Normal Values and Differences in Ascending Aortic Diameter in a Healthy Population of Adults as Measured by the Pediatric versus Adult American Society of Echocardiography Guidelines

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Background: There is a lack of uniformity across echocardiographic society guidelines as to how the diameter of the ascending aorta is to be measured. The aims of this study were to compare measurements done using the diastolic leading edge–to–leading edge and systolic inner edge–to–inner edge (SIE) techniques in a large cohort of healthy adult individuals and to report the normal values for adults using the SIE technique.

Methods: Aortic diameters obtained according to the two guideline recommendations at the aortic annuls, sinuses of Valsalva, sinotubular junction, and ascending aorta in 1,148 healthy adult volunteers were compared. Bland-Altman analysis, paired *t* tests, and intraclass correlation coefficients were evaluated at each segment. SIE values are reported as normative data, according to age, gender, and body surface area.

Results: The diastolic leading edge–to–leading edge convention yielded smaller diameters (compared with SIE) at the aortic annulus and ascending aorta and larger diameters at the sinus of Valsalva and sinotubular junction ($P < .001$ for all). There was excellent correlation between these techniques, with intraclass correlation coefficients of 0.88 to 0.96. Interobserver variability was minimal and similar for both techniques. Using the SIE technique, diameters were larger for men and increased with age and larger body surface area.

Conclusions: Although there was a statistically significant difference in aortic diameter measures between the two conventions used, this difference was very small and correlations were excellent, suggesting that the difference has no clinical significance. The authors recommend that a standard convention be adopted within the American Society of Echocardiography and across all professional cardiovascular imaging societies for consistency and improved communication. (J Am Soc Echocardiogr 2016;29:166-72.)

Keywords: Aorta, Aortic systolic dimensions, Guidelines, Chamber quantification

Aortic size has significant prognostic and therapeutic implications in patients with aortic disease. A dilated aorta requires close imaging follow-up because aortic diameter is the strongest predictor of catastrophic events such as dissection[1] and is used to determine appropriate timing for prophylactic surgery.[2,3] Therefore, accurate and standardized measurement techniques of the diameter of the thoracic aorta using various imaging modalities are of utmost importance. However, there is a lack of uniformity among experts regarding the methodology to be followed to perform such measurements using echocardiography.[3-8] Importantly, the American Society of Echocardiography (ASE) recommends different methodologies to be used for pediatric and adult patients. Although both guidelines recommend two-dimensional echocardiographic measurements to be performed in the parasternal long-axis view, they differ with regard to timing in the cardiac cycle and interface selection in performing aortic measurements. The guidelines for adult chamber quantification and multimodality imaging of the aorta recommend a diastolic leading edge–to–leading edge (DLE) technique,[5,7] while pediatric guidelines recommend a systolic inner edge–to–inner edge (SIE) technique,[8] a method also supported by the 2010 American College of Cardiology and American Heart Association guidelines.[3]

The magnitude of difference in terms of aortic dimensions as measured by the DLE and SIE techniques is unclear. A better understanding of this difference would be useful in an attempt to standardize techniques across all patient groups and in understanding potential

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Abbreviations

ASE = American Society of Echocardiography

BSA = Body surface area

DLE = Diastolic leading edge–to–leading edge

ICC = Intraclass correlation coefficient

SIE = Systolic inner edge–to–inner edge

clinical implications. In addition, normative data for the SIE technique in adults have been reported only in relatively small cohorts. The aims of this study were to report normal aortic diameters in adults as measured by the SIE technique and to explore the magnitude of difference and correlation between the two measurement techniques (DLE and SIE) in a large population of normal individuals.

