Cardiol Young 2002; 12: 339–344
© Greenwich Medical Media Ltd.
ISSN 1047-9511

Original Article

Cineangiographic aortic dimensions in normal children

Kalyani R. Trivedi, Jorge L. Pinzon, Brian W. McCrindle, Patricia E. Burrows,
Robert M. Freedom, Lee N. Benson

Departments of Pediatrics and Radiology, Division of Cardiology and the Variety Club Cardiac Catheterization Laboratories, The Hospital for Sick Children, University of Toronto School of Medicine, Toronto, Ontario, Canada

Abstract Knowledge of normal aortic dimensions is important in the management of children with aortic disease. So as to define such dimensions, we undertook a retrospective review of clinical data and aortic cineangiograms from 167 subjects without aortic disease having a mean age of 3.67 years, with a range from 0.01 to 14.95 years. Amongst the patients, 56 were without detectable cardiac lesions, 66 patients had mild pulmonary stenosis, 30 were seen with Kawasaki disease, and 15 with small interatrial defects within the oval fossa. Aortograms were available in all. No patient had any hemodynamic derangement that would have affected the aorta during intrauterine life or childhood. Systolic dimensions were measured in the ascending and descending aorta at the level of the carina, at the transverse aortic arch distal to the brachiocephalic, of the left common carotid artery at its origin, at the transverse aortic arch distal to the left common carotid artery, at the aortic isthmus, and of the aorta at the level of the diaphragm. A regression analysis model was used to establish the range of predicted normal values, with their confidence limits, standardizing the values to height as the biophysical parameter having the highest correlation to aortic dimensions. Normal ranges were established for all the levels of measurement. The data should prove useful in identifying abnormalities of the thoracic aorta during childhood, and when assessing the outcomes of interventions.

Keywords: Normal values; childhood; aorta; cineangiographic dimensions; cardiac measurements

KNOWLEDGE OF NORMAL AORTIC DIMENSIONS IS important for management of children with aortic disease. Reports in the literature of normal cineangiographic dimensions of the aorta in infancy and childhood are scarce.[1,2] Furthermore, the validity of the data which exists is limited, due to small size of the samples, and frequent extrapolation from data obtained in patients with lesions that cause significant alterations in hemodynamics.[1,2] Additionally, there is a poor correlation between data derived from autopsy or non-invasive modalities of imaging and cineangiocardiographic studies.[3–8] Cineangiography is an objective and an accurate method for determination of the dimensions of vessels. Decisions regarding surgical or catheter interventions are routinely based upon data obtained from cineangiographic studies.[9] The purpose of our study, therefore, was to establish normal values for the ascending and descending aorta and the transverse arch by studying aortic cineangiograms from a group of children. The subjects were chosen either because they were without aortic disease, or because any hemodynamic alterations present would have been so small that we deemed them unlikely to have affected the aorta or the pattern of flow within it. We then assessed various biophysical parameters of growth and age so as to identify the single parameter with the best correlation to aortic dimensions. This proved to be height, permitting us to establish reproducible data for normal aortic dimensions at different heights.

Materials and methods

We studied the medical records and cineangiograms of 167 patients seen at the Hospital for Sick Children, Toronto between January 1975 and December

---

Correspondence to: L. N. Benson MD, Division of Cardiology, Room 4515, The Hospital for Sick Children, 555 University Avenue, Toronto, Ontario, Canada M5G 1X8. Tel: 416 813 3523; Fax: 416 813 7547; Email: benson@sickkids.ca

Accepted for publication 15 February 2002

1989, selecting the patients from the computerized cardiac database. Selection was based upon adequate delineation of the aorta and its branches on cineangiography, and the absence of cardiac lesion of a magnitude deemed sufficient to have caused alteration of aortic patterns of flow or dimensions, either in intrauterine or postnatal life. Body surface area was calculated from the equation established by Dubois and Dubois based on height and weight.[10]

Retrograde cineangiocardiograms of the aorta and its branches had been obtained in the left anterior oblique projection at 60 frames/s using a non-ionic contrast injection (Isovue, Bracco, Montreal CA), with 1–2 ml of injectate per kilogram being delivered at 20 ml/s. Images were projected onto a white projection screen using a Cipro 35N, 35 mm cinematographic film projector (Seimens, Stockholm, Sweden). Correction for magnification was calculated from the known diameter of the catheter. Measurements of the largest dimension in systole were obtained perpendicular to the longitudinal axis of the vessel. Electronic calipers (Mitutoyo Corp, Japan) were used to trace the dimension to the nearest 0.5 mm.

