Validity of Echocardiographic Measurement in an Epidemiological Study

Project HeartBeat!

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Abstract—In Project HeartBeat!, a longitudinal study of cardiovascular disease risk factors in healthy children and adolescents, 3 samples of 40, 80, and 182 echocardiograms, respectively, were randomly selected and reread to evaluate intraobserver and interobserver variabilities and comparability between measurements of field echocardiographic technicians and reference readings at Texas Children’s Hospital. Included in the evaluation were 8 M-mode echocardiographic measurements, ie, aortic root diameter, left atrial diameter, and end-diastolic and end-systolic measurements of interventricular septal thickness, left ventricular (LV) diameter, and LV posterior wall thickness; 8 Doppler measurements; and a calculated LV mass. Means and SDs of the differences of the paired measurements were used to assess the relative bias and random error of the measurements. For the intraobserver comparison, means and SDs of the differences were very small, indicating that the echo measurements were performed consistently by each project echo technician. Interobserver comparison showed statistically but not clinically significant differences between the paired readings of end-diastolic septal thickness, end-systolic LV posterior wall thickness, and 5 Doppler measurements. Comparison with reference readings at Texas Children’s Hospital showed significant differences in diastolic LV diameter, systolic septal thickness, and right ventricular ejection time. These differences, however, were minimal with limited clinical significance. Mean differences in LV mass for the corresponding comparisons were –1.82, 4.50, and 0.0013 g, and the SDs were 18.79, 24.16, and 12.35 g, respectively. We conclude that the echocardiographic measurements taken from healthy children in a longitudinal study can be made accurately with acceptable reproducibility. (Hypertension. 1999;34:236-241.)

Key Words: echocardiography ■ left ventricular mass ■ observer variation ■ reproducibility of results ■ population study

The use of M-mode, 2-dimensional (2D), and Doppler echocardiography is an established, noninvasive clinical diagnostic method to examine various cardiac structure and functions. It has been increasingly used in population studies,1,2 including pediatric epidemiological studies,3 to access the role of the heart in human hypertension and other cardiovascular disease (CVD). Accurate and reproducible measurements are crucial to the success of this method in population studies and may be obtained only by both careful performance of echocardiographic imaging and consistent interpretation of the echocardiogram. Uniformity in the definition of an adequate echocardiogram and standardization of measurement methods are necessary to minimize intraobserver and interobserver variabilities and to facilitate interstudy comparison.4 Although these issues have been addressed previously, the magnitude of the intraobserver and interobserver measurement variabilities in population studies and its impact on interstudy comparison have not yet been explored systematically.

In Project HeartBeat!, a population-based, intensive longitudinal study to evaluate CVD risk factors as an interrelated set of growth processes in healthy children and adolescents, echocardiographic measurement of the cardiac geometry and function was an integral component. This provision allows assessment of the morphological and functional growth of the heart and determinants of different aspects of this growth process. A detailed quality assurance protocol was developed and implemented for echocardiographic measurements, including training, certification, and recertification of the echocardiographic technicians and continuous monitoring of data quality and measurement accuracy by a single pediatric echocardiographer or experienced technicians at Texas Children’s Hospital. This report presents the results of a quality assessment study designed to evaluate observer variability in echocardiographic measurements. Three aspects of the echocardiographic measurements were assessed: intraobserver variability, interobserver variability within Project HeartBeat! staff, and interinstitutional measurement variability between...
project echocardiographic technicians and experienced techni-
cians or a pediatric echocardiographer at Texas Children’s
Hospital. The latter also served as validation for echocardi-
ographic measurements collected in Project HeartBeat!.

Methods
Data collection of the Project HeartBeat! began October 1, 1991. Six
hundred seventy-eight children in 3 cohorts, 8, 11, and 14 years of
age in each cohort, respectively, were enrolled in the study from The
Woodlands and Conroe, Montgomery County, Tex. They were
followed and examined at 4-month intervals. Data collected included
hemodynamics (blood pressure, heart rate, echocardiography), blood
lipids, smoking (habits, cotinine levels), body size and composition,
maturity, diet and nutrition, physical fitness and activity, and
personal and family health history and health-related behavior.