METHODS

Study Population

The population in this study consisted of consecutive healthy adult individuals (not meeting exclusion criteria as described below) referred to two hospitals in Italy (San Antonio Hospital in San Daniele del Friuli, Udine, and Cava de Tirreni-Amalfi Coast University Hospital, Salerno) for full screening of cardiovascular diseases from June 2007 to February 2014 and was described in detail by Vriz *et al.*[9] The screening evaluation included a physical examination, complete transthoracic echocardiography, and a thorough questionnaire about medical history, use of medications, cardiovascular risk factors, and lifestyle habits (alcohol intake, smoking, and physical activity). Three blood pressure measurements were obtained from the right arm, and the results were averaged to determine systolic and diastolic pressure. Body surface area (BSA) was calculated according to the formula of Du Bois and Du Bois ($0.20247 \times \text{height [m]}^{0.725} \times \text{weight [kg]}^{0.425}$).[10] Patients were excluded if they had any of the following conditions: coronary artery disease, systemic arterial hypertension, diabetes mellitus, morbid obesity (body mass index >30 kg/m^2), significant valvular heart disease (any regurgitation or stenosis greater than mild), congenital heart disease, bicuspid aortic valve, congestive heart failure, cardiomyopathy, sinus tachycardia, or use of illicit drugs. Elite athletes and subjects with inadequate echocardiographic image quality were also excluded. The study was approved by the institution's ethics board, and informed consent was obtained from all participants.

Echocardiography

Standardized transthoracic echocardiographic examinations were performed with commercially available equipment (Aloka α10 [Aloka, Tokyo, Japan] and Vivid 7 [GE Healthcare, Milwaukee, WI]) as previously described.[9] All images were digitally acquired and analyzed offline using EchoPAC software (GE Healthcare). Left ventricular ejection fraction and left ventricular end-diastolic diameter were obtained according to ASE guidelines (biplane Simpson and two-dimensionally derived dimensions from the parasternal long-axis view, respectively).[6] With regard to aortic dimensions, images were obtained from a parasternal long-axis view and measurements performed from two-dimensional images, initially following the adult ASE guidelines (DLE; Figure 1A) at the level of the aortic annulus, sinus of Valsalva, sinotubular junction, and proximal ascending Aorta (at the level of the right pulmonary artery).[5-7,11,12] At a later time, the same aortic segments were remeasured in all subjects according to the pediatric ASE guidelines (SIE; Figure 1B),[8] blinded to the initial measurements performed using the adult ASE guidelines. In both instances, measurements were performed perpendicular to the long axis of the aorta in five consecutive beats and averaged.

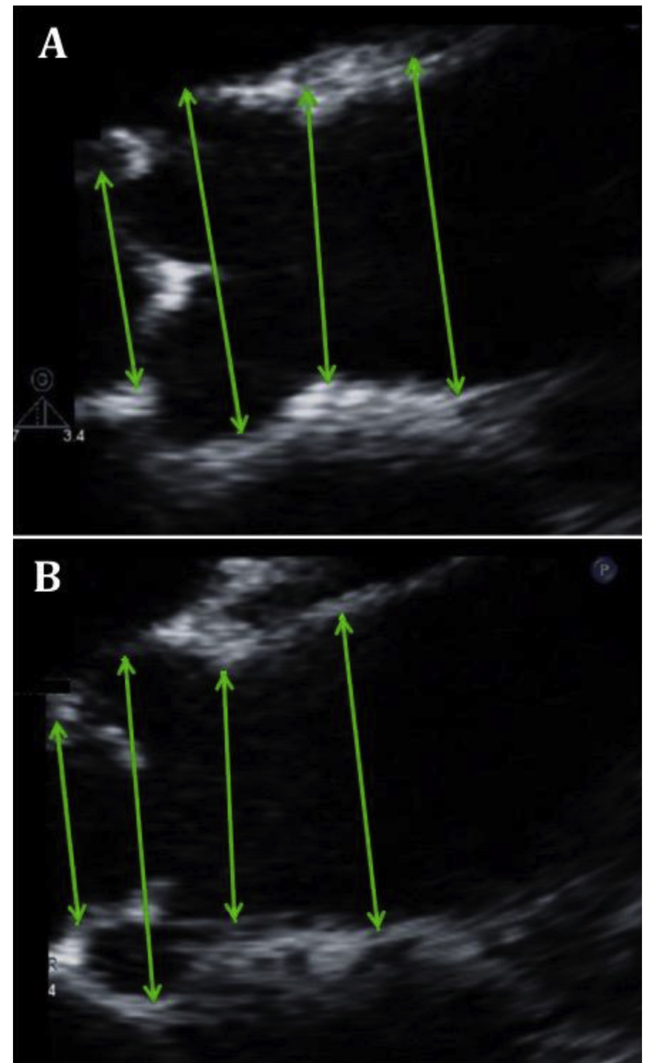

Figure 1 Ascending aorta measuring technique as recommended by the ASE guidelines for adults (DLE) **(A)** and pediatric patients (SIE) **(B)**. Note that adult guidelines recommend that measurements be performed in late diastole (aortic valve closed), including the anterior wall thickness (leading edge to leading edge, upper head of the caliper), while pediatric guidelines recommend mid-systole (valve is open), not including the anterior wall (inner edge to inner edge). *AAo*, Ascending aorta; *Ao* aorta; *LA*, left atrium; *LV*, left ventricle; *RPA*, right pulmonary artery; *RV*, right ventricle; *STJ*, sinotubular junction.[7,8]

