

Possible Applications of Three-Dimensional Ultrasound-Volumetrics in Obstetrics and Gynaecology

PhD THESIS

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Introduction

The success of ultrasound diagnostics has reached almost all clinical medical branches over the past four decades and has significantly altered medicine in our country. Currently it is still one of the most dynamically developing methods of imaging. Besides a high number of advantages, its relatively inexpensive nature, high test speed and the possibility of assessing the anatomic relations without ionizing radiation should be emphasized. It has revolutionized obstetrics-gynaecological examinations and allows the observation of the female pelvis and the state of the fetus in the natural, „in vivo”, „in utero” environment. Information provided by ultrasound diagnostics has changed our practice of obstetric care and this technology has become an indispensable device in obstetrics.

The three-dimensional (3-D) assay has resulted in significant improvement of diagnostic accuracy and rapidity. With the help of stereoscopic pictures, anatomic relations of the embryo and fetus can be analyzed more precisely, and many developmental disorders are detected earlier. The opportunities provided by 3-D ultrasound (US) are remarkable even in the initial weeks of a pregnancy. Fetal organ-volumetrics supplemented by 3-D flow tests allow for examination of normal and abnormal organ functions. There may be a way in the second and third trimesters of pregnancy to separate a risk group section from among pregnant women.

With technological improvement 3-D digital imaging and archivation became possible, which makes further examinations possible without the patient being present. With repeated examination of the recorded imagery, previously recognized anomalies can be refined, previously unrecognized changes can be filtered, and via the so-called telemedicine professional and interdisciplinary consultation, options can be accessed on national or even international levels.

In gynaecological diagnostics, examining the normal and abnormal states of the ovaries and the uterus organ-volumetrics can be supplemented with individual three-dimensional spatial flow tests: with the help of colour histogram-analysis quantitative tissue- and organperfusion examinations can be performed. Clinical significance of volume measurements is quite high in gynaecological and gynaecological-oncological diagnosis-

making, and may significantly influence therapeutic decisions. Monitoring measurement changes can prove the growth or regression of a tumor and the success of a therapy.

Aims

3-D ultrasound examination methods fundamentally define obstetric and gynaecological diagnostics. Formerly the VOCAL (Virtual Organ Computer-aided AnaLysis) method was used for 3-D ultrasound-volumetric estimations, recently, complementing this, the XI VOCAL (eXtended Imaging Virtual Organ Computer-aided AnaLysis) method has also become accessible. In case of irregularly shaped bodies using XI VOCAL as ultrasound-volumetrics method, a more accurate volumen estimation is possible as compared with the conventional VOCAL method. According to our previous studies, the XI VOCAL method gives a more real depiction of the spatial form of the target organ, than the VOCAL method, and there is no need for rotation steps.

At the beginning of the investigations I aimed the analysis of the application of XI VOCAL method in obstetrics and gynaecology for assessing 3-D ultrasound volume determination, which I intended to present in connection with three different topics. The general purpose of the application of 3-D ultrasound-volumetrics to have a reliable, non-invasive, reproducible, rapid, inexpensive and widely available diagnostic method. The XI VOCAL 3-D ultrasound-volumetric method was analyzed according to international literature, by location at the University of Pécs (PTE), Clinical Center (KK), Department of Obstetrics and Gynaecology, Ultrasound Laboratory.

Application of XI VOCAL 3D ultrasound-volumetrics on in vitro balloon models

The aim of our examination was to analyze the accuracy, inter- and intraobserver reliability of the XI VOCAL method on an in vitro balloon model with real volume, and to investigate the test time.

Examination of the reproducibility of XI VOCAL 3D ultrasound-volumetrics

Inter- and intraobserver reliability of XI VOCAL 3-D ultrasound-volumetrics was examined, reproducibility was analyzed prospectively during examination of irregularly shaped bodies, along eliminating the moving artifacts, and the test times of estimation methods were also determined. We selected the irregular shapes of a fetal ultrasound-phantom for our experiments.

