Cardiol Young 2005; 15: 119–124
© Cambridge University Press
ISSN 1047-9511

Original Article

Normative angiographic data relating to the dimensions of the aorta and pulmonary trunk in children and adolescents

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Abstract *Background:* Definition of normative data of the great arteries from neonatal to adult ages may aid in assessment of the growth of cardiovascular structures, thus guiding the timing and type of intervention in patients with congenital cardiac disease. *Methods:* We calculated the cross-sectional areas of the arterial roots at the basal attachment of the valvar leaflets, the sinuses, and standardized distal sites using cineangiograms of 59 normal children and adolescents with mean age of 5.4 plus or minus 4.7 years and a range from 0.1 to 16 years, the children having a mean weight of 21.2 plus or minus 15.7 kilograms, with a range from 2.2 to 68 kilograms, and mean height of 108 plus or minus 35 centimetres, with a range from 43 to 184 centimetres. Values at each site were calculated averaging end-diastolic and end-systolic measurements, and indexed to body surface area. Results are expressed as the mean plus or minus the standard deviation. *Results:* The diameter of the aortic root at the basal attachment of the leaflets was 249 plus or minus 26, the midpoint of the sinuses 379 plus or minus 59, the sinutubular junction 290 plus or minus 58, the isthmus 158 plus or minus 36, the postisthmic region 152 plus or minus 33, and the descending aorta at the level of diaphragm 130 plus or minus 18 millimetres squared per metre squared. The pulmonary root measured at the basal attachment of the leaflets was 253 plus or minus 28, the midpoint of the sinuses 352 plus or minus 58, the sinutubular junction 293 plus or minus 58, the right pulmonary artery 176 plus or minus 25, the left pulmonary artery 153 plus or minus 20, and sum of right and left pulmonary arteries 330 plus or minus 37 millimetres squared per metre squared. All indexes were consistent over a wide range for body surface areas. *Conclusions:* Definition of normative data of the great vessels may aid in the evaluation of congenital or acquired abnormalities, serving as guidelines for intervention during medical or surgical management and follow-up.

Keywords: Arteries; valves; normative values

ANGIOCARDIOGRAPHY IS A WELL-ESTABLISHED method for evaluating congenital cardiac malformations, providing quantitative data that aids in assessing the severity of cardiovascular abnormalities. Reliable measurements of the aorta and pulmonary trunk in several lesions have contributed significantly to decision making for medical management, follow-up[1] and surgical intervention,[2] sometimes impacting on surgical mortality, as in the Fontan operation.[3] Normal angiographic diameters at selected sites for the aorta,[1,4,5] the pulmonary trunk[6–8] and its branches,[9] as well as normal great vessel echocardiographic measurements of the arterial trunks,[10,11] have previously been reported. All the investigations cited above, however, do not report vessel cross-sectional areas, but focus on diameters, which they

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Accepted for publication 29 September 2004

mostly correlate with age or body surface area. As far as we are aware, cross-sectional areas indexed to body surface area have only been reported for the right pulmonary artery[12] and the sum of the cross-sectional areas of the right and left pulmonary artery, the latter termed the pulmonary arterial index, and showing consistency over a wide range of body surface areas.[13] With this in mind, we have calculated similar cross-sectional areas for various sites within the arterial roots and trunks.

Patients and methods

Patients

Our population consisted of 59 patients, 36 male and 23 female, with essentially normal hearts, who underwent cardiac catheterisation for evaluation of suspected cardiac disease in the era prior to echocardiography. Their mean age was 5.4 plus or minus 4.7 years, with a median of 4.3 years, and a range from 0.1 to 16 years. Their mean weight was 21.2 plus or minus 15.7 kilograms, with a median of 17 kilograms, and a range from 2.2 to 68 kilograms. The mean height was 108 plus or minus 35 centimetres, with a median of 108 centimetres, and a range from 43 to 184 centimetres. Their mean body surface area was 0.78 plus or minus 0.42 square metres, with a median of 0.72 square metres, and a range from 0.15 to 1.89 square metres. None of the patients had disturbances of conduction or arrhythmias, 24 had no detectable cardiac anomaly, while 35 had only mild anatomic abnormalities of no haemodynamic significance. Of the patients with mild anatomic abnormalities, 16 had pulmonary stenosis, with a systolic pressure gradient less than 15 millimetres of mercury, 4 had bicuspid aortic valves with systolic pressure gradients less than 15 millimetres of mercury, 2 had subvalvar aortic stenosis with systolic pressure gradients less than 15 millimetres of mercury, 5 had aberrant right subclavian arteries, 3 small patent arterial ducts, 2 small muscular ventricular septal defects, and 3 had Kawasaki syndrome without coronary arterial aneurysms. The patients with aortic valvar or subaortic abnormalities were excluded from the measurements made of the aortic root.