Interobserver agreement was tested by remeasuring diameters with the DLE and SIE techniques in 100 randomly selected cases by two independent readers. Readers were blinded to each other, and they were allowed to select the cardiac cycles to be measured, but the average of five consecutive beats was recorded. Descriptive data on aortic dimensions as measured by the SIE technique were analyzed to serve as normative data for adults and presented as mean ± SD.

Statistical Analysis

To determine agreement between aortic measurements obtained by the DLE and SIE methods, paired measurements were compared at

each aortic segment. Analyses at each of the prespecified aortic segments were carried out using Bland-Altman plots, the mean of absolute differences, paired *t* tests, and intraclass correlation coefficients (ICCs). An ICC of ≥0.8 indicated excellent agreement. *P* values < .05 were considered to indicate statistical significance. To determine interobserver agreement, a random sample of 100 transthoracic echocardiographic studies was reviewed by two echocardiographers, each conducting measures using the two methodologies, reported as the mean of absolute differences, paired *t* test, and ICC. In describing normal values for the SIE aortic dimensions, two-sample *t* tests were used to compare mean SIE measurements between male and female subjects, and analysis of variance was used to compare means among quartiles of BSA and age. Multivariate regression analysis was used to test the effects of gender, BSA, and age independently.

RESULTS

From June 2007 to February 2014, 1,148 consecutive healthy adults without significant cardiovascular conditions were enrolled. Baseline characteristics of the study population are displayed in Table 1. In brief, 53% were women the average age was 45.1 ± 15.5 years (median, 45 years; range, 16–92) range, the mean BSA was 1.79 ± 0.19 m^2, and the mean systolic blood pressure was 123.8 ± 12.2 mm Hg. As expected, echocardiographic parameters of left ventricular function and dimensions were within normal limits (left ventricular ejection fraction, 63.9 ± 5.7%; left ventricular end-diastolic diameter, 47.4 ± 5.1 mm).

Table 2 shows aortic diameters at each aortic segment according to methodology used, the difference between DLE and SIE measurements (reported as DLE − SIE), and the ICC. SIE dimensions were larger than DLE dimensions at the aortic annulus and ascending aorta (mean of difference, −0.21 and −0.26 mm, respectively). At the sinuses of Valsalva and sinotubular junction, however, DLE measurements were larger than SIE measurements (0.21 and 0.43 mm, respectively). In all cases, these differences were statistically significant. Overall, the agreement between the two groups was excellent (ICC ≥ 0.9). Scatterplots describing correlation between DLE and SIE techniques and Bland-Altman analyses at each of the four measured segments are shown in Figure 2.

Table 3 displays aortic diameters among men and women at each aortic segment, as measured by the DLE (panel A) and SIE (panel B) methods. The mean diameter was significantly larger in men than in women at each segment, regardless of methodology applied.

Interobserver agreement was tested by two observers reading 100 randomly selected cases by both methodologies. Table 4 shows the analysis of these 100 cases, reporting small, nonsignificant interobserver variability for DLE and SIE. The DLE − SIE mean of absolute differences (measurements performed by a single observer) for these specific 100 cases was not statistically significant at the annulus (*P* = .48) or ascending aorta (*P* = .71), in contrast to the results reported in Table 2 for all 1,148 cases, but was larger by the DLE technique at the sinuses of Valsalva and sinotubular junction by 1.1 ± 0.8 and 1.1 ± 0.7 mm, respectively (both *P* < .01).

Table 5 details the dimensions of each of the aortic segments in this population of healthy adults, as measured by the SIE method, according to their gender, age, and BSA (both divided by quartiles). All segments were larger in men than in women and consistently increased with increasing age and BSA (*P* < .001 all). On multivariate regression analysis, the effects of age, gender, and BSA on aortic size were independent of each other. Table 6 describes upper limits of normal aortic dimensions and dimensions indexed by BSA for the SIE technique according to age group and gender.

