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The variability and morphometry of the brachiocephalic trunk in human foetuses

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In prenatal and pediatric cardiovascular surgery knowledge of the various arrangements of the aortic arch and its branches as well as the normative data are essential. The variability and morphometric features of the brachiocephalic trunk in 131 human foetuses (65 male, 66 female) ranging from 15 to 34 weeks of gestation were studied by means of anatomical, digital and statistical methods. In all the foetuses examined the left aortic arches were found to have three different arrangements. In 74.05% of cases the usual pattern of the aortic arch with its three main branches were observed. A common origin of the brachiocephalic trunk and left common carotid artery occurred in 20.61% of individuals. In 5.34% of cases the left vertebral artery was an additional vessel and arose from the aortic arch between the left common carotid and subclavian arteries. No significant gender differences were found with respect to the brachiocephalic trunk ($p \geq 0.05$). The developmental increase in length ($r_1 = 0.78$) and diameter ($r_2 = 0.83$) correlated with a linear function but the increase in volume in relation to age corresponded to a quadratic function ($r_3 = 0.73$). Our results show the largest increases in the brachiocephalic trunk according to the following parameters: the length — between the 4th and 5th, and 7th and 8th months, diameter — between the 8th and 9th months and volume — between the 4th and 5th, and 7th and 9th months of gestation ($p \leq 0.01$). The present study constructs a normal range for the morphometric features of the foetal brachiocephalic trunk.

Key words: innominate artery, variability, length, diameter, volume, regression analysis, human foetuses

INTRODUCTION

Variations in the branching of the aortic arch are a guide to vascular surgery in ischaemic cerebrovascular disease [4, 16]. The number of primary branches may be reduced to 1–2 or increased to 4–6 [1, 3, 14, 19]. Non-invasive techniques such as ultrasonography, CT and MRI enable pathological changes in the brachiocephalic trunk and carotid arteries to be diagnosed [10]. Duplex-Doppler ultrasonography is a safe and effective method of examining aortic arch branching in foetuses [20]. In prenatal and paediatric cardiovascular surgery knowledge of the normative data of the diameters of the aortic arch and its branches is necessary to determine cardiac output and arterial blood flow [5]. No angiometric study of the brachiocephalic trunk in human foetuses has previously been reported. The present study was undertaken in order to construct a normal range for

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the morphometric features of the brachiocephalic trunk during gestation.

The aim of this study was to examine the following: the morphometric features (length, diameter and volume) of the brachiocephalic trunk; the influence of sex on the value of the features examined; the developmental trend of the morphometric features of the brachiocephalic trunk.

MATERIAL AND METHODS

The examinations were carried out on 131 foetuses of both sexes (65 male and 66 female) from spontaneous abortions or stillbirths, cardiovascular abnormalities having been excluded at necropsy. The gestational age ranged from 15 to 34 weeks (Table 1). Foetal age was established by crown-rump (CR) measurements. The arterial bed was filled with approximately 15–30 ml of white latex LBS 3060 through a catheter, which was introduced by dorsal access into the thoracic aorta. Specimens were fixed in a 10% neutral formalin solution and branches of the aortic arch were prepared under a stereoscope with Huygens ocular at a magnification of 25–50 times. Afterwards source pictures of aortic arch branching were analysed by Digital Image Analysis System Q 500 MC of Leica (Cambridge). The following measurements were made: the length [mm], external diameter [mm] and volume [mm^3] of the brachiocephalic trunk. The developmental growth of the brachiocephalic trunk was statistically analysed by means of regression analysis. Gender differences were analysed by means of Student's t test for two mean independent variables using the PC STAT 1.0 program. The correlation coefficients of the examined features with foetal age (r) were evaluated.