Angiography

All the patients underwent cardiac catheterisation in a fasting state after written informed consent was obtained from their parent or guardian. Biplane angiography was performed after collection of data relating to saturations and pressure data. Right ventriculograms and pulmonary angiograms were profiled in posteroanterior projection with or without 30 degrees cranial angulation, and in lateral projection.

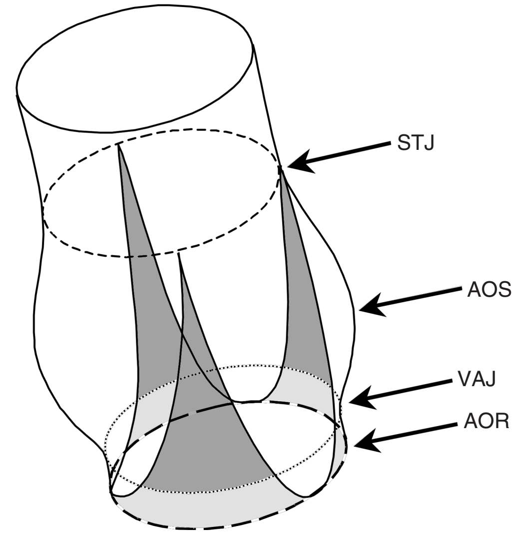

Figure 1.
Diagrammatic representation showing the structures throughout the length of the aortic root. AOR: aortic ring; AOS: aortic sinus; STJ: sinutubular junction; VAJ: ventriculo-arterial junction. (Adapted from Anderson RH. Clinical anatomy of the aortic root. Heart 2000; 84: 670–673.)

Left ventriculograms were profiled in posteroanterior and long axial oblique projections, the latter in 60 degrees left anterior oblique with 30 degrees cranial angulation. Calibration was done using the internal diameter of the angiographic catheter in 22 patients, and a grid of known dimensions filmed in the same projection in 37 patients. Measurements were performed on a Tagarno viewing screen (Tagarno, Denmark) projected in a single plane, assuming a tubular shape of the structure under examination, and taking care to choose good quality frames during sinus beats.

Measurements of the arterial roots were designed to take account of their length and complexity (Fig. 1) as previously described.[14] The ventriculo-arterial junction represents the site where the ventricular structures change to the fibroelastic aortic wall, while the sinutubular junction marks the transition from the sinuses to the ascending aorta at the level of distal attachments of the valvar commissures. The measurement chosen for the "ring" was at the level of the basal attachments of the leaflets. The same definition was applied for defining the site of the "ring" in the pulmonary root.

We measured the pulmonary ring, the area of the pulmonary arterial sinuses at their widest points, the pulmonary sinutubular junction (Fig. 2a), the right and left pulmonary arteries just before the origin of the first branch (Fig. 2b), the aortic ring, the aortic sinuses at their widest point, the aortic sinutubular junction (Fig. 2c), the descending aorta at the isthmic

https://doi.org/10.1017/S1047951105000272 Published online by Cambridge University Press