Table 1 Baseline population characteristics

Variable	Value	Range
Age (y)	45.1 ± 15.5 (45)	16–92
Women	607 (53%)	
Height (cm)	168.7 ± 9.5 (168)	144–198
Weight (kg)	69.7 ± 12.1 (70)	41–113
BMI (kg/m^2)	24.40 ± 3.1 (24.2)	24.2–32.8
BSA (m^2)	1.79 ± 0.19 (1.78)	1.06–2.76
Systolic BP (mm Hg)	123.8 ± 12.16 (125)	84–160
Diastolic BP (mm Hg)	76.1 ± 8.69 (78)	44–98
Mean BP (mm Hg)	92.1 ± 8.85 (93.3)	57.3–113.3
Pulse pressure (mm Hg)	47.6 ± 9.79 (48)	20–80
HR (beats/min)	71.0 ± 11.79 (70)	45–105

BMI, Body mass index; *BP*, blood pressure; *HR*, heart rate.
Data are expressed as mean ± SD (median) or as number (percentage).

Table 2 Comparison of thoracic aortic diameter at each aortic segment measured by the DLE and SIE technique with absolute measures, mean of absolute differences, and ICC

Aortic segment	*n*	DLE dimension (mm)	SIE dimension (mm)	DLE − SIE difference (mm)	*P* value (*t* test)	ICC
Aortic annulus	1,142	19.8 ± 2.1	20.0 ± 2.1	−0.21 ± 1.02	<.001	0.88
Sinuses of Valsalva	1,144	30.1 ± 3.6	29.8 ± 3.7	0.21 ± 1.35	<.001	0.93
Sinotubular junction	1,138	25.6 ± 3.3	25.1 ± 3.2	0.43 ± 1.44	<.001	0.90
Ascending aorta	1,113	28.2 ± 3.7	28.5 ± 3.5	−0.26 ± 0.98	<.001	0.96

Data are expressed as mean ± SD. *P* values indicate differences between the two methods.

DISCUSSION

ASE guidelines for adult populations recommend using a DLE technique to measure the sinuses of Valsalva and ascending aorta, a methodology described in the literature for >25 years.[12] Although the leading edge–to–leading edge technique is counterintuitive in that the dimension includes the anterior aortic wall rather than the aortic lumen alone, this was originally thought to overcome technical limitations of old ultrasound systems that would create artifacts at the level of the blood-tissue interface, affecting the accurate visualization of the inner edge of the anterior aortic wall. Other imaging modalities (e.g., computed tomography, magnetic resonance imaging) never adopted this approach, because this limitation is inherent to the physics of ultrasound. Most important, improvements in ultrasound systems over the years have decreased the aforementioned effect and minimized artifacts in that regard. In part for these reasons, guidelines in pediatric populations did not adopt the leading-edge approach and elected to use the SIE technique, resulting in discrepant methodologies used even between adult and pediatric echocardiographers.

