Clin Physiol Funct Imaging (2003) **23**, pp224–229

Normal aortic dimensions and flow in 168 children and young adults

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Accepted for publication
Received 24 March 2003;
accepted 25 March 2003

Key words
aortic dimensions; aortic flow; children; echocardiography

Summary

Background: Knowledge of normal aortic dimensions is important while evaluating children with aortic root dilatation.

Objective: The purpose of the study was to create normal values for aortic dimensions with two-dimensional echocardiography and for aortic flow velocities with Doppler echocardiography in healthy children and young adults.

Design and patients: One hundred and sixty-eight healthy children were studied by a single observer using digitized two-dimensional (2DE) and Doppler echocardiography.

Methods: The 2DE measurements were obtained at the level of aortic annulus, sinus, sinotubular junction, before the origin of innominate artery, before and after the origin of left carotid artery, after left subclavian artery and descending aorta at the level of the diaphragm. Doppler measurements were made from ascending aorta and from descending aorta.

Results: For the analysis the subjects were divided into five groups according to body surface area (BSA): 0·5–0·75 m^2, 0·75–1·0 m^2, 1·0–1·25 m^2, 1·25–1·5 m^2 and over 1·5 m^2. Aortic dimensions normalized to BSA were greater in smaller children at all levels. All diameters correlated closely with age, BSA, height and weight (for each $r>0{\cdot}75$, $P<0{\cdot}001$). The best predictor of aortic dimensions was BSA with r values over 0·84 for all estimates ($P<0{\cdot}001$). The diameters of ascending and descending aorta were similar in both genders when indexed to BSA. Flow velocities in descending aorta were greater than those measured in ascending aorta ($P<0{\cdot}001$ for all measurements). There were significant inverse correlations with heart rate and velocity time integral in ascending and descending aorta ($r = -0{\cdot}32$ and $-0{\cdot}53$, $P<0{\cdot}001$, respectively).

Conclusions: The presented aortic dimensions at eight levels from the valve annulus to the descending thoracic aorta by 2DE in conjunction with Doppler measurements of ascending and descending aorta in 168 healthy subjects will serve as reference data for further studies and clinical use in patients with various cardiac abnormalities.

Introduction

Knowledge of normal dimensions of the aorta in its various parts and their relationship to one another is important in the management of children with congenital heart disease. Aortic root dimensions can be accurately measured by two-dimensional echocardiography (2DE) (El Habbal & Somerville, 1989). Several studies report normal values of aortic dimensions measured with 2DE in children. However, sample sizes have been limited and measurements at one to four levels have been presented in each individual study (Snider *et al.*, 1984; Roman *et al.*, 1989; Sheil *et al.*, 1995).

In order to make precise distinction between normal and abnormal blood flow, Doppler flow characteristics of healthy people must be known. There are studies reporting flow velocities in ascending aorta in children (Levy *et al.*, 1985; Van Dam *et al.*, 1987, 1988; Seear *et al.*, 1991). Studies reporting flow velocities in both ascending and descending aorta in children are scarce (Wilson *et al.*, 1985).

Hence, we assessed aortic dimensions at eight levels from the valve annulus to the descending thoracic aorta by 2DE in conjunction with Doppler measurements in ascending and descending aorta in 168 children and young adults.

Methods

The study was carried out in Kuopio University Hospital. Written informed consent for the study was obtained from the parents or subjects. The study was approved by the research ethics committee of the hospital.

Study population

A total of 168 healthy children and young adults (85 males and 83 females) aged 2–27 years (mean 11·1 ± 5·1/median 10·5) were enrolled in the study. Their body surface areas (BSAs) ranged from 0·5 to 2·1 m^2 (median 1·2 m^2) (Dubois & Dubois, 1916). Blood pressure was recorded at phase I and V Korotkoff sounds. No subject had heart disease, as judged by history, clinical examination and echocardiography. For the analysis the subjects were divided into five groups according to BSA: 0·5–0·75, 0·75–1·0, 1·0–1·25, 1·25–1·5 and over 1·5 m^2.

Echocardiographic examination

Transthoracic echocardiographic examination was performed with the patient lying supine or in the left lateral semi-recumbent position. Sedation was not used. Examinations were carried out by a single observer (TP) using a GE Vingmed System FiVe ultrasound scanner (Horten, Norway) and saved in digital form on the hard disk of the ultrasound scanner. The transducer frequencies used were 2·2 MHz octave, 3·5 or 5 MHz. Standard parasternal, apical, subcostal and suprasternal views were used.

