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Reproducibility of Left Ventricular Dimension Versus Area Versus Volume Measurements in Pediatric Patients With Dilated Cardiomyopathy

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Disclosures
None.

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Abstract

Background—Multiple echocardiographic methods are used to measure left ventricular size and function. Clinical management is based on individual evaluations and longitudinal trends. The Pediatric Heart Network VVV study (Ventricular Volume Variability) in pediatric patients with dilated cardiomyopathy has reported reproducibility of several of these measures, and how disease state and number of beats impact their reproducibility. In this study, we investigated the impact of observer and sonographer variation on reproducibility of dimension, area, and volume methods to determine the best method for both individual and sequential evaluations.

Methods and Results—In 8 centers, echocardiograms were obtained on 169 patients prospectively. During the same visit, 2 different sonographers acquired the same imaging protocol on each patient. Each acquisition was analyzed by 2 different observers; first observer analyzed the first acquisition twice. Intraobserver, interobserver, interacquisition, and interobserver-acquisition (different observers and different acquisition) reproducibility were assessed on measurements of left ventricular end-diastolic dimension, area, and volume. Left ventricular shortening fraction, ejection fraction, mass, and fractional area change were calculated. Percent difference was calculated as (interobservation difference/mean)×100. Interobserver reproducibility for both acquisitions was better for both volume and dimension measurements ($P \leq 0.002$) compared with area measurements, whereas intraobserver, interacquisition (for both observers), and interobserver-acquisition reproducibilities (for both observer-acquisition sets) were best for volume measurements ($P \leq 0.01$). Overall, interobserver-acquisition percent differences were significantly higher than interobserver and interacquisition percent differences ($P < 0.001$).

Conclusions—In pediatric patients with dilated cardiomyopathy, compared with dimension and area methods, left ventricular measurements by volume method have the best reproducibility in settings where assessment is not performed by the same personnel.

Keywords

cardiomyopathy; echocardiography; ejection fraction; pediatrics; shortening fraction

Left ventricular (LV) size and systolic function measures are important determinants of clinical management decisions and are frequently used as end points in clinical trials.[1–3] Clinical management is based on both individual evaluations and longitudinal trends. Numerous echocardiographic parameters, both geometric and nongeometric, have been used to evaluate properties of LV size and systolic function.[4] Geometric parameters are based on LV dimension, area, or volume measurements and are influenced by LV shape, whereas nongeometric parameters based on Doppler echocardiography and other techniques such as the first derivative of pressure with respect to time do not rely on these measurements and are not affected by LV shape.

Pediatric Echocardiographic Quantification guidelines by the American Society of Echocardiography recommend 2 geometric methods to assess LV size and function: a linear approach and a volumetric approach.[5,6] The linear method involves measurement of diameters and wall thickness by 2-dimensional (2D) or M-mode imaging and calculation of shortening fraction (SF) from short-axis images obtained in parasternal or subxiphoid views. The 5/6 area-length volumetric method involves (1) measurement of areas from short-axis LV images; (2) measurement of long-axis lengths from long-axis images obtained in apical 4-chamber or subxiphoid long-axis views; and (3) calculation of volumes, ejection fraction (EF), and mass. An additional systolic function index that has mainly been reported for right ventricles in the literature is the fractional area change obtained in the apical view.[7]

Although there is a considerable body of data on reproducibility of echocardiographic indices of LV size and systolic function, most investigations have not included evaluation of the full spectrum of factors that impact longitudinal delivery of care including intraobserver and interobserver effects on both image acquisition and measurement.[8–10] This is an important clinical issue in pediatric patients with dilated cardiomyopathy, where longitudinal measurements are performed and change over time is particularly important for clinical decision making. The Pediatric Heart Network–sponsored VVV study (Ventricular Volume Variability) has reported the reproducibility of several measures used to assess LV size and function in this population, and how disease state and number of beats impact their reproducibility.[11–14] The goal of this study was to examine the net individual and combined impact of each of these factors on the reproducibility of *dimension* versus *area* versus *volume* methods to assess LV size and systolic function. We hypothesized that volume measurements would yield higher reproducibility than dimension or area for settings where assessments are not performed by the same personnel.

Methods

Patients

The VVV study, a multicenter prospective study in pediatric subjects with stable dilated cardiomyopathy, was conducted by the National Heart, Lung, and Blood Institute-sponsored Pediatric Heart Network.[11] Description of the study design and protocol have been published in the main results article.[11] In brief, in 8 clinical centers, patients/parents were invited to participate in the study if they were <22 years, had known or suspected dilated cardiomyopathy with a disease duration >2 months, and had anticipated longitudinal follow-up to occur at the same institution. The enrollment period was between May 2005 and July 2007. Enrolled subjects were followed for 18 months. A study protocol echocardiogram was obtained at each clinical outpatient visit during these 18 months. In the current study, we included analysis of the baseline echocardiograms only. The study was performed following the guidelines provided by the Data and Safety Monitoring Board of the Pediatric Heart Network and of each center Institutional Review Board.

