

Aortic size in children: Systolic measurements are different from diastolic measurements

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ABSTRACT

- Background** : Current guidelines recommended aortic measurements during diastole in adults and during systole in children. Recent studies in adults have demonstrated noteworthy differences in aortic measurements during systole and diastole in the same subjects. In the present study, we aimed to characterize systolic and diastolic differences in aortic measurements in healthy children.
- Materials and Methods** : This retrospective study included 272 children who had a complete echocardiogram and no heart disease. Aortic measurements at the annulus (ANN), aortic root (AOR), sinotubular junction (STJ), and ascending aorta (AAO) were performed. Systolic and diastolic values were compared by calculating the mean systolic to diastolic (SD) percent difference for each segment; if the SD difference was >5%, it was considered clinically important. Similar measurements were conducted by another observer in 18% of the subjects.
- Results** : Systolic measurements were larger than diastolic measurements with mean SD percent differences >5% ($P < 0.001$) for the AOR ($7.3\% \pm 5.5\%$), STJ ($10.24\% \pm 7.1\%$), and AAO ($9.8\% \pm 7.4\%$). There was no clinically significant SD difference for the ANN. There was an excellent intraclass correlation coefficient between observers (0.982–0.995).
- Conclusions** : Systolic measurements for the AOR, STJ, and AAO were larger than diastolic measurements. Normal reference values are utilized to design treatment for patients with abnormal aortic sizes, and the timing in the cardiovascular cycle used to decide the reference values should be equivalent to the timing used to make measurements in clinical practice. This is particularly imperative as patients transition their care from a pediatric to an adult cardiologist.
- Keywords** : Aorta, aortic diastolic dimension, aortic systolic dimension, guideline, pediatric cardiology

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INTRODUCTION

Aortic measurements and their normalized values are frequently used to assess disease severity and risk of further complications in children with heart disease. For example, aortic root (AOR) dilation in patients with Marfan syndrome is an important prognostic finding, indicating the need to increase surveillance for possible complications and to establish management strategies.^[1] Transthoracic echocardiography (TTE) is the primary modality used to measure aortic diameters and is widely considered a safe and reliable diagnostic tool.^[2,3] As per the guidelines of the American Society of Echocardiography (ASE), the aortic measurements should be performed during diastole in adult subjects using a leading edge-to-leading edge technique and during systole in pediatric subjects using an inner edge-to-inner edge technique.^[4,5] The pediatric guidelines highlight the fact that peak wall stress occurs when there is a maximum effect of vascular size on the function, correlating with peak flow during systole.^[5] However, the adult guidelines argue that end-diastolic measurements should be used because of the ease of identification using the QRS complex and the greater reproducibility from a more stable aortic pressure in late diastole.^[6] The best measurements for the aortic annulus (ANN) and proximal aortic structures (AOR, sinotubular junction [STJ], and ascending aorta [AAO]) are performed in parasternal long-axis views in both the guidelines.^[4,5] Previous studies have evaluated the differences between systolic and diastolic aortic measurements in the adult population, showing a statistically significant difference which is not clinically significant with a mean difference between the techniques of only 1–1.9 mm.^[7,8] The difference in measurement may have been influenced by the use of inner edge-to-inner edge measurements in systole and leading edge-to-leading edge measurements in diastole for these studies. A study comparing aortic systolic and diastolic measurements in adults using both the inner edge-to-inner edge technique and leading edge-to-leading edge technique found a 1–3 mm increase in size using the leading-edge technique in all measurements regardless of timing during a cardiac cycle.^[9] More patients with congenital heart disease are surviving into adulthood, thereby requiring long-term follow-up with serial measurements of aortic diameter. The transition from pediatric to adult cardiology care may be disrupted by the differences in methodology as it relates to aortic measurements.