Measurements were taken at the following sites (Fig. 1):

1. The ascending aorta, at the level of carina.
2. The descending aorta, at the level of carina.
3. The proximal transverse aortic arch between the brachiocephalic artery and the left common carotid artery.
4. The left common carotid artery, at its origin.
5. The distal transverse aortic arch between the left common carotid artery and the left subclavian artery.
6. The aortic isthmus, defined as the segment of the aorta distal to the left subclavian artery and proximal to the site of origin of the arterial duct.
7. The aorta, at the level of the diaphragm.

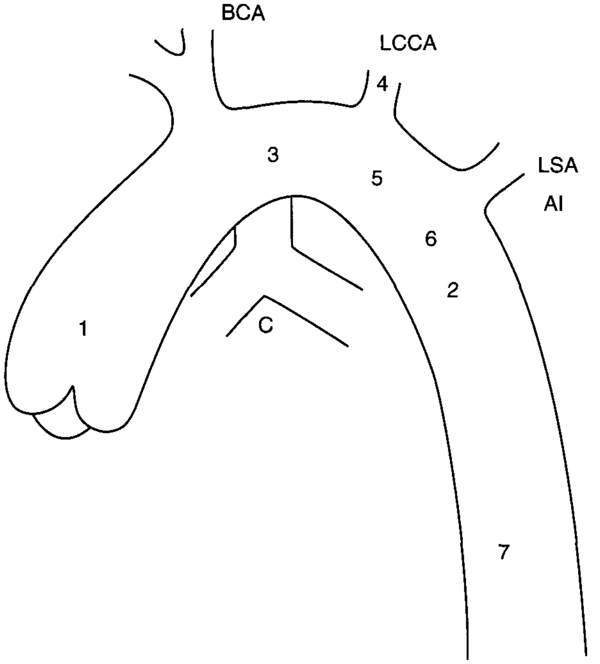

Figure 1.
Site of angiographic measurements. Abbreviations: AI: aortic isthmus; BCA: brachiocephalic artery; LCCA: left common carotid artery; LSA: left subclavian artery; C: tracheal carina.

Data analysis

Data are presented as frequencies, medians with range, and means with standard deviation. Where there was missing data, the number of non-missing values is given. As age, weight, height and body surface area, as well as all of the angiographic measurements, had a very skewed distribution, a normalizing transformation was performed using the natural logarithm. A general linear regression model was used to determine bivariable and multivariable associations between the natural logarithm of the angiographic measurements and gender, and the natural logarithm of age, weight and height, and body surface area. All analyses were performed with SAS Version 6.12 statistical software (SAS Institute, Inc., Cary, North Carolina). A p value of less than 0.05 was set as the level of statistical significance.

Results

Of the 167 patients, 87 (52%) were male and 81 were female. The median age at cineangiography was 2.9 years, with a range from 4 days to 15 years. The median weight, measured in 158 patients, was 14.1 kg, with a range from 2.8 to 51.6 kg. The median height, available in 145 patients, was 95 cm, and ranged from 50 to 166 cm. The median body surface area, calculated in 145 patients, was 0.60 m^2, and ranged from 0.19 to 1.47 m^2. In 56 patients (34%), there were no intracardiac lesions. Of the remainder, 66 (45%) had mild pulmonary stenosis, with gradients of less than 40 mmHg, a history of Kawasaki disease without known cardiac sequels had pre-existed in 30 (20%), and the other 15 (11%) had a small defect within the oval fossa, with a shunt of less than 1.5 to 1. There were no significant differences in gender regarding the natural logarithm of age, weight and height or body surface area.