Acquisition and Analysis

At each center, consented subjects underwent the imaging protocol twice, performed by 2 different sonographers (acquisition 1 and acquisition 2) during the same baseline visit

(Figure 1) using the same ultrasound machine. For each variable collected, at least 3 cardiac cycles were acquired. Height and weight were obtained. Body surface area was calculated using the Haycock formula.[15] To enable comparison of clinical site and core laboratory measurements, a single observer at each of the participating sites also performed a subset of the measurements performed at the core laboratory, which included all of the measurements used in this analysis (Figure 1). At the echocardiography core laboratory, 2 observers performed measurements on all echocardiograms to determine the intraobserver (same observer/same acquisition), interobserver (different observers/same acquisition for acquisition 1 and 2), interacquisition (same observer-different acquisition for observer 1 and 2), and interobserver-acquisition (different observer/different acquisition analysis for both sets) reproducibilities (Table 1). One core laboratory observer repeated all measurements for the first acquisition 1 month later to assess intraobserver reproducibility. As reported in prior publications, all measurements were performed using custom DICOM software (Echotrace; Marcus Laboratories, Boston, MA). The measurements performed were standard linear and area measurements with no automation. The accuracy of the measurements using this software has been verified using phantoms.

Echocardiographic Indices—LV end-diastolic dimension, LV end-systolic dimension, and LV posterior wall dimension were measured by 2D and M-mode in parasternal short-axis view. LV mass was calculated for M-mode measurements. SF was calculated for both 2D and M-mode measurements. Echocardiograms with septal flattening or wall motion abnormalities were excluded from the 2D and M-mode analysis for SF.[6] LV end-diastolic volume, LV end-systolic volume, LV mass, and LVEF were calculated using the 5/6 area-length method.[6] Fractional area change was obtained in apical 4- and 2-chamber views and parasternal short-axis view by the following formula: (end-diastolic area–end-systolic area)/ end-diastolic area.

Statistical Analysis

LV systolic function indices by linear (end-diastolic dimension, LV mass, and SF by M-mode or 2D), area (fractional area change by 4 and 2 chambers), and volume (end-diastolic volume and EF by 5/6 area-length) were included in the analysis. For all analyses, 3-beat averaging was used. Intraobserver, interobserver, interacquisition, and interobserver-acquisition reproducibilities (Table 1) were determined using the outcome measure of percent difference (%difference) and intraclass correlation coefficients. Bland–Altman plots were also examined to assess the differences between observers and acquisitions. The %difference for a variable was defined as the absolute difference between the 2 different measurements, divided by the mean of the 2 measurements. The median, mean, and SD of %difference for all the LV systolic function indices were calculated and compared between the linear, area, and volumetric methods.

Paired *t* tests of measurements between different readings were used to examine reproducibility on a subject level. Overall variability in %differences was compared using repeated-measures ANOVA with measurement and subject as the repeated measure. The interobserver (acquisitions 1 and 2) and interacquisition (observers 1 and 2) reproducibilities were compared by modeling the net variability, defined as combination of all the raw

%differences on a subject level (ie, 13 measurements listed in Table 2), by the source of reproducibility (interobserver versus interacquisition).

Finally, a mixed-effects model with estimates obtained by restricted maximum likelihood was used to assess whether %difference significantly varied by different measurement types. The models used a compound symmetry covariance structure and treated method as a fixed effect and subject as a random effect. Individual echo measurements were treated as nested factors within each method (area, dimension, volume). To assess whether differences in reproducibility (%difference) among the 3 methods differed by disease severity, a mixed model with disease severity as a nested factor within each method was used. Disease severity was assessed using tertiles of indices of dilation (LV end-diastolic volume *z* score) and dysfunction (LVEF) calculated using the 5/6 area-length method.

Results

Demographics

During the study period, 169 patients (46% males) were enrolled.[12] Median age was 9.5 [range, 0.2–20.6]. Eighteen (11%) patients were infants. The majority of the patients had idiopathic dilated cardiomyopathy (104, 62%) or anthracycline-induced cardiomyopathy (25, 15%).

Reproducibility

Table 2 summarizes the reproducibility of the LV measurements. As expected, for all comparisons, intraobserver reproducibility was the best among all reproducibility analyses ($P<0.001$). Overall, interobserver-acquisition %differences were significantly higher than interobserver and interacquisition %differences ($P<0.001$).

Interobserver reproducibility for both acquisitions was better for volume and dimension measurements ($P\leq0.002$) compared with area measurements. Intraobserver, interacquisition (for both observers), and interobserver-acquisition reproducibilities (ie, for both observer-acquisition sets) were best for volume measurements ($P\leq0.01$). Figure 2 depicts Bland–Altman plots for interobserver-acquisition reproducibility (comparison 1) for the dimension, area, and volume measurements.