Application of XI VOCAL 3D ultrasound-volumetrics in in vivo experiments

We present the 3-D ultrasound-volumetrics in a clinical in vivo model designed to substitute the invasive examination in clinical protocol. In case of difficulty passing urine following a gynaecological operation, residual bladder volume was determined using the two types of 3-D ultrasound-volumetric techniques and catheterized volume measurement. The aim of our study was to prospectively compare the adequacy, accuracy, sensitivity and specificity of the two types of 3-D volumetric methods (VOCAL, XI VOCAL) and furthermore to compare the predictive value of the positive and negative test results during an in vivo organ volume examination, the target volume of which was the postoperative residual bladder volume.

Materials and methods

Using XI VOCAL 3D ultrasound-volumetrics on in vitro models

In the prospective study of the XI VOCAL 3-D ultrasound-volumetric method on in vitro balloon models, performed at the University of Pécs (PTE), Clinical Center (KK), Department of Obstetrics and Gynaecology, Ultrasound Laboratory, four different, irregularly shaped liquid-filled bodies were placed into a 1000 ml glass flask container, containing a liquid suitable for ultrasound examination. Liquid content of the flask was filled with a liquid mixture similar in tissue density to those described in the international literature (distillated water – glycerol blend with graphite particles). Four irregularly

shaped condoms constituted the four bodies, containing four different liquids (1st phantom: cat, 2nd phantom: candle, 3rd phantom: pine tree, 4th phantom: normal condom). The phantoms of the experiment were filled with glycerol to sink slowly into the mixture of distilled water and glycerol in the flask container. Leakproof sealing of the phantoms was ensured by thin threads, and the rest of the condoms was cut off 3-4 mms above the thread. When preparing the phantoms, we tried to fill different amounts of liquid into each. Non-standardised phantoms were used in the experiment, since we did not wish to determine the absolute accuracy of the XI VOCAL method, but compare the test times and the accuracy of results of different ultrasound examinations, during the measurement of different target volumes.

Ultrasound volume-determination of the prepared balloon phantoms was performed with an Accuvix XQ (Medison Co., Seoul, South Korea) „real-time 3D scanner”, with a 4-7 MHz convex transabdominal volume-transducer. Each stored 3-D phantom-volume was analyzed by two examiners expert in the field of ultrasound diagnostics, using the „3-D extended imaging” (3DXI) (Medison Co., Seoul, South Korea) program. In all 20 of the 3-D phantom-volumes the target volumes were estimated by an advanced (B. Sz.) and a beginner (M. G.) ultrasound clinician with the help of the XI VOCAL program. In case of the four phantom-volumes, 5000 sectional contours were drawn during 400 volume- and test time measurements per examiner. After contours were drawn in each section outline, the estimated volume of the test phantom models appeared on the screen in units per milliliter, millesimal precision. Modified Archimedes-technique was used to determine the actual volume of the four phantom-models.

Examination of the reproducibility of XI VOCAL 3D ultrasound-volumetrics

An in vitro prospective study of bodies of unknown volumes was performed with 3-D XI VOCAL ultrasound-volumetrics at the University of Pécs (PTE), Clinical Center (KK), Department of Obstetrics and Gynaecology, Ultrasound Laboratory, by analyzing five different body parts (fetal head, four limbs) – as irregular shapes – of a 21-week ultrasound-phantom fetus model. The order of the five phantom test bodies came as follows: 1. head, 2. right forearm and hand, 3. left shin and foot, 4. left forearm and hand, 5. left shin and foot. Ultrasound volume-determination of the five fetal body parts was

performed with an Accuvix XQ (Medison Co., Seoul, South Korea) „real-time 3D scanner”, with a 4-7 MHz convex transabdominal volume-transducer. The off-line volumetrics assays were analyzed by two advanced examiners (V.M. and B. Sz.) expert in the field of ultrasound-volumetrics, using the XI VOCAL program. Both with 5, 10, 15 and 20 sectional representations, volume estimation was repeated seven times, and test time was recorded in seconds. In case of the five phantom-volumes, 1750 sectional contours were drawn during 140 volume- and test time perceptions per examiner. After contours were drawn in each section outline, the estimated volume of the test phantom models appeared on the screen in units per milliliter, millesimal precision.

