Advances in Fetal Echocardiography

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Fetal Echocardiography for Prenatal Diagnosis

Authored by Drs. Xin-Fang WANG and Ji-Peng Xiau
Wuhan Medical College, now Tongji Medical College, Huazhong University of Science & Technology, Wuhan, Central China
140 women / 147 fetuses examined w/ M-Mode

Study describes a technique for diagnosis of early pregnancy, observation of fetal heart and estimation of fetal cardiac size

Quantitative Real-time Cross-sectional Echocardiography in the Developing Normal Human Fetus and Newborn


Evaluation of Myocardial Mechanics in the Fetus by Velocity Vector Imaging

3D and 4D Evaluation of the Fetal Heart

**Gating**

3D Heart Acquisition

No Gating

**Temporal Fourier Analysis of the Periodic Cardiac Motion**


**Mechanical 4DUS Probes**
Spatio-temporal image correlation (STIC): new technology for evaluation of the fetal heart

G. R. DEVORE*, P. FALKENSAMMER†, M. S. SKANSKY‡ and L. B. PLATT§

*Fetal Diagnoses Center of Excellence, Perinatology, CA, USA, †M.D. Anderson System-Kent Physicians, Eggleton Avenue, ‡Division of Pediatric Radiology, Department of Radiology, University of Southern California Keck School of Medicine, Children's Hospital Los Angeles and §Center for Birth Defects and Women's Ultrasound, Los Angeles, CA, USA

STIC

SpatioTemporal Image Correlation

Retrospective gating algorithm

Synchronizes volumetric imaging data to the phase of the fetal cardiac cycle at the time of acquisition

Temporal information (motion) is incorporated into the final volume dataset

4D Fetal Echocardiography

What Does The Technology Allow?

Examination of the fetal heart in a systematic manner, offline, after volume dataset acquisition, in the absence of fetal movement

Correlation between image planes that are perpendicular to the main acquisition plane

Volume data can viewed by experts at a remote site

Tips for Volume Acquisition

Region of Interest (ROI)

Decreases frame rate

Y

X
Acquisition Angle

Acquisition angle determines Z (or depth)

**Acquisition Angle Selection**

Smaller angles for younger fetuses

Larger angles for older fetuses

**Acquisition Time**

Determines the duration of the 3D sweep

Slower acquisition = better spatial resolution

Caveat: fetal movement

General rule:

Slow sweep for fetuses that are still

Fast sweep for those that are moving or breathing

**Real-Time Three-Dimensional Fetal Echocardiography:**

Initial Feasibility Study

Mark S. Silberman, MD, Thomas Nelson, PhD, Michael Targoff, ECO, and Desiree Prenitz, MD

*2D Arrays for Real-Time 3D Echo Imaging*

![Image of 2D Arrays for Real-Time 3D Echo Imaging](image)

*G.T. van Beusechem and D.W. Smith, Real-time volumetric ultrasound imaging, 3D imaging (1991), pp. 27–60


X6-1 Matrix Transducer

- 9,212 elements
- self-contained beam former
- frequency range 1-6 MHz
- active aperture 36 x 17 mm

Multiplanar Display and Navigation

A transverse

B sagittal

C coronal

Scroll in the original plane of acquisition

**3-Step Technique to Systematically Visualize the Outflow Tracts**


Transposition of the great arteries


Transposition of the great arteries

Low-Risk n = 112

- Tetralogy of Fallot (n=5)
- Interrupted Ao arch (n=1)
- Complete TGA (n=3)
- Corrected TGA (n=1)

Outflow tract anomalies n = 10

- 1 case of hypoplastic left heart correctly diagnosed

Office Analysis Blinded examiners Three-step technique

Rizzo et al. Fetal Diagn Ther 2008;24:126-131

Examination of the Fetal Heart by Four-Dimensional Ultrasound with Spatiotemporal Image Correlation during Routine Second-Trimester Examination: The ‘Three-Step Technique’

Giuseppe Rizzo*, Alessandra Capponi, Andrea Miscetelli*
Ortensia Cavichione*, Marianna Vendittà*, Demetrio Ardizzone*

*Department of Obstetrics and Gynecology, Università di Roma ‘Tor Vergata’, and **Department of Obstetrics and Gynecology, Ospedale GB Rossi, Rome, Italy