Table 3 summarizes the %differences between the local site versus observer 1 in the core laboratory. When compared, the overall interobserver reproducibility within the core laboratory (observers 1 and 2, Table 2) was better than the interobserver reproducibility between the local site and observer 1 ($P=0.001$).

Clinical Application

To provide a clinical frame of reference for the magnitude of the impact of the documented measurements variability, Table 4 demonstrates the lower and upper range of error of measurements for a hypothetical patient with normal LV size and function and another one with abnormal LV size and function. The %difference from interobserver-acquisition comparison 2 (different observer, different acquisition) was used.

Net Variability

To determine if having 2 observers versus 2 sonographers has a larger impact on reproducibility, we compared the net variability of interobserver reproducibility (combined for acquisitions 1 and 2) with the net variability of interacquisition reproducibility (combined for observers 1 and 2). The analysis demonstrated that there is a small but statistically significant difference between interacquisition and interobserver net variability (P=0.05). The interacquisition least squared mean was 12.45, and the interobserver least squared mean was 13.05.

Disease Severity

Figure 3 depicts the reproducibility comparisons by method relative to the degree of LV dilation and dysfunction (tertiles). Severity of LV dysfunction had a more significant impact on reproducibility compared with severity of LV dilation (the lower the LVEF the higher %difference). Also, significant differences were observed more frequently in reproducibility of interacquisition and interobserver-acquisition comparisons rather than interobserver and intraobserver comparisons. Overall, reproducibility of volume measurements was superior to area and dimension measurements regardless of disease severity.

Discussion

Prior VVV publications of reproducibility have been based on inter- and intraobserver variability for a single image acquisition.[11–13] The %differences reported in the current study are within the same range of prior VVV publications for analyzing the same set of data; however, an important aspect of this study is the demonstration that repeat image acquisition (the realistic clinical scenario) has a significant impact on reproducibility that is often overlooked.

As expected, in this study, intraobserver reproducibility was best for all variables among all comparisons, whereas interobserver-acquisition had the highest %differences (different acquisition and different observer). Most importantly, this multicenter study demonstrated that using volume methods instead of dimension or area methods to assess LV size and systolic function results in highest reproducibility in settings where a different sonographer and a different observer are used for serial echocardiographic evaluations. Furthermore, the reproducibility of volume measurements was less affected by disease severity compared with dimension or area measurements. Although the interacquisition variability was statistically significantly lower than interobserver variability, the overall effect size of both was sufficiently close that there is unlikely to be a clinically significant difference. Eliminating either source of variability (ie, using same sonographer or observer or both) will independently improve reproducibility and the decision to do so will depend on feasibility and cost.

This study has several important implications for this patient population. The clinical management of these patients over time relies on serial assessment of LV size and function, and our results imply that comparison of serial echocardiograms may be most valid if volume methods are used. It is worth noting that in the current study, SF by M-mode or 2D

has almost twice the %difference of EF by the 5/6 area-length algorithm when images are obtained by 2 different sonographers during the same visit and interpreted by 2 different observers. An important research implication of our findings is that in most research in pediatric populations, patient recruitment is the primary obstacle to study success; therefore, reducing the variance in end point measurements is a particularly important consideration to maximize study power. Furthermore, any reduction in sample size for clinical trials enabled by the enhanced reproducibility of data would reduce costs.

Although the importance of reproducible quantitative data on LV size and function is widely recognized, it is equally widely acknowledged that such data are not currently available in pediatrics.[6] A review by Cantinotti et al[16] examined the currently available literature and described the significant limitations faced in the field, including a lack of standardized approaches to measurements, as well as the lack of a robust database of measurements based on a large population of healthy children. Recently, normative values in children have been published based on the 5/6 area-length method as used in this study.[17] In addition, Lytrivi et al[18] published normal values for the 5/6 area-length method using subcostal imaging planes rather than the parasternal/apical planes used in our study. The superior reproducibility of the 5/6 area-length volume method over the dimension or area methods in different acquisition/observer analysis in this study can be explained by the fact that the combination of parasternal short-axis area measurement and measurement of LV length in the apical 4-chamber plane is less likely to be technician or observer dependent.

There are only a few specific studies analyzing reproducibility of LV size and systolic function, and these studies have been mainly in adults focusing on contrast injection to improve the variability of LVEF.[9,19] A study by Lipshultz et al[8] reported an intraclass correlation coefficient of 0.64 for SF by M-mode in 735 pediatric HIV patients where the images were reviewed locally and at a central core laboratory. In our study, the SF (M-mode) %difference was 13.4% when images were reviewed at the local site versus at the core laboratory.