Application of XI VOCAL 3D ultrasound-volumetrics in in vivo experiments during assessment of urinary retention following radical hysterectomy

Residual bladder volumes were prospectively measured via transabdominal 3-D ultrasound examinations at the University of Pécs (PTE), Clinical Center (KK), Department of Obstetrics and Gynaecology between 2007. 10. 01. and 2008. 03. 31. in cases of radical hysterectomies following a malignant cervical cancer. The study group consisted of 17 patients. The extended abdominal hysterectomies were performed in all cases according to Wertheim-Meigs (Piver III). The youngest patient was 29, the eldest 79 years old, their mean age at the operation being 45,4 (SD: $\pm 13,7$). The mean body mass index of the patients was 25,2 kg/m² (SD: $\pm 5,9$). All patients received detailed information on the examination, and agreed to participate in the study.

A permanent catheter was placed during the radical abdominal hysterectomy. In all patients the permanent catheter was removed 72 hours after the surgery. According to clinical protocol, after the removal of the catheter in the postoperative period, if the residual bladder volume is ≥ 100 ml following spontaneous urination, re-catheterization is required. After the removal of the catheter and following the first spontaneous urination, on the fourth – in one of the patients, on the fifth – day of the postoperative period, ultrasound examinations were performed in the ultrasound laboratory of our clinic. The 3-D bladder-volumes obtained by 3-D ultrasound-volumetrics were archived immediately in the memory of the ultrasound machine to carry out further off-line analyses. Within 5 minutes of our 3-D ultrasound-volumetric measurements, evacuation of the residual urine

was performed by sterile catheterization of the bladder. Measurement of the catheterized urine was conducted in all cases with a professional staff who were not present during the ultrasound volume estimations. In the study period 3-D ultrasound-volumetrics, volumen estimation and catheter measurements were done in 35 cases. Examination of the urine retention of the bladder was performed with an Accuvix XQ „real-time 3D scanner”, with a 4-7 MHz convex transabdominal volume-transducer. All the stored bladder-volumes were analyzed by the VOCAL and the XI VOCAL methods as well.

Results

Examination of XI VOCAL 3D ultrasound-volumetrics on in vitro balloon models

Determining real volumes of phantoms

The order of the four phantoms used in the study came as follows: 1st phantom (cat): 19,88 ml (SD \pm 0,91; range: 18,4-21,2 ml), 2nd phantom (candle): 19,21 ml (SD: \pm 1,16; range: 17,6-21,1 ml), 3rd phantom (pine tree): 16,92 ml (SD: \pm 1,32 ml; range: 15,0-19,3 ml), 4th phantom (normal condom): 31,78 ml (SD: \pm 1,26 ml; range: 29,8-33,4 ml). The results show that the differences between the measurements (min-max values) are relatively large, the standard deviation is equal to or higher than 1,0 ml. The width of the confidence interval for the expected values is 1,5-2,0 ml, real volume values are uncertain even in rounded ml-values. Relative inaccuracy is at least around 5-10%.

Deviation from real volumes

With the XI VOCAL ultrasound-volumetric method both examiners underestimated the real volumes for each of the four phantoms. The 25 XI VOCAL volume measurements per examiner and per phantom were compared to the average result of 10 calibrating volume measurements. The average rounded value deviations in case of the first examiner in the 5, 10, 15 and 20 slice volume estimations were -20%, -10%, -10%, -10%, respectively, while in case of the second examiner: -20%, -20%, -20%, -20%, respectively.

The smallest and largest deviation of individual measurement data from the average results of the calibration outcomes for the real volume of the phantoms in case of the first examiner in the 5, 10, 15 and 20 slice volume estimations were -41% - +2%, -39% - +10%, -31% - +8%, és -28% - +4%, respectively, while with the second examiner's data were as follows: -53% - +20%, -55% - +2%, -55% - +12%, és -60% - +11%, respectively.

Measured data analysis

Based on the results of XI VOCAL ultrasound-volumetrics we wanted to determine the factors influencing volume estimations with the help of ANOVA. According to the statistical processing, volume determination depends on the examiner ($p < 0,001$), the shape of the body ($p < 0,001$), the number of layers ($p < 0,001$), and the imaging of the phantom-volume ($p < 0,05$). During volume estimations we have found interaction between the examiner and the number of layers ($p < 0,001$), the examiner and the shape of the body ($p < 0,01$), the 3-D US imaging and the shape of the body ($p < 0,01$), and in context of three factors between the examiner, the 3-D US imaging and the shape of the body ($p < 0,05$).

