# THREE AND FOUR DIMENSIONAL ULTRASOUND IN OBSTETRICS

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JOHNS HOPKINS MEDICINE

JOHNS HOPKINS HEALTH SYSTEM



## 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)

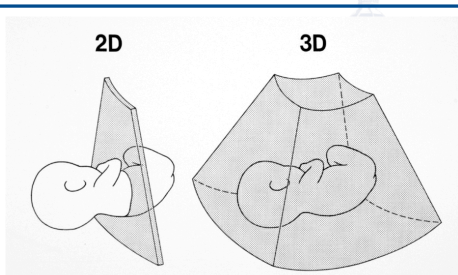


## 4-D ULTRASOUND
### Basic principles

- 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



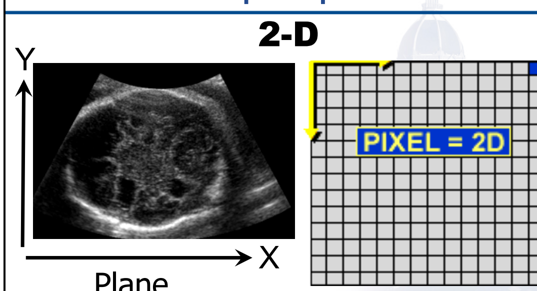
## 3-D ULTRASOUND
### Basic principles



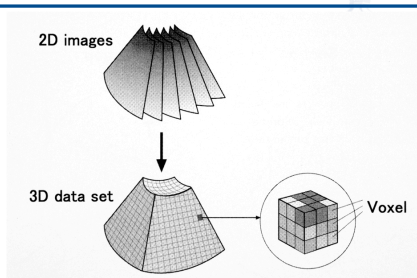

Kurjak & Jackson, Atlas of 3- & 4-D Sono in OB-GYN 2004



## 3-D ULTRASOUND
### Basic principles

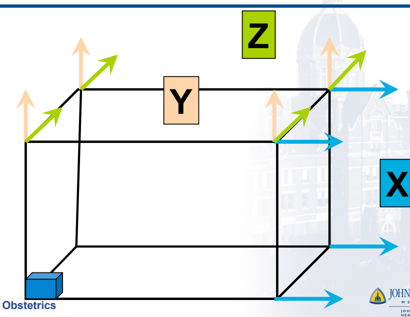


## 3-D ULTRASOUND
## Basic principles




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

## 3-D ULTRASOUND
## Basic principles




Gynecology and Obstetrics

## ACQUISITION AND VISUALIZATION OF VOLUMES

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## 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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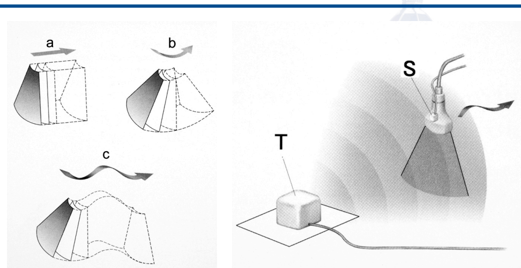
## 3-D ULTRASOUND
## Manual acquisition




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

## 3-D ULTRASOUND
## Automatic 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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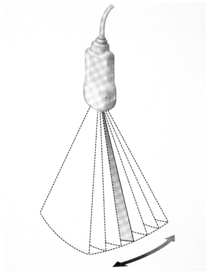
## 3-D ULTRASOUND
## Automatic acquisition




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

## 3-D ULTRASOUND
## Automatic acquisition

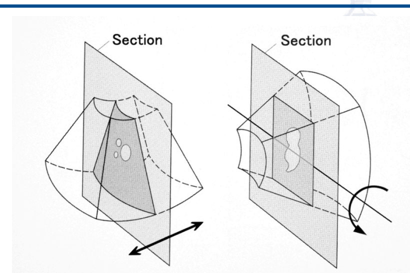


## 3-D ULTRASOUND
## Volume visualization

- 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
## Section reconstruction





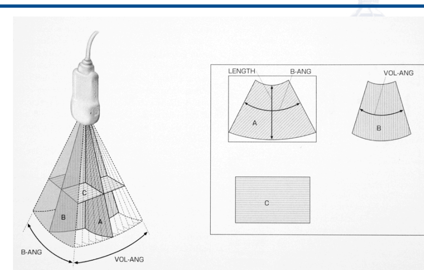
Kurjak & Jackson, Atlas of 3- & 4-D Sono in OB-GYN 2004