MATERIALS AND METHODS

The Institutional Review Board at Nicklaus Children's Hospital (NCH) approved this retrospective study. A retrospective chart review of 272 patients with structurally normal hearts in the Nicklaus Children's

Hospital System (NCHS) electronic medical record (EMR) was conducted between January 1, 2016, and December 15, 2016. All newborns with a corrected gestational age of >37 weeks to patients 21 years of age who underwent a complete echocardiogram at NCHS were eligible for this study. Exclusion criteria included acquired or congenital heart disease as determined by history, physical examination, or radiographical studies (other than hemodynamically insignificant cardiac lesions such as patent foramen ovale, small patent ductus arteriosus, mild peripheral pulmonic stenosis, or a small coronary artery fistula); known or suspected systemic disorders with associated cardiovascular manifestations (such as Marfan syndrome, neoplasm, rheumatic fever, autoimmune disorder, and systemic hypertension); and patients with poor echocardiographic windows.

Measurements during systole and diastole were performed on all selected patients using digitally stored echocardiograms. Measurements of the proximal aorta during systole and diastole were performed using standard methodology using the inner edge-to-inner edge technique in two-dimensional parasternal long-axis view at the aortic ANN, AOR, STJ, and AAO. A second investigator reviewed 50 patients and independently performed the same set of measurements. The following data were gathered from the NCHS EMR: demographic and morphometric information (age, ethnicity, height, weight, body mass index, and body surface area) and medical information (primary diagnosis, other medications, family history of cardiac disease, and past medical history). Medical records were reviewed by the principal investigator and sub-investigators.

Demographic and clinical characteristics were presented as means with standard deviations for continuous variables or frequencies for categorical variables. Aortic systolic and diastolic measurements were compared using percent differences ($100 \times [\text{systole} - \text{diastole}] / \text{systole}$) as well as a one-tailed, one-sample *t*-test for each of the four areas (aortic ANN, AOR, STJ, and AAO). A difference >5% between systolic and diastolic measurements of aortic diameter was considered clinically significant. This cutoff was chosen as previous studies on reproducibility thresholds have shown measurement variability that may be responsible for up to 5% difference in measurement.^[10] Mean indexed aortic diameter measurements were calculated using the square root of body surface area with the Haycock method ($\text{mm}/\text{BSA}^{0.5}$). Linear multivariable regression of the mean indexed aortic diameter was utilized to understand the relationships between demographic factors (age, sex, race, and body surface area) and the percent difference in aortic diameter for each of the measurement areas. Due to the potential variation in measurement readings by the investigators, the reliability of the reviewer's observations was assessed by computing correlation coefficient.

RESULTS

During the retrospective chart review, 272 patients were included in the study. The demographics of the study population are shown in Table 1. The indications for the echocardiograms are also shown in Table 1, with abnormal electrocardiogram (20.2%), chest pain (18.4%), and murmur (39.3%) being the most common presentations. All patients had normal systolic aortic diameter measurements with Z-score between -2 and 2 using Boston Z-scores. Results of multivariable regression comparing the demographic data with a percent difference in aortic diameter are shown in Table 2. Females and Hispanic patients were noted to have statistically larger aortic ANN size, and African-American patients were noted to have statistically larger AAO size. However, the 95% confidence interval (CI) for percent difference was larger than 5% in only the AAO measurements in African-Americans when compared to white patients (95% CI: 0.48–7.76). Systolic measurements were noted to be larger than diastolic measurements in all four segments of the aorta. The difference in mean indexed aortic diameter and mean percent difference for the four segments are shown in Figure 1. The mean systolic-to-diastolic percent differences was $>5\%$ for the AOR ($7.3\% \pm 5.5\%$),

STJ ($10.24\% \pm 7.1\%$), and AAO ($9.8\% \pm 7.4\%$). The mean percent difference for the aortic ANN was $<5\%$ ($4.4\% \pm 8.1\%$). The mean indexed aortic diameter difference was statistically larger in all four segments with a difference of 0.69 at the aortic ANN, 1.51 at the AOR, 1.75 at the STJ, and 1.80 at the AAO. Intraclass correlation coefficient using measurements made by a second reader for 50 patients chosen randomly revealed excellent interobserver correlation (0.982–0.995).