Echocardiographic analysis

The echocardiographic data were analysed by a single observer (TP). Thirty patients were examined on the same day independently by another observer (TT) for the purpose of interobserver analysis.

M-mode

The M-mode measurements of aortic sinus were made according to the recommendations of the American Society of Echocardiography (ASE) (Sahn *et al.*, 1978).

2DE

The diameters of aortic annulus, aortic sinus and sinotubular junction in systole were measured using the parasternal long axis view. The other aortic measurements were made before the origin of innominate artery, before and after the origin of left carotid artery and after left subclavian artery and at descending aorta at the level of the diaphragm. Measurements were made perpendicular to the long axis of the aorta from the inner edges in views showing the largest aortic diameters.

Doppler echocardiography

Aortic flow was recorded from the apical five chamber view and from the suprasternal notch. Measurements obtained on three consecutive heart cycles were averaged.

Statistical analysis

Interobserver variability of 2DE was determined between the examinations and analyses made by observer 1 (TP) and observer 2 (TT). Interobserver variability was calculated as the standard deviation of the differences between two measurements and expressed as percentage of the averaged value. Differences between means were assessed with Student's paired or unpaired *t* test or one way analysis of variance. The Kolmogorov–Smirnov test was used to check the normal distribution of variables. In case of non-normality the non-parametric Mann–Whitney/Wilcoxon test was used. Pearson's correlation coefficient was used when parameters were normally distributed; otherwise Kendall's correlation coefficient was used. The data are given as the mean (SD). The aortic dimensions were plotted against BSA as median and 95th and fifth percentiles, because some of the diameters were non-normally distributed.

Results

All subjects were in good clinical condition with normal exercise tolerance. Seven children had asthma without symptoms at the time of examination. Three of the children with asthma had medication with inhaled corticosteroids. Echocardiographic measurements of aorta at all eight levels were successful in 88% of the subjects.

Reproducibility of AO measurements

Interobserver variabilities for aortic dimensions at the level of aortic annulus, sinus, sinotubular junction, before the origin of innominate artery, before and after the origin of left carotid artery, after left subclavian artery and descending aorta at the level of the diaphragm were 6·1, 5·4, 8·8, 7·7, 11·7, 10·4, 14·9 and 9·0% with the respective correlations being 0·78 ($P<0·001$), 0·89 ($P<0·001$), 0·66 ($P<0·001$), 0·77 ($P<0·001$), 0·66 ($P<0·001$), 0·57 ($P = 0·004$), 0·51 ($P = 0·012$) and 0·80 ($P<0·001$). The overall reproducibility was acceptable for the echocardiographic measurements.

M-Mode and 2DE measurements

The results of aortic measurements are presented in Table 1. Aortic dimensions calculated in relation to BSA were greater in smaller children at all levels. 2DE produced greater estimates for aortic sinus than M-mode ($P<0·05$ in all BSA groups). However, the measurements made by the two methods correlated well ($r = 0·87$, $P<0·001$). Significant

Table 1 Aortic dimensions and flow measurements of the subjects.

	0·5–0·75 m^2	0·75–1·0 m^2	1·0–1·25 m^2	1·25–1·5 m^2	≥1·5 m^2
Subjects	16	41	34	29	48
Heart rate (beats min^{-1})	100 (16)	84 (10)	76 (10)	73 (8)	67 (12)
M-mode					
Aortic sinus/BSA (mm m^{-2})	25·1 (2·0)	21·3 (1·7)	18·7 (2·2)	16·8 (1·7)	15·2 (1·4)
2DE					
Aortic annulus/BSA (mm m^{-2})	20·4 (1·4)	17·6 (1·5)	15·1 (1·1)	13·7 (1·2)	12·4 (0·9)
Aortic sinus/BSA (mm m^{-2})	26·2 (2·6)	23·5 (2·2)	19·5 (1·7)	17·8 (1·7)	16·0 (1·4)
Ao sinotubu/BSA (mm m^{-2})	21·5 (2·0)	18·9 (1·9)	15·7 (1·3)	14·7 (1·2)	13·0 (1·0)
Ao before innom art/BSA (mm m^{-2})	20·3 (1·3)	18·8 (1·5)	16·4 (1·6)	15·0 (1·2)	12·9 (1·4)
Ao before left car art/BSA (mm m^{-2})	18·1 (1·4)	16·8 (1·3)	14·1 (1·2)	13·2 (1·2)	11·8 (1·1)
Ao before left subcl art/BSA (mm m^{-2})	16·6 (1·3)	15·0 (1·3)	12·6 (1·3)	11·5 (1·0)	10·5 (1·0)
Ao after left subcl art/BSA (mm m^{-2})	14·7 (0·6)	13·2 (1·1)	11·1 (1·5)	10·0 (1·0)	9·3 (0·9)
DTA/BSA (mm m^{-2})	12·4 (1·4)	10·9 (1·1)	9·6 (0·8)	8·8 (0·6)	8·1 (0·8)
Doppler					
AO asc VTI (cm)	21·5 (3·6)	22·9 (3·8)	24·9 (5·0)	24·3 (4·0)	24·9 (4·9)
AO asc max velocity (m s^{-1})	1·18 (0·31)	1·23 (0·20)	1·22 (0·20)	1·16 (0·18)	1·15 (0·17)
AO asc mean velocity (m s^{-1})	0·79 (0·19)	0·81 (0·12)	0·81 (0·13)	0·80 (0·11)	0·78 (0·11)
AO desc VTI (cm)	23·1 (2·8)	23·9 (3·2)	26·7 (3·5)	28·6 (5·0)	29·8 (4·5)
AO desc max velocity (m s^{-1})	1·28 (0·12)	1·23 (0·14)	1·23 (0·12)	1·26 (0·18)	1·27 (0·15)
AO desc mean velocity (m s^{-1})	0·83 (0·19)	0·88 (0·11)	0·90 (0·12)	0·94 (0·14)	0·90 (0·10)