The VVV study group has previously reported the superior reproducibility of using 3-beat averaging compared with using single beat[11] and using 5/6 area-length method compared with biplane Simpson or modified Simpson method to measure LV volume and systolic function.[13] Therefore, the current study used 3-beat averaging and 5/6 area-length method based on these previously published data. This approach is not commonly used clinically and could also improve longitudinal reproducibility.

In summary, in an era where LV function is not assessed routinely by volume methods (EF) in several pediatric echocardiographic laboratories, our study provides important information on reproducibility that could impact long-term management of children with dilated cardiomyopathy.

Limitations

As stated in prior VVV publications, although these analyses assessed the reproducibility of LV function assessment, the study was not designed to assess accuracy. It should be recognized, however, that clinical management of patients relies extensively on the

assessment of temporal trends, making reproducibility as or more important than accuracy. In addition, factors that may impact reproducibility of M-mode and 2D measurements, such as patient age, body size, disease severity, use of sedation, and technical factors about image acquisition, such as the use of harmonics or different transducers, were not examined in this analysis. In this aspect, the methods in this study mirror the typical clinical setting where the sonographer uses his/her best judgment to acquire the optimal images. In addition, decisions on therapeutic interventions rely on both echocardiographic and clinical variables. Although our analyses showed statistically significant differences in reproducibility and between the methods used in assessment of LV size and systolic function, the study design did not permit assessment of the clinical significance of these differences. Finally, at the initiation of the study, the centers and the core laboratory did not have the capacity to perform automated measurements. Similarly, 3D imaging capability was not present in all centers.

Conclusions

In pediatric patients with dilated cardiomyopathy, we found that compared with dimension and area methods, LV measurements by volume method have the best reproducibility in settings where assessment is not performed by the same personnel. This is an important finding with implications for the long-term evaluation of these patients by echocardiography.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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CLINICAL PERSPECTIVE

There are multiple echocardiographic methods in common clinical use for measuring left ventricular size and function. Clinical management is often based on both individual evaluations and longitudinal trends, but it is generally not possible or practical to have the same personnel perform and interpret the echocardiographic assessment over time. The Pediatric Heart Network VVV study (Ventricular Volume Variability) in pediatric patients with dilated cardiomyopathy has reported reproducibility of several of these measures, and how disease state and number of beats impact their reproducibility. In this study, we investigated the impact of observer and sonographer variation on reproducibility of dimension, area, and volume methods to determine the most reproducible method for both individual and sequential evaluations. We found that compared with dimension and area methods, left ventricular measurements by volume method have the best reproducibility in settings where assessment is not performed by the same personnel. In an era where left ventricular function is not assessed routinely by volume methods (such as ejection fraction) in many pediatric echocardiographic laboratories, our study provides important information on reproducibility that could impact long-term management of children with dilated cardiomyopathy.

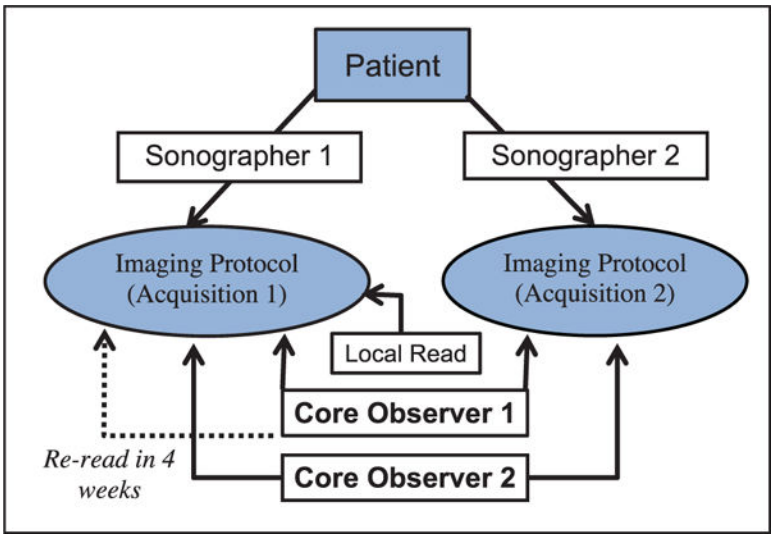

Figure 1.

Study flow. This schematic depicts the workflow for the acquisition and analysis of the echocardiograms.

