Morphometrics

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Ultrasound Based Measurements

Comparison of 2DUS and 3DUS volume measurement methods

• 2DUS measurements
  - assume a geometric model
  - uncertainty in key measurements may lead to inaccuracies and variabilities
  - difficult to ensure reproducibility of region being measured for serial studies

• 3DUS measurements
  - measure the geometry of the organ
  - utilize complete organ structure
  - accommodate irregularity in the structure
  - structure can be viewed in optimum orientation.

• 3DUS quantitative measurements can be both accurate and reproducible:
  - Distance optimum plane can be selected for measurement
  - Area optimum cross-section can be selected for area measurement
  - Volume structure volume can be measured accurately using: manual planimetry and automated algorithm
**Measurement of Cardiac Volume**

- **Treece et al.,** 3D ultrasound measurement of large organ volume, *Medical Image Analysis* 5 (2001) 41–54

- **Krenning et al.,** Assessment of left ventricular function by three-dimensional echocardiography, *J Cardio US*, 2003

**FIGURE 1.** Acquisition of full-volume volumetric datasets by RT3DE.

A. After visualizing an apical 4-chamber view as the reference image by 2-dimensional echocardiography, 4 sectors of short-axis slices were scanned during 4 consecutive heart beats without moving the transducer.

B. The 4 subvolumes were automatically integrated, and the entire pyramidal dataset was obtained.

**FIGURE 2.** LV volume measurement by RT3DE with the average rotation method. The endocardial border of the left ventricle was traced in each cross-sectional image (0°, 45°, 90°, and 135°) at end-diastole and end-systole.

**FIGURE 3.** Reconstructed LV cavity in patients with wall motion abnormality (arrows) in the (A) inferior wall and (B) apical wall (end-diastole at left, end-systole at right). "inf" = inferior, "sep" = septum.

**FIGURE 4.** LV volume measurement by RT3DE with the average rotation method. The endocardial border of the left ventricle was traced in each cross-sectional image (0°, 45°, 90°, and 135°) at end-diastole and end-systole.

Measurement of Ovarian Cyst Volume

(A) Photograph of an anesthetized mouse positioned on the heating pad with an ECG monitor, and the Scanhead 704 placed above the knee to image the PLN with the US machine.

(B) 2D image of the PLN (red arrow) obtained under B-mode scan. Note the dark PLN surrounded by the triangle fat pad (bright white).

(C) Reconstructed 3D image of the PLN generated with US 3D-mode scan and Amira analysis software. The PLN (green) is placed above the knee to image the PLN with the US machine.

(D) A linear regression analysis was performed by plotting the PLN volume (mm³) measured by MRI (Y-axis) versus US (X-axis). The slope and highly significant R² value are also presented. The volumes of 16 PLNs were determined by MRI, and are embedded in surrounding soft tissue (yellow).

Measurement of Thyroid Nodule Volume

(Fetal Volumetry)

The 3D volume datasets from 3D fetuses at 11-14 weeks of gestation using a commercially available ultrasound system showed that XI VOCAL (with 10, 15 and 20 slices) can be used interchangeably with the multiplanar techniques (1-mm interval) for the measurement of fetal volume. XI VOCAL (10 slices) and VOCAL (12 slices) can be used interchangeably, as can XI VOCAL (15 slices) and VOCAL (12 slices), for the measurement of fetal volume.

Cheong et al., Comparison of inter- and intra-observer agreement between three types of fetal volume measurement technique (XI VOCAL, VOCAL and multiplanar), Ultrasound Obstet Gynecol 2009; 33: 287-294
Excellent intra- and inter-observer reliability for fetal cardiac volumes assessed by XI VOCAL demonstrating highly reproducible performance for 19-34 weeks. Barreto et al. Reproducibility of fetal heart volume by 3D-sonography using the XI VOCAL method, Cardiovascular Ultrasound 2010, 8:17

Factors may impair the quality of the three-dimensional data acquired. A recent report validated this technique in vitro with high reliability and reproducibility and demonstrated accuracy slightly higher than the rotational technique (VOCAL method) [10].

In our study ICC and the mean of differences were 0.998 and 0.12 cm$^3$ for intraobserver, and 0.899 and 0.05 cm$^3$ for interobserver reproducibility. In a previous study Chang et al [5] assessed fetal cardiac volume of 50 fetuses between 20 to 30 weeks of pregnancy using multiplanar method with 1.0 mm space between sections and found a mean of differences for interobserver reproducibility of -0.03 cm$^3$, very similar to our findings. Another study by Peralta et al [6] assessed cardiac volume of 650 fetuses

The mean percentage difference between measurements performed using the VOCAL technique and the multiplanar technique was +/-0.04 and the 95% limits of agreement were +/-8.17 and 8.09. There is good agreement between the VOCAL and multiplanar techniques for assessment of total fetal thigh volume. Measurements performed using both methods are repeatable and reproducible. For prediction of birth weight, the formulas generated in this study can be used interchangeably.