## 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



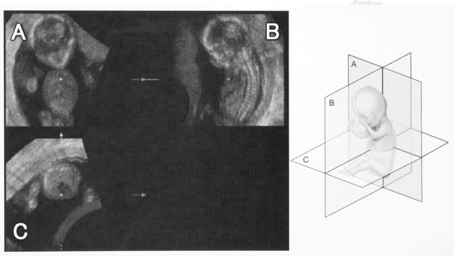
## 3-D ULTRASOUND
## Multiplanar display





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

## 3-D ULTRASOUND
## Multiplanar display




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

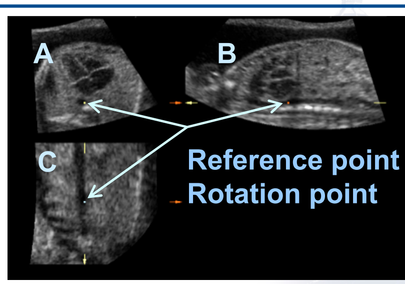


## 3-D ULTRASOUND
## Multiplanar display

- 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 display




Courtesy Alfred Abuhamad, M.D.

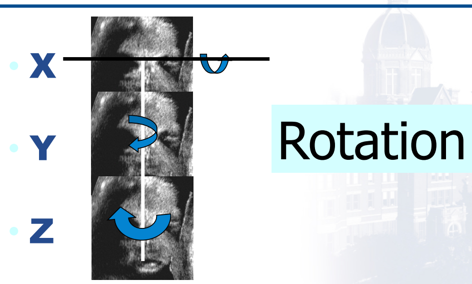


## 3-D ULTRASOUND
## Multiplanar navigation

- 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
## Multiplanar navigation



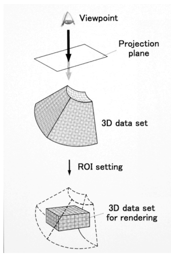

Courtesy Alfred Abuhamad, M.D.

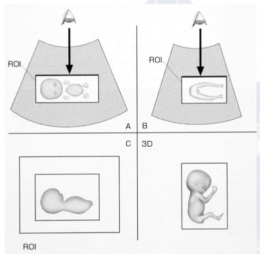


## 3-D ULTRASOUND
## Rendering (3-D image generation)

- 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



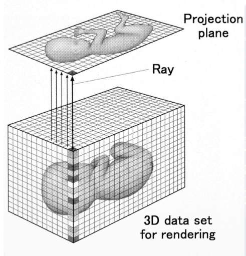

 Kurjak & Jackson, Atlas of 3- & 4-D Sono in OB-GYN 2004

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

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



## 3-D ULTRASOUND
## Volume rendering



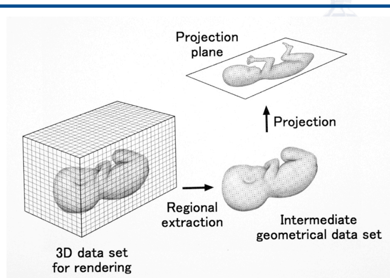

 Kurjak & Jackson, Atlas of 3- & 4-D Sono in OB-GYN 2004

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

- 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

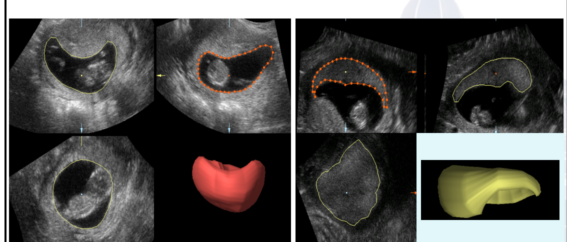


## 3-D ULTRASOUND
## Surface rendering




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

## 3-D ULTRASOUND
## Volume measurement

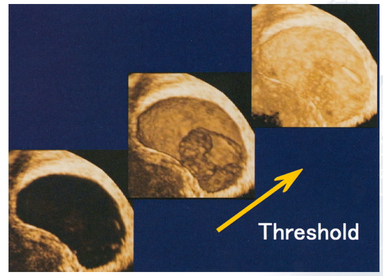


## 3-D ULTRASOUND
## Rendering display options

- 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)