Echocardiograms were performed with the Interspec XL (Apogee)
Annular Phased Array echocardiographic machine with either a 5- or
3.5-MHz transducer and recorded on VHS videotapes. The participants
were required to rest for 5 minutes before data collection. Echocard-
ionic examinations were done with the participants in supine position with a pillow under the right shoulder. The heart was imaged with 2D echocardiography in the parasternal long-axis view, parasternal short-axis view, apical view, subxiphoid
views, and suprasternal notch image. M-mode echocardiography,
2D, and 2D directed pulsed-wave Doppler recordings were obtained
by standard methods, and measurements were made online with the Interspec Apogee measurement software package. M-mode measurements followed the standards of the American Society of
Echocardiography (ASE). Eight M-mode echocardiographic mea-
surements and 8 Doppler measurements were specified as the core
measurements in the study protocol. They are aortic root diameter,
left atrial diameter, end-diastolic interventricular septal thickness,
diastolic interventricular septum, end-diastolic left ventricular (LV) diameter, end-diastolic LV posterior
wall thickness, end-systolic interventricular septal thickness, end-systolic LV diameter, end-systolic LV posterior wall thickness,
right ventricular (RV) prejection period, RV ejection time, isovolu-
metric relaxation time (IVRT), aortic peak velocity, aortic time-
velocity integral, heart rate, RV prejection period, and LV ejection
time. These 16 core original measurements and LV mass (LVM),
calculated from the formula reported by Devereux et al., were
included for quality assessment.

Quality assessment was based on samples reviewed from 3600
studies completed by October 1994 and recorded on videotapes.
Altogether, 4 persons were trained and certified as project echocar-
diographic technicians who performed the studies, although only 2
were active in the project at any given time. Three samples of
echocardiograms were chosen for quality assessment to evaluate
(1) intraobserver variability (sample 1), (2) interobserver variability
(sample 2), and (3) comparability between measurements of field
echocardiographic technicians and reference readings by experi-
enced technicians or the pediatric echocardiographer at Texas
Children’s Hospital (sample 3). No single echocardiographic record-
ing was included in >1 sample. For sample 1, 20 echocardiograms
from each of the 2 current echocardiographic technicians (40 total)
were randomly selected to be reread by the same project technician.
For sample 2, a total of 80 echocardiograms, 20 from the files for
each of the 4 echo technicians, were selected and remeasured by 1 of
the 2 current technicians, assigned to exclude their own originally
measured echocardiograms. For sample 3, 5% of the echocardi-
ograms from each of the 4 echo technicians, 182 in all, were randomly
selected and reviewed at Texas Children’s Hospital by an experi-
enced technician or a pediatric echocardiographer. All remeasure-
ments were made with the technician blinded to the original results.

Completeness and quality of all echocardiograms were determined
at the end of each study. Among the total 302 echocardiograms
selected for quality assessment, 3 at original measurement and 6 at
repeated measurement were rated clinically as suboptimal because of
poor acoustic windows in the participants. Pediatric cardiologists at
Texas Children’s Hospital concluded that even those studies consid-
ered to have imperfect image quality clinically permitted various
measurements that provided data of acceptable quality. Thus, all 302
echocardiograms were included in the quality assessment.

Analyses were performed with the SPSS statistical package. Differences between the repeated measures (observation 1 minus
observation 2) were first plotted against the mean of the repeated
measures (observation 1 plus observation 2) divided by . Differences
and SDs of the differences were then calculated, and the correspond-
ing paired t tests were performed. Means and SDs were also
computed for the original and repeated measurements.

Results
All 3 samples consisted of echocardiograms from project
participants 10 to 17 years of age (mean, 12.7 to 13.2 years). Twenty-two (55%) were male and 34 (85%) were nonblack in
sample 1. Thirty-six (45%) were male and 75 (93.8%) were
nonblack in sample 2. The corresponding numbers in sample
3 were 93 (51%) and 163 (89.6%), respectively.

Seventeen plots of the differences between repeated mea-
sures (observation 1 minus observation 2) versus the mean of
the repeated measures (observation 1 plus observation 2) divided by 2 for each of the 3 samples were generated (plots
not shown). These plots provided visual information on the
magnitude of disagreement, both random error and systematic
bias, and on the relationship of the differences and size of the
measurements. Most plots revealed uniform distribution pat-
tterns with most points on or near the zero-difference refer-
ence line. No easily discernible dependence of the differences
on measurement size was observed.