Table 1. Age and sex of investigated foetuses

Foetal age			Sex	
Months	Weeks	Number	Male	Female
4	15	12	6	6
	16	11	5	6
5	18	11	5	6
	19	9	5	4
6	22	12	7	5
	23	13	6	7
7	25	14	8	6
	26	9	4	5
8	29	11	3	8
	30	10	7	3
9	33	14	6	8
	34	5	3	2
Total		131	65	66

RESULTS

In all the foetuses examined the left aortic arches were found to have three different arrangements (Fig. 1) and to be without gender differences. In 74.05 % of cases the usual pattern of the aortic arch (Figs. 1a, 2) with its three main branches (brachiocephalic trunk, left common carotid artery and left subclavian artery) was observed. A common origin of the brachiocephalic trunk and left common carotid artery (Fig. 1b) occurred in 20.61% of individuals. In 5.34% of cases the left vertebral artery was an additional vessel and originated from the aortic arch between the left common carotid and subclavian arteries (Fig. 1c). There were no high or low types of division of the brachiocephalic trunk in the foetuses examined. The statistical analysis of the examined features of the brachiocephalic trunk did not show gender dimorphism ($p \geq 0.05$). For this reason the morphometric values obtained are presented without regard to sex (Table 2). The morphometric features of the brachiocephalic trunk indicated the differing developmental dynamic. The largest increase in length of the brachiocephalic trunk was characteristically between the 4th and 5th and between the 7th and 8th months of prenatal life ($p \leq 0.01$). The largest increase in diameter ($p \leq 0.01$) took place between 8th and 9th months. The largest growth in volume occurred between the 4th and 5th, and 7th and 9th months of gestation ($p \leq 0.01$). The length and diameter revealed an increase in values with increased foetal age according to the regression line (Figs. 3, 4). The increase in volume in relation to age corresponded to the quadratic function (Fig. 5). Positive correlation coefficients of these parameters with foetal age were statistically significant ($p \leq 0.01$) and reached the following values: $r_1 = 0.78$ for length, $r_2 = 0.83$ for diameter and $r_3 = 0.73$ for volume.

DISCUSSION

The brachiocephalic trunk develops from the ascending part of the right dorsal aorta [1, 3, 7, 15]. Regression of the right dorsal aortic root (between the right subclavian artery and the descending aorta) and the right *ductus arteriosus* leaves the normal left aortic arch. The proximal segments of the third pair form the common carotid arteries. Variation in

