Evaluation of the right and left ventricles: An integrated approach measuring the area, length, and width of the chambers in normal fetuses

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Abstract

Introduction: The purpose of this study was to simultaneously measure with speckle tracking software the end-diastolic ventricular area (A), basal transverse width (BW), mid-chamber transverse width (MW), and basal-apical length (BAL) in normal fetuses and those with pathology.

Methods: The 4-chamber view of the fetal heart was obtained in 200 control fetuses between 20 and 40 weeks of gestation and in 9 third-trimester fetuses with heart malformations. The mean and standard deviation for the A, BW, MW, and BAL were computed from the control fetuses and Z scores computed from the 9 fetuses with cardiac malformations.

Results: The A, BAL, BW, and MW were correlated with 7 somatic and age-independent variables ($R^2 = .63-.85$). The highest $R^2$ values occurred for the head circumference, estimated fetal weight, and ultrasound mean gestational age (.82-.85). Z-score values and centiles from the 9 fetuses with cardiac malformations suggested that the A, BW, MW, and BAL were below or above the 5th and 95th centiles as expected for the corresponding ventricular pathology.

Conclusions: This study reports an integrated approach to evaluate the end-diastolic size of the right and left ventricular chambers and demonstrated clinical utility in fetuses with cardiac malformations.

1 INTRODUCTION

A recent scientific statement from the American Heart Association (AHA) focusing on the fetal cardiovascular system suggested that various fetal conditions may alter the size of the right ventricle (RV) and/or the left ventricle (LV). In some cases, quantitation of ventricular size may improve the ability to provide accurate counseling regarding prognosis and the anticipated postnatal course. However, the AHA statement only recommended evaluation of ventricular size by measuring the end-diastolic basal-apical length of the right and left ventricular chambers. Since ventricular chamber size may be altered in planes other than the basal-apical length, a more robust approach to the quantitative evaluation of ventricular size is warranted. Among prior studies measuring fetal ventricular chamber width and length, only one study by Schneider et al examined the end-diastolic area of the RV and LV. In addition to using gestational age (GA) as an independent variable, they measured the biparietal diameter (BPD) and femur length (FL). However, the resultant nomograms were not tested in a population of fetuses with congenital heart defects nor were correlations with chamber length and width examined to determine their relationships with the ventricular area. The purpose of this study was to (1) provide equations in which the area, length, and width of the ventricular chambers were regressed against additional fetal biometric and age variables in normal fetuses, (2) determine if the end-diastolic ventricular area is correlated with end-diastolic longitudinal and transverse measurements of the ventricular chamber, (3) compare the results with previously published studies, and (4) demonstrate the clinical utility in a small cohort of fetuses with congenital heart malformations.

2 MATERIALS AND METHODS

All patients signed a consent form allowing the use of images obtained during their examination for study purposes. The University of California at Los Angeles institutional review board approved the study protocol.
2.1 | Control population

Two hundred control fetuses with accurate first- and/or second-trimester dating ultrasound were examined between 20 and 40 weeks of gestation to create a normal distribution between these GAs. The fetuses were not at risk for congenital heart defects or growth restriction and were free from ultrasound-detected malformations and growth disturbance at the time of the examination.9-11 The 200 fetuses were the same cohort used in previous studies from our group.11-16 All measurements were performed by a single examiner (G.R.D.) in an outpatient facility offering second- and third-trimester screening ultrasound for patients referred by obstetricians. Two-dimensional images of the 4-chamber view from the control fetuses were obtained from a Voluson E10 (GE Healthcare, Milwaukee, Wisconsin). Images were optimized to enhance the borders between the blood pool and the endocardium. Three-second cine clips of the 4-chamber view were stored as Digital Imaging and Communications in Medicine (DICOM). The DICOM image frame rate was equivalent to the frame rate acquisition at the time of the examination.17

2.2 | Fetuses with cardiac malformations

A sample of 9 fetuses was identified from our database that represented a spectrum of congenital heart defects of the LV (n = 5) and RV (n = 4). Two-dimensional DICOM images of the 4-chamber view were retrieved from a database at the UCLA Mattel Children's Hospital, Los Angeles, California. The images of the 4-chamber view were acquired with a Voluson E8 (GE Healthcare) for 3 to 10 seconds. The DICOM image frame rate was equivalent to the frame rate acquisition at the time of the examination. All congenital heart defects evaluated in utero were confirmed postnatally.