The ‘spin’ technique: a new method for examination of the fetal outflow tracts using three-dimensional ultrasound

G. R. DeVore*, B. Polanco*, M. S. Selansky* and L. D. Platt

*Fetal Diagnostic Center of Examinations, Paediatric and Division of Cardiology, Department of Pediatrics, University of Southern California, Los Angeles, and **Fetal Diagnostic Center of Examinations, Universitario Hospital, Los Angeles, and Department of Paediatrics and Neonatology, Los Angeles, CA, USA
Spin Technique For Evaluation Of The LVOT

Spin Technique for Evaluation of the RVOT

Spin Technique for Evaluation of the Aortic Arch

The Role of the Sagittal View of the Ductal Arch in Identification of Fetuses With Conotruncal Anomalies Using 4-Dimensional Ultrasonography

Tetralogy of Fallot
Transposition of the Great Arteries

Truncus Arteriosus

Pulmonary Atresia

Visualization rates for the ductal arch

Rendered Views

“The lack of visualization of the sagittal view of the ductal arch should raise the index of suspicion for conotruncal anomalies.”
Inversion Mode
Visualization of Hollow Structures Without Doppler

How is Invert Mode Rendering Generated?

Inversion Mode Example
4D Rendering with Inversion

NORMAL

TRANSPOSITION

Interrupted IVC
w/ azygous continuation

B-Flow Imaging

Technology that digitally enhances signals from weak blood reflectors from vessels and, at the same time, suppresses strong signals from surrounding tissues.

Does not rely on Doppler methods to display blood flow, is angle independent and interferes less with the frame rate.

B-Flow Rendering of the Aortic and Ductal Arches

Picture of the Month
New application of B-flow sono-angiography in perinatology

R. K. FOOH
Department of Obstetrics and Gynecology, Clinical Research Institute, National Zamalek Hospital, Egypt, Egypt.
Comparison Between Different Algorithms for 3D Rendering of the Aortic and Ductal Arches

24 weeks

B-Flow  Power Doppler  Color Doppler

Novel application of 4D sonography with B-flow imaging and spatio-temporal image correlation (STIC) in the assessment of the anatomy of pulmonary arteries in fetuses with pulmonary atresia and ventricular septal defect

Espinoza et al. JUM 2009;28:1375-1378

200 consecutive patients (13 – 40 weeks)
Transverse acquisitions
4-chamber view as the initial point of image acquisition
4CH, 5CH, 3VV, 3VTV
Adjustments in image distance allowed until desired views were identified

DeVore & Polanko. JUM 2005;24:1685

Transverse acquisitions
44-chamber view as the initial point of image acquisition
4CH, 5CH, 3VV, 3VTV
Adjustments in image distance allowed until desired views were identified


Prenatal Diagnosis of Coarctation of the Aorta With the Multiplanar Display and B-Flow Imaging Using 4-Dimensional Sonography

Espinos et al. JUM 2006;28:1275-1278

Tomographic Ultrasound Imaging of the Fetal Heart
A New Technique for Identifying Normal and Abnormal Cardiac Anatomy

Tomographic Ultrasound Imaging

200 consecutive patients (13 – 40 weeks)
Transverse acquisitions
4-chamber view as the initial point of image acquisition
4CH, 5CH, 3VV, 3VTV
Adjustments in image distance allowed until desired views were identified

Devore & Polanko. JUM 2005;24:1685

Tomographic Ultrasound Imaging

Hypoplastic Right Ventricle Pulmonary Atresia

Coarctation of the Aorta

Hypoplastic Left Heart Syndrome

Automation
Diagnosis of complete TGA in 10 confirmed cases

<table>
<thead>
<tr>
<th>View</th>
<th>Normal</th>
<th>Abnormal</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>%</td>
<td>N</td>
</tr>
<tr>
<td>4CH</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>LVOT (cardiac plane 1)</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>RVOT (cardiac plane 2)</td>
<td>3</td>
<td>7</td>
</tr>
</tbody>
</table>

In all cases an abnormal ventriculoarterial connection was shown after activation of either cardiac plane 1 or 2.

Clinical Questions

How Often Are Volumes of Diagnostic Quality Acquired?