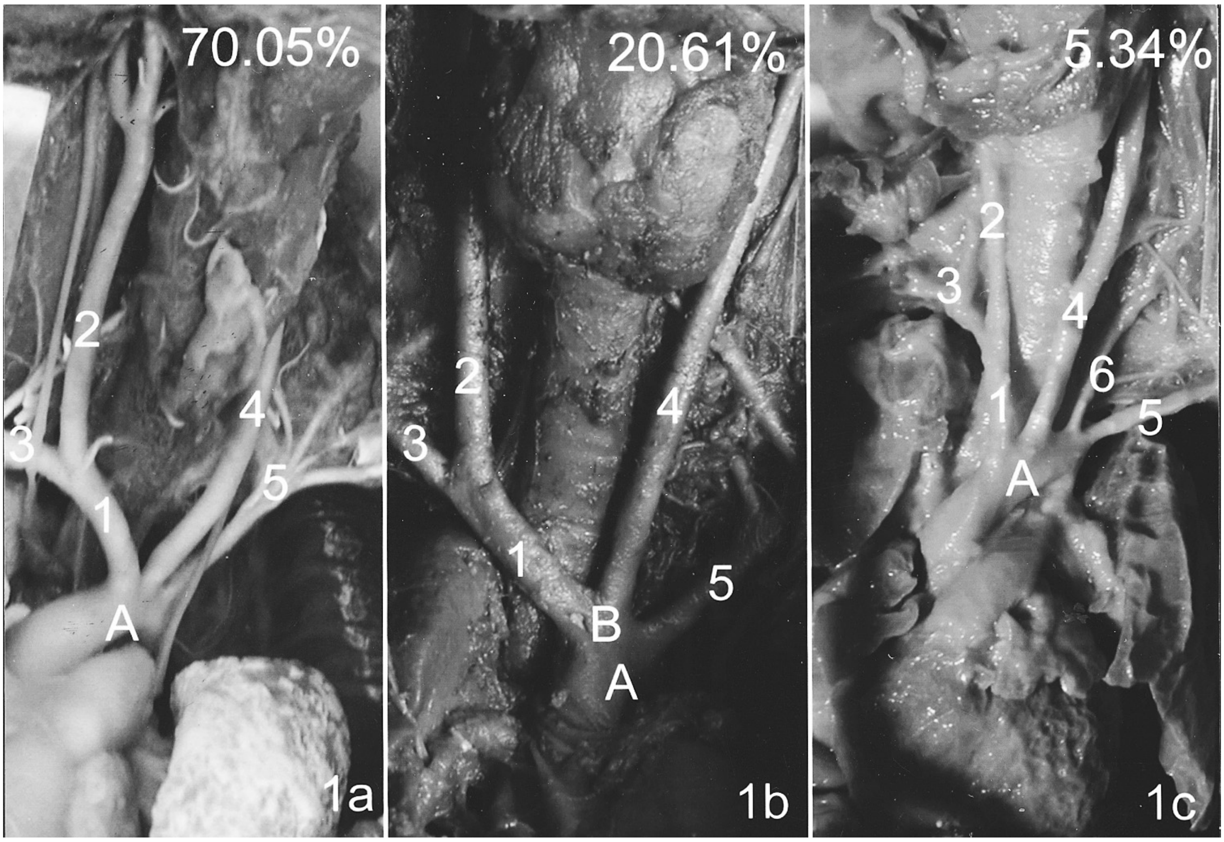

Figure 1. Three different arrangements of aortic arch branching: **a.** The usual pattern of the aortic arch, **b.** Reduction to 2 derived branches of the aortic arch, **c.** Increase to 4 derived branches of the aortic arch: A — aortic arch, B — bicarotid trunk, 1 — brachiocephalic trunk, 2 — right common carotid artery, 3 — right subclavian artery, 4 — left common carotid artery, 5 — left subclavian artery, 6 — left vertebral artery.

the origin of the brachiocephalic trunk is closely dependent on the type of aortic arch branching. The right brachiocephalic trunk is characteristic for the left aortic arch and this pattern occurs in 99.9% [3, 7]. The normal left brachiocephalic trunk is typical for the right aortic arch [8]. This rare variety (0.1%) results from persistence of the right fourth branchial arch. Savastano et al. [16] presented agenesis of brachiocephalic trunk in one case and a hypoplastic right brachiocephalic trunk in two specimens.

According to Anson's examination [3] of 1000 adult cadavers, the arrangement regarded as "normal" for man (Type I) is actually encountered more frequently (64.9%) than all other types combined. Three branches leave the aortic arch in the following order from right to left: the brachiocephalic trunk, the left common carotid artery and the left subclavian artery. In Type II of Anson (27.1%) there is a common origin of the brachiocephalic trunk and left common carotid artery. This arrangement is distinguished by a reduction in the number of stems to two. Bilateral common carotid arteries arising from the bicarotid trunk were described by Niżankowski et al. [12] in 0.9% only. In our material the normal pattern of brachiocephalic trunk was observed in 74.05%, while a bicarotid trunk was found in 20.61% of cases. The number of large arteries of the aortic arch might be reduced to one or increased to 6 vessels [3, 9, 14, 19], but these anomalies were absent in the material under examination. We noted in 5.34% of individuals the origin of the left vertebral artery from the aortic arch. This pattern occurred in Anson's investigation [3] in 3.8% of cases (Types III, IV, VII, XIV). In his material the brachiocephalic trunk was absent in 0.5% of cases (Type VI). Anson described a bi-innominate sequence (Type IX) in 1.2% of cases. In this the normal left and right brachiocephalic trunks derived from the left aortic arch. In Anson's material derivation of all the main branches from a single trunk was found in 0.3% of cases. Roberts et al. [13] observed a left aortic arch with a retro-oesophageal aberrant right brachiocephalic trunk. Moes and Freedom [11], on the other hand, described a left aberrant brachiocephalic trunk with