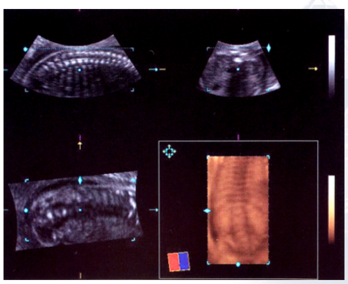
## 3-D/4-D ULTRASOUND
## Threshold





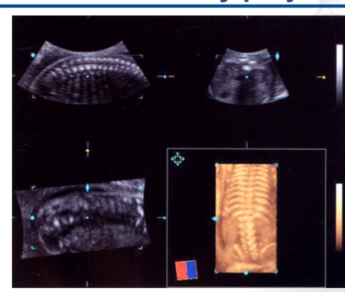
Kurjak & Jackson, Atlas of 3- & 4-D Sono in OB-GYN 2004

## 3-D/4-D ULTRASOUND
## Mean intensity projection




Sanders & Winter, Clinical Sonography 2007

## 3-D/4-D ULTRASOUND
## Maximum intensity projection



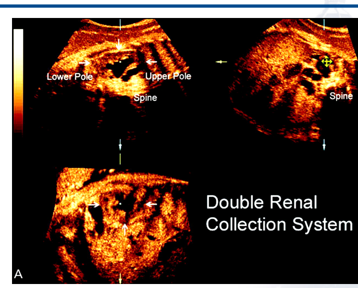

Sanders & Winter, Clinical Sonography 2007

## 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



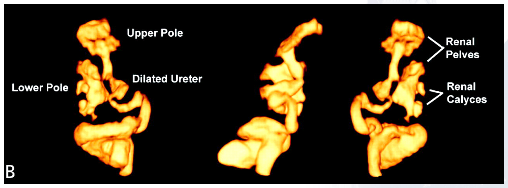
## 3-D ULTRASOUND
## Inversion mode





J Ultrasound Med 2005;24:201

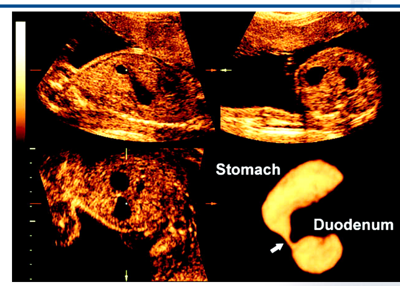
## 3-D ULTRASOUND
## Inversion mode




J Ultrasound Med 2005;24:201



## 3-D ULTRASOUND
## Inversion mode




J Ultrasound Med 2005;24:201

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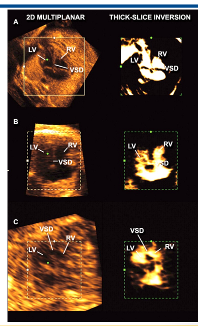
## 3-D ULTRASOUND
## Inversion mode

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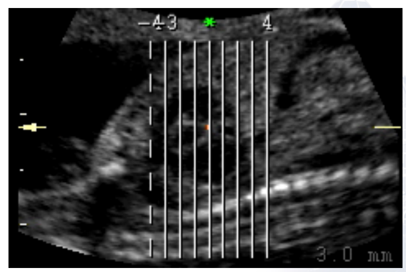
## 3-D ULTRASOUND
## Tomographic imaging



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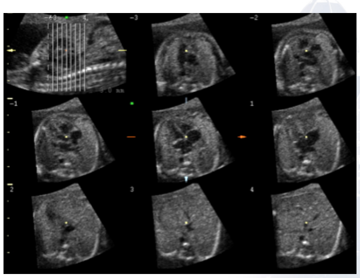
## 3-D ULTRASOUND
## Tomographic imaging



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## 3-D ULTRASOUND
## 3-D cutting


Uncropped 3D image

Cropped 3D

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## 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



## SCANNING METHOD

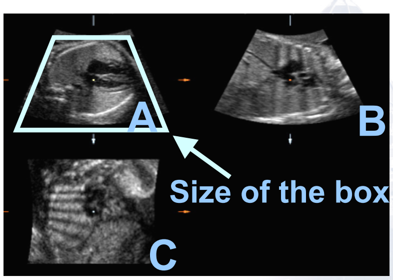


## 3-D ULTRASOUND
## Scanning method

- 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



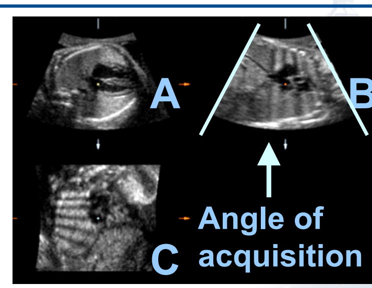
## 3-D ULTRASOUND
## Scanning method




Courtesy Alfred Abuhamad, M.D.