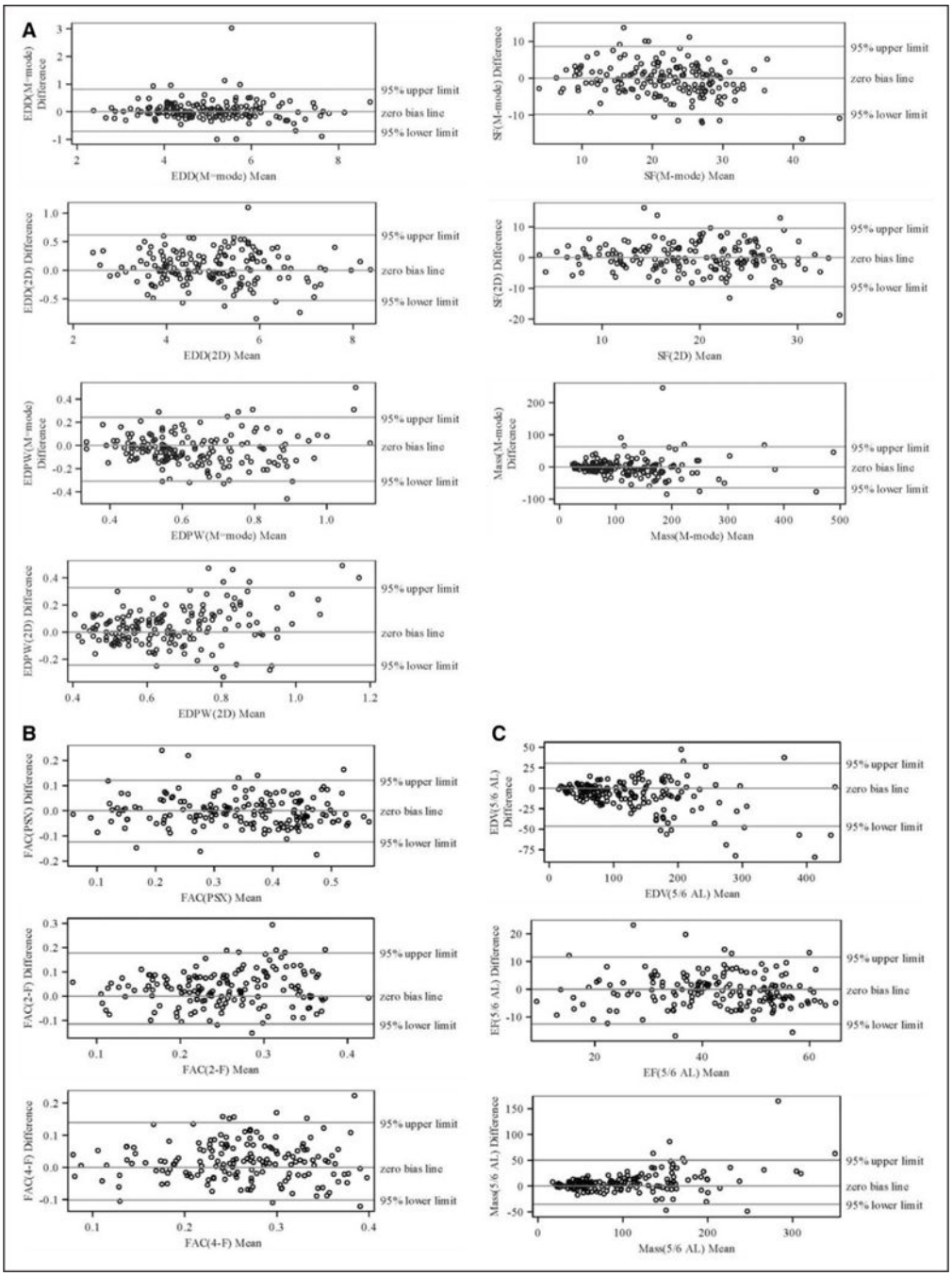

Figure 2.

Bland–Altman plots for the interobserver-acquisition variability (first reader and first acquisition vs second reader second acquisition) for dimension (**A**), area (**B**), and volume (**C**) measurements. 2D indicates 2 dimensional; 2-F, Fractional Area Change in apical 2 chamber view; 4-F, Fractional Area Change in apical 4 chamber view; 5/6 AL, 5/6 area-length method; EDD, end-diastolic dimension; EDPW, end-diastolic posterior wall; EDV, end-diastolic volume; EF, ejection fraction; FAC, fractional area change; PSX, parasternal; and SF, shortening fraction.