DISCUSSION

In the present study, we analyzed the aortic systolic and diastolic measurements in children as performed using standard methodology with inner edge-to-inner edge technique. We observed that the systolic measurements for the AOR, STJ, and AAO were significantly larger than diastolic measurements with a percent difference of $>5\%$. Currently, Z-score data does not exist for diastolic measurements of aortic diameter in the pediatric population. Many measurements made in the pediatric population are normalized based on BSA. We provided normalized data based on the square root of BSA ($\sqrt{m^2}$) for both systolic and diastolic measurements, which also revealed a statistically significant larger measurement in systole for the AOR, STJ, and AAO. The aortic ANN measurement was also statistically larger when normalized with BSA, but the difference was notably less than the remaining aortic segments.

Current ASE guidelines call for different measurement techniques for aortic diameters in the pediatric and adult population with a diastolic leading edge-to-leading edge technique in adults and a systolic inner edge-to-inner edge technique in the pediatric population.^[4,5] Previous studies have attempted to explore the difference in aortic diameter measurements using the different techniques in the adult population.^[7,8] Current guidelines may lead to difficulties in following patients with aortopathies who require follow-up from childhood through adulthood. As these patients are transitioned from pediatric to adult cardiology care, the method used to measure aortic diameters also changes. This may lead to errors in the assessment of disease progression, affect the timing

Table 1: Demographic and clinical characteristics

Patient characteristics (n=272)	
Age (years), mean±SD	9.17±5.6
Male, n (%)	151 (55.5)
Race, n (%)	
White	245 (90.1)
Black	24 (8.8)
Other	3 (1.1)*
Ethnicity, n (%)	
Hispanic	200 (73.5)
Non-Hispanic	72 (26.5)
Indication, n (%)	
Abnormal EKG	55 (20.2)
Chest pain	50 (18.4)
Murmur	107 (39.3)
Syncope	26 (9.6)
Palpitations	24 (8.8)
Other	10 (3.7)

*These patients were excluded from the analysis. SD: Standard deviation, EKG: Electrocardiogram

Table 2: Associations between patient characteristics and percent differences between systole and diastole for four aortic measurement sites

Predictor (n=269)	Aortic annulus (% difference)			Sinuses of valsalva (% difference)			Sinotubular junction (% difference)			Ascending aorta (% difference)		
	β	95% CI	P	β	95% CI	P	β	95% CI	P	β	95% CI	P
Age (years)	0.02	-0.47-0.50	0.946	-0.35	-0.67--0.03	0.035	-0.41	-0.83-0.01	0.057	-0.51	-0.95--0.08	0.022
Sex (reference=male)	2.08	0.11-4.05	0.039	1.11	-0.21-2.43	0.099	-0.82	-2.55-0.90	0.347	0.26	-1.53-2.06	0.773
Black (reference=white)*	1.80	-2.19-5.80	0.375	-0.13	-2.81-2.56	0.927	3.23	-0.27-6.73	0.070	4.12	0.48-7.76	0.027
Hispanic (ref=non-Hispanic)	2.67	0.06-5.28	0.045	-0.06	-1.82-1.69	0.942	-0.04	-2.32-2.25	0.973	0.19	-2.19-2.56	0.878
Body Surface Area	2.05	-3.39-7.49	0.458	1.48	-2.16-5.13	0.424	2.41	2.35-7.17	0.319	4.94	-0.01-9.89	0.051

*Only black and white patients were included in the analysis due to extremely small sample of "other." P-values generated from multivariable linear regression. CI: Confidence interval

