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Standardized Assessment to Enhance the Diagnostic Value of Prostate Volume; Part I: Morphometry in Patients With Lower Urinary Tract Symptoms

René G. Aarnink, Jean J.M.C.H. de la Rosette, Anton L. Huynen, Robert J.B. Giesen, Frans M.J. Debruyne, and Hessel Wijkstra

BACKGROUND. The diagnostic value of prostate volume results has been evaluated in patients with prostate problems of benign cause.

METHODS. For 247 patients, automated volume results were compared to manual results of planimetric reference volume and of the classical ellipsoid formula. Also, transition zone volume was estimated and growth curves of the prostate and prostate dimensions over age were investigated.

RESULTS. Application of automated volume determination gives accurate results compared to the reference volume (Pearson correlation $R = 0.938$). The ellipsoid volume results were slightly less correlated ($R = 0.921$). Average growth of the entire prostate was 1.7% per year, for the transition zone the growth was 4.3%. Compared to growth rates for a community-based population, comparable growth rates were found for our group that had higher mean prostate volume.

CONCLUSIONS. The results indicate that the age of onset of volume growth is the determining factor in developing benign prostate enlargement not a change in growth rate.

INTRODUCTION

When investigating patients with lower urinary tract symptoms (LUTS), the prostate volume can be an important parameter. In case of surgical treatment of patients suffering from benign prostate enlargement (BPE) or prostate cancer, the result of the volume measurement is used to decide between transurethral resection of the prostate (TURP) and open prostatectomy [1]. Also, the prostate volume can be used as a selection criterion for alternative treatments like visual laser ablation of the prostate (VLAP), transurethral microwave thermotherapy (TUMT), or drug therapy. It is believed that larger prostates have a better response to TUMT, while smaller prostates respond better to VLAP (unpublished results). Also for clinical studies of drug therapy efficacy for prostate volume reduction, an accurate and reproducible method is necessary to determine (the decrease in)

the size of the prostate gland at intervals. Moreover, interpretation of prostate-specific antigen (PSA) values may be improved by using volume-corrected PSA levels to distinguish between patients with BPE and those with prostate cancer. Overlap in PSA levels occurs in these patients and correction for the prostate volume (PSA density [PSAD]) may improve the discriminating power of PSA [2].

A fast estimate of the prostate volume can be calculated using the prostate height, width, and length, obtained in transrectal ultrasound (TRUS) images, in the classical ellipsoid formula. Collins et al. [3] presented a study of prostate volume measurements in...
patients with benign prostatic hyperplasia using the ellipsoid formula. A more accurate volume measurement can be obtained with the planimetric volumetry by outlining the prostate contour in sequential cross-sections of the prostate. Bosch et al. [4] presented a study on prostate volume and shape in a community-based population using planimetric volumetry.

TRUS, however, is an operator-dependent technique and a small interpretation error in the ultrasonographic image can lead to a considerable miscalculation of the prostate volume. Therefore, Benson [5] concluded in an editorial comment about PSA that the development of rapid, accurate, and automated prostate volume determinations will be of great value in making PSAD a more user-friendly and reproducible technique. To reduce the variability in TRUS volume assessment caused by different volumetry methods or human interpretation errors, we have developed an automated method for prostate volume determination. This method is based on step-section volumetry and detects the prostate contour automatically in transverse cross-sections using image-processing tools [6]. This manuscript evaluates the data of volume determinations in a group of patients with LUTS. It also describes the growth patterns of the prostate volume, transition zone volume, and prostate dimensions over age. The data obtained for our group of patients are compared to data presented in the literature: the BPE group as presented by Collins et al. [3], the community-based population as presented by Bosch et al. [4], data presented by Jakobsen et al. [7], and the data from an autopsy study by Berry et al. [8]. This information may expand the knowledge of the natural history and impact of benign enlargement of the human prostate.