When we assessed the cineangiographic measurements, we found no significant associations between gender and type of lesion, with the exception of the aortic dimension at the level of the diaphragm. Significantly greater diameters were found in the

Table 1. Associations between angiographic measurements and biophysical characteristics.*

Measurement	Age** (n = 157)	Weight (n = 157)	Height (n = 145)	BSA (n = 145)
Ascending aorta	0.59	0.68	0.73	0.72
Descending aorta	0.66	0.74	0.77	0.75
TA at BCA	0.66	0.72	0.77	0.75
TA at LCA	0.67	0.69	0.72	0.71
TA at LSA	0.70	0.74	0.79	0.77
Isthmus	0.75	0.79	0.82	0.81
Aorta at diaphragm	0.65	0.72	0.75	0.73

*All data were normalized with a natural logarithmic transformation before analysis; **Data in all columns represent Pearson correlation coefficients; all p values were <0.0001

Abbreviations: TA: transverse arch; BCA: brachiocephalic artery; LCA: left common carotid artery; LSA: left subclavian artery; BSA: body surface area

Table 2. General linear regression analysis of angiographic measurement (mm) versus patient height (cm).*

Measurement site	r^2	RMSE	Intercept	Parameter estimate
Ascending aorta	0.54	0.1458	−0.0410	0.5969
Descending aorta	0.59	0.1528	−0.7715	0.6911
TA at BCA	0.59	0.1378	−0.2802	0.6247
TA at LCA	0.52	0.1547	−1.1883	0.6178
TA at LSA	0.62	0.1370	−0.5598	0.6672
Isthmus	0.68	0.1423	−1.1581	0.7758
Aorta at diaphragm	0.57	0.1474	−0.7102	0.6352

*All analyses represent relationship between the natural logarithm of the 2 variables; all model p values were <0.0001

Abbreviations as for Table 1. RMSE: root mean square error

83 males, with a median of 9.2 mm, and a range from 5.2 to 14.4 mm, compared to the 74 females, in whom the median was 8.7 mm, and the range from 4.3 to 14.8 (p = 0.02). Gender was, therefore, excluded as an important covariant in further analysis. The associations between age, weight, height, and body surface area are shown in Table 1. The greatest correlation coefficients were noted with height for all of the angiographic measurements. After entering height into the general linear regression models, none of the other variables were significant. The details of the linear regression models are shown in Table 2, and represented graphically in Figure 2.

The aorta was noted progressively to taper from its ascending to descending component at the level of the diaphragm. When patients less than 30 months of age were compared to the total population (Fig. 3), there appeared to be a relative decrease of the dimension of the aortic isthmus.

Discussion

Establishment of accurate normal dimensions of cardiac structures has to take into account several

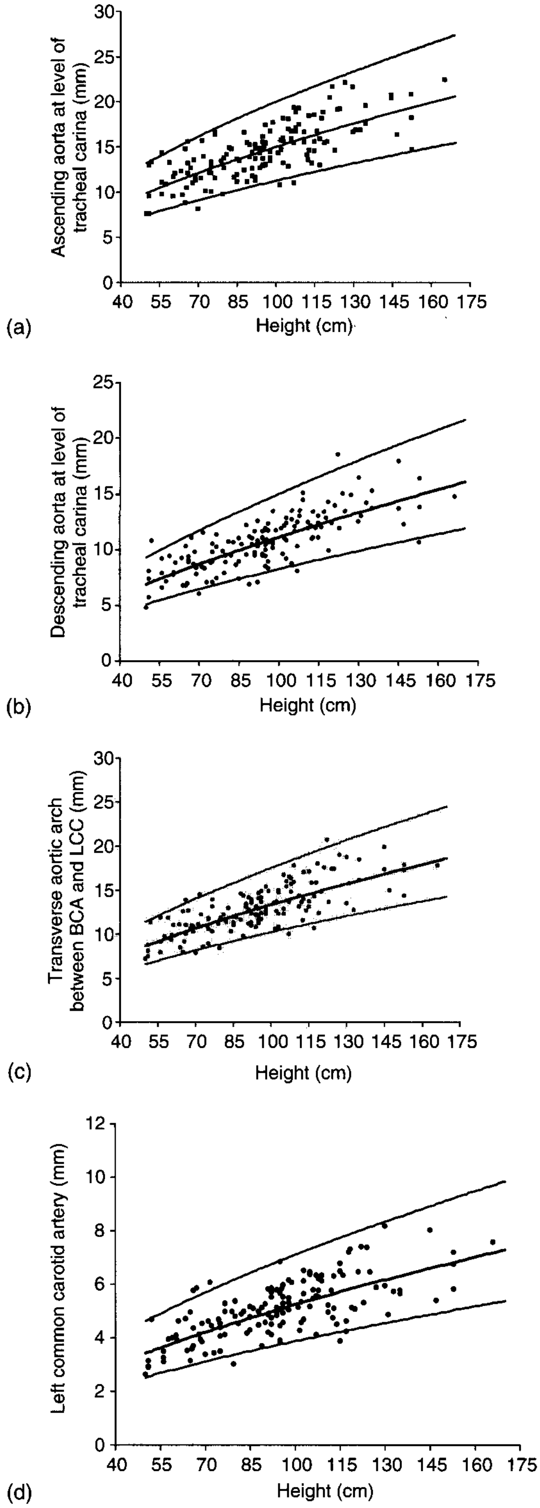

Figure 2.