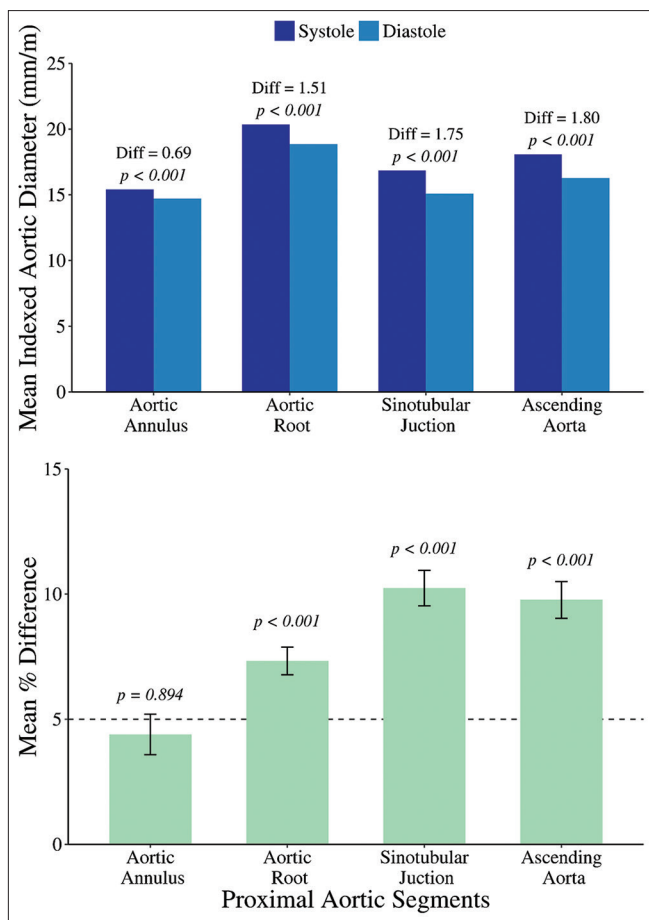


Figure 1: The difference in mean indexed aortic diameter and mean percent difference for the four segments

of intervention, and result in additional unnecessary imaging. On initial evaluation by adult cardiologists of patients at risk of developing aortopathies, a change in methodology may result in uncertainty of disease progression based on previous echo data obtained by their pediatric colleagues. This may result in additional unnecessary testing or more advanced imaging that may have been avoided if similar guidelines were used.

Our study revealed a statistically significant difference in aortic measurements in normal pediatric patients between systole and diastole with larger measures in all four segments during systole. The difference is less pronounced in the aortic ANN than the remaining segments which may reflect the increased distensibility of more distal aortic structures. The percent differences were clinically significant for the AOR, STJ, and AAO. In performing our measurements, we chose to do so using only the inner edge-to-inner edge technique. This was done to limit the confounding variable of including the anterior wall of the aorta while measuring the aortic diameter in diastole. The inner edge-to-inner edge technique also correlates better with advanced imaging modalities such as computed tomography and cardiac magnetic resonance imaging, which also use the inner-edge technique to measure the

aortic diameter.^[11] Advances in echocardiography have also allowed for improved resolution with the ability to localize the blood-tissue interface.^[12] However, this produces a limitation in this study in comparing the adult and pediatric guideline as the adult guideline currently calls for a leading edge-to-leading edge technique. The inclusion of the anterior wall of the aorta in the adult guideline may result in larger measurements during diastole which may decrease the percent difference between systolic and diastolic measurements found in this study. This study was performed on a patient with structurally normal hearts and no systemic disease and may not be generalizable to patients with structural heart disease or patients with aortopathies. Further research is needed to evaluate the difference in aortic diameter measure using the different techniques in these patient populations. An effort to modify the pediatric and adult guidelines regarding aortic measurements may improve the ability of providers to follow patients at risk for aortopathies and aid in the transition from pediatric to adult cardiologists. If a consensus on the method of measurement cannot be made, then the echocardiogram report should include a description of the method used for measurement, as this would need to be considered for serial measurements performed by different providers as well as when comparing echo measurements with other imaging modalities.

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Conflicts of interest

There are no conflicts of interest.

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