PATIENTS AND METHODS

From December 1993 to June 1994, a series of transverse ultrasonographic cross-section images was recorded of 254 males (mean age: 61, 28−87 years) with LUTS. Also, the central longitudinal image was stored for every patient. These patients were subjected to the following investigations. First, a blood sample was taken to determine the PSA level (Hybritech Tan
dem-R, normal range: 0−4 ng/mL (Hybritech Inc., San Diego, CA)). Then, a digital rectal examination (DRE) was performed. If the DRE was abnormal and indicated suspicion for prostate cancer, the patient was scheduled for ultrasonographically guided puncture biopsies during a next visit. Only when DRE revealed no abnormalities was TRUS performed following DRE to examine the prostate visually. During this TRUS session, the prostate volume was determined automatically with step-section volumetry using image-processing tools on transverse ultrasonographic images [9]. Moreover, the investigator checked the prostate for lesions suspected for carcinoma. If either TRUS and/or PSA indicated an increased probability for prostate malignancy, puncture biopsies were performed. In case of suspected TRUS, directed biopsies were taken at suspicious areas, otherwise systematic sextant biopsies were taken. A more extensive description about the exclusion of prostatic malignancy is given in the accompanying paper [10].

For imaging of the prostate, a Kretz Combison 330 ultrasound scanner with standardized settings was used in combination with a 7.5 MHz transrectal transducer (Multi-plane 3-D VRW 77AK). A personal computer (80486DXII, 66 MHz) with additional frame grabber card (PCVisionplus-512-3-50) was connected to the video signal to store the TRUS images on hard disc.

During the ultrasonographic examinations, first a longitudinal cross-section was stored for off-line length measurements for use in the ellipsoid formula. The method for automated assessment of the prostate volume is based on step-section volumetry and uses transverse cross-sections through the prostate every 4 mm. A series of transverse cross-sections was recorded starting at the base. Using a fixture, the probe was retracted 4 mm in every step and the next image was stored until the apex of the prostate was reached. Once the series of cross-sections was stored on hard disc, the ultrasonographic examination was finished and the volume determination was started off-line.

In every image recorded for volume determination, the prostate contour was defined automatically using image-processing tools: edge detection techniques were applied to locate possible gray level transitions and knowledge-based features were used to select the best possible boundary parts. Interpolation techniques were applied to form a closed prostate contour. Once the contour was determined (in about 20 sec per image), the contribution (the area within the detected contour) to the total prostate volume was calculated. By summation of all contributions, the size of the gland was determined in a total processing time of about 5 min per prostate [6]. The resulting volume was stored in a database-oriented structure on hard disc. Once the clinical data were known, the results of the blood analysis were stored in the computer as well.

The accuracy of the automated prostate volume assessment was checked by off-line manual outlining of the cross-section images by an experienced ultrasonographer (JdIR). In a cadaver study, Hendrikx et al. [11] showed a good correlation between the planimetric volume obtained with TRUS and the prostate volume measured in a water jug after prostatectomy.
Diagnostic Value of Prostate Volume

The gold standard. Therefore, we concluded that the results of manual outlining by a urologist experienced with ultrasonography during an off-line drawing session in a quiet surrounding can serve as a reference volume [9]. Furthermore, an off-line ellipsoid volume was obtained by measuring the transverse (TV), anterior-posterior (AP), and prostatic urethral (PU) diameter of the prostate in the stored images and using these in the classical formula for ellipsoid volume \( V_E = \pi TV \cdot AP \cdot PU / 6 \). Also the volume of the transition zone was estimated by measuring the AP diameter of the transition zone in the largest transverse cross-section and assuming the transition zone to be spherical: \( V_T = 4/3 \pi (TD/2)^3 \).

The automated volume was correlated to the resulting reference volume. The off-line ellipsoid volume was used to get an idea of the error introduced by assuming an ellipsoid shape in determining the prostate volume. Besides, the PU length as measured for the ellipsoid volume was compared to the length obtained with planimetric volumetry. The literature states that the difficulty in measuring the PU length, or cephalocaudal diameter, using TRUS is the determining factor in the accuracy of the ellipsoid formula [12,13]. Therefore, the ellipsoid volume was calculated with the measured PU length as well as with the length obtained with planimetric volumetry (number of cross-sections multiplied by the intersection distance). Also, the correlation between both lengths was obtained.

