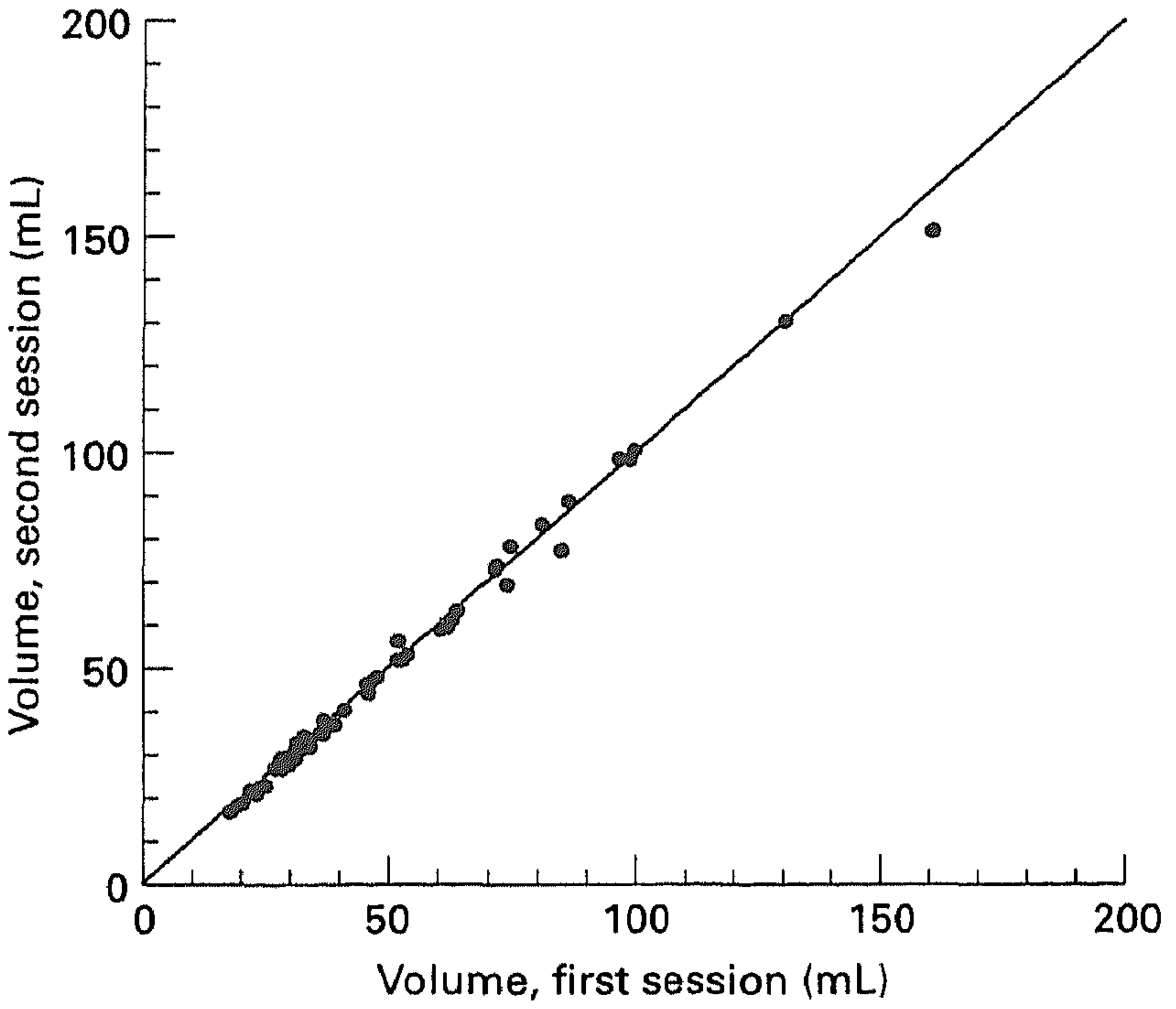

Fig. 7. The combined results of manual outlining of the second series as a function of the combined results of the first.

variation of 4.9%. The mean absolute difference was 1.5 mL, with a maximum deviation of 10 mL.

In the assessment of the reproducibility of outlining, the difference in area ranged between 4.2% and 0.9 %, with an absolute mean (SD) difference of 1.4 (1.4)% and there was no indication that the error increased with time.

Discussion

Because the assessment of prostate volume using DRE is inaccurate and subjective, TRUS has become routine in measuring prostate size. The use of TRUS in the qualitative and quantitative evaluation of prostatic diseases has been extensively studied. Although controversy exists about the positive predictive value of TRUS in the detection of prostate cancer [7], its application to volume determination is unquestioned. Initially, suprapubic ultrasonography was used to measure prostate size, but this technique required urine in the bladder, whereupon the prostate may be beyond the ultrasonic focal point, being too distant from the probe [8]. The introduction of TRUS improved the image quality markedly and step-section planimetry was proposed as an accurate method for volumetry. Because planimetry is dependent on the operator, there may be differences in interpretation when outlining consecutive cross-sections. To overcome this subjectivity, computerized outlining may be used to detect the boundaries of the prostate.