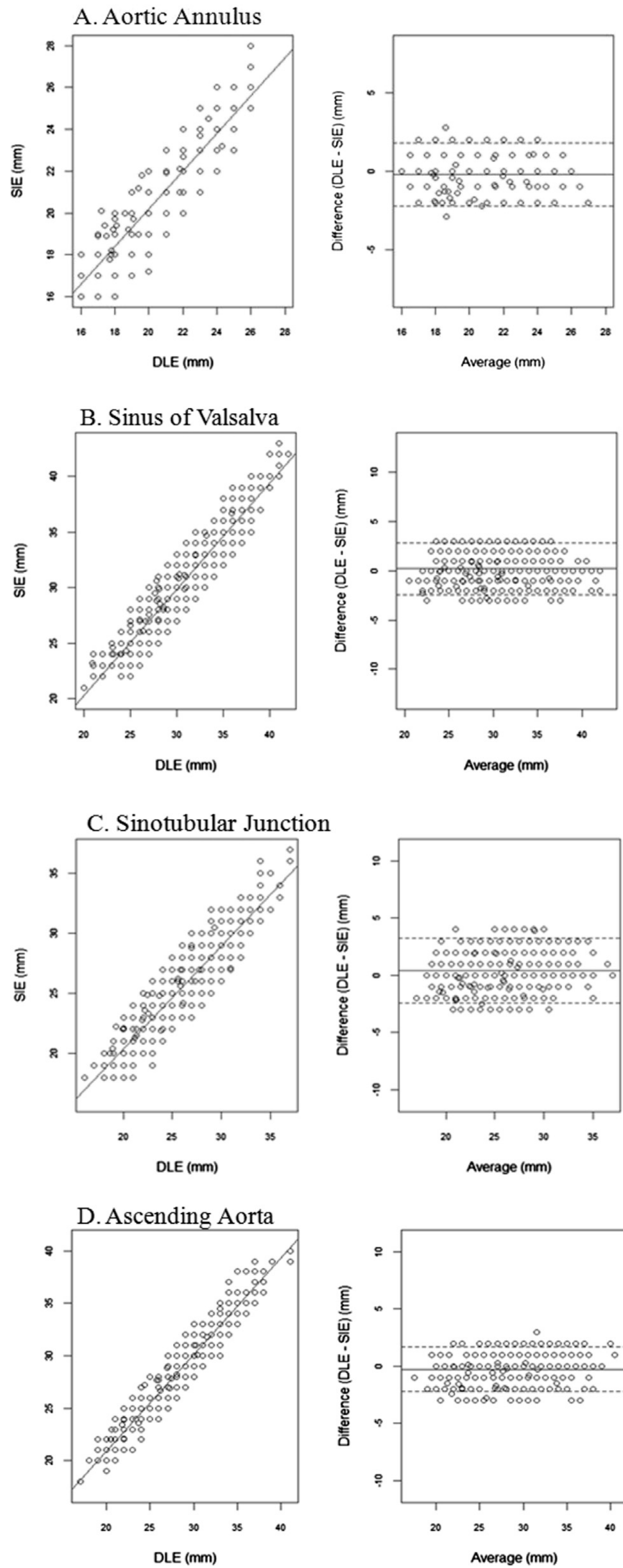

Figure 2 Scatterplots with regression line *(left)* and Bland-Altman plots *(right)* with difference (in mm) between the DLE and SIE measurements at the level of the aortic annulus **(A)**, sinuses of Valsalva **(B)**, sinotubular junction **(C)**, and ascending aorta **(D)**.

Table 3 Gender differences in aortic dimensions as measured by the DLE and SIE techniques

Dimension	Diameter (mm)		
	Men	Women	*P*
DLE technique			
Aortic annulus	21.0 ± 1.9	18.7 ± 1.5	<.001
Sinuses of Valsalva	31.8 ± 3.5	28.5 ± 2.9	<.001
Sinotubular junction	26.9 ± 3.4	24.3 ± 2.7	<.001
Ascending aorta	29.3 ± 3.8	27.3 ± 3.2	<.001
SIE technique			
Aortic annulus	21.2 ± 2.0	18.9 ± 1.5	<.001
Sinuses of Valsalva	31.7 ± 3.6	28.2 ± 2.9	<.001
Sinotubular junction	26.6 ± 3.1	23.8 ± 2.5	<.001
Ascending aorta	29.7 ± 3.6	27.4 ± 3.1	<.001

Data are expressed as mean ± SD.

The discrepant methodologies could have significant clinical implications, such as inability to compare serial dimensions, or a fictitious change in dimensions for a given patient while transitioning from childhood to adulthood, particularly important in patients with aortopathies at a young age (genetically related aortopathies such as Marfan syndrome). Indeed, a recent report from the National Registry of Genetically Triggered Aaortic Thoracic Aneurysms and Cardiovascular Conditions described that at centers of excellence for the care of patients with aortopathies, echocardiographers favor using the SIE technique even when imaging adult patients.[13] Therefore, it seems reasonable to attempt to unify the measuring techniques. On the other hand, most data on the prognostic value of aortic dimensions in adults come from studies in which measurements were obtained using the DLE technique.[1,14-16] A careful understanding of the differences in dimensions obtained by DLE and SIE techniques becomes critical and forms the basis for our analysis in this large cohort of healthy adult subjects.