Table 1 displays the results of a comparison of original and
repeated measurements by the same Project HeartBeat! echo-
cardiographic technicians for the 16 core measurements. All
the means of differences in Table 1 were very small compared
with the magnitude of the measurements, and paired t tests
suggested no statistically significant systematic differences
between the original and repeated measurements. SDs of the
differences were also small, indicating high reproducibility of
within-observer measurements.

Results of interobserver comparisons are shown in Table 2.
As expected, most means and SDs of the differences were larger
than those of intraobserver differences. Differences
between the first and second readings of end-diastolic septal thickness, end-systolic LV posterior wall thickness, and 5
Doppler measurements were statistically significant. How-
ever, all these differences were small with very limited
clinical significance. Relatively large SDs of the differences
were found for end-diastolic LV posterior wall thickness,
end-systolic septal thickness, and end-systolic LV posterior
wall thickness.

Repeated measurements done at Texas Children’s Hospital
were compared with the original measurements by the Project
HeartBeat! echo technicians. Results are shown in Table 3.
The means and SDs of the differences were very close to those
of intraobserver differences and were smaller than those of
the interobserver comparison. Differences of 0.19 mm in
end-diastolic LV diameter, −0.25 mm in systolic septal
thickness, and −0.003 second in RV ejection time were
found to be statistically significant. These differences, how-
ever, were minimal with limited clinical significance. The
small SDs of the differences also suggested high comparabil-
ity of the echocardiographic measurements observed by
project echo technicians and experienced technicians and by pediatric echocardiographers at Texas Children’s Hospital.

The intraobserver, interobserver, and intersite comparisons of LVM are presented in Table 4. Means of differences were \(-1.82\), \(4.50\), and \(0.0013\) g for the paired measurements by the same project observers, by different project observers, and by project echo technicians and Cleveland Children’s Hospital echocardiographers, respectively. Mean differences were small, and none was statistically significant. The corresponding SDs were \(18.79\), \(24.16\), and \(12.35\) g, respectively, which were smaller than the corresponding SDs of original and repeated LVM measurements.

### Table 1. Intraobserver Comparison of Echocardiographic Measurements by Paired t Test

<table>
<thead>
<tr>
<th>M-mode measurements, mm</th>
<th>Observation 1</th>
<th>Observation 2</th>
<th>Difference (Obs 1−Obs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Aortic root diameter</td>
<td>40</td>
<td>23.58</td>
<td>2.66</td>
</tr>
<tr>
<td>Left atrial diameter</td>
<td>40</td>
<td>29.50</td>
<td>3.85</td>
</tr>
<tr>
<td>Septal thickness, diastolic</td>
<td>40</td>
<td>7.05</td>
<td>1.43</td>
</tr>
<tr>
<td>LV diameter, diastolic</td>
<td>40</td>
<td>44.03</td>
<td>4.38</td>
</tr>
<tr>
<td>LV posterior wall thickness, diastolic</td>
<td>40</td>
<td>7.45</td>
<td>2.26</td>
</tr>
<tr>
<td>Septal thickness, systolic</td>
<td>40</td>
<td>9.00</td>
<td>1.75</td>
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<tr>
<td>LV diameter, systolic</td>
<td>40</td>
<td>29.08</td>
<td>3.73</td>
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<tr>
<td>LV posterior wall thickness, systolic</td>
<td>40</td>
<td>12.08</td>
<td>2.72</td>
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Doppler measurements

<table>
<thead>
<tr>
<th></th>
<th>Observation 1</th>
<th>Observation 2</th>
<th>Difference (Obs 1−Obs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>RV prejection period, s</td>
<td>38</td>
<td>0.085</td>
<td>0.019</td>
</tr>
<tr>
<td>RV ejection time, s</td>
<td>38</td>
<td>0.323</td>
<td>0.031</td>
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<tr>
<td>IVRT, s</td>
<td>39</td>
<td>0.065</td>
<td>0.013</td>
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<tr>
<td>Aortic peak velocity, m/s</td>
<td>38</td>
<td>1.120</td>
<td>0.137</td>
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<td>Aortic time-velocity integral, mm</td>
<td>38</td>
<td>223.7</td>
<td>30.1</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>39</td>
<td>71.44</td>
<td>12.00</td>
</tr>
<tr>
<td>LV prejection period, s</td>
<td>39</td>
<td>0.091</td>
<td>0.016</td>
</tr>
<tr>
<td>LV ejection time, s</td>
<td>39</td>
<td>0.284</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Obs indicates observation.