Association between height and angiographic measurements. Outside bands represent 95% confidence intervals, with the centerline representing the predicted value based on height. (a) Height versus ascending aorta at the level of the carina; (b) Height versus descending aorta at the level of the carina; (c) Height versus transverse aortic arch between the brachiocephalic artery and the left common carotid artery; (d) Height versus the left common carotid artery; continued on next page

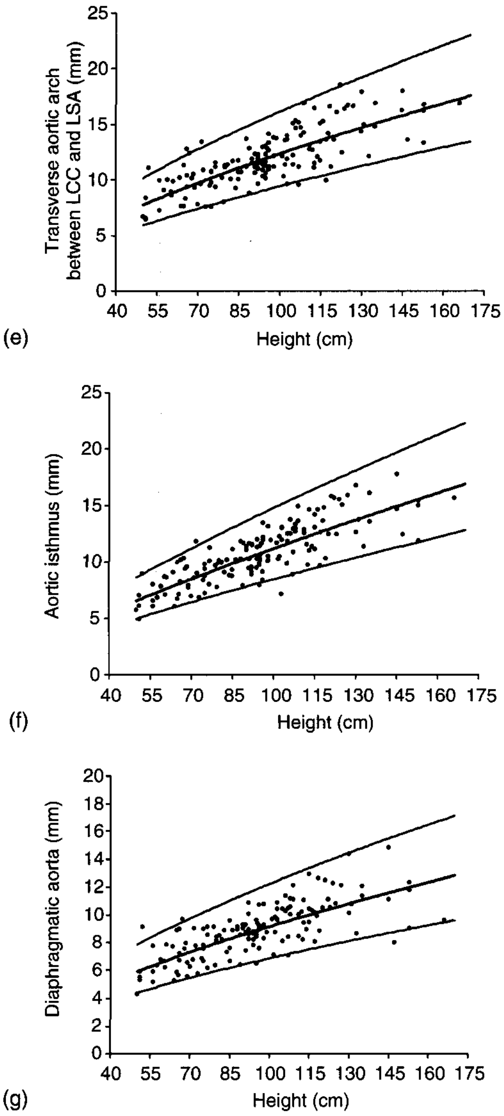

Figure 2. (*Contiuned*)

(e) Height versus transverse aortic arch, between the left common carotid artery and the left subclavian artery; (f) Height versus aortic isthmus; (g) Height versus aorta, at the level of the diaphragm. Abbreviations: cm: centimeters; BCA: brachiocephalic artery; LCC: left common carotid artery.

factors related to body growth.[11,12] Complicating the characterization of the relationship between the size of a cardiac structure and body growth is its non-linearity, which requires linearization of the data set. Additionally, the normal variance in the dimension of a cardiac structure for any given body size must also to be taken into account. To this end, the use of a natural logarithm–natural logarithm form linearizes the relation between body growth and the size of a cardiac structure, and stabilizes the variance throughout the range of body sizes. Amongst the various measures that represent body size, we found height to have the best correlation to aortic dimensions