We present the largest study to date comparing transthoracic echocardiography–based measurements of the ascending aorta performed as recommended by the pediatric ASE (SIE) and the adult ASE (DLE) guidelines,[5,7,8] and we report the largest series of normal values for aortic dimensions in adults as measured with the SIE technique. The three major findings of our study are as follows. First, although there was a statistically significant difference between the two measurement techniques, the differences were very small (mean, <1 mm) and unlikely to be clinically relevant. Second, there was excellent correlation between the two measuring techniques. Third, in a subset of 100 patients, agreement between techniques and between observers was high, suggesting that at least part of the intertechnique differences could be related to measure/remeasure variability and that reproducibility is equally high for both techniques.

Similar to our findings, Son *et al.*[17] reported in a smaller study of 112 healthy Korean volunteers that diastolic aortic diameters were larger than systolic diameters at the sinus of Valsalva and the sinotubular junction but smaller at the level of the ascending aorta. Systolic distension of the ascending aorta was thought to account for this reverse relationship, one that does not have such a dramatic effect on the more proximal segments. The absolute differences in diameter, however, were larger than in our study (mean difference up to 1.9 mm). In

Table 4 Interobserver comparison between two echocardiographers among 100 cases measured with the DLE and SIE techniques

Dimension	*n*	Observer 1 (mm)	Observer 2 (mm)	Absolute differences (mm)	*P*	Percentage absolute difference	ICC
DLE technique							
Aortic annulus	100	19.8 ± 1.9	19.71.8	0.03 ± 0.7	.67	2.0 ± 2.9	0.93
Sinuses of Valsalva	100	29.6 ± 3.4	29.6 ± 3.6	0.02 ± 0.8	.81	1.9 ± 2.1	0.97
Sinotubular junction	100	26.0 ± 3.0	26.2 ± 3.0	−0.12 ± 0.8	.06	1.3 ± 1.9	0.98
Ascending aorta	100	27.9 ± 3.1	28.0 ± 3.2	−0.05 ± 1.0	.62	2.6 ± 2.7	0.94
SIE technique							
Aortic annulus	100	19.7 ± 1.8	19.5 ± 1.8	0.16 ± 0.9	.08	3.4 ± 3.3	0.87
Sinuses of Valsalva	100	28.5 ± 3.2	28.4 ± 3.3	0.01 ± 0.7	.89	1.6 ± 2.1	0.97
Sinotubular junction	100	24.9 ± 2.9	24.9 ± 2.9	−0.01 ± 0.5	.84	1.0 ± 1.8	0.98
Ascending aorta	100	28.0 ± 3.1	28.0 ± 3.2	−0.05 ± 0.8	.57	2.3 ± 2.3	0.96

Data are expressed as mean ± SD.

a study comparing systolic and diastolic measurements as well as leading-edge and inner-edge methodologies, Muraru *et al.*[18] reported that leading-edge measurements were 1 to 2 mm larger than inner-edge measurements at all segments when both were performed at the same timing of the cardiac cycle. Similarly, when using the same interface (leading edge or inner edge), systolic measurements were 1 to 2 mm larger than diastolic measurements. It is foreseeable that our findings of minimal variation in the DLE versus SIE dimensions could be explained as a result of systolic measurements (larger than diastolic) offsetting the inner-edge factor (smaller than the leading edge), concordant with Muraru *et al.*'s findings.

Confining our study to individuals free of cardiovascular disease poses an inherent limitation of generalizability to those with aortic pathology. Differences in measurement technique may become more discrepant among individuals with significant vascular calcification or with atherosclerosis or in postoperative individuals. In such cases, thicker tissue and greater shadowing can lead to larger values, as obtained by the DLE method. Increased or decreased vascular distensibility in pathologic states may further affect measurement discrepancies. Performing a similar analysis among individuals with thoracic aortic aneurysms or significant atherosclerotic disease may further clarify this issue. Finally, an absolute difference in measuring technique that is irrelevant for adults may become relevant for pediatric patients because their aortic diameters are smaller (e.g., a difference of 1 mm would be less relevant for an adult aorta measuring 30 mm than for a pediatric aorta measuring 15 mm).