### Table 2. Interobserver Comparison of Echocardiographic Measurements by Paired t Test

<table>
<thead>
<tr>
<th>M-mode measurements, mm</th>
<th>Observation 1</th>
<th>Observation 2</th>
<th>Difference (Obs 1−Obs 2)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SD</td>
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<tr>
<td>Aortic root diameter</td>
<td>79</td>
<td>23.25</td>
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<td>Left atrial diameter</td>
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<td>3.57</td>
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<tr>
<td>Septal thickness, diastolic</td>
<td>80</td>
<td>7.26</td>
<td>1.44</td>
</tr>
<tr>
<td>LV diameter, diastolic</td>
<td>80</td>
<td>43.99</td>
<td>4.86</td>
</tr>
<tr>
<td>LV posterior wall thickness, diastolic</td>
<td>80</td>
<td>7.23</td>
<td>1.75</td>
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<td>Septal thickness, systolic</td>
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<td>9.40</td>
<td>2.10</td>
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<tr>
<td>LV diameter, systolic</td>
<td>80</td>
<td>29.01</td>
<td>4.19</td>
</tr>
<tr>
<td>LV posterior wall thickness, systolic</td>
<td>80</td>
<td>12.19</td>
<td>2.34</td>
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Doppler measurements

<table>
<thead>
<tr>
<th></th>
<th>Observation 1</th>
<th>Observation 2</th>
<th>Difference (Obs 1−Obs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>RV prejection period, s</td>
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<td>0.088</td>
<td>0.017</td>
</tr>
<tr>
<td>RV ejection time, s</td>
<td>69</td>
<td>0.307</td>
<td>0.026</td>
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<tr>
<td>IVRT, s</td>
<td>66</td>
<td>0.075</td>
<td>0.017</td>
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<tr>
<td>Aortic peak velocity, m/s</td>
<td>77</td>
<td>1.117</td>
<td>0.153</td>
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<tr>
<td>Aortic time-velocity integral, mm</td>
<td>77</td>
<td>218.6</td>
<td>34.8</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
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<td>73.96</td>
<td>11.74</td>
</tr>
<tr>
<td>LV prejection period, s</td>
<td>69</td>
<td>0.093</td>
<td>0.016</td>
</tr>
<tr>
<td>LV ejection time, s</td>
<td>69</td>
<td>0.283</td>
<td>0.021</td>
</tr>
</tbody>
</table>

Obs indicates observation.
Measurements of a valid measuring process should be both accurate and reproducible. In epidemiology, accuracy of a measurement process is defined as the degree to which a measurement represents the true value of the attribute being measured. Reliability and, in common usage, both repeatability and reproducibility refer to the capacity to produce the same result on each occasion under identical conditions. A measurement process is accurate, or unbiased, if the expected value of the measurement is the true value of the parameter being estimated. A reliable process may produce the same result each time but may not give accurate measurements. A measurement of accuracy is the mean difference between a series of replicate determinations and the same true quantity. The reproducibility of the process is measured by the SD of the differences between the replicate determinations and the true quantity. A larger mean difference indicates larger systematic bias and lower accuracy of the process. Similarly, a larger SD suggests larger random errors and lower reproducibility.

The accuracy of a particular measurement process may be assessed only if the “true” value or “gold standard” value is known. Such true values were not known in the present study. An alternative method was then used to estimate the “relative” accuracy of the measurements. A series of paired determinations were obtained, and mean and SD of the differences were calculated. If the paired observations were the same except for random error, the mean of the differences would be expected to be 0, and the paired \( t \) test was used to test this hypothesis. Thus, the mean of differences offered a measure for average systematic differences (relative bias) between original and repeated measurements. The SD of the paired differences, which indicated variability of the difference between the first and second measurements and thus provided estimates of random errors, was the measure of reproducibility of the measurement process. Independence of

### TABLE 3. Comparison of Echocardiographic Measurements Between Project HeartBeat! Field Center and Texas Children’s Hospital by Paired \( t \) Test