Inter- and intraobserver reliability

Intraobserver reliability was expressed with volume results measured by the second examiner, presented depending on the data of the first examiner (r^2 : 0,485). According to the Bland-Altman plot used to characterize intraobserver reliability, increasing the number of layers in the experiment does not improve the accuracy of the method, and preciseness of the second observer stays below the results of the first. For additional investigation of intraobserver reliability, intraclass correlation coefficient (ICC) index was determined. The statistical analysis showed high failure rate and that the volume range of the four phantoms used was narrow, thereby the ICC values were further away than usual from 1. In case of individual measurements ICC values were in the range of 0,66-0,78 (depending on the number of layers) - the 95% CI was approximately $\pm 0,1$. For the averages, the ICC was broadly in the range of 0,8-0,88 (depending on the number of layers) - the 95% CI was approximately $\pm 0,05$ -0,08. From these results it can be concluded again, that increasing the number of layers does not ameliorate the values.

Analysis of measurement times

Based on the analysis of the test time, it can be assessed, that test time almost linearly increases with the number of layers. There was a definite difference between the two observers, which however did not occur in case of the 5-layer volume estimation with XI VOCAL.

Reproducibility of XI VOCAL 3D ultrasound- volumetrics

During the examination of the 21-week fetal ultrasound-phantom, estimated volume data analysis of the five target objects was done with ANOVA, from which the difference between the observers could be concluded ($p < 0,001$): the first examiner estimated smaller volumes than the second. A significant difference came up between volumes of the irregularly shaped bodies ($p < 0,001$). There was a significant difference between volume estimation data of XI VOCAL with different number of layers ($p < 0,001$), for instance the 20-layer measurement showed typically less volume. When two variables were compared, a significant difference showed in relation of body \times observer ($p < 0,001$), which was measured differently by the examiners in cases of the first and second bodies, however was practically the same for the fourth and fifth bodies. There was a significant difference in relation of body \times layer ($p < 0,001$), where the dependence on the number of layers is probably dependent on the shape as well. The significant difference in relation of layer \times observer ($p < 0,001$) means that beyond the difference between layers, there is a dependence on the observer. XI VOCAL volumetrics was dependent on the overall effect of the three variables as well, and there was a significant difference in relation of body \times layer \times observer in the course of examinations ($p < 0,001$).

Inter- and intraobserver reliability

The average of the variation coefficient (CV) was used to measure intraobserver reliability in case of the volume-determination results of the five standardized target-organs. Variation coefficient is the standard deviation expressed in the percentage of the mean (CV%). CV was consistently higher with the first examiner than the second. This difference between the observers was relevant in the CV values of the first, second and third bodies (1st body: 5,20 – 1,17, 2nd body: 8,50 – 4,64, 3rd body: 6,23 –

3,39). The discrepancy occurs with the 4th and 5th bodies as well, but to a lesser degree (4th body: 3,72 – 2,86, 5th body: 4,84 – 4,07). The CV-result of the first observer was 5,7%, while that of the second was 3,9%.

For additional measurement of the intraobserver reliability, the interclass correlation coefficient (ICC) was used, calculating with the 28 volume data of the 5 target organs, which meant a total of 140 single data, paired according to those of the first and second examiners. The ICC value for the individual measurement points was 0,984 (95% CI: 0,978-0,989). ICC values for the 5 examined bodies analysed according to the different number of layers (with 35 measurement pairs per layer) were as follows: 5 layers: 0,997 (95% CI: 0,995-0,999), 10 layers: 0,984 (95% CI: 0,968-0,992), 15 layers: 0,967 (95% CI: 0,936-0,983) and 20 layers: 0,988 (95% CI: 0,977-0,994). Using the correlation coefficient calculations for determining intraobserver reliability, and based on the data of the 4 small volume bodies we can proclaim the accuracy of the method to be 87,7%. Considering the volume data of all five bodies, the accuracy of the XI VOCAL method is 98,9%.