In addition, we provide a detailed description of the normal values for aortic dimensions in healthy adults measured using the SIE technique according to gender, age, and BSA, variables shown in this study to independently affect aortic size. This is the largest cohort presented to date and should be used as reference normative data, as presented in Table 6 (upper limits of normal dimensions). Before this study, the largest report providing adult echocardiographic reference values via the SIE convention consisted of only 281 individuals.[18]

CONCLUSIONS

Although there was a statistically significant difference in aortic diameter between the two conventions used, this difference was very small and correlations were excellent, suggesting that the difference has little clinically significance. We believe that a unified standard convention should be adopted within the ASE and across all professional cardiovascular imaging societies for consistency and improved communication. The small, albeit statistically significant, difference and excellent correlation should facilitate such unifying process. Geared toward this goal, we report normal values for aortic dimensions in adults, according to gender, age, and BSA, as measured with the SIE technique. This may be an initial move toward unified standards for echocardiography that could potentially expand to other imaging modalities.

REFERENCES

1. Jondeau G, Detaint D, Tubach F, Arnoult F, Milleron O, Raoux F, et al. Aortic event rate in the Marfan population: a cohort study. Circulation 2012;125:226-32.
2. Erbel R, Aboyans V, Boileau C, Bossone E, Bartolomeo RD, Eggebrecht H, et al. 2014 ESC Guidelines on the diagnosis and treatment of aortic diseases: document covering acute and chronic aortic diseases of the thoracic and abdominal aorta of the adult. The Task Force for the Diagnosis and Treatment of Aortic Diseases of the European Society of Cardiology (ESC). Eur Heart J 2014;35:2873-926.
3. Hiratzka LF, Bakris GL, Beckman JA, Bersin RM, Carr VF, Casey DEJ, et al. 2010 ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM guidelines for the diagnosis and management of patients with Thoracic Aortic Disease: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. Circulation 2010;121:e266-369.
4. Evangelista A, Flachskampf FA, Erbel R, Antonini-Canterin F, Vlachopoulos C, Rocchi G, et al. Echocardiography in aortic diseases: EAE recommendations for clinical practice. Eur J Echocardiogr 2010;11:645-58.
5. Goldstein SA, Evangelista A, Abbara S, Arai A, Asch FM, Badano LP, et al. Multimodality imaging of diseases of the thoracic aorta in adults: from the American Society of Echocardiography and the European Association of Cardiovascular Imaging: endorsed by the Society of Cardiovascular Computed Tomography and Society for cardiovascular Magnetic Resonance. J Am Soc Echocardiogr 2015;28:119-82.
6. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards

Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr 2005;18:1440-63.

7. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015;28:1-39.
8. Lopez L, Colan SD, Frommelt PC, Ensing GJ, Kendall K, Younoszai AK, et al. Recommendations for quantification methods during the performance of a pediatric echocardiogram: a report from the Pediatric Measurements Writing Group of the American Society of Echocardiography Pediatric and Congenital Heart Disease Council. J Am Soc Echocardiogr 2010;23:465-95. quiz 576–7.
9. Vriz O, Aboyans V, D'Andrea A, Ferrara F, Acri E, Limongelli G, et al. Normal values of aortic root dimensions in healthy adults. Am J Cardiol 2014;114:921-7.
10. Du Bois D, Du Bois EF. A formula to estimate the approximate surface area if height and weight be known. Nutrition 1989;5:303-11. discussion 312–3.
11. Devereux RB, de Simone G, Arnett DK, Best LG, Boerwinkle E, Howard BV, et al. Normal limits in relation to age, body size and gender of two-dimensional echocardiographic aortic root dimensions in persons >/=15 years of age. Am J Cardiol 2012;110:1189-94.
12. Roman MJ, Devereux RB, Kramer-Fox R, O'Loughlin J. Two-dimensional echocardiographic aortic root dimensions in normal children and adults. Am J Cardiol 1989;64:507-12.
13. Asch FM, Yuriditsky E, Prakash SK, Roman MJ, Weinsaft JW, Weissman G, et al. The need for standardized methods for measuring the aorta: multimodality core lab experience from the National Registry of Genetically Triggered Thoracic Aortic Aneurysms and Cardiovascular Conditions (GenTAC). J Am Coll Cardiol Img. In press.
14. Clouse WD, Hallett JWJ, Schaff HV, Gayari MM, Ilstrup DM, Melton L Jr. Improved prognosis of thoracic aortic aneurysms: a population-based study. JAMA 1998;280:1926-9.
15. Davies RR, Goldstein LJ, Coady MA, Tittle SL, Rizzo JA, Kopf GS, et al. Yearly rupture or dissection rates for thoracic aortic aneurysms: simple prediction based on size. Ann Thorac Surg 2002;73:17-27. discussion 27–8.
16. Roman MJ, Rosen SE, Kramer-Fox R, Devereux RB. Prognostic significance of the pattern of aortic root dilation in the Marfan syndrome. J Am Coll Cardiol 1993;22:1470-6.
17. Son MK, Chang SA, Kwak JH, Lim HJ, Park SJ, Choi JO, et al. Comparative measurement of aortic root by transthoracic echocardiography in normal Korean population based on two different guidelines. Cardiovasc Ultrasound 2013;11:28-35.
18. Muraru D, Maffessanti F, Kocabay G, Peluso D, Dal Bianco L, Piasentini E, et al. Ascending aorta diameters measured by echocardiography using both leading edge-to-leading edge and inner edge-to-inner edge conventions in healthy volunteers. Eur Heart J Cardiovasc Imaging 2014;15:415-22.