<table>
<thead>
<tr>
<th></th>
<th>Observation 1*</th>
<th>Observation 2*</th>
<th>Difference (Obs 1–Obs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>M-mode measurements, mm</td>
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<td></td>
<td></td>
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<tr>
<td>Aortic root diameter</td>
<td>180</td>
<td>22.78</td>
<td>2.75</td>
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<tr>
<td>Left atrial diameter</td>
<td>179</td>
<td>28.40</td>
<td>3.50</td>
</tr>
<tr>
<td>Septal thickness, diastolic</td>
<td>179</td>
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<td>1.37</td>
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<td>LV diameter, diastolic</td>
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<td>LV posterior wall thickness, diastolic</td>
<td>173</td>
<td>6.60</td>
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<td>LV posterior wall thickness, systolic</td>
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<td>11.11</td>
<td>2.21</td>
</tr>
<tr>
<td>Doppler measurements</td>
<td></td>
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</tr>
<tr>
<td>RV prejection period, s</td>
<td>151</td>
<td>0.081</td>
<td>0.017</td>
</tr>
<tr>
<td>RV ejection time, s</td>
<td>151</td>
<td>0.310</td>
<td>0.025</td>
</tr>
<tr>
<td>IVRT, s</td>
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<td>0.076</td>
<td>0.014</td>
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<tr>
<td>Aortic peak velocity, m/s</td>
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<td>1.117</td>
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<td>Aortic time-velocity integral, mm</td>
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<td>212.3</td>
<td>32.3</td>
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<td>Heart rate, bpm</td>
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<td>77.27</td>
<td>12.16</td>
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<td>LV prejection period, s</td>
<td>178</td>
<td>0.083</td>
<td>0.017</td>
</tr>
<tr>
<td>LV ejection time, s</td>
<td>174</td>
<td>0.281</td>
<td>0.024</td>
</tr>
</tbody>
</table>

*Observation (Obs) 1, measured by Project HeartBeat! field center echo technician; observation 2, repeated measurements performed by Texas Children’s Hospital echo fellow or experienced echo technician.

### TABLE 4. Comparisons of LVM Calculated From Data Recorded by the Same Observer, a Different Observer, and in Field and Reference Settings by Paired \( t \) Test

<table>
<thead>
<tr>
<th>LVM Comparisons</th>
<th>Observation 1, g</th>
<th>Observation 2, g</th>
<th>Difference (Obs 1–Obs 2), g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Same observers</td>
<td>40</td>
<td>100.29</td>
<td>38.39</td>
</tr>
<tr>
<td>Different observers</td>
<td>80</td>
<td>98.17</td>
<td>28.17</td>
</tr>
<tr>
<td>Field vs reference setting*</td>
<td>173</td>
<td>86.69</td>
<td>29.65</td>
</tr>
</tbody>
</table>

*“Field” is observation (Obs) 1, measured by Project HeartBeat! field center echo technician; reference setting is observation 2, repeated measurements performed by Texas Children’s Hospital echo fellow or experienced echo technician.
the differences and size of the measurements is the prerequisite for the analyses described above.\(^\text{12}\)

The correlation coefficient between original and repeated measurements, often used in reproducibility studies of echo measurements, was not adopted in the present study because it is a measure of association, which is dependent on both the variation between study subjects (ie, between the true values) and the variation within study subjects (measurement error).\(^\text{12}\)

A high correlation coefficient does not necessarily indicate good agreement. An example of this is the unmodified ASE-cube LVM formula, which systematically overestimated LVM by 25%, with a correlation coefficient between calculated and necropsy LVM of 0.90.\(^\text{9}\)

The present quality assessment addressed 3 questions: How consistent were the Project HeartBeat! field echocardiographic measurements in the present study were either smaller and showed minimum mean percent uncertainties of 13.5%, 11.2%, 8.2%, 14%, 19.5%, and 23.4%, respectively, when the ASE convention was used for measurement. The percent uncertainty was calculated for each measurement on each observer. Leonardis and Cinelli\(^\text{15}\) compared measurements of aortic root diameter, left atrial diameter, end-diastolic and systolic LV diameters, and end-systolic septal thickness, and diastolic LV posterior wall thickness showed statistical significance. Comparison between Project HeartBeat! observers and Texas Children's Hospital observers revealed statistical significant differences of 0.19 mm for end-diastolic LV diameter and 0.01 mm for end-systolic septal thickness. Magnitudes of all these differences, however, were small compared with available results.