Values are mean (SD). BSA, body surface area; DTA, descending thoracic aortae; AO asc, ascending aortae; AO desc, descending aortae; VTI, velocity time integral.

Table 2 Correlation coefficients between aortic dimensions and age, BSA, height and weight.

	n	Age	BSA	height	weight
M-mode					
Aortic sinus (mm)	168	0·76*	0·87*	0·86*	0·86*
2DE					
Aortic annulus (mm)	168	0·83*	0·92*	0·91*	0·90*
Aortic sinus (mm)	168	0·81*	0·88*	0·87*	0·86*
Ao sinotubu (mm)	167	0·82*	0·89*	0·88*	0·88*
Ao before tr brach (mm)	148	0·78*	0·84*	0·83*	0·82*
Ao before left car art (mm)	147	0·82*	0·88*	0·86*	0·86*
Ao before left subcl art (mm)	151	0·80*	0·87*	0·85*	0·86*
Ao after left subcl art (mm)	148	0·75*	0·84*	0·80*	0·83*
DTA (mm)	150	0·78*	0·89*	0·86*	0·89*

*P<0·001.
Values are mean (SD). BSA, body surface area; DTA, descending thoracic aortae.

Table 3 Relationship of BSA and aortic diameters measured by 2DE.

Aortic dimensions	Equation	r	r^2
Aortic annulus	0·716 × BSA + 0·896	0·92	0·85
Aortic sinus	0·902 × BSA + 1·207	0·88	0·77
Ao sinotubularis	0·757 × BSA + 0·949	0·89	0·79
Ao before innominate art	0·700 × BSA + 1·039	0·84	0·70
Ao before left car art	0·681 × BSA + 0·854	0·88	0·76
Ao before left subcl art	0·613 × BSA + 0·751	0·87	0·75
Ao after left subcl art	0·550 × BSA + 0·646	0·83	0·70
Descending thoracic aorta	0·514 × BSA + 0·504	0·89	0·80

BSA, body surface area; r, correlation coefficient.

correlations were found between dimensions of ascending and descending aorta and age, BSA, height and weight (Table 2). The best correlation was achieved between BSA and aortic dimensions. Also, height correlated closely with the aortic measurements. Table 3 shows the regression equations for the estimates of aortic dimensions calculated in relation to BSA. Figure 1 shows the dimensions of the aorta in systole plotted against BSA and Fig. 2 shows serial aortic measurements at eight points in five BSA groups.

The effect of gender on aortic dimensions

Aortic dimensions at aortic sinus and at sinotubular junction were greater in males than in females (P<0·05) in all but the smallest BSA group (0·5–0·75 m^2). Also the diameters of aortic annulus and descending thoracic aorta were greater in males than in females in BSA groups 1·0–1·25 and over 1·5 m^2 (P = 0·006, 0·013 and P<0·001,<0·01, respectively). Nevertheless, the diameters of ascending and descending aorta were similar in both genders when indexed to BSA.