Table 5 Aortic dimensions using the SIE technique in healthy adults, according to gender, age quartiles, and BSA quartile

Dimension	Gender			Age (y)					BSA quartile				
	Male (*n* = 541)	Female (*n* = 607)	*P*	16–34 (*n* = 300)	35–45 (*n* = 276)	46–56 (*n* = 299)	57–92 (*n* = 273)	*P*	1 (*n* = 287)	2 (*n* = 293)	3 (*n* = 282)	4 (*n* = 286)	*P*
Aortic annulus (mm)	21.2 ± 2.0	18.9 ± 1.5	<.001	19.7 ± 1.9	20.2 ± 2.2	20.0 ± 2.1	20.3 ± 2.2	.001	18.7 ± 1.6	19.4 ± 1.6	20.4 ± 1.9	21.6 ± 2.1	<.001
Sinuses of Valsalva (mm)	31.7 ± 3.6	28.2 ± 2.9	<.001	27.5 ± 2.9	29.8 ± 3.4	30.5 ± 3.2	31.8 ± 3.9	<.001	28.0 ± 3.1	28.7 ± 3.1	30.8 ± 3.5	32.0 ± 3.6	<.001
Sinotubular junction (mm)	26.6 ± 3.1	23.8 ± 2.5	<.001	23.1 ± 2.6	25.0 ± 2.9	25.8 ± 2.8	26.7 ± 3.2	<.001	23.5 ± 2.7	24.1 ± 2.7	26.1 ± 2.9	26.8 ± 3.1	<.001
Ascending aorta (mm)	29.7 ± 3.6	27.4 ± 3.1	<.001	26.0 ± 2.7	27.9 ± 3.0	29.5 ± 3.0	30.8 ± 3.3	<.001	27.0 ± 3.1	27.8 ± 3.1	29.2 ± 3.3	30.0 ± 3.6	<.001

Data are expressed as mean ± SD.

Table 6 ULN values for diameters at each aortic segment measured by the SIE technique in men and women, in different age groups.

Aortic segment	Gender	Age 16–29 y	Age 30–49 y	Age 50–69 y	Age ≥ 70 y
ULN absolute values (mm)					
Aortic annulus	Men	24.1	25.2	25.4	26.9
	Women	21.4	22.1	21.9	23.0
Sinuses of Valsalva	Men	34.3	37.7	40.3	42.8
	Women	29.7	33.1	34.0	37.5
Sinotubular junction	Men	29.3	31.6	33.7	36.6
	Women	25.9	27.8	29.1	31.6
Ascending aorta	Men	31.8	35.3	37.8	40.4
	Women	29.1	31.6	34.3	36.5
ULN indexed to BSA (mm)					
Aortic annulus	Men	13.1	13.7	13.2	14.9
	Women	13.4	13.6	13.6	14.5
Sinuses of Valsalva	Men	18.4	20.3	21.3	23.9
	Women	18.4	20.5	21.1	23.5
Sinotubular junction	Men	15.8	17.0	18.0	20.1
	Women	15.9	17.1	17.9	19.8
Ascending aorta	Men	17.2	19.0	20.3	21.8
	Women	18.1	19.5	20.9	22.2

ULN, Upper limit of normal.
The described values are based on the mean + 2 SDs.