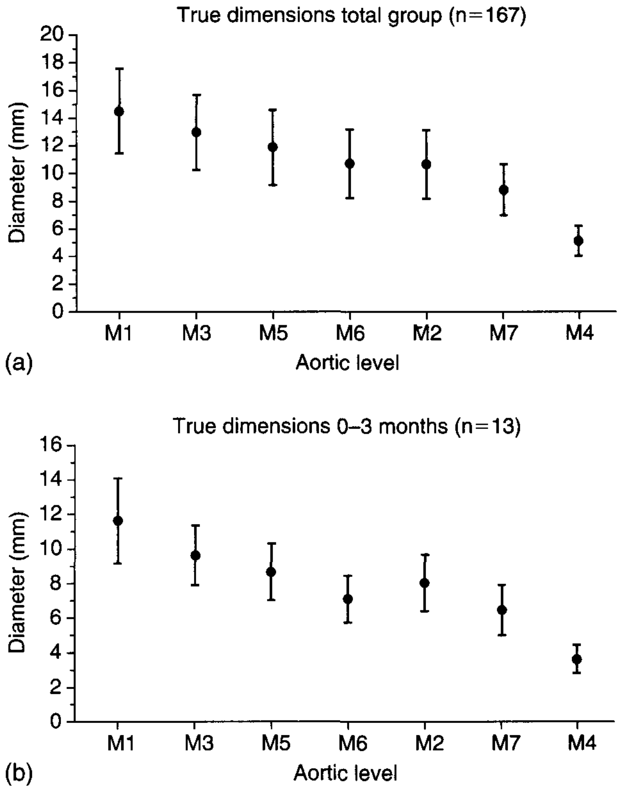

Figure 3.

Aortic tapering in the total population, and in infants aged less than 3 months (see (a) for aortic levels). Abbreviations: mm: millimeters.

(Table 1). Regression equations for aortic dimensions at 7 sites (Fig. 1) were developed after transforming the dimensions and the variables in height to a natural logarithm–natural logarithm form (Table 2).

Objective and accurate methods for the determination of the dimensions of vessels are available using a variety of imaging technologies, such as echocardiography, computerized axial tomography, and magnetic resonance imaging.[13] These modalities have been used to evaluate the size of the aorta and its branches in various diseases.[14–19] Attempts at defining normative data, in contrast, have been limited. Unfortunately, data obtained at autopsy, or based on non-invasive modalities,[2–8,16] have not been found to correlate well with measurements made cineangiographically, making longitudinal comparisons between the values inaccurate. In this regard, criterions for surgical or catheter based intervention, and assessment at follow-up, are frequently determined from angiographic appearance. Normative data of aortic dimensions obtained by this method, therefore, have important clinical utility. Furthermore, the validity of the existing data is limited, due to the small size of samples, and the frequent extrapolation of data obtained from populations of children with lesions that cause hemodynamic alterations.[12]

We have defined ranges of normal aortic dimensions at 7 different sites (Fig. 1), studying children of all ages and sizes, and with an equal gender distribution. The group did not have cardiovascular lesions that were likely to affect patterns of flow in the aorta, or growth from the fetus through to adolescence. The indications for obtaining cineangiograms of the aorta were for surveillance in children with Kawasaki Disease, or for those with lesions of the right heart of mild severity when non-invasive assessment was not available. One-third of out population had no cardiovascular lesions, and statistical methods did not identify significant associations between the measured dimensions of the aorta at different sites and the known cardiovascular lesions in the overall group.

The sites for measurement of aortic dimension (Fig. 1) were chosen with consideration to normal variability, reproducibility and clinical utility.[1,2,4,5,20–22] The level of the carina as an anatomical landmark for measuring the ascending and descending aorta has not been described before, and is a consistent landmark that is easily identified on cineangiograms and by other modalities such as computerized tomography or magnetic resonance. The dimensions of the transverse arch are useful in defining the adequacy of the arch itself, while the aortic diameter at the level of the diaphragm is conventionally used to normalize a variety of indexes, such as the McGoon index.[23] The aortic isthmus is subject to lower flows[22] in intrauterine life, and is smaller than the descending aorta both in fetal life and postnatally to approximately 3 months of age.[20,24,25] After this period, the isthmus remodels in all but 3%, and equalizes to the descending aortic diameter and the diameter at the diaphragm. This variability in size due to unique patterns of flow in fetal life, and its changes, makes it an important site to include in a study of normative aortic dimensions.

Our data confirms previous observations[3,5,26–28] of an increase in aortic dimensions with growth. Of the various biophysical properties, we found height to have the best correlation with dimension (Table 1). We have created, therefore, normal values with their 95% confidence intervals for height (Fig. 2). As an easily measured biophysical parameter, height is generally not affected by nutritional status, nor subject to variations in the methods of calculation as in body surface area. The pattern of growth of the isthmus, shown in previous studies, were confirmed in our study.[20,22,24,25] We also found that 3% of the population continue to have smaller isthmuses after 3 months of age. Equalization was noted, however, between the isthmus and the dimensions of the descending aorta after 30 months of age.