2.3 | Evaluation of the 4-chamber view using offline speckle tracking software

Once 2-dimensional images of the 4-chamber view were obtained and stored in the DICOM format, they were imported into an offline cardiac software program for analysis (2D Cardiac Performance 1.2 or 2D CPA) developed by TomTec Imaging Systems, GmbH (Munich, Germany), using criteria that have been previously described.17 The endocardial border for each ventricle was traced from the junction of the lateral wall annulus to the apex and from the apex to the base at the junction of the septal wall annulus. Following the tracing, automated analysis detected the endocardial borders during diastole and systole.17

2.4 | Computation of ventricular area

Once the analysis for each ventricle was completed, the raw data were exported to a text file containing pixel-tracking information transferred into a Cartesian coordinate system. The text file was imported into an Excel spreadsheet that had been programmed to convert the X and Y pixel coordinates of the end-systolic and end-diastolic locations.12 Once imported into Excel, the XY tracking coordinates were arranged in rows and columns from which 49 spatial tracking points were computed and displayed as an endocardial contour for each chamber (Figure 1). The end-diastolic area was calculated from the pixel coordinates by closing the open chamber contour and then applying an area of an irregular polygon algorithm (Figure 1).

\[
\text{Area} = \frac{(x_1 y_2 - y_1 x_2) + (x_2 y_3 - y_2 x_3) + \cdots (x_{48} y_{49} - y_{48} x_{49})}{2}
\]

The numbers of pixels from the above analysis were converted to cm².

2.5 | Computation of end-diastolic longitudinal ventricular lengths

Using the same speckle tracking and computational technique, the end-diastolic length was measured from the mid-portion of the tricuspid and mitral annular hinge points to the apex of the ventricle (Figure 1). The mid-base was derived from a line drawn between the base of the septal and lateral walls where these structures interfaced with the annulus of the atrioventricular valve at end-diastole (Figure 1).

2.6 | Computation of the end-diastolic transverse widths

Using a previously described speckle tracking technique in which 24 transverse end-diastolic segments were measured from the base to the apex of the ventricle, 2 end-diastolic transverse segments were
selected to represent the base (segment 1) and mid-portion of the ventricular chamber (segment 12) (Figure 1).12

2.7 | Statistical analysis

The end-diastolic area, the basal-apical length, and the transverse widths were regressed against independent somatic growth and age variables (head circumference [HC], BPD, abdominal circumference [AC], FL, estimated fetal weight [EFW], ultrasound mean GA [USGA], and clinical GA) using a curve-fitting program that evaluates 44 fractional polynomial equations (NCSS 11, Kaysville, Utah).9 The area, length, and width were compared between the RV and the LV using within subject repeated measure of variance (NCSS 11). Pearson correlation analysis was used to evaluate the relationships between the end-diastolic areas, the basal-apical lengths, and the 2 transverse widths (NCSS 11).

Thirty additional fetuses, selected at random from our database, were examined to compute the intra-observer variability using Lin concordance correlation coefficient (NCSS 11) and the Kappa coefficient to test for interobserver variability. In addition, the right and left ventricular end-diastolic areas, basal-apical length, and transverse segments 1 and 12 from the 30 fetuses were measured using a DICOM viewer (Escape Medical Viewer, Greece) by tracing the endocardial borders and lengths by hand and comparing the values with the measurements obtained by speckle tracking measurements.

The results from 200 control fetuses were compared with the results from previously published studies for the area, basal-apical length, and basal transverse width (segment 1) for the RV and LV using the technique described by Salomon et al18 as follows:

\[
Z \text{ score} = \frac{\text{measured value}_{\text{control fetuses}} - \text{predicted mean value}_{\text{current study control fetuses}}}{\text{predicted standard deviation}_{\text{current study control fetuses}}}
\]

Delta Z scores, equivalent to the standard deviation (SD), that fell outside +/-1 were considered significantly different from our study.

3 | RESULTS

The GAs of the 200 control fetuses were normally distributed, as previously reported.11-16,19 The mean fetal heart rate was 144
African control patient population consisted of Asian (6%), White (66%), and Latino (22%) patients. The mean maternal age was 32 (+/-6) years old.

### 3.1 Control fetuses

#### 3.1.1 Left and right ventricular end-diastolic areas

Fractional polynomial regression analysis demonstrated $R^2$ values for the end-diastolic area to be between .77 to .82 for the LV and .81 to .85 for the RV for all of the independent variables (BPD, HC, AC, FL, EFW, USGA, and GA) (Supporting Information S1). The data were normally distributed with $P$ values for the Shapiro-Wilk analysis greater than .05 (Supporting Information S1). The 5th, 10th, 50th, 90th, and 95th centile values were computed from the mean and SD equations and listed in tables and depicted in graphs (Supporting Information S2 and S3). Comparing the right and left ventricular end-diastolic areas demonstrated that the LV area was significantly greater than the RV area ($P = .0005$).