Because it is generally believed that the transition zone is the growing part when developing BPE, the transition zone volume was correlated to age. Besides, the development of the prostate dimensions (determined for use in the ellipsoid formula) over age was evaluated using the logarithmic description of the growing function \( V = V_0 (1 + \text{growth factor})^{AGE} \). The average growth in percentage per year can be derived by least squares regression analysis of the logarithmically transformed volumes or dimensions and age:

\[
\ln(\text{volume}) = \ln(V_0) + \ln(1 + \text{growth factor}) \cdot \text{age}
\]

Growth curves were determined for prostate volume, transition zone volume, and prostate dimensions. These growth curves were also determined for the data as presented in the literature. For qualitative analysis of the detected curves, the Pearson product moment correlation coefficient was calculated between age and logarithmically transformed volumes and dimensions.

RESULTS

In 7 of the 254 patients malignancy was detected by puncture biopsies of the prostate shown on TRUS images and/or by increased PSA level. These patients were excluded from the study population. Of the remaining 247 clinically benign patients, the results of the automated prostate volume determination showed a mean volume of 40.4 mL with a range of 10–126 mL. The manual outlining by an experienced urologist, used as the reference volume, resulted in a mean prostate volume of 43.0 mL with a range of 7–175 mL. The distribution of the reference volume is presented in Figure 1. In Table I, an overview of these results is presented, including the average absolute error between the reference and automated volume with standard deviation and the ratio between the automated (AV) and reference volume (RV). Besides, the Pearson product moment correlation coefficient \( R \) is given. Moreover, the results for the off-line ellipsoid volume (OEV) and the transverse off-line ellipsoid volume (aOEV), calculated using the prostate length obtained with the stored transverse cross-sections, are presented. For 25 patients (10%), the automated results differed more than 25% from the reference volume, while the ellipsoid volume results had an error of more than 25% in 42 patients (17%) when compared to the reference volume. In Figures 2 and 3, a graphical representation of the automated volume results and the ellipsoid volume results is presented as a function of the planimetric reference volume.

The mean transition zone volume in our group of patients with LUTS was 6.9 mL with a range from 0.4 to 49 mL. In Figure 4, a graphical representation of the transition zone volume is presented as a function of the reference volume. The Pearson product moment correlation coefficient \( R \) was 0.82. The mean
percentage of the prostate belonging to the transition zone was 14.1%, ranging between 2.0 and 60.9%.

In Table II, the prostate lengths measured in the stored longitudinal sections are compared to the prostate lengths as obtained with planimetric volumetry. The prostate length is obtained in the longitudinal image by measuring the distance between the bladder neck and the point of juncture of the prostatic apex and distal urethra. The planimetric length is expressed as the number of cross-sections stored for automated volume assessment multiplied by the intersection distance. In Figure 5, a graphical representation of the planimetric length as a function of the measured length is given. The planimetric length is obtained with discrete steps containing a maximum error of one step when calculating the length from the number of cross-sections. When defining the line between these points as axis of the prostate, it can be calculated from Table II that the prostate axis is tilted over 20°, compared to the probe axis.

To investigate the development of the prostate during aging, the prostate volume, transition zone volume, and the transition zone volume relative to the reference volume were correlated to age. In Table III an overview of the results is presented including the average growth rate with volume at age = 0 ($V_0$) and the Pearson correlation coefficient for logarithmically transformed volumes. The average growth of the entire prostate is 1.7% per year, while for the transition zone 4.3% per year was found. In Figures 6–8, the reference prostate volume, the absolute transition zone volume, and the relative transition zone volume are plotted on a logarithmic axis as a function of age together with the least squares regression lines.