Examination of reproducibility

Bland-Altman plot statistical analysis was performed to express the reproducibility of XI VOCAL 3-D volumetrics. In case of the first and fifth bodies no improvement could be seen with the increase of the number of layers. With the second, third and fourth bodies however, if the accuracy from the 5-layer samples (error range) is considered 100%, there was an approximate 60-70% improvement in the results (accuracy improvement) with both the 10- and 15-layer samples, and a 30-40% improvement in results (accuracy improvement) with the 20-layer sample (accuracy further improves). In case of the second and third bodies, the increase in the number of layers decreased the percent of volume estimation mistakes from 20% to 10%, and with the fourth body it decreased from under 10% to below 5%. However, the results should be assessed taking into account that the actual margin of error decreases from 2 ml to 0,5 or even lower. This error-limit is the threshold under which the expected number of effectively realized measurements is 1 out of 20, so the difference from the real volume is less than this threshold in case of 19 measurements out of 20.

In possession of these results, it can be stated, that with the first and fifth bodies, even though the increase on the number of layers did not bring forth an improvement in determining volumes, though possibly a rise in the number of layers in case of irregularly shaped test objects might give a more accurate result, this improvement may not prove to be relevant from a clinical point of view.

Analysis of measurement times

On examining the test time with ANOVA, significant differences were found between observers ($p < 0,001$), between bodies ($p < 0,001$), between layers ($p < 0,001$), in the relation of body \times observer ($p < 0,001$), and in the relation of body \times layer ($p < 0,001$). We found a difference close to significant in the relation of layer \times observer ($p = 0,058$), and a significant difference value in the interactions of body \times layer \times observer ($p < 0,001$).

Application of XI VOCAL 3-D ultrasound-volumetrics in in vivo experiments, during assessment of urinary retention following radical hysterectomy

Both volumetric systems slightly underestimated the actual volume of the bladder during determination of the postoperative urinary retention, the mean deviation being -7,7 and -12,3 ml with the VOCAL and XI VOCAL methods respectively. The differences between the standard deviations were not statistically significant. Estimated volume results of the 3-D volumetric methods, and catheter volume measurement results did not differ significantly. The two volumetric methods relative to one another did not differ significantly either. Both volumetric methods showed a high correlation value as compared with the amount of catheterized urine. On a linear regression graph the correlation coefficient with the VOCAL method was 0,985 ($p < 0,001$), in case of the XI VOCAL method, 0,990 ($p < 0,001$). The accuracy of the two systems were 97% versus 98% ($r^2 = 0,970$ vs. 0,980). Correlation progresses by further analysis of catheter volumes less than 300 ml ($n = 29$), the mean deviations with the VOCAL method being closer to the average of the actual mean of data. The average of these deviations was 0,03 ml with the VOCAL method ($p = 0,987$), in contrast to the result of the XI VOCAL method, which was -3,34 ml ($p = 0,030$). In case of catheter volumes higher than 300 ml ($n = 6$), average

deviation from the actual volume results was -45,0 (p=0,189) and -55,5 ml (p=0,081) for VOCAL and XI VOCAL methods respectively. Below 300 ml actual urine content, correlation coefficient with the VOCAL method was 0,985 (p<0,001), with the XI VOCAL: 0,993 (p<0,001). In cases of lesser volumes, accuracy of the two systems was 97% versus 98% ($r^2=0,970$ vs. 0,986). The differences between the two volumetric methods and the results of the catheter measurements were not significant.

Bland-Altman plot bandwidth for catheter volumes under 300 ml was higher with the VOCAL method (-22,06 and +22,06 ml), in contrast, with the XI VOCAL method these were lower (-19,05 and +12,45 ml), under which the result is more accurate. For catheter volumes above 300 ml, Band-Altman plot bandwidth was likewise higher with the VOCAL method as compared with the XI VOCAL method (-190,0 and +100,0 ml vs. -180,14 and +69,14 ml).

So far as the amount of catheter urine is high (≥ 300 ml), inaccuracies of both 3-D ultrasound-volumetric methods increase. Furthermore the XI VOCAL method is far more precise than the VOCAL both below and above 300 ml catheter urine amounts. Paired t-tests were used to express deviations of the VOCAL and XI VOCAL systems compared to one another. Comparison data showed that below the 300 ml threshold, the discrepancy is barely not significant (p=0,057), above that, not significant (p=0,454). If catheterization of the bladder is considered necessary above an estimated residual urine-extent of 100 ml, then sensitivity and specificity of the VOCAL and XI VOCAL methods is equally 100% high, the positive and negative predilection values being 100% as well.