Feasibility of STIC in Clinical Practice

STIC incorporated in clinical practice over a 2 month period:

- High risk fetuses / no suspected CHD
- 2 experienced sonographers
- No more than 4 attempts per exam

Factors associated with high quality volume datasets

- BMI:
  
  \[23.8 \text{ kg/m}^2 \times 26.5 \text{ kg/m}^2, \ p = 0.04\]

- Posterior placenta:
  
  \[56.0\% \times 30.3\%, \ p = 0.05\]
Objective:
To determine how frequently a STIC volume dataset could be obtained in nonobese patients at 18-22 weeks of gestation

Frequency of satisfactory images for screening
45 minutes maximum time allowed for volume acquisition

| Table 1. Frequency of Satisfactory Images for Screening Obtained by STIC Stratified by Reviewer and Type of Cardiac View |
|---|---|---|---|---|
| Examiner | L. Chamber, % | RHOF, % | LUS1, % | All 3 Views, % |
| 1 & 2 (C) | 96.4 | 77.3 | 82.2 | 70.3 |
| 3 (D) | 81.0 | 85.5 | 87.4 | 83.8 |

| Table 2. Frequency of Satisfactory Images for Screening Stratified by Fetal Spine Position |
|---|---|---|---|
| Position | 4-6 Chambers | RHOF | LUS1 |
| 1 & 2 (C) | 83.6 | 56.6 | 48.8 |
| 3 (D) | 93.0 | 82.9 | 78.9 |

| Table 3. Frequency of Satisfactory Images for Screening Stratified by Imaging Plane |
|---|---|---|
| Plane | 4-6 Chambers | RHOF | LUS1 |
| 1 & 2 (C) | 88.4 | 87.8 | 82.5 |
| 3 (D) | 98.8 | 77.1 | 77.1 |

STIC: Spatiotemporal Image Correlation

Cohen et al. JUM 2009;28:1645-1650

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**Telemmedicine**

100 fetuses between 18 and 37 weeks
Volume acquisition by a general obstetrician with no expertise in fetal echocardiography
Acquisition time = 7.5 s
Acquisition angle = 30°
Volumes stored for later review by an expert:
Scrolling in the original plane of acquisition
Multiplanar display

Cohen et al. JUM 2009;28:1645-1650
Visualization rates slightly better, but not significantly different between scrolling in the original plane vs. multiplanar display.

Visualization rates lower for apex/stomach continuity and three-vessel and trachea view.


Prenatal diagnosis of congenital heart disease using four-dimensional spatio-temporal image correlation (STIC) telemedicine via an Internet link: a pilot study

E. Viñals, L. Monedero, J. G. Mercedez, and E. Gutiérrez

2 examiners instructed on how on perform a STIC volume acquisition by email
- Acquisition time = 7.5 s
- Acquisition angle = 30 s

Specific instructions on how to avoid common artifacts
- Volumes uploaded to a web server
- Review by a sonologist with experience in fetal echocardiography

50 fetuses (77 volumes)
- 20 – 36 weeks of gestation
- 20 to 40 min for 25-30 Mb volume upload
- Internet speed 128 to 300 kb/s

2 examiners instructed on how on perform a STIC volume acquisition by email
- Acquisition time = 7.5 s
- Acquisition angle = 30 s

Specific instructions on how to avoid common artifacts
- Volumes uploaded to a web server
- Review by a sonologist with experience in fetal echocardiography

Outcome


First Trimester

12 week pregnancy

STIC w/ tomographic imaging
Fetal echocardiography at 11 + 0 to 13 + 6 weeks using four-dimensional spatiotemporal image correlation telemedicine via an Internet link: a pilot study

Assessed whether early pregnancy heart volumes could be obtained by non-experts with remote interpretation by experts via telemedicine link

49 singleton pregnancies between 11 and 13+6 weeks

Acquisition parameters: 7.5 s / 15 degree angle / gray and color Doppler

Successful acquisition = 39/45 cases (71%)

Table 1. Concordance of visualizing different structures and views of the fetal heart using spatiotemporal image correlation telemedicine by two observers