## 3-D ULTRASOUND
## Scanning method



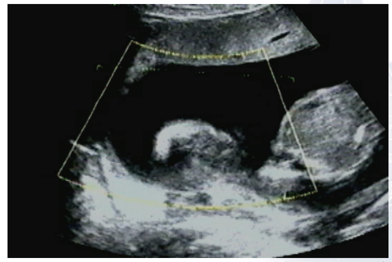

Courtesy Alfred Abuhamad, M.D.

## 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



## 3-D ULTRASOUND
## Scanning method





## 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



## 4-D ULTRASOUND
## Scanning method



## 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)



## 3-D ULTRASOUND
## Clinical applications - OB

- 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



## 3-D ULTRASOUND
## Clinical applications - OB

- 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

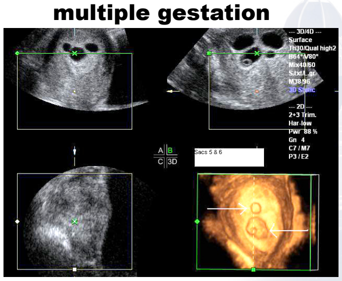


## CLINICAL EXAMPLES



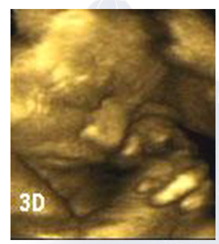
## 3-D ULTRASOUND
## Clinical examples

**multiple gestation**






2D Image – 30 weeks

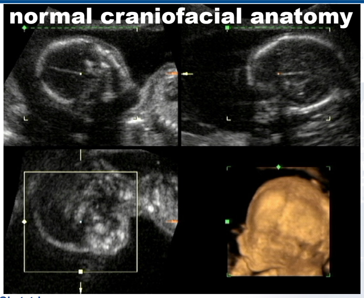



3D Image Same Fetus



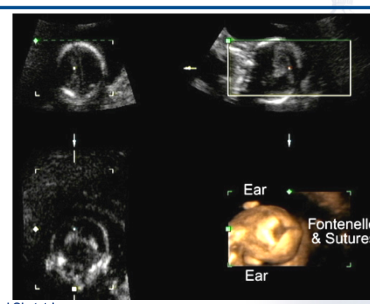
## 3-D ULTRASOUND
## Clinical examples

**normal craniofacial anatomy**



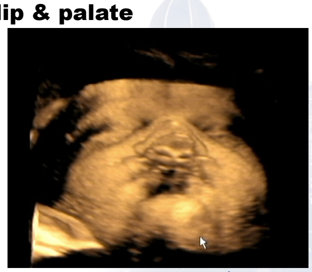


## 3-D ULTRASOUND
## Clinical examples



## 3-D ULTRASOUND
## Clinical examples

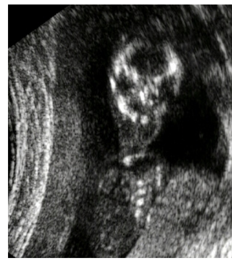
**cleft lip & palate**

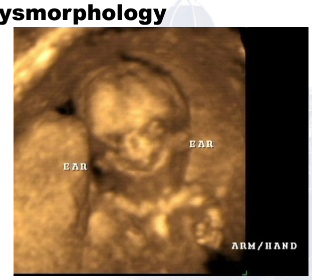




## 3-D ULTRASOUND
## Clinical examples

**facial dysmorphology**

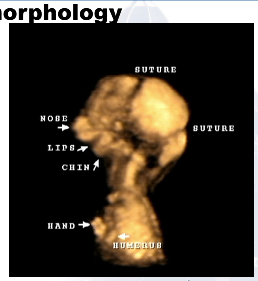







## 3-D ULTRASOUND
## Clinical examples

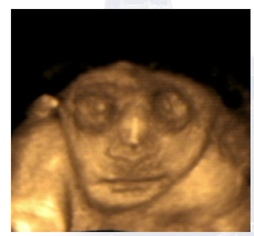
**facial dysmorphology**



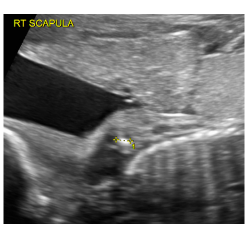

## 3-D ULTRASOUND
## Clinical examples

**anencephaly**



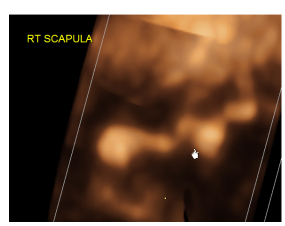


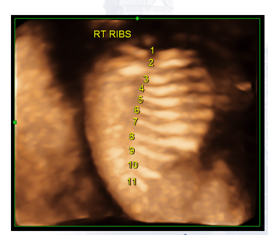
**Campomelic dysplasia**



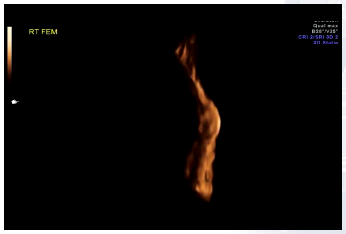






