THREE AND FOUR DIMENSIONAL ULTRASOUND IN OBSTETRICS

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BASIC PRINCIPLES

3-D ULTRASOUND
Basic principles

• Consecutive tomographic 2-D images are acquired
  – approx 1 mm apart
  – arc of 60-90 degrees
• 3-D data set composed of voxels (volume elements) is constructed
• Data set is processed for display on a 2-D screen (volume visualization)

4-D ULTRASOUND
Basic principles

• Also called “real-time 3-D”, “live 3-D”
• Displays “moving” 3-D image by continuous 3-D scanning
  – multiple 3-D volumes per second
• Speed is limited by speed of ultrasound in soft tissue
3-D ULTRASOUND
Basic principles

2D images
3D data set Voxel

Gynecology and Obstetrics
Kurjak & Jackson, Atlas of 3- & 4-D Sono in OB-GYN 2004

ACQUISITION AND VISUALIZATION OF VOLUMES

3-D ULTRASOUND
Acquisition of volumes

- Large number of consecutive 2-D images are acquired with positional information
- Two primary methods
  - manual – sonographer physically moves transducer across field
  - automatic – 3-D transducer containing elements which move

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3-D ULTRASOUND
Manual acquisition

- More accurate and reproducible
- Larger transducer
- Three mechanisms – linear, tilt, rotational
  - tilt – most commonly used in OB
    - images arranged in fan shape
    - loss of resolution with depth
    - best resolution in focal zone

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Kurjak & Jackson, Atlas of 3- & 4-D Sono in OB-GYN 2004
3-D ULTRASOUND
Automatic acquisition

3-D ULTRASOUND
Volume visualization

• Section reconstruction – 3-D data set is “cut” and arbitrary sections are displayed on a 2-D screen
• Display modalities
  – multiplanar (orthogonal)
  – 3-D rendering
    • volume rendering
    • surface rendering

3-D ULTRASOUND
Multiplanar display

• 3 planes perpendicular to each other are displayed (longitudinal, transverse & coronal)
  – planes are labeled A, B and C
  – plane A represents the 2-D image from which volume acquisition began

3-D ULTRASOUND
Section reconstruction

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3-D ULTRASOUND
Multiplanar display

Reference point ("marker dot")
- displayed in all planes
- location selected by user
- represents point at which planes intersect – “marks” the same point or structure in each plane
- also identifies point of rotation

3-D ULTRASOUND
Multiplanar navigation

Translation (parallel shift) – displacement of the center of rotation, like shuffling cards
Rotation – about the x-, y-, and z-axes
- planes can be rotated simultaneously
- X-rotation – up and down, like nodding head ("yes")
- Y-rotation – side to side, like shaking head ("no")
- Z-rotation – turning around like a turntable

3-D ULTRASOUND
Rendering (3-D image generation)

Smaller 3-D data set is extracted from original data set (region of interest) and projected onto a 2-D plane
- Two methods
  - volume rendering
  - surface rendering
3-D ULTRASOUND
Rendering – region of interest

• Volume rendering
  – data set is projected directly onto a 2-D plane
  – good for observation but not volume measurement

3-D ULTRASOUND
Volume rendering

• Surface rendering
  – technical computer graphics term, not the same as surface image or display
  – data set transformed into intermediate geometrical data before projection
  – accurate volume of the object can be calculated

3-D ULTRASOUND
Surface rendering

3-D ULTRASOUND
Volume measurement
**3-D ULTRASOUND**

**Rendering display options**

- Rendered image can be rotated in the 3 cardinal directions (X, Y and Z axes)
- Light mode and filtering levels change the image to emphasize different structures
  - maximum intensity – displays brightest intensity echoes (e.g. skeleton)
  - minimum intensity – displays lowest intensity echoes (e.g. fluid filled structure)

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**3-D/4-D ULTRASOUND**

**Threshold**

- Maximum intensity projection
- Mean intensity projection

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**3-D ULTRASOUND**

**Rendering display options**

- Inversion mode – inverts gray scale of voxels
  - anechoic structures become echogenic
  - echogenic structures become anechoic
- Tomographic imaging – multislice display of volume at fixed intervals (similar to CT, MR)
- “Electronic scalpel” (3-D cutting) – “cuts” or crops unnecessary part of rendered image
3-D ULTRASOUND
Rendering display options

- Ultrasound vendors use different terms for display options
- Controls and their operation differ between equipment

3-D ULTRASOUND
Spatiotemporal image correlation (STIC)

- Cardiac gating technique
- Images acquired by automatic volume sweep are analyzed according to their spatial and temporal domain
- Display options
  - multiplanar
  - rendered

3-D ULTRASOUND
Scanning method

- Image parameters similar to 2-D, ↑ contrast
- Scan region of interest (ROI)
  - use most anatomically important plane for acquisition – best resolution in volume
  - set box size and angle of acquisition – affect acquisition speed
- Position transducer over center of ROI

Size of the box

Angle of acquisition

Courtesy Alfred Abuhamad, M.D.
3-D ULTRASOUND
Scanning method

- Wait until fetus is inactive
- Ask patient to hold breath
- Hold transducer steady, acquire volume
- Review volume – scroll through a plane to confirm ROI is imaged and movement is minimal

4-D ULTRASOUND
Scanning method

- Image parameters similar to 3-D
- Set up with 2-D localizing image
  - identify region of interest
  - fluid adjacent to fetus
- Activate 4-D, place rendering line in fluid adjacent to region of interest
- Hold transducer still, allow fetus to move
- Displayed image is 90° to scanning plane
- Volume can be rotated while scanning