Discussion

Application of XI VOCAL 3-D ultrasound-volumetrics on in vitro balloon models

To determine the actual volumes of the four pre-shaped balloon-phantoms, we used a method based on the Law of Archimedes in our study. When putting the phantoms into flasks filled to the brim with distilled water, the amount of displaced water may have differed, and during refillment the extent of load may have varied, leading to repeated errors. Due to the surface wetting abilities of the liquid, water displaced by the phantoms

and its measurement by automatic pipettes offered chances for additional mistakes. Standard deviation of volume values for each phantom measured 10 times each, reached and even exceeded 1 ml. Relative error was at least 5-10%. During the actual volume measurements, both those performed before and after ultrasound-volumetrics resulted in smaller values in case of all four bodies, hence it can be assumed that sealing of the balloon phantoms was inadequate – leakage occurred during the ultrasound examination due to internal pressure, this again might have led to false results.

Volume decrease was significant for the fourth body, was close to significant for the third, and was not significant for the second body.

Results of the ultrasound volume estimations were smaller than the actual phantom volumes: real volumes were underestimated. These deviations were on the average of -10 - -20% with both observers, for all of the four bodies, 29 out of 32 of these discrepancies were significant. Increasing the number of layers did not substantially improve accuracy.

Results of XI VOCAL volumetrics and ANOVA showed a significant dependence of the estimated volume of the phantoms on the number of layers, the volume of the examined object, shape irregularity, and practice of the observer.

Similarly to the previous examinations it should be noted that theoretically only the properties of the body and perhaps the number of layers can affect the results in a precise measurement process. The fact that the observer itself is not of such relevant importance is a warning sign, however not that surprising considering the antecedents. Influence of the observer cannot be predicted since it depends on other factors and interactions as well.

Test time almost linearly increases with the rise of the number of layers, but there is a definite difference between the two observers, that did not appear with the 5-layer examination. Beside the linear increase of test time, volume estimation data of the beginner (second) observer – having less experience – were the same on the average, likewise those of the advanced (first) observer in cases of 10-15-20 slices, though a trifle better as compared with the 5-slice. In possession of these combined volume results, using more than 10 slices does not seem valid. A linear regression graph was made to justify intraobserver reliability, on which standard deviation of volume results were notable.

The following points could be assumed in the background of the measurement inaccuracies during the in vitro examination:

- Volumes of the four prepared phantoms stood within a close volume range (15-31 ml), and two of these had an almost equal volume, thus their statistical distinction could not be done. Based on these only an examination of ultrasound-volumetrics within a small volume range could be attained.
- During the construction of phantoms, when sealing the condoms, the endpoint did not become point-like, thus defining the „start-plane” depended on the judgement of the observer, which might have resulted in a notable standard deviation of volumes in case of small-volume phantoms.
- The distilled water – glycerol mixture used for the ultrasound examinations and construction of phantoms could not be applied during filling of the phantoms, because tiny air bubbles trapped in the liquid disturbed the image quality of the ultrasound. Hence, phantom floating in the medium could not be achieved. In possession of these information, we filled the phantoms with glycerol, which resulted in a sinking of the bodies in the medium, and faults could have occurred on the area of points of the lower wall of the objects touching the wall of the flask

To confirm intraobserver reliability we used the results of the Bland-Altman plot, according to which a definite improvement could be seen with the advanced (first) observer in case of 10-15-20 layer measurements, while the beginner (second) observer's results rather declined with the increase of the number of layers. It seems to be clear, that the increase of the number of layers does not improve accuracy.

Due to the grand errors and narrow volume interval, value of ICC is further away from 1 than usual. Depending on the number of layers, ICC for the averages is in the range of 0,8-0,88. It can be stated unequivocally, that the increase in the number of layers does not improve the values.

Reproducibility of XI VOCAL 3-D ultrasound-volumetrics

The five allotted irregularly shaped target volumes of the fetal phantom in the present study were the fetal head and the four fetal limbs. The volume of the bodies was estimated with the help of XI VOCAL volumetrics, and we have also defined the applicability of the method.