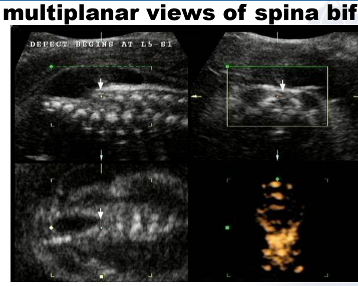



## Campomelic dysplasia



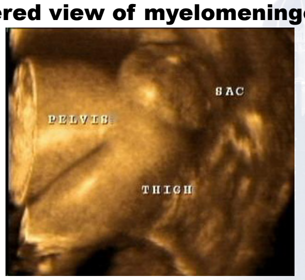



## multiplanar views of spina bifida





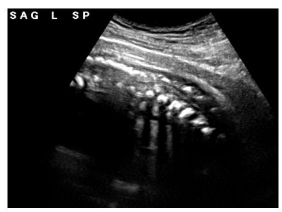

## rendered view of myelomeningocele






# 3-D ULTRASOUND
# Clinical examples

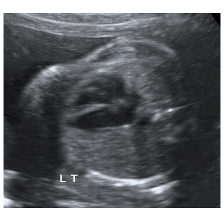
## vertebral anomaly





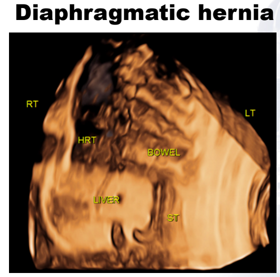


## Diaphragmatic hernia

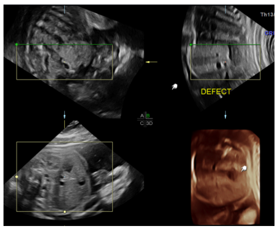





## Diaphragmatic hernia



### Diaphragmatic hernia

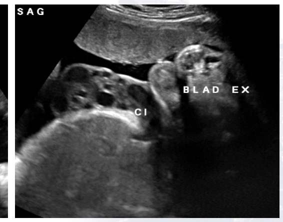






## 3-D ULTRASOUND
## Clinical examples

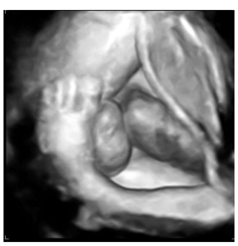
### bladder exstrophy

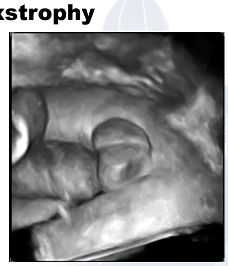






## 3-D ULTRASOUND
## Clinical examples

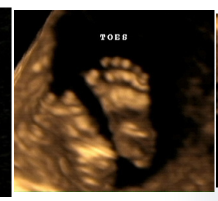
### bladder exstrophy

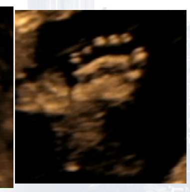






### polydactyly



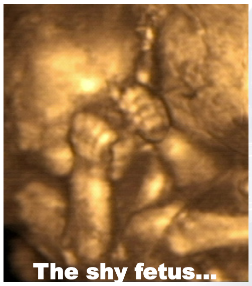


## PITFALLS, LIMITATIONS, AND ARTIFACTS

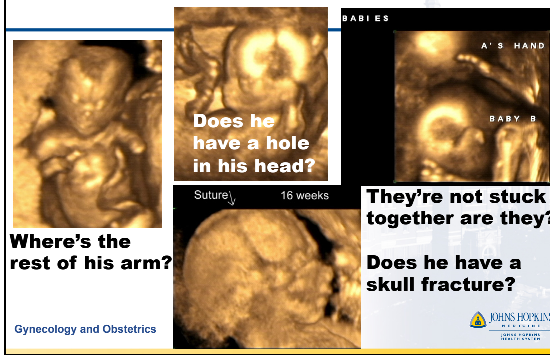


## 3-D/4-D ULTRASOUND
## Pitfalls and limitations

- 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








# ADVANCED TECHNOLOGIES AND FUTURE DIRECTIONS



## 3-D/4-D ULTRASOUND Advanced technologies

- Spatio-temporal image correlation
- Volume analysis
- Automation

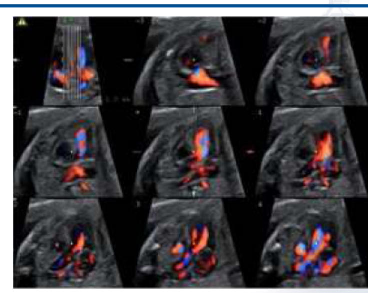


## SPATIO-TEMPORAL IMAGE CORRELATION

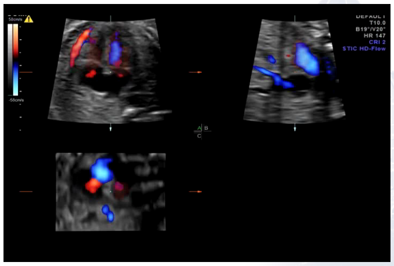
- 4-D cine sequence of fetal heart cycle
- Data acquired by single, automatic volume sweep
- Data analyzed according to spatial and temporal domain



## SPATIO-TEMPORAL IMAGE CORRELATION



## SPATIO-TEMPORAL IMAGE CORRELATION



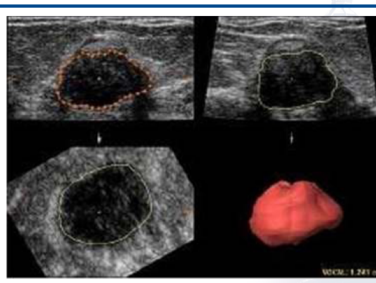