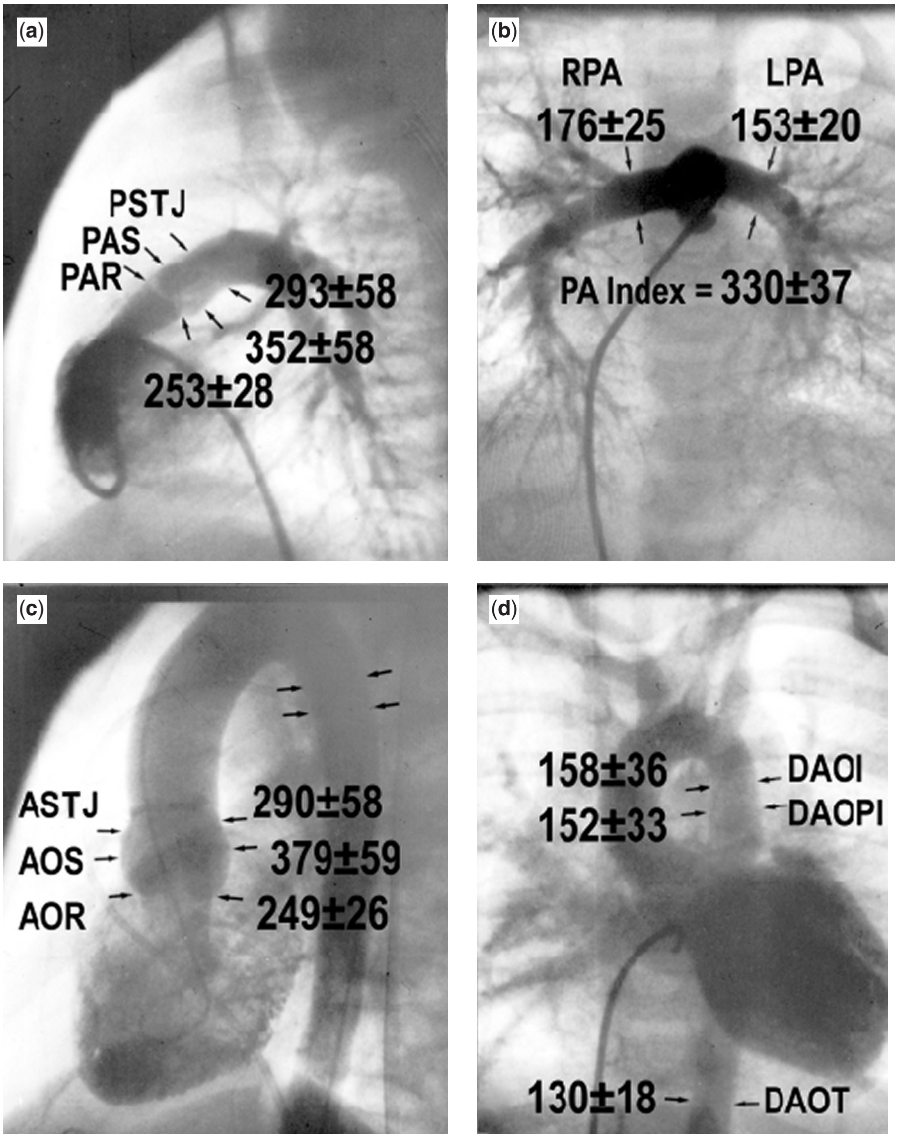

Figure 2.
*Sites of measurement (arrows) and mean values plus or minus standard deviations for the indexes in the pulmonary trunk (**a**), the right and left pulmonary arteries (**b**), the ascending aorta (**c**), and descending aorta (**d**). AOR: aortic ring; AOS: aortic sinus; ASTJ: aortic sinutubular junction; DAOI: descending aorta at the isthmic region; DAOPI: descending aorta at the post-isthmic region; DAOT: descending thoracic aorta at the level of the diaphragm; LPA: left pulmonary artery; RPA: right pulmonary artery; PA Index: pulmonary arterial index; PAR: pulmonary arterial ring; PAS: pulmonary arterial sinus; PSTJ: pulmonary sinutubular junction.*

region, the postisthmic region, and at the level of the diaphragm (Fig. 2d). Measurements were repeated at both end-diastole and end-systole, or at the largest and smallest diameter during each cardiac cycle, and the mean was calculated. The cross-sectional areas, and indexation to body surface area, of the various cardiovascular structures were calculated as follows:

- Cross-sectional area (millimetres^2) = $\pi \times$ (diameter/2)^2
- Index (millimetres^2/metres^2) = cross-sectional area/body surface area
- Pulmonary arterial index (millimetres^2/metres^2) = (right pulmonary artery cross-sectional area + left pulmonary artery cross-sectional area)/body surface area[13]

Statistical analysis

Data are expressed as mean plus or minus standard deviations. Student's paired t-test was used to determine the statistical significance of differences in cross-sectional areas between systole and diastole. Values of less than 0.05 were considered statistically significant. Interobserver variability was determined in 20 angiograms by two independent observers.

Results

The various indexes for the great vessels, calculated as described above, were constant over a wide range of body surface areas, and their mean values plus or minus the standard deviations are depicted in Figure 2. The index for the aortic ring was 34 percent smaller