After processing the results of XI VOCAL volumetrics we concluded that based on the ANOVA, the estimated volume of the target organ significantly depends on the number of layers, the volume of the examined body, shape irregularities and experience of the observer ($p < 0,001$).

Variation coefficient was used to measure intraobserver reliability. By expressing the mean volume values in percentages, comparison of standard deviations of the two observer's volume estimation results is possible. Based on this, it can be concluded, that the mean CV-result of the first examiner was 5,7%, that of the second: 3,9%. Discrepancies between the results of the two examiners were notable in case of the first, second and third bodies, however the difference lessened for the fourth and fifth bodies. It is apparent from the result that during the use of XI VOCAL volumetrics a sort of learning or practicing effect prevails.

To further analyse intraobserver reliability, the intraclass coefficient (ICC) was used. Taking into account 28 volume data of the 5 target organs, ICC values for the 5-, 10-, 15- and 20-layer volume estimations were 0,997; 0,984; 0,967; and 0,988 respectively, which corresponds with international literature.

In the course of result processing it was found that the smallest volume values originated from the 20-slice measurements in almost all examined bodies. Following a logical interpretation of XI VOCAL volumetrics, in case of irregular target organs multislice volumetrics would give the more precise results, while with lesser slices, detailed imaging of the surface irregularities of the bodies is not possible. In the study actual volumes of target organs of the ultrasound test-phantom were unknown.

Correlation coefficient was used to express intraobserver reliability of the method, based on which intraobserver reliability proved to be excellent ($y = 1,15x - 0,845$; $r = 0,994$;

$r^2=0,989$; $p<0.001$). For the four volumes close to each other $r=0,937$, for all bodies it was 0,994, which means 94 and 99% accuracy respectively.

According to the outcomes of ANOVA test time is significantly dependent on the number of layers, volume of the examined object and its irregularities in shape, and practice of the observer ($p<0,001$). When comparing the 5-slice use to the 20-slice, test time almost linearly tripled in cases of the 5-, 10-, 15- and 20-slice examinations.

At the same time, we found no evidence that multislice experiments give significantly more accurate results. Therefore we recommend 5-slice measurements (10 at most), which are quick, but give a result of adequate accuracy all the same.

Based on the results of the Bland-Altman plot we can state that a slight improvement of reproducibility (concord) of volume measurement results can be achieved by increasing the number of layers. Advantages of precise layer-dependent volume estimation are relatively small-scale, in contrast to the considerably increasing test time, based on which at best only the switch from 5 to 10 layers seems reasonable, 15-20 layer volumetrics is only recommended for crucial measurement tasks.

Application of XI VOCAL 3-D ultrasound-volumetrics in in vivo experiments during assessment of urinary retention following radical hysterectomy

In our present clinical study we chose two well-known 3-D ultrasound-volumetric methods, the VOCAL and the XI VOCAL to determine postoperative urine content of the urinary bladder. Visualization of the bladder by two-dimensional transabdominal ultrasound is simple, clear to outline and can be performed without considerable practice in ultrasound diagnostics. On the other hand 3-D ultrasound technique is a reliable, accurate, reproducible, non-invasive measurement method, though it requires special training and practical skills. Based on our results we can conclude that postoperative urine content determined by the XI VOCAL method showed a more precise correlation with the actual catheterized residual urine volume than the VOCAL method ($r = 0,990$ vs. $r = 0,985$).

In case of higher residual bladder volume both volumetric systems underestimate to a great extent. In such cases mobile ROI-window of the 3-D transducer and the volume sector angle can be maximalised. Joint raise of the ROI-window and volume sector angle is not sufficient to cover the whole target organ in some cases of 300 ml plus bladder volumes. Therefore expected inaccuracy of volume estimation results increases compared to the catheterized urine amount.

Those cases when defining the outline of the bladder is obstructed because of intestine shadows or a really small volume, application of the method is detained.