#### 3.1.2 Left and right ventricular basal-apical lengths

Fractional polynomial regression analysis demonstrated $R^2$ values for the end-diastolic basal-apical length to be between .63 to .67 for the LV and .63 to .70 for the RV for all of the independent variables (BPD, HC, AC, FL, EFW, USGA, and GA) (Supporting Information S1). The data were normally distributed with $P$ values for the Shapiro-Wilk analysis greater than .05 (Supporting Information S1). The 5th, 10th, 50th, 90th, and 95th centile values were computed from the mean and SD equations and listed in tables and depicted in graphs (Supporting Information S2 and S3). Comparing the right and left ventricular basal-apical lengths demonstrated that the LV length was significantly greater than the RV length ($P = .0001$).

#### 3.1.3 Left and right transverse widths

For all of the independent variables (BPD, HC, AC, FL, EFW, USGA, and GA) fractional polynomial regression analysis demonstrated $R^2$ values for the end-diastolic transverse widths for segments 1 and 12 of the LV to be between .68 to .70 and .69 to .72, respectively (Supporting Information S1). The RV demonstrated $R^2$ values for segments 1 and 12 to be between .68 to .72 and .71 to .75, respectively. The data were normally distributed with $P$ values for the Shapiro-Wilk analysis greater than .05 (Supporting Information S1). The 5th, 10th, 50th, 90th, and 95th centile values were computed from the mean and SD equations and listed in tables and depicted in graphs (Supporting Information S2 and S3). Comparing the right and left ventricular end-diastolic transverse widths for segments 1 and 12 demonstrated that there was no significant difference between the RV and the LV.

### TABLE 1  Intraobserver variability using Lin concordance analysis

<table>
<thead>
<tr>
<th>End-diastolic Measurements</th>
<th>Correlation Coefficient</th>
<th>2-Sided 5% Confidence Limits</th>
<th>2-Sided 95% Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left ventricular area</td>
<td>0.96</td>
<td>0.93</td>
<td>0.98</td>
</tr>
<tr>
<td>Right ventricular area</td>
<td>0.98</td>
<td>0.95</td>
<td>0.99</td>
</tr>
<tr>
<td>Left ventricular basal-apical length</td>
<td>0.97</td>
<td>0.94</td>
<td>0.98</td>
</tr>
<tr>
<td>Right ventricular basal-apical length</td>
<td>0.97</td>
<td>0.94</td>
<td>0.98</td>
</tr>
<tr>
<td>Left ventricular transverse width: segment 1</td>
<td>0.92</td>
<td>0.83</td>
<td>0.96</td>
</tr>
<tr>
<td>Right ventricular transverse width: segment 1</td>
<td>0.93</td>
<td>0.86</td>
<td>0.96</td>
</tr>
<tr>
<td>Left ventricular transverse width: segment 12</td>
<td>0.95</td>
<td>0.9</td>
<td>0.97</td>
</tr>
<tr>
<td>Right ventricular transverse width: segment 12</td>
<td>0.95</td>
<td>0.9</td>
<td>0.98</td>
</tr>
</tbody>
</table>

### TABLE 2  Comparison of speckle tracking and free-hand measurements using Lin concordance analysis

<table>
<thead>
<tr>
<th>End-diastolic Measurements</th>
<th>Correlation Coefficient</th>
<th>2-Sided 5% Confidence Limits</th>
<th>2-Sided 95% Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left ventricular area</td>
<td>0.98</td>
<td>0.96</td>
<td>0.99</td>
</tr>
<tr>
<td>Right ventricular area</td>
<td>0.99</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>Left ventricular basal-apical length</td>
<td>0.99</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>Right ventricular basal-apical length</td>
<td>0.97</td>
<td>0.93</td>
<td>0.98</td>
</tr>
<tr>
<td>Left ventricular transverse width: segment 1</td>
<td>0.98</td>
<td>0.96</td>
<td>0.99</td>
</tr>
<tr>
<td>Right ventricular transverse width: segment 1</td>
<td>0.99</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>Left ventricular transverse width: segment 12</td>
<td>0.96</td>
<td>0.92</td>
<td>0.98</td>
</tr>
<tr>
<td>Right ventricular transverse width: segment 12</td>
<td>0.97</td>
<td>0.92</td>
<td>0.98</td>
</tr>
</tbody>
</table>
3.1.4 Correlation of ventricular end-diastolic areas with transverse and longitudinal end-diastolic lengths

The $R^2$ correlation coefficients comparing the RV and LV end-diastolic areas with their corresponding end-diastolic basal-apical lengths and transverse width for segments 1 and 12 ranged between .71 and .85 (Figure 2). The highest correlation was observed for the basal-apical length, followed by segments 12 and 1.