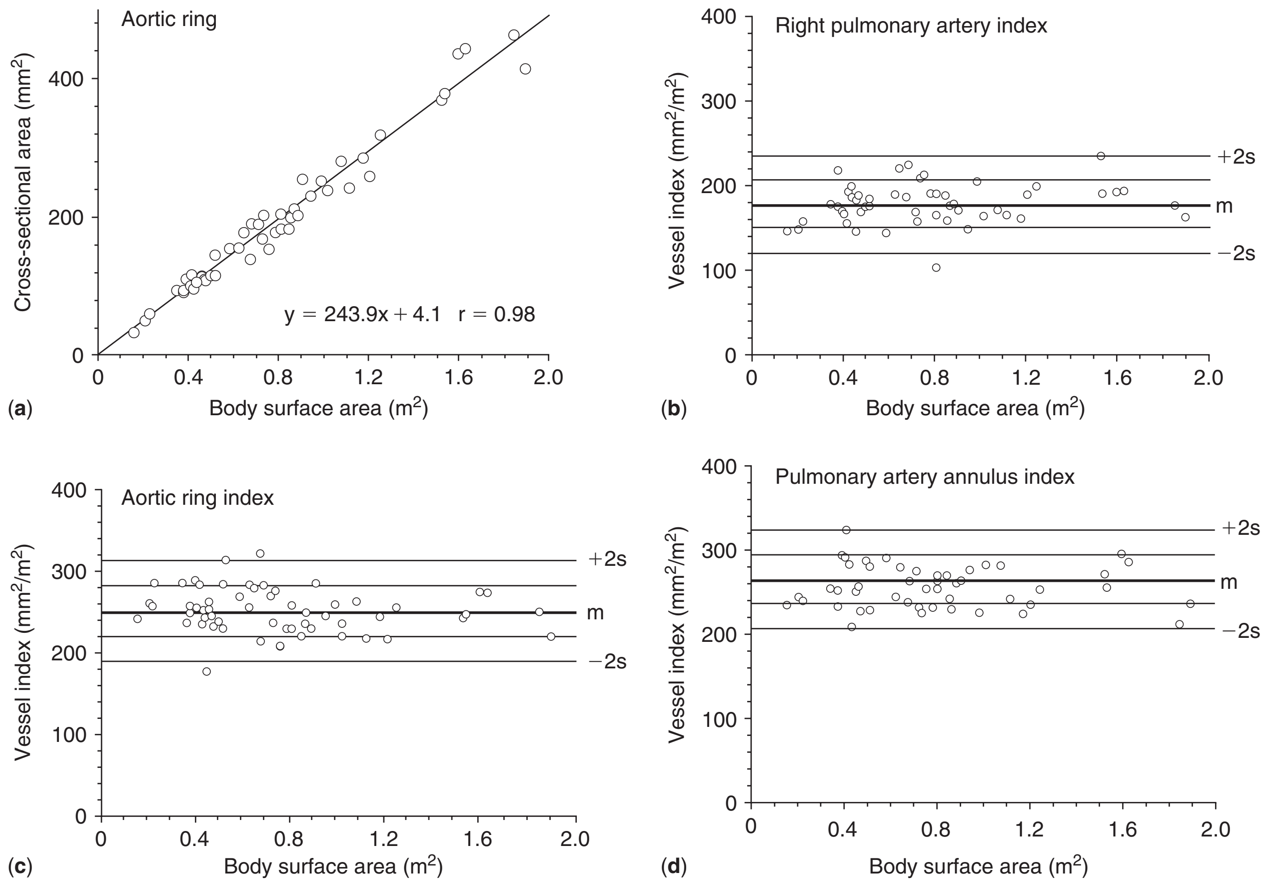

Figure 3.
*Regression of the cross-sectional area of the aortic ring to body surface area (**a**). Scatter plots of the right pulmonary arterial index (**b**), aortic ring index (**c**) and pulmonary ring index (**d**), to body surface area.*

than that for the aortic sinuses, and 14 percent smaller than that for the aortic sinutubular junction. The index for the pulmonary ring was 2 percent larger than that for the aortic ring, 28 percent smaller than the index for the pulmonary arterial sinuses, and 14 percent smaller than that for the pulmonary sinutubular junction. The index for the right pulmonary artery was 13 percent larger than for the left pulmonary artery. The ratio of the sum of the indexes for the right and left pulmonary arteries, or the pulmonary arteries indexed to the descending aorta at the diaphragm, was 2.5. The difference between systolic and diastolic diameters of the vessels ranged between 5 percent and 20 percent, and was 13 percent for the pulmonary ring, and 5 percent for the aortic ring. The interobserver error ranged from 0 to 11.3 percent, with a mean of 4.2 percent.

Systolic, diastolic and mean cross-sectional areas were correlated to body surface area ($r = 0.904$–0.980), weight ($r = 0.897$–0.975) and height ($r = 0.976$–0.968). All regressions were linear, and stronger for body surface area. The strongest correlation was found between body surface area and cross-sectional areas of the left pulmonary artery, pulmonary ring, aortic ring, and descending aorta at diaphragm ($r = 0.97$–0.98). Figure 3 shows scatter plots of the mean cross-sectional area of the aortic ring (Fig. 3a), and the indexes of the right pulmonary artery (Fig. 3b), aortic ring (Fig. 3c), and pulmonary ring (Fig. 3d) versus the body surface area.