Doppler echocardiography

Flow velocities of ascending and descending aorta are shown in Table 1. Flow velocities of descending aorta analysed in all

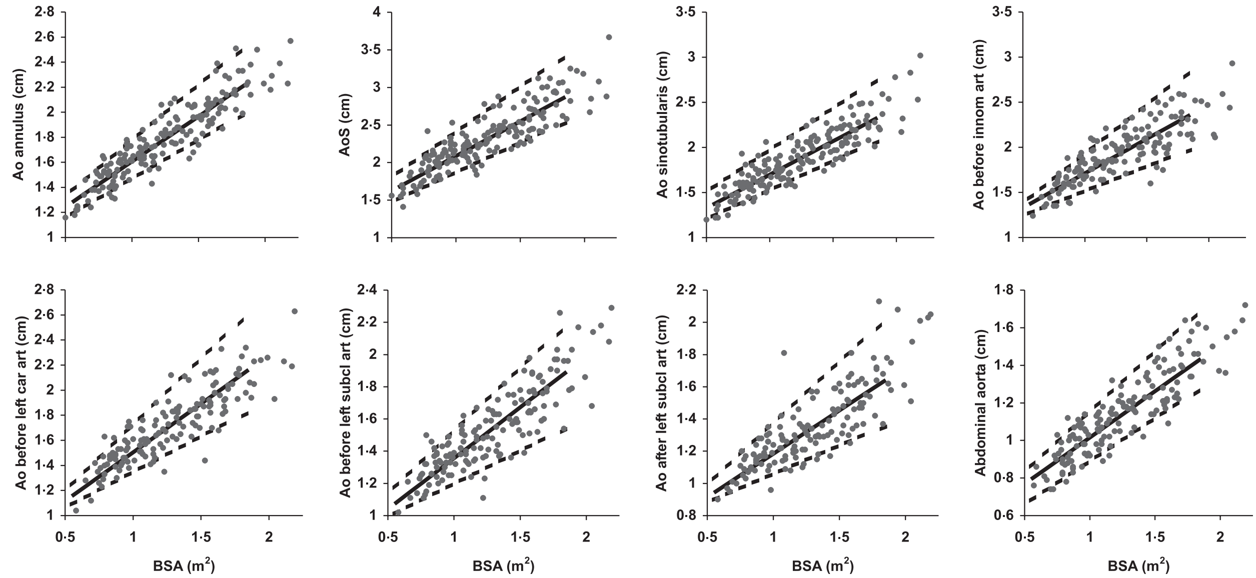

Figure 1 Aortic dimensions at eight levels plotted against body surface area in 168 subjects. The solid line represents median dimensions and the dashed lines represent 95th and fifth percentile values of the dimensions.

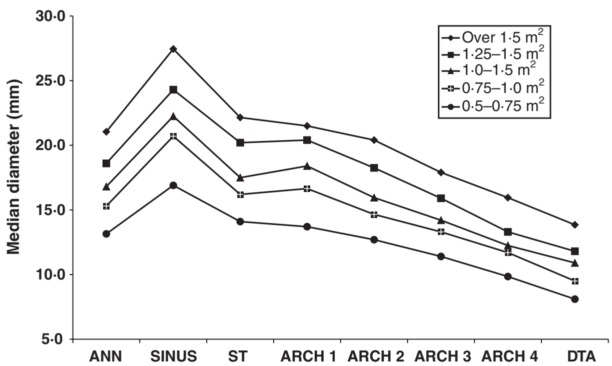

Figure 2 Median aortic dimensions at eight levels in five body surface area groups. ANN, aortic annulus; SIN, aortic sinus; ST, sinotubular junction; ARCH 1, ao before innom art; ARCH 2, ao before left car art; ARCH 3, ao before left subcl art; ARCH 4, ao after left subcl art; DTA, descending thoracic aorta.

children were greater than those measured in ascending aorta ($P<0.001$ for all measurements). In group analysis, velocity time integral (VTI) and mean velocity were greater ($P<0.05$) when measured from descending aorta than from ascending aorta in all but the smallest BSA group (0·5–0·75 m^2). Maximal velocity in descending aorta was greater in the two highest BSA groups than in the other groups ($P<0.05$ for both). VTI, maximal and mean velocities in ascending and descending aorta correlated significantly ($r = 0.56$, 0·51 and 0·51, $P<0.001$ for all). Significant inverse correlations with heart rate were found for VTI of ascending and descending aorta ($r = -0.32$ and -0.53, $P<0.001$, respectively). Flow measurements of descending aorta correlated weakly with systolic blood pressure (VTI $r = 0.28$; desc max $r = 0.28$; desc mean $r = 0.21$, $P<0.01$ for all).

Discussion

This study presents dimensions of aorta at eight levels from valve annulus to the descending thoracic aorta measured by 2DE in 168 healthy children and young adults. All aortic measurements increased linearly with growth. The measurements were similar in both genders when indexed to BSA.