In Table IV, the prostate dimensions are compared to age. Presented are the AP dimension, the TV dimension, and the PU dimension as obtained for use in the ellipsoid volume formula, as well as the transition zone diameter. Also, the average growth of each prostate dimension was obtained. As presented in Table IV, the average growth of the transition zone diameter is the largest, meaning that the transition zone diameter is the prostate diameter that is growing fastest when aging: 1.4% per year on the average. The best correlation is found for the development of the transition zone diameter over age. Although the AP diameter of the prostate showed a growth factor of 0.8%, this number is entirely caused by the increase of the transition zone diameter: no significant growth could be measured when the transition zone diameter was left out in the analysis of the prostatic AP diameter.

In Table V, data are collected on prostatic volume development over age as presented in the literature for different patient populations. Presented are the mean prostate volume as presented by Bosch et al. [4] in combination with Jakobsen et al. [7] and by Collins et al. [14] for discrete ranges of age. The autopsy data by Berry et al. [8] are presented in weight. In Table VI, an overview of the different studies is presented, concerning number of patients, study population,
TABLE I. Volume Measurement Results of Clinically BPE Patient Population (247 patients)*

<table>
<thead>
<tr>
<th></th>
<th>RV</th>
<th>AV</th>
<th>OEV</th>
<th>aOEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (mL)</td>
<td>43.0</td>
<td>40.4</td>
<td>38.2</td>
<td>35.7</td>
</tr>
<tr>
<td>Range (mL)</td>
<td>7-175</td>
<td>10-126</td>
<td>7-116</td>
<td>7-120</td>
</tr>
<tr>
<td>Average absolute error ± SD (mL)</td>
<td>—</td>
<td>5.1 ± 6.7</td>
<td>6.9 ± 7.3</td>
<td>7.7 ± 7.1</td>
</tr>
<tr>
<td>Rc ± SD</td>
<td>—</td>
<td>0.918 ± 0.152</td>
<td>0.879 ± 0.164</td>
<td>0.823 ± 0.117</td>
</tr>
<tr>
<td>R</td>
<td>—</td>
<td>0.938</td>
<td>0.921</td>
<td>0.955</td>
</tr>
</tbody>
</table>

*Presented are the mean prostate volume, the range, the average absolute error when compared to the reference volume, the ratio coefficient with the reference volume, and the Pearson product moment correlation. RV = reference volume; AV = automated volume; OEV = off-line ellipsoid volume; aOEV = transverse OEV.

TABLE II. Prostate Length Obtained From the Stored Step-Section Images (PlanLength) Compared to the Length Measured in the Stored Longitudinal Cross-Section (MLength)*

<table>
<thead>
<tr>
<th></th>
<th>MLength</th>
<th>PlanLength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (mm)</td>
<td>46.3</td>
<td>43.4</td>
</tr>
<tr>
<td>Range (mm)</td>
<td>14.1-72.6</td>
<td>28.0-72.0</td>
</tr>
<tr>
<td>Average absolute error ± SD</td>
<td>—</td>
<td>6.1 ± 4.4</td>
</tr>
<tr>
<td>Rc ± SD</td>
<td>—</td>
<td>0.941 ± 0.176</td>
</tr>
<tr>
<td>R</td>
<td>—</td>
<td>0.621</td>
</tr>
</tbody>
</table>

*Presented are mean and range of both lengths, the average absolute error in the planimetric length when compared to the measured length, the ratio coefficient between the measured length and planimetric length, and the Pearson correlation coefficient.

Fig. 4. The transition zone volume results as a function of the reference volume. Also, the line obtained with linear regression is plotted.

Table: Prostate length obtained from stored step-section images (PlanLength) compared to the length measured in the stored longitudinal cross-section (MLength) for 247 patients.

Prostate volume distribution, and transition zone volume distribution.