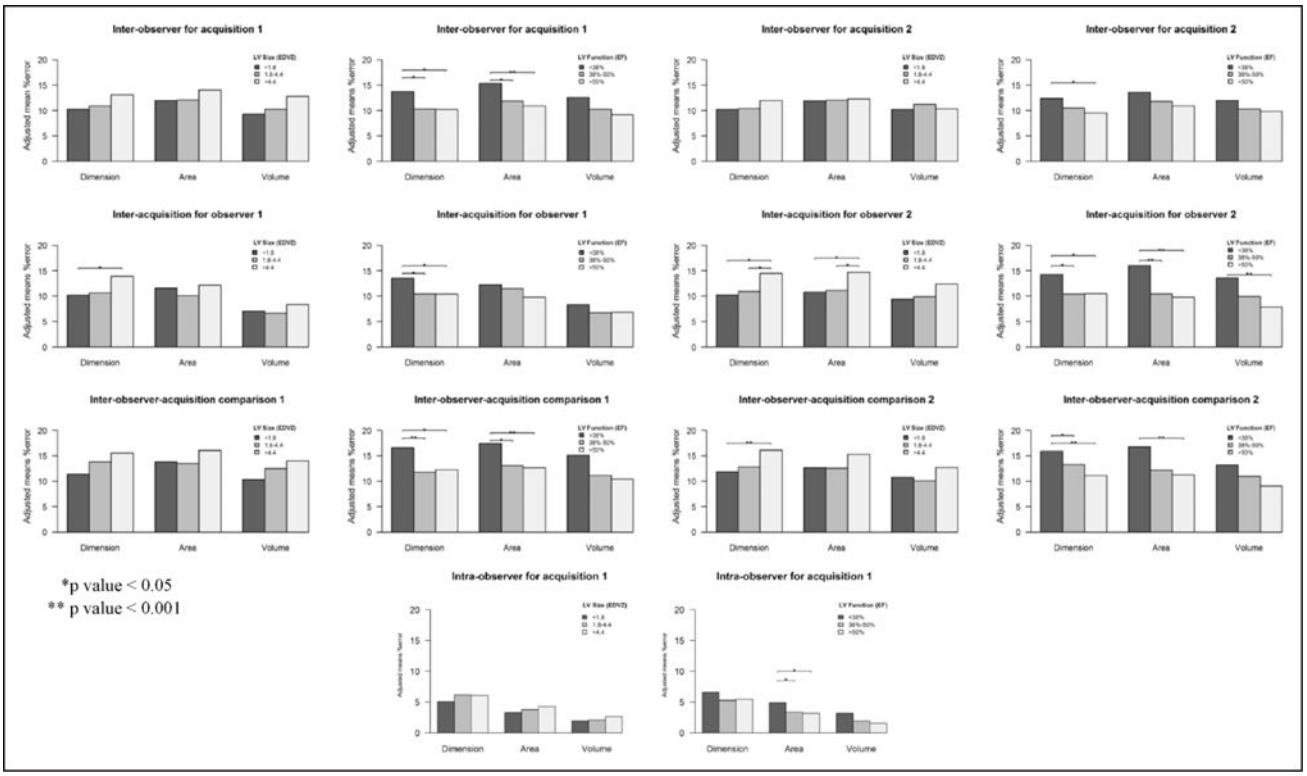

Figure 3.

Reproducibility comparisons by method and disease severity. This figure demonstrates the reproducibility comparisons by method relative to the degree of left ventricular (LV) dilation and dysfunction (tertiles). EDV indicates end-diastolic volume; and EF, ejection fraction.

Table 1

Reproducibility Analysis

	Observer 1 Reading Acquisition 1	Observer 1 Rereading Acquisition 1*	Observer 1 Reading Acquisition 2	Observer 2 Reading Acquisition 1	Observer 2 Reading Acquisition 2
Intraobserver for acquisition 1	x	x			
Interobserver for acquisition 1	x			x	
Interobserver for acquisition 2			x		x
Interacquisition for observer 1	x		x		
Interacquisition for observer 2				x	x
Interobserver-acquisition comparison 1	x				x
Interobserver acquisition comparison 2			x	x	

*One month later.