Dimensions of ascending and descending aorta measured in the present study agree with the earlier studies on aortic dimensions in children (Snider *et al.*, 1984; Roman *et al.*, 1989; Nidorf *et al.*, 1992; Sairanen & Louhimo, 1992; Sheil *et al.*, 1995). In our study, the growth of aortic dimensions was found to be linear in relation to BSA in children and young adults aged from 2 to 27 years. However, data on children younger than 2 years could have changed the linear relationship between aortic dimensions and BSA. A 2DE study of cardiac dimensions in 196 children (aged from 6 days to 18 years) has reported that heart and great vessels grow at a predictable rate after birth, reaching 50% of their adult dimensions at birth, 75% by 5 years and 90% by 12 years. A few studies, including also newborns and infants, have reported a logarithmic relationship between BSA and aortic dimensions (Nidorf *et al.*, 1992; Sairanen & Louhimo, 1992). Also, linear relations with BSA and aortic dimensions in children aged from 1 month to 15 years have been reported (Roman *et al.*, 1989). Aortic dimensions have been related to both BSA (Snider *et al.*, 1984; Roman *et al.*, 1989; Sairanen & Louhimo, 1992) and height (Nidorf *et al.*, 1992; Sheil *et al.*, 1995). In the present study height and weight correlated well with aortic measurements, while the best correlations were achieved with BSA.

We found slight differences in aortic measurements between genders, but the measurements were similar when indexed to BSA. Our results are in accordance with the findings in a previous study (Roman *et al.*, 1989). These investigators found aortic root diameters to be greater in men than women, but the diameters were similar when indexed by BSA. In children, growth of aortic root dimensions has found to be independent of gender (Roman *et al.*, 1989; Nidorf *et al.*, 1992).

In the present study, greater VTI and maximal flow velocity were measured in descending aorta than in ascending aorta despite diminished blood flow in descending aorta because of blood flow into vessels leaving from the aortic arch. Flow velocity in ascending aorta decreased slightly with increasing age, agreeing with earlier studies (Hatle, 1984; Levy *et al.*, 1985; Van Dam *et al.*, 1987, 1988). In contrast, velocities in ascending and descending aorta were similar in 110 subjects aged 14 days to 35 years (Wilson *et al.*, 1985). The mean aortic velocity in the present study remained relatively constant for all ages, as seen also in a previous study, suggesting that increase in cardiac output with age is governed with contemporary growth of the aortic lumen so that mean flow velocities remain within fairly narrow limits (Seear *et al.*, 1991).

Aortic root dilatation is seen in 60–80% of adults with Marfan's syndrome (Bruno *et al.*, 1984.) In younger children with Marfan's syndrome, aortic root diameters are usually above or at the upper normal limit (El Habbal, 1992). In older children and adolescents, aortic root dilatation is not uncommon and a rapid increase in aortic size is associated with an increased risk of complications (El Habbal, 1992). Aortic root is affected first in most cases, but other parts of the thoracic aorta may become dilated with time. Aortic root dilatation is a common finding in aortic stenosis, and it is not related to the severity of aortic stenosis (Crawford & Roldan, 2001). A dilatated aortic root has also been demonstrated in patients after surgical repair of tetralogy of Fallot (Niwa *et al.*, 2002). Clinically relevant abnormalities of the aorta are frequently found with bicuspid aortic valve. In a community-based study, bicuspid aortic valve was associated with an alteration of aortic dimensions even in the absence of haemodynamically significant aortic valve stenosis or regurgitation (Nkomo *et al.*, 2003). In addition to conditions with aortic dilatation, hypoplasia and stenosis at different levels of aorta needs to be estimated in relation to body size. As the aorta widens with growth in childhood in the normal population, normal data on aortic dimensions at different levels is important in diagnosis and follow-up of patients with various cardiac abnormalities.

The greater estimates for aortic sinus by 2DE than by M-mode may lead to false diagnoses aortic root dilatation if adequate reference data are not used. In a study by Roman *et al.* (1989) aortic root dilatation was found in 40% of normal children when 2DE measurements were compared with M-mode nomograms. Thus, the normality of 2DE aortic root measurements should be compared with normal values assessed by 2DE.

Accurate 2DE measurements can be obtained with modern digital echocardiographic machines. With 2DE reference data now available, the use of 2DE in measurements of aortic dimensions should be favoured. The presented aortic measurements at eight levels obtained from a large group of healthy subjects will serve as normal data for further studies in patients with various cardiac abnormalities.

Acknowledgment

This study was supported by The Parent Organization for Children with Heart Disease, Finland.

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