Sahn et al\(^\text{8}\) evaluated measurements on 5 echocardiograms by 76 observers for aortic root diameter, left atrial diameter, diastolic and systolic LV diameters, diastolic interventricular septal thickness, and diastolic LV posterior wall thickness and showed maximum mean percent uncertainties of 13.5%, 11.2%, 8.2%, 14%, 19.5%, and 23.4%, respectively, when the ASE convention was used for measurement. The percent uncertainty was calculated for each measurement on each recording as the 95th percentile confidence limit, determined as 1.97 SD, divided by the mean for the measurement times 100. Schieken et al\(^\text{17}\) reported interobserver measurement precision for aortic root diameter, left atrial diameter, end-diastolic interventricular septal thickness, end-diastolic LV diameter, end-diastolic LV posterior wall thickness, end-systolic LV diameter, and LV ejection time of 0.5, 0.6, 0.9, 2.3, 1.6, and 1.1 mm and 0.1 second, respectively. Again, the SDs reported here should be comparable to about twice the precision reported by Schieken et al.\(^\text{17}\) The estimates of “precision” for interobserver variability (SDs in Table 2 divided by 2) were larger in the present study for aortic root diameter and left atrial diameter but smaller for end-diastolic septal thickness and end-diastolic and end-systolic LV diameters, whereas they were similar for end-diastolic LV posterior wall thickness. By the same comparison, the estimates of precision for interobserver variability (SDs in Table 3 divided by 2) for the same echo parameters in the present study were either similar or smaller.

LVM has been repeatedly associated with CVD death in adults. Use of echocardiographic measurement of LVM as an outcome measure in epidemiological investigation of hypertension still poses a challenge regarding measurement precision and comparability across studies.\(^\text{19}\) Reproducibility of measurement of LVM has been studied by use of a variety of methods.\(^\text{4,15,20}\) A recent report from the Treatment of Mild Hypertension Study showed acceptable measurement accuracy and reproducibility in adults.\(^\text{18}\) The means and SDs of
intraobserver difference in LVM were reported from that study to be −0.0 and 20.4 g for 1 cardiologist and −6.1 and 26.8 g for another. The means and SDs for interobserver difference were 7.9 and 34.7 g between the 2 cardiologists and 5.7 and 46.1 g between the cardiologist and echo technicians. Means and SDs of intraobserver and interobserver measurement differences from our study in healthy children and adolescents were either similar or smaller. Minimal mean differences and small variation of the paired measurements by project echo technicians and experienced technicians or pediatric echocardiographers at Texas Children’s Hospital further suggest that echocardiographic measurement of LVM from population studies could be comparable to that from a clinical setting.

Doppler measurements of RV prejection period, RV ejection time, IVRT, aortic peak velocity, aortic time-velocity integral, heart rate, LV prejection period, and LV ejection time were included in the present analysis. Except for LV ejection time, no earlier results were available for between-study comparison. In our results, no significant difference was found for intraobserver comparison. Interobserver comparison showed only significant differences for RV prejection period, RV ejection time, IVRT, LV prejection period, and LV ejection time, and the interinstitutional comparison showed significant differences only for RV ejection time. The magnitudes of these differences, however, were trivial. Overall, the results showed good agreement between original and repeated measurements.

Variation of echocardiographic measurements arose from a variety of sources.1,4 Several factors can affect image quality and thus influence the definition of anatomic structures: participant’s body habitus; respiratory status and cooperation; the technician’s experience in recognizing the correct image signal and Doppler position and envelope, along with transducer orientation and placement; and the technician’s familiarity with echocardiographic equipment. Although criteria regarding these factors had been defined in the study protocol, their effects on measurement variability were not evaluated in the present study. The proportion of adequate echocardiograms in population studies has been reported variably from a minimum of 28% during the first 5 months of a population study to a recent report of 93%.2,4,20 Although several individual measurements were not possible and thus not included in the present analysis, all echocardiograms were included in the quality assessment study. This fact, with the intention to include as many as possible measures for each cardiac parameter, may have sacrificed reproducibility of measurements from a few technically imperfect echocardiograms, resulting in increased differences of the paired measurements and SDs of the differences.

We conclude that the echocardiographic measurements taken from healthy children in a longitudinal study can be made accurately with acceptable reproducibility. Echocardiographic measurements from an epidemiological study can compare favorably with those taken in a clinical setting with experienced technical support. Thus, these measurements can be applied meaningfully to clinical observation.

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