Gender did not have a significant influence on the aortic dimensions, even in adolescence where growth differences were to be expected. Additionally, no significant differences were noted between the sexes, except for the aortic dimension at the level of the diaphragm. At this level, the dimension was smaller by about 5 mm in females than in males.

Previous studies of cineangiograms have demonstrated the trend in growth of the aorta with age, and produced a range of normal values, but the validity of these data sets is limited due to small size of the samples.[1,2] Our larger study has now provided an improved dataset for predicted values of aortic dimensions by ensuring statistical power and established the best correlate amongst different biophysical characteristics (Table 1).

References

1. Clarkson PM, Brandt PW. Aortic diameters in infants and young children: normative angiographic data. Pediatr Cardiol 1985; 6: 3–6.
2. Sievers HH, Onnash DGW. Dimensions of the great arteries, semilunar valve roots and right ventricular outflow tract during growth: normative angiocardiographic data. Pediat Cardiol 1983; 4: 189–196.
3. Aronberg DJ, Glazer HS, Madsen K, Sagel SS. Normal thoracic aortic diameters by computed tomography. J Comput Assist Tomogr 1984; 8: 247–250.
4. De la Cruz MV, Anselmi G, Romero A, Monroy G. A qualitative and quantitative study of the ventricles and great vessels of normal children. Am Heart J 1960; 60: 675–690.
5. Fitzgerald SW, Donaldson JS, Poznanski AK. Pediatric thoracic aorta: normal measurements determined with CT. Radiology 1987; 165: 667–669.
6. Fletcher BD, Jacobstein MD. MRI of congenital abnormalities of the great arteries. Am J Roentgenol 1986; 146: 941–948.
7. Gomes AS, Lois JF, George B, Alpan G, Williams RG. Congenital abnormalities of the aortic arch: MR imaging. Radiology 1987; 165: 691–695.
8. Roge CL, Silverman NH, Hart PA, Ray RM. Cardiac structure growth pattern determined by echocardiography. Circulation 1978; 57: 285–290.
9. Freedom RM, Culham JAG. Physical principles of image formation and projections in angiocardiography. In: Freedom RM, Mawson JB, Yoo SJ, Benson LN (eds). Congenital Heart Disease Textbook of Angiocardiography, Vol. 1, Edn 1. New York: Futura Publishing Company, Inc., 1997, pp 39–94.
10. Dubois D, Dubois EF. Clinical calorimetry: a formula to estimate the approximate surface area if height and weight be known. Arch Intern Med 1916; 17: 863–871.
11. Daubeney PE, Blackstone EH, Weintraub RG, Slavik Z, Scanlon J, Webber SA. Relationship of the dimension of cardiac structures to body size: an echocardiographic study in normal infants and children. Cardiol Young 1999; 9: 402–410.
12. Sluysmans T, Colan SD. Normal Growth-related Changes of Cardiovascular Dimensions. Department of Pediatric Cardiology, Cliniques St Luc, UCL, Brussels, Belgium and Department of Cardiology, Children's Hospital Harvard Medical School, Boston, Massachussets, USA. 1997; 11–38.
13. Freedom RM, Macdonald C. Imaging modalities in Pediatric Cardiovascular Disorders. In: Freedom RM, Mawson JB, Yoo SJ, Benson LN (eds). Congenital Heart Disease Textbook of Angiocardiography, Vol. 1, Edn 1. Futura Publishing Company, Inc., New York, 1997, pp 1–38.