3.1.5 Comparing the end-diastolic areas, basal-apical lengths, and transverse widths from the current study with previously published studies

Figure 3 summarizes the data from 7 prior studies that were compared with our data. The measurements and independent variables differed among the studies. The area was only measured by Schneider et al. with the BPD having more values falling within 1 $Z$ score than when using the GA and FL as the independent variables (Figure 3).

The studies by Tan et al., Schneider et al., and Krishnan et al. measured the basal-apical length and compared it with the GA. The results from Tan et al. and Krishnan et al. had values greater than 2 $Z$ scores from 25 to 30 weeks of gestation. The results from Schneider et al. fell within 2 $Z$ scores from 22 to 36 weeks of gestation for the RV and 25 to 40 weeks for the LV. When using the BPD and FL to evaluate the basal-apical length, only the study by Schneider et al. fell within 2 $Z$ scores of our data while the study by Krishnan et al. demonstrated an upward trend throughout pregnancy, exceeding 2 $Z$ scores in the third trimester.

3.2 Fetuses with right ventricular cardiovascular abnormalities

Table 3 lists the $Z$ scores and centiles for the 4 fetuses with right ventricular malformations. The average acquisition frame rate was 60 frames per second. Figure 4 illustrates the individual measurements plotted against right ventricular reference curves using the HC as the independent variable.

3.2.1 Right ventricle analysis

The area was normal for the fetus with Ebstein anomaly. However, there was an increased transverse width for segments 1 and 12. The fetus with a dysplastic tricuspid valve had an increased area and increased transverse lengths for segments 1 and 12, with a normal basal-apical length. The fetus with pulmonary stenosis had a normal area and transverse segment lengths, but the basal-apical length was decreased. The fetus with cardiomyopathy had a decreased area, as well as a decreased basal-apical length.

![Regression curve and equations](image-url)

**FIGURE 2** Regression curve and equations. The basal-apical length and the transverse widths for segments 1 and 12 were correlated with their respective ventricular area. Red represents the left ventricular (LV) data and blue the right ventricular (RV) data.
The fetus with Ebstein anomaly had a decreased LV area and decreased basal-apical length, with normal transverse width segments. The fetus with a dysplastic tricuspid valve only had increased LV transverse segment widths. The fetus with pulmonary stenosis had an increased LV area and basal-apical length. The fetus with cardiomyopathy had a normal LV area, but a decreased basal-apical length, and an increased transverse width of segment 1.

### Table 3

<table>
<thead>
<tr>
<th></th>
<th>Ebstein Malformation</th>
<th>Dysplastic Tricuspid Valve</th>
<th>Pulmonary Stenosis</th>
<th>Cardiomyopathy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Z score, % (N = 1)</td>
<td>Z score, % (N = 1)</td>
<td>Z score, % (N = 1)</td>
<td>Z score, % (N = 1)</td>
</tr>
<tr>
<td>Head circumference, cm</td>
<td>31.2</td>
<td>26.6</td>
<td>27.3</td>
<td>29.8</td>
</tr>
<tr>
<td>Right ventricle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End-diastolic area</td>
<td>1.12 (86.87%)</td>
<td>6.77 (&gt;99%)</td>
<td>−0.63 (26.43%)</td>
<td>−2.98 (&lt;1%)</td>
</tr>
<tr>
<td>End-diastolic basal-apical length</td>
<td>0.44 (66.83%)</td>
<td>0.82 (79.36%)</td>
<td>−1.39 (8.27%)</td>
<td>−3.87 (&lt;1%)</td>
</tr>
<tr>
<td>End-diastolic transverse length: segment 1</td>
<td>4.02 (&gt;99%)</td>
<td>9.54 (&gt;99%)</td>
<td>0.83 (79.81%)</td>
<td>0.08 (53.16%)</td>
</tr>
<tr>
<td>End-diastolic transverse length: segment 12</td>
<td>1.61 (94.59%)</td>
<td>7.32 (&gt;99%)</td>
<td>0.47 (68.16%)</td>
<td>−1.04 (14.81%)</td>
</tr>
<tr>
<td>Left ventricle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End-diastolic area</td>
<td>−1.99 (2.34%)</td>
<td>1.14 (87.25%)</td>
<td>1.73 (95.78%)</td>
<td>−0.28 (38.96%)</td>
</tr>
<tr>
<td>End-diastolic basal-apical length</td>
<td>−2.33 (&lt;1%)</td>
<td>−0.27 (39.20%)</td>
<td>1.39 (91.84%)</td>
<td>−1.34 (9.01%)</td>
</tr>
<tr>
<td>End-diastolic transverse length: segment 1</td>
<td>−1.09 (13.87%)</td>
<td>4.54 (&gt;99%)</td>
<td>1.05 (85.2%)</td>
<td>1.39 (91.75%)</td>
</tr>
<tr>
<td>End-diastolic transverse length: segment 12</td>
<td>−0.29 (38.67%)</td>
<td>2.33 (&gt;99%)</td>
<td>0.96 (83.03%)</td>
<td>0.42 (66.38%)</td>
</tr>
</tbody>
</table>