Discussion

The anatomy of the arterial roots is complex,[14,15] but its understanding remains crucial in the practice of paediatric and adult cardiology and cardiac surgery. Reference data for dimensions at various sites of the pulmonary and aortic roots, the pulmonary trunk and its branches, and the aorta, as determined using angiography, are scarce in children. Our retrospective angiographic study systematically describes normal cross-sectional areas of the aorta and pulmonary arteries at twelve specific sites, as well as their indexes calculated relative to body surface area.

The pulmonary arterial index as calculated in our study was similar to that previously described,[13]

https://doi.org/10.1017/S1047951105000272 Published online by Cambridge University Press

while the remaining indexes have not, as far as we know, previously been reported. The indexes at all the examined sites were remarkably similar over a wide range of body surface areas from infancy to adolescence, thus proving to be parameters applicable for use, and easy to remember, in paediatric cardiological practice.

The changes in the diameters of the vessels between systole and diastole that we observed in our study are also similar to those previously described.[1,7,11] Due to the significant differences noted during the cardiac cycle, we used mean values of the measurements made in our study, in accordance with previous reports.[13] The differences between the indexes calculated for the right and left pulmonary arteries probably reflect the increased flow of blood to the larger right lung. The difference between the indexes for the areas of the aortic and pulmonary roots at the levels of the basal attachments of the leaflets, the so-called "rings", may be due to the muscular nature of the right ventricular infundibulum as opposed to the partially fibrous nature of the left ventricular outflow tract.

The normative data we have produced for the arterial roots and the great arteries are important for decision making in interventional catheterisation during balloon valvoplasty, angioplasty, or placement of stents, as they may provide guidelines for the minimal,[16] optimal and target cross-sectional areas of a vessel or valve in the growing individual during consecutive interventions. They may also help in choosing between corrective versus palliative surgery in various circumstances, such as in patients with tetralogy of Fallot with or without pulmonary atresia, and those with functionally univentricular physiology. Successful total repair, the choice of a valved versus a nonvalved conduit to be placed between the right ventricle and the pulmonary arteries, and the degree of postoperative right ventricular hypertension and pulmonary insufficiency in tetralogy of Fallot, are all influenced by the pulmonary arterial size and cross-sectional area.[2,16] The surgical approach to patients with functionally univentricular physiology, namely the need for a bidirectional Glenn shunt, and the suitability for the Fontan operation, is also highly dependent on the pulmonary arterial size and capacitance.[3,17] Hypoplastic pulmonary arteries may cause right ventricular hypertension and failure in tetralogy of Fallot, and low cardiac output syndrome in patients put forward for the Fontan operation, both conditions with high postoperative morbidity and mortality.

The ratios between the diameters of the right and left pulmonary arteries relative to the diameter of the ascending or descending aorta have previously been used to predict good or acceptable postoperative results.[2,17] In the setting of congenital cardiac disease, however, the quantity and distribution of flow of blood may differ from normal, making the dimensions of the ascending and descending aorta smaller or larger than in the healthy child. A descending thoracic aorta that is smaller than normal, as is common in tetralogy of Fallot, would lead to an increased ratio between the pulmonary arteries and the descending aorta, thus falsely overestimating the size of the pulmonary arteries.

Our study, and angiographic measurements in general, does have certain limitations. Errors may arise from the assumption that vessels and valves are cylindrical three-dimensional structures that can be measured by taking two-dimensional views in different angiographic planes. The best view would be at a right angle perpendicular to the long axial wall of the vessel, but this view is not always possible to acquire. Moreover, errors in the correction for magnification must be taken into account, as in all previous angiographic reports. Only a few patients in our study had body surface areas less than 0.4, or more than 1.6 metres squared, so consistency of the indexes for cross-sectional area over the whole range of body surface areas is not proven. Further studies may be needed to assess the indexes for body surface areas outside the range discussed above.

In conclusion, we have shown that the normal cross-sectional areas of the arterial valves and great arteries are highly correlated to body surface area, and their ratio or index is a consistent parameter applicable throughout congenital cardiac disease. Angiographic quantitation is a useful tool for determination of normal or abnormal growth of cardiac structures in paediatric cardiology and cardiac surgery. This information may assist in electing types of operation, predicting postoperative complications and mortality for a variety of conditions, and choosing the optimal diameters of balloons and stents during interventional catheterisation.

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