<table>
<thead>
<tr>
<th>Variable</th>
<th>Kappa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streaks on the left</td>
<td>1</td>
</tr>
<tr>
<td>PVC and abnormal atrial arrangement</td>
<td>0.389</td>
</tr>
<tr>
<td>Normal heart rate</td>
<td>1</td>
</tr>
<tr>
<td>Normal atrial septum on right side in atrium</td>
<td>0.639</td>
</tr>
<tr>
<td>Cardiac axis 45°</td>
<td>1</td>
</tr>
<tr>
<td>Two equal atrial sizes</td>
<td>0.61</td>
</tr>
<tr>
<td>Two equal atrial chamber volumes</td>
<td>1</td>
</tr>
<tr>
<td>Intact ventricular septum in 4CV</td>
<td>0.62</td>
</tr>
<tr>
<td>Intact aorta</td>
<td>0.893</td>
</tr>
<tr>
<td>At least one pulmonary vein in left atrium</td>
<td>0.336</td>
</tr>
<tr>
<td>Intact ventricular septum in LV chamber need</td>
<td>0.466</td>
</tr>
<tr>
<td>No atrial septal abnormalities</td>
<td>0.351</td>
</tr>
<tr>
<td>No atrial discordance</td>
<td>0.928</td>
</tr>
<tr>
<td>Great atrioventricular communications</td>
<td>0.478</td>
</tr>
<tr>
<td>Great arteries equidistant in size</td>
<td>0.619</td>
</tr>
<tr>
<td>Atrial and duct similar in size in transverse view</td>
<td>0.721</td>
</tr>
<tr>
<td>Forward flow in both atria</td>
<td>0.633</td>
</tr>
<tr>
<td>Left atrial echo</td>
<td>0.624</td>
</tr>
</tbody>
</table>

4CV, four-chamber view; 4VC, anterior views; LV, left ventricle.

Table 2. Summary of cases with abnormal findings or missing abnormal findings in the spatiotemporal image correlation telemedicine (STIC/4D) as compared to the first heart and atrium with abnormal findings

<table>
<thead>
<tr>
<th>Case</th>
<th>CRL (mm)</th>
<th>4D</th>
<th>3D</th>
<th>STIC/4D</th>
<th>Date</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69</td>
<td>4B</td>
<td>4A</td>
<td>4B</td>
<td>6/12</td>
<td>Normal</td>
</tr>
<tr>
<td>2</td>
<td>69</td>
<td>4B</td>
<td>4A</td>
<td>4B</td>
<td>6/12</td>
<td>Normal</td>
</tr>
<tr>
<td>3</td>
<td>46</td>
<td>4B</td>
<td>4A</td>
<td>4B</td>
<td>6/12</td>
<td>Normal</td>
</tr>
<tr>
<td>4</td>
<td>46</td>
<td>4B</td>
<td>4A</td>
<td>4B</td>
<td>6/12</td>
<td>Normal</td>
</tr>
<tr>
<td>5</td>
<td>46</td>
<td>4B</td>
<td>4A</td>
<td>4B</td>
<td>6/12</td>
<td>Normal</td>
</tr>
<tr>
<td>6</td>
<td>46</td>
<td>4B</td>
<td>4A</td>
<td>4B</td>
<td>6/12</td>
<td>Normal</td>
</tr>
<tr>
<td>7</td>
<td>46</td>
<td>4B</td>
<td>4A</td>
<td>4B</td>
<td>6/12</td>
<td>Normal</td>
</tr>
<tr>
<td>8</td>
<td>46</td>
<td>4B</td>
<td>4A</td>
<td>4B</td>
<td>6/12</td>
<td>Normal</td>
</tr>
<tr>
<td>9</td>
<td>46</td>
<td>4B</td>
<td>4A</td>
<td>4B</td>
<td>6/12</td>
<td>Normal</td>
</tr>
<tr>
<td>10</td>
<td>46</td>
<td>4B</td>
<td>4A</td>
<td>4B</td>
<td>6/12</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Color STIC acquisitions = 10 seconds / 20 degrees

Transabdominal only 92%

Additional transvaginal 8%

Standardization of the first-trimester fetal cardiac examination using spatiotemporal image correlation with volumetric ultrasound and color Doppler imaging

107 consecutive singleton pregnancies at 11 to 13+6 weeks

Transabdominal only 92%

Additional transvaginal 8%
First 3 volume datasets of high quality in 80%
20% required up to 9 volume acquisitions until a satisfactory quality was achieved
12 anatomic landmarks, including:
  - 4 chamber view seen 100% of patients
  - two great arteries of equal size and crossing in 93% of patients