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Table 2

Reproducibility of Left Ventricular Measurements in the Core Laboratory

Left Ventricular Measurements	Intraobserver (1) for Acquisition 1 (%diff.)* ICC	Interobserver for Acquisition 1 (%diff.)	Interobserver for Acquisition 2 (%diff.)	Interacquisition for Observer 1 (%diff.)	Interacquisition for Observer 2 (%diff.)	Interobserver-Acquisition Comparison 1 (%diff.)†	Interobserver-Acquisition Comparison 2 (%diff.)
Dimension							
EDD (M-mode)	1.5±1.6	3.8±6.8	3.5±7.0	4.5±4.7	5.0±6.7	4.6±5.9	5.5±7.4
	n=166	n=167	n=165	n=164	n=166	n=165	n=165
	ICC:1.0	ICC:0.95	ICC:0.94	ICC:0.96	ICC:0.93	ICC:0.95	ICC:0.92
EDD (2D)	1.6±1.4	3.8±3.0	3.1±2.7	3.9±3.5	3.8±3.1	4.6±3.8	4.3±3.4
	n=167	n=168	n=165	n=165	n=165	n=165	n=165
	ICC:1.0	ICC:0.98	ICC:0.98	ICC:0.98	ICC:0.98	ICC:0.97	ICC:0.97
EDPW (M-mode)	8.2±8.9	14.7±13.1	16.2±13.0	14.5±12.5	13.0±11.9	16.7±13.0	17.7±15.5
	n=166	n=167	n=165	n=164	n=166	n=165	n=165
	ICC:0.89	ICC:0.72	ICC:0.70	ICC:0.74	ICC:0.77	ICC:0.67	ICC:0.63
EDPW (2D)	7.1±6.7	15.9±13.2	13.4±11.0	11.1±8.9	11.3±9.8	16.0±12.4	14.4±11.8
	n=167	n=168	n=165	n=165	n=165	n=165	n=165
	ICC:0.91	ICC:0.63	ICC:0.75	ICC:0.80	ICC:0.84	ICC:0.63	ICC:0.72
SF (M-mode)	7.1±9.4	13.7±11.4	12.1±9.7	15.6±14.2	18.0±16.2	17.9±16.5	18.4±14.4
	n=166	n=167	n=164	n=163	n=166	n=165	n=164
	ICC:0.97	ICC:0.92	ICC:0.91	ICC:0.84	ICC:0.81	ICC:0.82	ICC:0.81
SF (2D)	10.3±10.8	17.1±14.9	15.3±14.7	19.2±17.5	19.7±20.0	20.6±19.3	19.2±19.4
	n=167	n=168	n=164	n=165	n=164	n=164	n=165
	ICC:0.96	ICC:0.89	ICC:0.89	ICC:0.85	ICC:0.81	ICC:0.78	ICC:0.84
Mass (M-mode)	6.6±6.3	13.0±17.4	14.4±17.2	12.9±12.9	15.0±18.8	16.2±16.5	16.7±20.7
	n=166	n=167	n=165	n=164	n=166	n=165	n=165
	ICC:0.99	ICC:0.94	ICC:0.91	ICC:0.96	ICC:0.90	ICC:0.92	ICC:0.88
Area							
FAC (PSX)	3.2±6.8	13.6±14.8	12.8±12.3	11.4±15.4	14.9±14.3	15.9±17.8	14.4±14.8
	n=167	n=168	n=164	n=164	n=165	n=165	n=164

Left Ventricular Measurements	Intraobserver (1) for Acquisition 1 (%diff.)* ICC	Interobserver for Acquisition 1 (%diff.)	Interobserver for Acquisition 2 (%diff.)	Interacquisition for Observer 1 (%diff.)	Interacquisition for Observer 2 (%diff.)	Interobserver-Acquisition Comparison 1 (%diff.)†	Interobserver-Acquisition Comparison 2 (%diff.)
	ICC:0.99	ICC:0.91	ICC:0.91	ICC:0.91	ICC:0.90	ICC:0.87	ICC:0.90
FAC (2-C)	9.7±8.9	23.6±18.2	20.7±19.0	22.5±17.1	22.0±18.1	26.1±19.2	23.8±19.8
	n=166	n=164	n=143	n=149	n=154	n=156	n=147
	ICC:0.93	ICC:0.65	ICC:0.65	ICC:0.67	ICC:0.68	ICC:0.52	ICC:0.63
FAC (4-C)	5.8±5.7	18.4±15.1	17.9±17.5	17.8±16.5	14.9±12.3	20.0±16.4	19.2±19.1
	n=167	n=168	n=164	n=164	n=166	n=166	n=164
	ICC:0.98	ICC:0.73	ICC:0.76	ICC:0.76	ICC:0.82	ICC:0.67	ICC:0.73
Volume‡							
EDV (5/6 AL)	1.2±1.4	8.1±5.6	10.1±7.4	5.7±6.3	9.1±6.3	10.9±7.8	9.2±7.7
	n=167	n=168	n=162	n=162	n=165	n=165	n=162
	ICC:1.00	ICC:0.98	ICC:0.98	ICC:0.99	ICC:0.98	ICC:0.97	ICC:0.98
EF (5/6 AL)	2.5±4.0	11.1±10.2	10.7±11.1	8.7±11.7	11.7±10.6	12.8±14.2	11.3±10.5
	n=167	n=168	n=162	n=162	n=165	n=165	n=162
	ICC:0.99	ICC:0.91	ICC:0.91	ICC:0.93	ICC:0.91	ICC:0.88	ICC:0.90
Mass (5/6 AL)	2.8±2.6	12.6±10.6	11.7±8.3	7.3±7.3	10.3±7.7	12.8±10.3	12.3±10.3
	n=167	n=168	n=161	n=161	n=165	n=156	n=161
	ICC:1.00	ICC:0.94	ICC:0.95	ICC:0.99	ICC:0.97	ICC:0.94	ICC:0.94

%diff. indicates percent difference; 2-C, 2 chamber; 2D, 2 dimensional; 4-C, 4 chamber; 5/6 AL, 5/6 area-length method; EDD, end-diastolic dimension; EDPW, end-diastolic posterior wall; EDV, end-diastolic volume; EF, ejection fraction; FAC, fractional area change; ICC, intraclass correlation coefficient; interobserver-acquisition, different observer and different acquisition; PSX, parasternal; and SF, shortening fraction.