Abnormal values are listed in red.
3.3 | Fetuses with left ventricular cardiovascular abnormalities

Table 4 lists the Z scores and centiles for the 5 fetuses with LV malformations. The average acquisition frame rate was 65 frames per second. Figure 5 illustrates the individual measurements plotted against LV reference curves for the HC.

3.3.1 | Left ventricle analysis

All 5 fetuses with left heart malformations demonstrated areas below the 1st centile. The fetuses with Shone syndrome, coarctation of the aorta, and hypoplastic LV also demonstrated abnormal values for the basal-apical length and transverse segments 1 and 12. The fetus with aortic stenosis had a decreased transverse width for segment 12. The fetus with critical aortic stenosis had a decreased basal-apical length but normal transverse widths.

3.3.2 | Right ventricle analysis

The fetuses with critical aortic stenosis and a hypoplastic LV had increased areas of the RV with corresponding increased values of the transverse width for segment 12. The fetus with Shone syndrome had a normal area but increased values for the transverse width of segments 1 and 12. The fetus with coarctation of the aorta only had an increased width for segment 1.

4 | DISCUSSION

Recent studies in adults and pediatric patients have suggested that evaluation of cardiac size as a function of the size of the individual is nonlinear and follows an allomorphic model and is expressed as $y = aX^b$, which is equivalent to $\ln Y = \ln a + b\ln X$. Using the concept of the allometric model in which the heart does not grow at the same rate as the body, our study used 44 fractional polynomial equations ($y = aX^b$) to identify the best equation to compute the mean value for 7 independent variables that represented the size and age of the fetus. The $R^2$ was higher for the area measurements than the length and width measurements for both ventricles were associated with corresponding changes in the somatic growth and age variables (Supporting Information S1). We also computed the SD for each dataset using the criteria described by Altman and Chitty, we were able to derive the 5th, 10th, 90th, and 95th confidence intervals for each of the regression equations (Supporting Information S1 and S2) to be used when examining fetuses with pathology of the RV and/or LV.

The purpose for evaluating the correlation coefficient between the end-diastolic area vs the basal-apical length and the transverse widths for segments 1 and 12 was to determine if they were interrelated because the area can be derived from linear measurements of

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**FIGURE 4** Plots of measurements from fetuses with right ventricular malformations. The graphs represent the 95th, 90th, 50th, 10th, and 5th centiles for (A) the area, (B) the basal-apical length, (C) the transverse width for segment 1, and (D) the transverse width for segment 12. C, right ventricular cardiomyopathy; E, Ebstein anomaly; PS, pulmonary stenosis; RV, right ventricle; TD, tricuspid valve dysplasia.