14. Hausmann D, Friedrich G, Soni B, Daniel WG, Fitzgerald PJ, Yock PG. Validation of Automated Border Detection in Intravascular Ultrasound Images. Echocardiography 1996; 13: 599–608.
15. Kandarpa K, Piwnica-Worms D, Chopra PS, et al. Prospective double-blinded comparison of MR imaging and aortography in the preoperative evaluation of abdominal aortic aneurysms. J Vasc Interv Radiol 1992; 3: 83–89.
16. Rubin GD, Paik DS, Johnston PC, Napel S. Measurement of the aorta and its branches with helical CT. Radiology 1998; 206: 823–829.
17. Stern HC, Locher D, Wallnofer K, Weber F, Scheid KF, Emmrich P, Buhlmeyer K. Noninvasive assessment of coarctation of the aorta: comparative measurements by two-dimensional echocardiography, magnetic resonance, and angiography. Pediatr Cardiol 1991; 12: 1–5.
18. Thurnher SA, Dorffner R, Thurnher MM, et al. Evaluation of abdominal aortic aneurysm for stent-graft placement: comparison of gadolinium-enhanced MR angiography versus helical CT angiography and digital subtraction angiography. Radiology 1997; 205: 341–352.
19. Weber HS, Mosher T, Mahraj R, Baylen BG. Magnetic resonance imaging demonstration of "remodeling" of the aorta following balloon angioplasty of discrete native coarctation. Pediatr Cardiol 1996; 17: 184–188.
20. Angelini A, Allan LD, Anderson RH, Crawford DC, Chita SK, Ho SY. Measurements of the dimensions of the aortic and pulmonary pathways in the human fetus: a correlative echocardiographic and morphometric study. Br Heart J 1988; 60: 221–226.
21. DeVore GR, Siassi B, Platt LD. Fetal echocardiography. M-mode measurements of the aortic root and aortic valve in second and third-trimester normal human fetuses. Am J Obstet Gynecol 1985; 152: 543–550.
22. Rudolph AM, Heymann MA, Spitznas U. Hemodynamic considerations in the development of narrowing of the aorta. Am J Cardiol 1972; 30: 514–525.
23. Piehler JM, Danielson GK, McGoon DC, Wallace RB, Fulton RE, Mair DD. Management of pulmonary atresia with ventricular septal defect and hypoplastic pulmonary arteries by right ventricular outflow construction. J Thorac Cardiovasc Surg 1980; 80: 552–567.
24. Langdon TJ, Boerboom LE, Olinger GN, Rodriguez ER, Ferrans VJ. Rheologic genesis of aortic coarctation in a canine model. Am Heart J 1988; 115: 489–492.
25. Yen Ho S, Anderson RH. Coarctation, tubular hypoplasia and the ductus arteriosus. Histological study of 35 specimens. Br Heart J 1979; 41: 268–274.
26. Henry WL, Gardin JM, Ware JH. Echocardiographic measurements in normal subjects from infancy to old age. Circulation 1980; 62: 1054–1061.
27. Ichida F, Aubert A, Denef B, Dumoulin M, Van der Hauwaert LG. Cross sectional echocardiographic assessment of great artery diameters in infants and children. Br Heart J 1987; 58: 627–634.
28. 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: 507–512.

Appendix

The formula describing the relationship between height and aortic dimension at any of the designated sites is:

$$\begin{aligned}&\text{Natural log of aortic dimension (mm)}\\&= \text{Intercept} + (\text{Parameter estimate})\\&\times (\text{Natural log of height (cm)})\end{aligned}$$

The predicted normal dimension for a patient can be calculated from Table 2, by taking the antinatural logarithm of the result from solving the following equation:

$$\text{Intercept} = \begin{bmatrix}\text{Parameter}\\\text{estimate}\end{bmatrix} \times \begin{bmatrix}\text{Natural log of}\\\text{Patient height}\\\text{(cm)}\end{bmatrix}$$

The Z score, which relates the measurement in terms of the number of standard deviations it departs from the mean normal value, can be calculated from the following equation:

$$\frac{\begin{bmatrix}\text{Natural log of}\\\text{actual measurement}\\\text{(mm)}\end{bmatrix} - \begin{bmatrix}\text{Natural log of}\\\text{predicted measurement}\\\text{(mm)}\end{bmatrix}}{\text{Root mean square error}}$$

For example, a child whose height is 77 cms, the normal dimension of the ascending aorta can be predicted by first solving the following equation:

$$\begin{aligned}&-0.0410\,(\text{Intercept}) + 0.5969\,(\text{Parameter estimate})\\&\times \text{Natural log of } 77\ (\text{Natural log of height (cm)})\end{aligned}$$

The natural logarithm of 77 is 4.34. The solved equation equals 2.54. The antinatural logarithm of 2.54 is 12.7, which is the predicted normal dimension of the ascending aorta in millimetres. Further, if the measured value of the ascending aorta was 11 mm, the Z score can be calculated by solving the equation:

$$\frac{(\text{Natural log } 11 - \text{Natural log } 12.7)}{0.1458} = -0.97.$$