*Overall, intraobserver reproducibility had lowest %differences (P<0.001).

†Overall, interoberver-acquisition reproducibility had highest %differences (P<0.001).

‡Mixed model results demonstrated that both volume and dimension measurements had better interobserver reproducibility compared with area measurements, whereas volume measurements had best intraobserver, interacquisition, and intraobserver-acquisition reproducibility compared with dimension and area measurements.

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Table 3

Interobserver Reproducibility of Echocardiographic Measurements Between Local Site and Core Laboratory Versus Within Core Laboratory*

Measurements	n	Local Site Reader vs Observer 1 in Core Laboratory %difference	n	Observer 1 vs Observer 2 for Acqusition 1 in Core Laboratory %difference
Dimension				
EDD (M-mode)	167	4.3±3.8	167	3.8±6.8
		ICC:0.97		ICC:0.95
EDD (2D)	168	5.3±4.4	168	3.8±3.0
		ICC:0.95		ICC:0.98
EDPW (M-mode)	167	26.1±19.6	167	14.7±13.1
		ICC:0.37		ICC:0.72
EDPW (2D)	168	21.3±16.1	168	15.9±13.2
		ICC:0.53		ICC:0.63
SF (M-mode)	167	13.4±14.2	167	13.7±11.4
		ICC:0.92		ICC:0.92
SF (2D)	168	20.5±18.8	168	17.1±14.9
		ICC:0.86		ICC:0.89
Mass (M-mode)	167	20.1±16.1	167	13.0±17.4
		ICC:0.91		ICC:0.94
Area				
FAC (PSX)	167	16.5±16.6	168	13.6±14.8
		ICC:0.87		ICC:0.91
FAC (2-C)	164	22.6±18.9	164	23.6±18.2
		ICC:0.59		ICC:0.65
FAC (4-C)	167	19.4±17.7	168	18.4±15.1
		ICC:0.72		ICC:0.73
Volume				
EDV (5/6 AL)	167	10.3±9.5	168	8.1±5.6
		ICC:0.98		ICC:0.98
EF (5/6 AL)	167	12.8±12.6	168	11.1±10.2
		ICC:0.89		ICC:0.91
Mass (5/6 AL)	166	16.6±15.2	168	12.6±10.6
		ICC:0.94		ICC:0.94

%diff. indicates percent difference; 2-C, 2 chamber; 2D, 2 dimensional; 4-C, 4 chamber; 5/6 AL, 5/6 area-length method; EDD, end-diastolic dimension; EDPW, end-diastolic posterior wall; EDV, end-diastolic volume; EF, ejection fraction; FAC, fractional area change; ICC, intraclass correlation coefficient; PSX, parasternal; and SF, shortening fraction.

*P=0.001, determined from repeated-measures ANOVA with measurement and subject as repeated measure.

Table 4

Upper and Lower Range of Errors in 2 Hypothetical Clinical Scenarios (Interobserver-Acquisition Comparison 2)

Patient With Normal Echocardiographic Indices (2-Year Old, BSA 0.73)				
	Normal Values*	**%difference**	**Lower Range of Error**	**Upper Range of Error**
EDD (M-mode), cm	3.5	5.5	3.3	3.7
SF (M-mode), %	37	18.4	30.2	43.8
SF (2D), %	37	19.2	29.9	44.1
Mass (M-mode), gm	51.2	16.7	42.6	59.7
FAC (4-C), %	50	19.2	40.4	59.6
EDV (5/6 AL), cc	48	9.2	43.6	52.4
EF (5/6 AL), %	65	11.3	57.7	72.3
Mass (5/6 AL), gm	40	12.3	35.1	44.9
Patient with Abnormal Echocardiographic Indices (2-year old, BSA 0.73)				
	Abnormal values†	%difference	Lower range of error	Upper range of error
EDD (M-mode), cm	4.8	5.5	4.6	5.1
SF (M-mode), %	23	18.4	18.8	27.2
SF (2D), %	23	19.2	18.6	27.4
Mass (M-mode), gm	153.5	16.7	127.8	179.1
FAC (4-C), %	20	19.2	16.2	23.8
EDV (5/6 AL), cc	90	9.2	81.7	98.3
EF (5/6 AL), %	36	11.3	31.9	40.1
Mass (5/6 AL), gm	95	12.3	83.3	106.7

2D indicates 2 dimensional; 4-C, 4 chamber; 5/6 AL, 5/6 area-length method; BSA, body surface area; EDD, end-diastolic dimension; EDV, end-diastolic volume; EF, ejection fraction; FAC, fractional area change; and SF, shortening fraction.

*Z score close to 0.

†Z score of +5 or −5.