Using the mean prostate volumes for the smallest intervals in age presented in the above papers (5- or 10-year intervals), growth curves were calculated from these data and plotted in Figure 9 with the mean prostate volume on a logarithmic axis. The growth factors are given in Table V as well. When evaluating these numbers, the data of a community-based population presented by Bosch et al. [4] showed the fastest growth rate: 2.4%. Bosch et al. [4] presented the data on prostatic volume only for a small range of age. When taking the data in the range of 30-50 years of age as presented by Jakobsen et al. [7] into account, the growth rate decreased to 1.6%. The growth rate obtained from the BPE group as presented by Collins et al. [3,14] was 1.7%. For the autopsy study, an average growth rate of 1.3% was found. For our group of patients with LUTS, a mean growth rate of 2.0% was found using the mean prostate volumes at 5-year intervals. The growth rate obtained for the individual volume results of 247 patients was 1.7% (see Discussion section).

Bosch et al. [4] presented for their group of patients between 55 and 75 years of age a growth rate of 2.0% for the entire prostate volume while for the transition zone volume a 3.5% increase per year was obtained. Analyzing the growth rate for our patients between 55 and 74 years (n = 146) gave the same results as for normal prostates: 2.0% for entire prostate volume and 3.5% for the transition zone volume.

**DISCUSSION**

Depending on the purpose of the measurement, the prostate volume should be determined planimetrically or with the ellipsoid formula. For treatment selection, a quick estimation using the ellipsoid formula gives in general sufficient information, although an underestimation of the volume may be expected [15], as also illustrated by the ellipsoid reference volume (average absolute error for 247 patients: 6.9 cc or 16%). This volume was obtained off-
The planimetric prostate length is plotted as a function of the prostate length measured in longitudinal images. Also, the line planimetric length = measured length is plotted.

**TABLE III. Reference Volume, Automated Volume, Transition Zone Volume, and Transition Zone Volume Relative to Reference Volume Correlated to Age**

<table>
<thead>
<tr>
<th>Trans/</th>
<th>Ref (mL)</th>
<th>Auto (mL)</th>
<th>Trans (mL)</th>
<th>Ref (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth factor</td>
<td>1.7%</td>
<td>1.6%</td>
<td>4.3%</td>
<td>2.5%</td>
</tr>
<tr>
<td>V₀</td>
<td>13.5</td>
<td>13.9</td>
<td>0.4</td>
<td>2.7</td>
</tr>
<tr>
<td>R</td>
<td>0.448</td>
<td>0.437</td>
<td>0.520</td>
<td>0.438</td>
</tr>
</tbody>
</table>

*Presented are the average growth percentages obtained with the growth curves with intercept and the Pearson product moment correlation coefficient for logarithmically transformed volumes.

The planimetric length is smaller than the measured length: the planimetric length is the distance between the projection of apex/distal urethra juncture and the bladder neck on the probe axis. Because of the projection and the maximum error of one step, the use of the planimetric length in the ellipsoid formula can lead to smaller volume estimates. For studies on drug therapy efficacy or PSA density, planimetric volumetry is favorable, although some disadvantages are attached to it. Terris and Stamey [13] concluded that step-section planimetry is accurate but extremely
time-consuming, tedious for the sonographer, and prolongs the discomfort of the examination for the patient. These disadvantages were reason for us to develop a computerized system that could do the outlining automatically in stored cross-sections obtained with step-section volumetry. By storing the images on hard disk before outlining, valuable time is saved during the ultrasonographic investigation. The outlining is performed automatically, so human interpretation errors are overcome.

This manuscript shows that application of the automated method for prostate volume determination in a clinical surrounding for a large number of patients gives accurate results, leading to an average absolute error of 12% compared to the reference volume. In the study population, all patients with LUTS and negative DRE were evaluated, including patients with catheters. Although the catheter could give distortions in the ultrasonographic images leading to misplaced automated contour outlining, these patients were included to illustrate a true clinical application of the automated method. Also, no manual corrections were made on the detected contours, although a correction possibility with manual outlining is implemented in the software. The selection of the step size of 4 mm was based on a computer simulation to determine the theoretical influence of the step size on the results of planimetric volumetry using a computer model of the prostate. In theory, the error range in volume measurements for prostates with natural dimensions is bounded by $-1.8$ and $2.3\%$ [16]. From a clinical evaluation by calculating the automated volume results for an 8 mm step size using the images stored with 4 mm it was concluded that the variability in the measurements with 8 mm was 5.9% for 214 patients when compared to the results obtained with 4 mm. Based on this, it was concluded that an accuracy of 95% in planimetric volume measurements can be obtained using an intersection distance of 4 mm [16].