Gynecology and Obstetrics

## 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

Gynecology and Obstetrics

## COMPUTER AIDED VOLUME ANALYSIS



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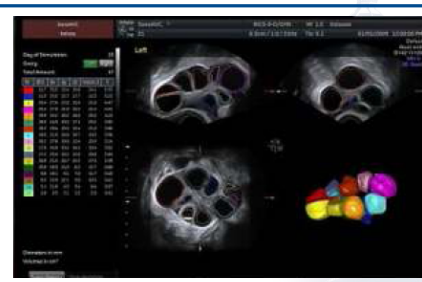
## AUTOMATED VOLUME CALCULATION



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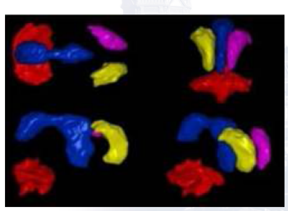
## AUTOMATED VOLUME CALCULATION

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## 3-D ULTRASOUND Current issues

- Lack of standardization
- Limited reproducibility
- Human error factor
- Gap between technology and skills

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## STANDARDIZATION AND AUTOMATION

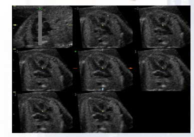
- Ultrasound vs MR and CT
  - MR and CT characterized by standardization, reproducibility, image recognition
    - image improves with technology
  - ultrasound is operator dependent
    - gap between technology and skills



## 3-D ULTRASOUND Automation

Technical Shift

Operator "image retrieval"



Computer-assisted "image retrieval"



## 3-D ULTRASOUND Standardization

- Volume acquisition
  - reference plane
  - acquisition box
  - acquisition angle
- Volume display
  - reference marker
  - multiplanar display



## 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



## 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



## FUTURE DIRECTIONS

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

## 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)

Radiology 2006;238:988



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## THANK YOU

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