*DEVORE ET AL.*
TABLE 4  
Z score and centile measurements in fetuses with left ventricular abnormalities

<table>
<thead>
<tr>
<th>Condition</th>
<th>Aortic Stenosis</th>
<th>Shone Syndrome</th>
<th>Coarctation of the Aorta</th>
<th>Critical Aortic Stenosis</th>
<th>Hypoplastic Left Ventricle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Z score, % (N = 1)</td>
<td>Z score, % (N = 1)</td>
<td>Z score, % (N = 1)</td>
<td>Z score, % (N = 1)</td>
<td>Z score, % (N = 1)</td>
</tr>
<tr>
<td>Head circumference, cm</td>
<td>31.5</td>
<td>31.65</td>
<td>28.8 cm</td>
<td>32</td>
<td>30.5</td>
</tr>
<tr>
<td>Left ventricle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End-diastolic area</td>
<td>-3.63 (11%)</td>
<td>-3.77 (11%)</td>
<td>-4.42 (11%)</td>
<td>-2.5 (11%)</td>
<td>-4.26 (11%)</td>
</tr>
<tr>
<td>End-diastolic basal-apical length</td>
<td>-10 (159%)</td>
<td>-3.62 (11%)</td>
<td>-3.55 (11%)</td>
<td>-2.91 (11%)</td>
<td>-4.07 (11%)</td>
</tr>
<tr>
<td>End-diastolic transverse length: segment 1</td>
<td>-1.13 (1284%)</td>
<td>-1.31 (9.55%)</td>
<td>-3.47 (11%)</td>
<td>-0.74 (22.91%)</td>
<td>-3.56 (11%)</td>
</tr>
<tr>
<td>End-diastolic transverse length: segment 12</td>
<td>-3.98 (&lt;1%)</td>
<td>-2.03 (2.14%)</td>
<td>-3.05 (11%)</td>
<td>-0.02 (49.22%)</td>
<td>-2.48 (&lt;1%)</td>
</tr>
<tr>
<td>Right ventricle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End-diastolic area</td>
<td>-0.19 (42.64%)</td>
<td>-0.33 (37.22%)</td>
<td>0.04 (48.4%)</td>
<td>3.55 (&gt;99%)</td>
<td>1.82 (96.54%)</td>
</tr>
<tr>
<td>End-diastolic basal-apical length</td>
<td>-0.15 (44.11%)</td>
<td>-1.12 (13.10%)</td>
<td>-0.98 (16.32%)</td>
<td>1.00 (84.14%)</td>
<td>0.00 (50.0%)</td>
</tr>
<tr>
<td>End-diastolic transverse length: segment 1</td>
<td>-1.21 (113.9%)</td>
<td>1.67 (93.25%)</td>
<td>1.87 (96.95%)</td>
<td>1.20 (88.41%)</td>
<td>0.75 (77.35%)</td>
</tr>
<tr>
<td>End-diastolic transverse length: segment 12</td>
<td>-0.11 (45.65%)</td>
<td>2.83 (96.87%)</td>
<td>1.03 (84.90%)</td>
<td>2.17 (98.51%)</td>
<td>3.12 (&gt;99%)</td>
</tr>
</tbody>
</table>

Abnormal values are listed in red.

Comparing our data with previous studies suggested that using the length and width (area = 3.14 * (basal apical length/2) * (transverse width/2)) of the heart might be a better choice for the independent variable. However, the greatest number of values for the RV and LV suggests this might be a better choice than the BPD because of its potential for changes in the shape of the fetal head that can occur.
software to derive our end-diastolic area data, the area can be computed using generic measurement tools available on all ultrasound machines since the correlation coefficient between speckle tracking and free-hand measurements for the end-diastolic area, basal-apical length, and transverse segments 1 and 12 was greater than .96. (4) Measuring the BPD and FL, as was done in previous studies, is less desirable than the HC, EFW, and mean ultrasound GA because of their higher $R^2$ values (Supporting Information S1).

The weakness of our study is that while we selected a cohort of fetuses with congenital heart defects to illustrate the utility of the measurements examined in this study, further studies of a larger cohort evaluating specific types of heart defects are required for further determination of the significance of abnormal ventricular chamber size and neonatal outcome. In addition, the technique used for obtaining our measurements may not be available to all clinicians.

5 | CONCLUSIONS

This study reports an integrated approach to evaluate the end-diastolic size of the right and left ventricular chambers that demonstrates the clinical utility with examples from fetuses with congenital heart defects.

CONFLICTS OF INTEREST

Drs Satou and Sklansky have no relationship with TomTec; Gn Dr DeVore purchased the TomTec software for clinical use. Berthold Klas works for TomTec and has assisted Dr DeVore in the development of the Excel spreadsheet. The work product of the Excel spreadsheet is not available commercially. Dr DeVore has not received any compensation for his work on this project from TomTec nor has he compensated TomTec for the work provided by Berthold Klas.

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REFERENCES


SUPPORTING INFORMATION
Additional Supporting Information may be found online in the supporting information tab for this article.