The mean percentage of the prostate volume belonging to the transition zone was 14.1%, which is markedly smaller than reported in the literature. Hammerer et al. [17] presented in a study towards the volume of the individual glandular zones a percentage of prostate tissue belonging to the transition zone of 37% in the cystoprostatectomy BPE group and even 60% in the radical prostatectomy BPE group. Bosch et al. [4] showed a percentage between 47% and 59%, while Collins et al. [3] reported a mean adenoma/prostate percentage of 45%, ranging from 36% to 60% depending on the size of the prostate. In our group, we found a mean ratio percentage of 15.7% using the ellipsoid volume as prostate volume. Also, differences were found in the growth factor of the transition zone volume: with the data on adenoma volumes as presented by Collins et al. [3], a mean growth factor of 2.9% was found, while Bosch et al. [4] presented a growth of 3.5% of central prostate volume (age range: 55–75 years). In our group (age range: 30–85 years), we found an average growth rate of 4.3% for the transition zone volume. One reason for the discrepancies can be found in the differences between the patient groups used: Hammerer’s group consisted of patients with confirmed BPE, resulting in much larger mean prostate volume in the radical prostatectomy group [17]. The prostate volume measurements in a community-based population [4] resulted in a smaller mean prostate volume in a selected range of age (55–75 years). Not only the transition zone volume was measured, but also the median lobe volume, which was not taken into account in our group. Moreover, the way of measuring was different: we used the spheroid approximation to estimate the transition zone volume while the other two used planimetric volumetry.

For determination of the growth factors, the mean prostate volume per range of age was used. When using the data of individual patients, these factors may differ because the volumes are weighted by the number of patients in that range. Also, the number of patients in each range may differ and using a small number of patients can influence the validity of the mean prostate volume. Bosch et al. [4] presented a growth rate of 2.0% for the entire prostate using the individual volumes, while we calculated a growth
TABLE IV. Anterior-Posterior (AP), Transverse (TV), and Prostatic Urethral (PU) Dimensions and Transition Zone (Tz-AP) Diameter Compared to Age*

<table>
<thead>
<tr>
<th></th>
<th>AP (mm)</th>
<th>TV (mm)</th>
<th>PU (mm)</th>
<th>Tz-AP (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>29.4</td>
<td>50.7</td>
<td>46.3</td>
<td>21.5</td>
</tr>
<tr>
<td>Range</td>
<td>16.6–49.5</td>
<td>27.6–76.0</td>
<td>14.1–72.6</td>
<td>1.4–45.4</td>
</tr>
<tr>
<td>R</td>
<td>0.464</td>
<td>0.232</td>
<td>0.433</td>
<td>0.557</td>
</tr>
<tr>
<td>Growth factor</td>
<td>0.8%</td>
<td>0.3%</td>
<td>0.6%</td>
<td>1.4%</td>
</tr>
<tr>
<td>D₀</td>
<td>18.2</td>
<td>42.9</td>
<td>30.9</td>
<td>8.8</td>
</tr>
</tbody>
</table>

*Presented are the mean and range, and the Pearson product moment correlation coefficient for logarithmically transformed volumes. Also, the average growth per year was calculated using an exponential fitting curve and presented are the growth factor and the dimension at age = 0, D₀.