ARCHIVING AND CODING

3-D/4-D ULTRASOUND
Data archiving options

- What:
  - entire 3-D volume
  - single image of multiplanar display and/or 3-D rendered volume
  - cine or video clip of 3-D or 4-D volume
  - single or multiple volumes from 4-D acquisition
3-D/4-D ULTRASOUND

Data archiving options

- Where:
  - on hard disc in ultrasound machine
  - CD ROM or other storage device
- Saved volumes can be reviewed on ultrasound machine or workstation

3-D ULTRASOUND

Coding

- 76376 – 3-D rendering… not requiring image post processing on an independent workstation
- 76377 – 3-D rendering… requiring image post processing on an independent workstation
- Both are add on codes

CLINICAL APPLICATIONS

3-D/4-D ULTRASOUND

Clinical applications - OB

- Adjunct to 2-D – improved visualization of normal and abnormal anatomy
  - face, ear, brain, skull, heart, spine, genitourinary tract, extremities
- Realistic presentation of fetal anatomy to family (normal and abnormal)
- Volume measurements (gestational sac, fetal bladder, fetal lungs)
- Fetal behavior (4-D)

Merz et al, J Perinat Med 1995
- 242 normal, 216 anomalous fetuses
- 46% diagnostic gain with multiplanar
- 64% diagnostic gain with 3-D rendered image
- 72% diagnostic gain with both

Merz et al, Ultrasound Obstet Gynecol 1995
- 204 anomalous fetuses
- 62% diagnostic gain with 3-D
- 36% equivalent information
- 2% disadvantage with 3-D
3-D ULTRASOUND
Clinical applications - OB

- Dyson et al, Ultrasound Obstet Gynecol 2000
  - 63 anomalous fetuses
  - 51% diagnostic gain with 3-D
  - 45% equivalent information
  - 4% disadvantage with 3-D

CLINICAL EXAMPLES

3-D ULTRASOUND
Clinical examples

multiple gestation

2D Image – 30 weeks
3D Image Same Fetus

3-D ULTRASOUND
Clinical examples

normal craniofacial anatomy
3-D ULTRASOUND
Clinical examples

cleft lip & palate

facial dysmorphology

facial dysmorphology

anencephaly

Campomelic dysplasia
Campomelic dysplasia

multiplanar views of spina bifida

rendered view of myelomeningocele

vertebral anomaly

Diaphragmatic hernia

Diaphragmatic hernia
3-D ULTRASOUND
Clinical examples

Diaphragmatic hernia

bladder extrophy

3-D ULTRASOUND
Clinical examples

bladder extrophy

3-D/4-D ULTRASOUND
Pitfalls and limitations

PITFALLS, LIMITATIONS, AND ARTIFACTS

• Learning curve – steep and variable
• Unfavorable scanning conditions (maternal habitus, oligohydramnios) cause same problems as 2-D
• Size of scanned volume is limited
• Artifacts – motion, shadowing, region of interest boundaries
The shy fetus…

Where's the rest of his arm?

Does he have a hole in his head?

They're not stuck together are they?

Does he have a skull fracture?

**ADVANCED TECHNOLOGIES AND FUTURE DIRECTIONS**

- Spatio-temporal image correlation
- Volume analysis
- Automation

**3-D/4-D ULTRASOUND**

Advanced technologies

**SPATIO-TEMPORAL IMAGE CORRELATION**

- 4-D cine sequence of fetal heart cycle
- Data acquired by single, automatic volume sweep
- Data analyzed according to spatial and temporal domain
**SPATIO-TEMPORAL IMAGE CORRELATION**

**VOLUME ANALYSIS**
- Computer aided volume analysis
  - requires operator to trace area of interest, sometimes several times
- Automated volume count
  - evaluation of any hypoechoic structure
  - volume and mean diameter are calculated automatically

**COMPUTER AIDED VOLUME ANALYSIS**

**AUTOMATED VOLUME CALCULATION**

**3-D ULTRASOUND**
Current issues
- Lack of standardization
- Limited reproducibility
- Human error factor
- Gap between technology and skills
STANDARDIZATION AND AUTOMATION

• Ultrasound vs MR and CT
  – MR and CT characterized by standardization, reproducibility, image recognition
    • image improves with technology
  – ultrasound is operator dependent
    • gap between technology and skills

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3-D ULTRASOUND

Automation

Technical Shift

Operator “image retrieval”

Computer-assisted “image retrieval”

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3-D ULTRASOUND

Standardization

• Volume acquisition
  – reference plane
  – acquisition box
  – acquisition angle
• Volume display
  – reference marker
  – multiplanar display

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CONCEPT OF AUTOMATION

• Acquired volume of a structure contains all of the 2-D anatomical planes needed for a complete evaluation of the structure
• For every organ, the 2-D anatomical planes needed for a complete evaluation are organized in a consistent anatomic relationship to each other

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CONCEPT OF AUTOMATION

• Automation – computerized program to automatically display all 2-D planes required for complete evaluation of a structure
  – fetal heart
  – fetal CNS
  – neonatal CNS

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FUTURE DIRECTIONS

• Volume sonography
• Image recognition software
• Full automation software
• Real time applications in matrix technology
• Education and simulation

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3-D ULTRASOUND
Using volumes for fetal anatomic survey

- Standard 2-D examination plus five 3-D volume sweeps obtained by sonographer in 50 patients
- Volumes reviewed by 3 independent physicians
- Sonographer time 19.6 min (2-D) vs. 1.8 min (3-D)
- Physician time (3-D) 4.79-5.53 min (review volumes, measure BPD and femur)
- ≥ 94% of fetal anatomic landmarks identified by 3-D compared to 2-D (except arms and CSP)