In the present study, the most important variable in step-section volumetry, the inter-section distance, was set to 4 mm, a value based on a computer simulation to obtain the best possible compromise between the duration and accuracy of step-section volumetry. A smaller step size gives more images in the session and therefore extends the investigation; a larger step size reduces the accuracy. From a computer analysis, it was concluded that an inter-section distance of 4 mm gave an accuracy of $\geqslant$95% for prostates longer than 24 mm [5].

The influence of the selection of the first step and the interpretation of the images were investigated by assessing two consecutive sessions of planimetric volumetry. The mean variation of the automated and manual results were accurate to within 95%. However, some measurements showed a larger variation, indicating that factors other than the theoretical error of numerical integration were important. For instance, the number of cross-sections between corresponding series should not differ by more than one, depending on the starting point [5], but for four series the number of cross-sections differed by two or three. The quality of the image may be important for correct outlining; with poor quality, it is the reproducibility of the interpolation algorithm (which completes the gaps between the detected boundary sections) which is assessed, instead of the correct detection of the grey-level transitions of the prostate boundary.

The reproducibility of outlining a series of cross-sections twice within a week was very good, with a mean accuracy of >98% and a maximum deviation between the series of 4.9%. Thus, an experienced urologist can reproduce volumetric measurements with an accuracy of $\geqslant$95%; the accuracy was not complete probably because there were difficulties in outlining the exact area seen, as illustrated in the contour-following test, which gave a mean difference with the predefined contour of 1.4% and a maximum deviation of −4.2%.

The mean percentage variation of the automated method was larger than that for accurate manual outlining but the absolute mean difference was similar (3.5, 3.6 and 3.2 mL for automated, first and second manual outlining, respectively). This indicates that computerized outlining creates larger errors in smaller prostates, which was also suggested by the systematic overestimation of 7.8 mL calculated by linear regression analysis. One reason for this may be the incorrect detection of the boundary at the prostatic apex; instead of small cross-sections of the prostate, pelvic muscles may be selected as parts of the prostatic boundary, causing overestimated areas at the end of the series. The slope of the regression line was similar to those for other groups of patients; in the pilot study, the regression slope was 0.92 for a group of 55 patients [3], and for a larger population of 247 patients with lower urinary tract symptoms [9]. From this study, it may be concluded that the mean variation of the automated method is within the clinically acceptable range. The automated determination of volume may be a good alternative to overcome the time-consuming, subjective and tedious procedure of manual outlining of a series of prostate images.

References

1. Aarnink, RG, de la Rosette JJMCH, Debruyne FMJ, Wijkstra H. Formula-derived prostate volume determination. *Eur Urol* 1996; **29**: 399–402
2. Terris MK, Stamey TA. Determination of prostate volume by transrectal ultrasound. *J Urol* 1991; **145**: 984–7
3. Aarnink RG, Huynen AL, Giesen RJB, de la Rosette JJMCH, Debruyne FMJ, Wijkstra H. Automated prostate volume determination with ultrasonographic imaging. *J Urol* 1995; **153**: 1549–52
4. Collins GN, Lee RJ, Barbara Russell E, Raab GM, Hehir M. Ultrasonographic determined patterns of enlargement in benign prostatic hyperplasia. *Br J Urol* 1993; **71**: 451–6
5. Aarnink RG, Giesen RJB, de la Rosette JJMCH, Huynen AL, Debruyne FMJ, Wijkstra H. Planimetric volumetry of the prostate: how accurate is it? *Physiol Meas* 1995; **16**: 141–50
6. Aarnink RG, Giesen RJB, Huynen AL, de la Rosette JJMCH, Debruyne FMJ, Wijkstra H. A practical clinical method for contour determination in ultrasonographic prostate images. *Ultrasound Med Biol* 1994; **20**: 705–17
7. Denis L. Diagnosing benign prostatic hyperplasia versus prostate cancer. *Br J Urol* 1995; **76** (Suppl.1): 17–23
8. Stone NN, Ray PS, Smith JA *et al.* Ultrasound determination of prostate volume: comparison of transrectal (ellipsoid v planimetry) and suprapubic methods. *J Endourol* 1991; **5**: 251–4
9. Aarnink RG, de la Rosette JJMCH, Huynen AL, Giesen RJB, Debruyne FMJ, Wijkstra H. Standardized assessment to enhance the diagnostic value of prostate volume; Part I: morphometry in patients with lower urinary tract symptoms. *Prostate* 1996: in press

Authors

R.G. Aarnink, MSc, Biomedical Engineer.
J.J.M.C.H. De La Rosette, MD, PhD, Director of Prostate Centre.
F.M.J. Debruyne, MD, PhD, Professor.
H. Wijkstra, MSc, PhD, Director of the Biomedical Engineering Unit.
Correspondence: R.G. Aarnink, University Hospital, Department of Urology, Biomedical Engineering Unit, PO Box 9101, 6500 HB Nijmegen, The Netherlands.