TABLE V. Mean Prostate Volume (Weight in Case of Autopsy Study by Berry et al. [8]) for Different Ranges of Age as Presented in the Literature (Also, Growth Factors are Presented Together with the Intercept)

<table>
<thead>
<tr>
<th>Age</th>
<th>This study</th>
<th>Bosch et al. [4]</th>
<th>Collins et al. [3]</th>
<th>Berry et al. [8]</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>23.0</td>
<td>{26.0}</td>
<td>26.9a</td>
<td>18.1</td>
</tr>
<tr>
<td>30</td>
<td>24.0</td>
<td>{26.1}</td>
<td>25.7a</td>
<td>19.1</td>
</tr>
<tr>
<td>40</td>
<td>31.3</td>
<td>{26.2}</td>
<td>25.0</td>
<td>20.2</td>
</tr>
<tr>
<td>50</td>
<td>36.8</td>
<td>{24.3}</td>
<td>27.0</td>
<td>22.6</td>
</tr>
<tr>
<td>60</td>
<td>38.3</td>
<td>{24.7}</td>
<td>30.9</td>
<td>27.1</td>
</tr>
<tr>
<td>70</td>
<td>51.7</td>
<td>{24.9}</td>
<td>37.9</td>
<td>30.9</td>
</tr>
<tr>
<td>80</td>
<td>57.6</td>
<td>{27.1}</td>
<td>40.0</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>71.1</td>
<td>{27.2}</td>
<td></td>
<td>38.8</td>
</tr>
</tbody>
</table>

Growth     | 2.0% | 2.4%/1.6% | 1.7% | 1.3%

*Presented by Jakobsen et al. [7]

*Using the data given by Jakobsen et al. [7] as well.

rate of 2.4% from their mean data. The same was found for the data concerning our group: 1.7% growth when the individual volume results were used while 2.0% was found for the mean prostate volumes. This can be explained by the fact that weight factors are applied during fitting with the individual volumes in our group: the majority of patients are between 45 and 70 years old, with only a few patients below and above this range. Using the mean prostate volume at 5-year intervals, the mean values in all intervals have the same contribution to the fit, while different numbers of patients are used to obtain this mean volume: the few younger and older patients become more important.

When we compare the growth rate of the entire prostate obtained in a community-based population to the growth rate in a group of patients with LUTS in the same range of age, no difference is found. Be-
cause these growth rates are comparable and the rates are constant for a range between 40 and 75 years (see Fig. 9), it may be concluded that an earlier start of growing of the prostate is the determining factor in developing BPE. Care has to be taken when comparing the growth rates of the different studies: not only the patient population differed, but also the method for volume determination. Collins et al. [3] used the ellipsoid formula, which gives an underestimation of the prostate volume, while Bosch et al. [4] used planimetric volumetry.

The intercepts $V_0$ in Table V represent the expected prostate volumes at the age of 0 years. The intercepts presented are all around 12 mL, except for the population of Bosch et al. [4] without using the data of Jakobsen et al. [7]. Using the dimensions at age = 0 as presented in Table IV in the ellipsoid volume formula, a volume of 12.6 mL is obtained at age = 0, with a transition zone volume of 0.4 mL. However, this extrapolation to age = 0 does not seem to be valid, because of the strong development of the prostate during puberty, when the prostate reaches a fully functional state [8].

The correlation between age and the logarithmically transformed prostate volume and transition zone volume found in our group was rather weak. The reason for the poor correlation can be the fact that the group consists of patients with the same prostatic complaints although at different ages. On the other hand, some patients may have developed BPE causing the complaints, while other patients of the same age may have prostatitis causing the same problems. Because of this poor correlation, the average growth factors cannot be applied to individual patients. To obtain the growth rates that indicate an increased probability for developing BPE, longitudinal measurements should be performed during long-term follow-up of prostate development in young males.

**CONCLUSIONS**

Application of the automated method for prostate volume determination gives better results than the ellipsoid reference volume obtained off-line. Modest correlations were found between age and logarithmically transformed prostate volume and transition
zone volume in a group of patients with LUTS. Determination of the growth curves indicated an average growth rate of 1.7% for the prostate volume over age. The average growth rate of the transition zone volume (4.3%) was larger than for the entire prostate volume, which indicates that the growing of the transition zone is the determining factor in the development of BPE. The growth rates for normal men between 55 and 75 years as presented in the literature were comparable to the ones found for patients with LUTS in the same range of age and appear to be constant for a large range of age (40–75 years). The development of complaints caused by BPE is therefore not dependent on an increase in growth rate but on the age of onset of prostate growing.

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