The results showed that if the amount of catheterized urine is ≥ 300 ml, standard deviation of the postoperative residual bladder volume estimated by ultrasound-volumetrics increases. Diagnostic notability of these discrepancies is however small, since indication for re-catheterization of patients is a residual bladder volume of 100 ml or more. If, by introducing a 100 ml threshold 3-D ultrasound-volumetrics possesses high sensitivity, specificity and predilection values, from a clinical point of view the increase in diagnostic errors of ultrasound-volumetrics in case of a target volume above 300 ml does not affect necessity of catheterization. Sensitivity, specificity, and predilection values of 3-D ultrasound-volumetrics with the 100 ml threshold used in our clinic are excellent. Both below and above a 300 ml residual catheterized urine threshold, XI VOCAL ultrasound-volumetrics provided more precise results than the VOCAL method. In case of higher residual catheterized volume values inaccuracy of both 3-D volumetric methods increases. Nevertheless, results of the XI VOCAL volumetric method on the whole did not differ significantly from those of the conventional VOCAL method. Since in vitro and in vivo validation of the VOCAL method took place in the international literature previously, we can state that in our present study we have now proved in vivo clinical applicability of the new volumetric method, XI VOCAL.

Conclusions

The in vitro balloon model analysis proved to be inaccurate in determining the real volumes of the phantoms used. Standard deviation of the volume data estimated by XI VOCAL volumetrics is significant, which originates from errors not calculated during the planning phase of the model. From the estimated volume data it can be deduced, that in case

of irregular bodies XI VOCAL volumetrics verified a nexus amid irregularity, number of layers, test time, and practice of the observer. Accuracy of the method depends on the take of the examiner: which parts of the body are considered the front and the endpoint that mark the boundaries of the target volume. Interpretation by the observer might be the most difficult point of the XI VOCAL volume estimation technique, and this can be made responsible for its significant discrepancies. Readings in case of irregular test bodies proved irregularity-, number of layers-, test time- and observer's learning curve – dependent reproducibility. Based on our results we can conclude that – considering the ICC values – intraobserver reliability of the method is good, and is not dependent on the chosen number of layers, and the shape and size of the examined irregular body.

Based on both observer's readings, a practicing, learning process can be presumed. Intraobserver reliability of the method is excellent. Reproducibility of XI VOCAL volumetrics scarcely improves with the increase of the number of layers, however, the necessary test time rises. Volume estimation with the so-called „multi-slice” XI VOCAL technique (more than 10 layers/volume) is recommended only in need of an extremely precise volume estimation.

In our in vitro experiment we have pointed out one of the crucial, previously mentioned points of volume measurement difficulties. Marking off the initial and end-points („start- and end-plane”) is done individually by the observer, therefore inter- and intraobserver reliability may decrease, which can cause discrepancies between measured and real volumes. This difficulty can be lessened with the practice of the ultrasound examiner.

Bladder catheterization is an accepted method to determine residual urine content in everyday clinical use, although it increases the risk of infection. In those patients, where autonomic neural pathways of the bladder are damaged during radical pelvic surgery, the anatomic structures are altered, or there is an increased risk for urinary infections, the risk multiplies.

Urinary tract infections lengthen hospital inpatient care and increase costs. In order to avoid catheterization precise 3-D ultrasound measurement of the bladder content may be used to prevent a number of iatrogenic urinary infections, and may decrease the costs of care as well. The amount of urine retention determined in a non-invasive way by either the VOCAL

or the XI VOCAL system from the 3-D volumetric techniques, showed significant correlation with the amount of urine disposed via catheterization of the bladder.

Precise determination of the amount of postoperative residual bladder volume by 3-D ultrasound technique, VOCAL and XI VOCAL methods, may help to avoid unnecessary catheterizations which consequently may lead to a decrease in iatrogenic lower urinary tract infections, and thereby moderation of hospital care costs. In those obstetric-gynaecological patients where partial or total micturition disturbances occurred, an obstetric-gynaecologist with experience and practice can securely estimate the residual bladder volume. Examination is quick, non-invasive, painless, reliable, cost effective and can be repeated indefinitely.

Since the evaluation of our results in the clinic, we have started to use 3-D ultrasound-volumetrics primarily for postoperative bladder content determination, replacing the previous invasive catheter examinations

XI VOCAL 3-D ultrasound-volumetrics is a new, useful, easily reproducible volume estimation method for the examination of irregularly shaped objects, that is greatly suitable and reproducible for clinical uses. Intrauterin retardation, placenta volumetrics and histogram-analysis, preterm gastric emptying, severe pelvic inflammatory diseases and tumor volumetrics present further opportunities for research.

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