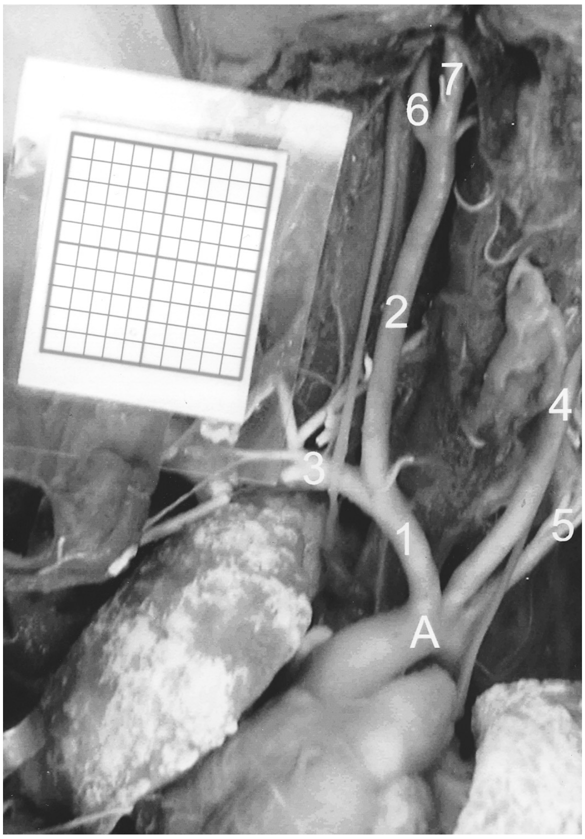

Figure 2. The usual pattern of the aortic arch in human foetus aged 5 months: A — aortic arch, 1 — brachiocephalic trunk, 2 — right common carotid artery, 3 — right subclavian artery, 4 — left common carotid artery, 5 — left subclavian artery, 6 — internal carotid artery, 7 — external carotid artery.

mirror-image branching. Szpinda [17] presented a new typological variant of the left aortic arch in which a left aberrant hypoplastic brachiocephalic trunk passed behind the trachea and the oesophagus.

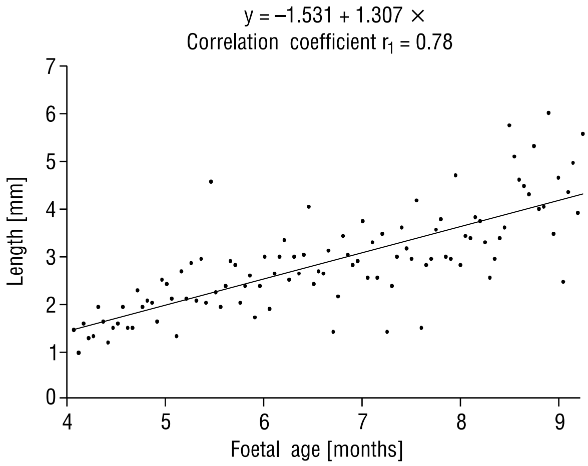

Figure 3. Regression line for the length of the brachiocephalic trunk in relation to foetal age. Linear function: length = –1.531 + + 1.307 × age; r_1 = 0.78.

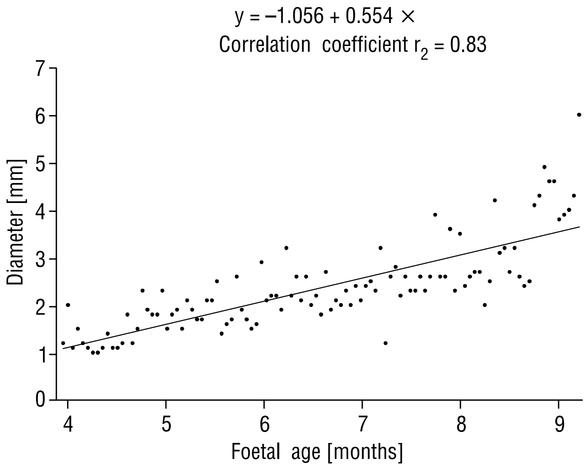

Figure 4. Regression line for the diameter of the brachiocephalic trunk in relation to foetal age. Linear function: diameter = –1.056 + + 0.554 × age; r_2 = 0.83.