Accuracy

1,163 singletons
21-36 weeks

- CHD w/o VSD
  - n=43
- CHD w/ VSD
  - n=56

- Simple VSD
  - n=21 (36%)
- Complex CHD
  - n=37 (64%)

VSD size = 2 - 10 mm
1 false-positive diagnosis by 2D
2 VSDs missed by both 2D and STIC

Dan-den et al. Arch Gynecol Obstet 2010 (online publication 5/6/2010)

Accuracy of four-dimensional spatiotemporal image correlation echocardiography in the prenatal diagnosis of congenital heart defects

M. Benussi*1, J. M. Martínez*, O. Gómez*, E. Bartrons*, A. Cifuentes*, R. Fueyo* and E. Grau-Cos*

Compared STIC vs. 2D accuracy in a high-risk population
STIC performed after fetal echo by fetal medicine specialists well-trained in routine screening but inexperienced in fetal echocardiography
Standard acquisition: 4-chamber view, preferably apical
Volume review by specialists 1 year after acquisition


342 w/ suspected CHD
14-40 weeks

- Normal
  - n=167 (48.8%)
- CHD
  - n=175 (51.2%)

Successful acquisition 98%
Overall accuracy 91.2% for STIC and 94.2% for 2D

STIC
False negatives (n=9)

VSD (n=8)

Aortic arch interruption type B (n=1)

342 w/ suspected CHD
14-40 weeks

Normal
n=167 (48.8%)

CHD
n=175 (51.2%)

Successful acquisition 98%
Overall accuracy 91.9% for STIC and 94.2% for 2D

VSD (n=2)

Persisted left SVC (n=1)

Table 4: 1st trimester or 4th trimester results of CHD scans using 4D STIC and conventional 2D ultrasound (2D) for detecting congenital heart defects

Parameter
4D-STIC
Conventional 2D-STIC
Sensitivity
96.9 (95.8-97.7)
98.3 (97.3-98.7)
Specificity
83.3 (75.2-90.8)
87.8 (85.1-90.1)
Negative predictive value
99.0 (98.9-99.9)
98.8 (98.7-99.1)
Positive predictive value
92.2 (89.8-95.0)
89.2 (82.0-93.5)
Total accuracy
94.2 (93.2-95.0)
94.7 (93.8-95.7)

Data are expressed as %, n or P. P = 0.05 for total accuracy.


342 w/ suspected CHD
14-40 weeks

Normal
n=167 (48.8%)

CHD
n=175 (51.2%)

Successful acquisition 98%
Overall accuracy 91.9% for STIC and 94.2% for 2D

VSD (n=11)

Table 5: 1st trimester or 4th trimester results of CHD scans using 4D STIC and conventional 2D ultrasound (2D) for detecting congenital heart defects

Parameter
4D-STIC
Conventional 2D-STIC
Sensitivity
94.9 (94.5-95.7)
98.3 (97.3-98.7)
Specificity
88.4 (84.1-91.5)
90.4 (87.8-93.1)
Negative predictive value
99.0 (98.9-99.9)
98.8 (98.7-99.1)
Positive predictive value
90.1 (86.1-93.2)
89.2 (82.0-93.5)
Total accuracy
92.0 (90.9-93.3)
94.7 (93.8-95.7)

Data are expressed as %, n or P. P = 0.05 for total accuracy.


Conclusion

"...we present a large series of CHDs evaluated with STIC technology and conclude that, in a high-risk population, 4D-STIC echocardiography could be incorporated into a clinical setting, with a high accuracy for offline reassurance of normality and diagnosis of any anomaly in the whole spectrum of CHD"
Each center uploaded 20 volume datasets of fetuses with and without CHD, 18-26 weeks, B-mode or Color, 1 volume/case, 90 randomly selected for analysis.

<table>
<thead>
<tr>
<th>Diagnostic</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
<th>PL</th>
<th>PLr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>93% (77-100%)</td>
<td>96% (84-100%)</td>
<td>96% (83-100%)</td>
<td>93% (79-100%)</td>
<td>96% (83-100%)</td>
<td></td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypoplastic LM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium LAD stenosis</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>MH/LH ductus</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right ventricle</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Tricuspid regurgitation</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ventricular septal defect</td>
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</tbody>
</table>

Median time to upload/download each dataset = 2 min (1-3 min)
Median time to analyze each volume = 6 min (2-15 min)
Datasets with limited quality = 10%