Beninni et al., Fetal thigh volumetry by three-dimensional ultrasound: comparison between multiplanar and VOCAL techniques, Ultrasound Obstet Gynecol 2010; 35: 417-425

<table>
<thead>
<tr>
<th>Author et al.</th>
<th>Object</th>
<th>N</th>
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Krenning et al., Assessment of left ventricular function by three-dimensional echocardiography, J Cardiovasc 2003

Measurement of Fetal Stomach Volume

Ultrasound images of the fetal stomach at 20 weeks' gestation showing volume measurement by Virtual Organ Computer-aided Analysis (VOCAL). A 30° rotational angle was used and the organ contours were manually traced (Panel A). Panels B and C show the trace in the transverse and coronal sections. Panel D displays a three-dimensional image of the fetal stomach. The volume is expressed in cubic centimeters. Ultrasound Obstet Gynecol. 2008 February; 31(2): 177-186.
Reproducibility

• Schematic diagram showing: an idealized image of a high contrast edge; the image of the idealized edge obtained with a high resolution imaging system; and the image of the idealized edge obtained with a low resolution imaging system. The gray scale profiles are shown below with the location of the edge as well as the region over which the measurement location often is.

Duin et al., Reproducibility of fetal renal pelvis volume measurement using three-dimensional ultrasound, Ultrasound Obstet Gynecol 2008; 31: 657-661
Ultrasound Image Artifacts Affecting Boundary Contour Detection

- Shadowing, e.g. by calcifications in organs, arterial plaques, bony structures or gas which cause distal structures to be obscured;
- Speckle, which causes the boundary or surface of an object to be discontinuous and not smooth;
- Attenuation of the sound that causes signal drop-off in deep structures, which causes distal boundaries to become less distinct, or invisible at times.

Deficiencies of Organ Volume Measurement Strategies

- Some normal geometric model of the organ that only approximates the organ shape, must be assumed, so that an estimate of the organ volume may be calculated from its "key dimensions in a few 2D cross-sections"
- The measured estimate of a key dimension may be inaccurate because of the difficulty in orienting the ultrasound probe so that the 2D image plane is correctly located within the organ
- The optimal location of the 2D image plane is sometimes inaccessible, due to the restrictions imposed on the orientation of the ultrasound probe by the patient's anatomy
- It is difficult to orient the ultrasound probe so that the 2D image plane is placed at exactly the same location as in an earlier exam, in serial monitoring of organ volume, resulting in the inability to follow small changes

Deficiencies in Geometric Methods for Estimating Volume

- Many organs (e.g. prostate) are generally non-ellipsoidal, so that the choice of which three chords in the 2D images are to be selected to measure H, W, and L is not obvious, and subject to observer preference, resulting in high inter-observer variability.
- Even for a single observer, the choice of chords is still arbitrary, leading to high intra-observer variability.
- The placement of the thin 2D image planes within the organ is variable and arbitrary, increasing further the variability of the selected chord locations, and hence the intra- and inter-observer variabilities.

Sources of Error in Geometric Methods for Estimating Volume
Sources of Error in Geometric Methods for Estimating Volume

Recommendations for Implementation

- Make sure that the 3DUS system is properly calibrated
- Make sure that there are no motion artifacts
- Make sure that the resolution is optimized in all 3DUS data directions
- DISTANCE: Place measurement cursor at the midpoint of contrast transition (not the bottom or top).
- AREA: For planimetric tracing of the boundary, make sure that the steps along the boundary are sufficiently small to follow the contour accurately.
- AREA: For automated techniques, make sure to verify and edit the contour if it is not correct to accommodate shadowing artifacts.
- VOLUME: For measurements using areas from multiple parallel slices, make sure that the interslice distance is sufficiently small.
- AREA & VOLUME: In manual planimetry, verify that the edge has been outlined by viewing it also from orthogonal planes.

3D ultrasound measures - detection, classification, or monitoring over time.
- Absolutely quantitative or relative - quantitative
- accuracy should be achieved when the profile is followed - better than 5%
- Techniques and potential biomarkers measured - length, area and volume
  - manual, semi-automated, automated
  - further algorithm improvements needed
- Degree of fit with QIBA biomarker selection criteria:
  - Transformative - not so much
  - Translational - perhaps
  - Feasible - in clinical use today
  - Practical (basic techniques already in clinical use) - yes
  - Collaborative - ??
- Numbers of exams that might be involved in the US and worldwide by use of the biomarker:
  - routine 2DUS and 3DUS in Ob/Gyn, Pediatrics, Adult imaging
- Implementations by the various manufacturers - most have some capability
- QUALY’s saved, or most important impact estimates that can be made