Table 2. Angiometric analysis of the brachiocephalic trunk for length, diameter and volume

Foetal age [months]	Brachiocephalic trunk					
	Length [mm]		Diameter [mm]		Volume [mm³]	
	Mean	SD	Mean	SD	Mean	SD
4	3.38[A]	0.61	1.23	0.27	3.62[G]	1.43
5	5.34[B]	1.37	1.87	0.38	12.98[H]	5.45
6	6.42	1.41	2.29	0.36	25.57	11.66
7	7.39[C]	1.54	2.62	0.56	42.13[I]	24.64
8	9.57[D]	2.41	2.84[E]	0.61	60.32[J]	25.71
9	9.89	2.34	4.45[F]	0.64	162.27[K]	87.45

Means lengths marked by the letters A and B, C and D indicate the largest increases ($p \leq 0.01$). Mean diameters marked by the letters E and F indicate the largest increases ($p \leq 0.01$). Mean volumes marked by the letters G and H, I, J and K indicate the largest increases ($p \leq 0.01$).

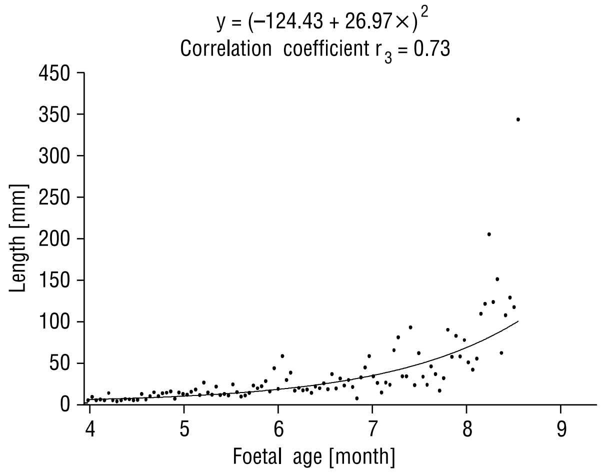

Figure 5. Regression line for the volume of the brachiocephalic trunk in relation to foetal age. Quadratic function: volume = = (–124.43 + 26.97 × age)^2; r_3= 0.73.

It should be noted that we observed no statistically significant gender differences with respect to either the various arrangements or the values of the morphometric features. The length of the brachiocephalic trunk depends on the level of its origin and on the level of its bifurcation into subclavian and common carotid arteries. The long type of brachiocephalic trunk corresponded with a high division and the short type of brachiocephalic trunk is characteristic when the division is low, but these types were absent in the material under examination. Our earlier study indicated that during foetal development the termination of the brachiocephalic trunk apparently descended by one vertebra [18].

The angiometric study of the brachiocephalic trunk during gestation showed developmental growth in the length (r_1 = 0.78) and diameter (r_2 = 0.83) correlated with a linear function, while the increase in volume in relation to age (r_3 = 0.73) corresponded to a quadratic function. Similar observations concerning these common relations between aortic growth and foetal age have been confirmed by other authors [2, 20]. Therefore, in children and adults no systematic correlation has been found between arterial length and diameter with increased age, the relation being best described as a function of the natural logarithm of the body weight [6]. Our results show the largest growth of the brachiocephalic trunk concerning the following parameters: the length — between the 4th and 5th and the 7th and 8th months, the diameter — between the 8th and 9th months and the volume — between 4th and 5th and the 7th and 9th months of prenatal life ($p \leq 0.01$). Our findings indicated that in the age range examined the volume of the brachiocephalic trunk increased approximately 45-fold, from 3.62 ± 1.43 mm^3 to 162.27 ± 87.45 mm^3. This result was obtained from the product of the length and the squared diameter, which increased approximately 3-fold and 4-fold, respectively.

The morphometric features of the brachiocephalic trunk presented in this paper have not previously been discussed in the professional literature. The normative data of the brachiocephalic trunk established in this work may be helpful in the early diagnosis of developmental anomalies, especially in prenatal life in the assessment, with the use of duplex-Doppler ultrasonography, of the condition of foetuses in pregnant women with hypertension, diabetes or twin pregnancy [9, 10, 12]. The angiometric parameters of the brachiocephalic trunk complement current measurement data obtained during invasive (arteriography) and non-invasive (ultrasonography, CT, MRI) techniques.

This study has demonstrated that the normal ranges of the brachiocephalic trunk presented may serve as a basis for comparison of the measurements of the same parameters in foetuses with congenital defects of the heart, the aortic arch and the branches of the aortic arch.

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