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External diameters of the pulmonary arteries in human foetuses: an anatomical, digital and statistical study

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This study defines the growth patterns for the external diameters of the pulmonary arteries in human foetuses, including relationships with sex, side of body (right–left) and foetal age. Using anatomical dissection, digital-image analysis (system of Leica Q Win Pro 16) and statistical analysis (ANOVA, regression analysis), a range of external diameters for the right and left pulmonary arteries in 128 spontaneously aborted human foetuses aged 15–34 weeks was examined. No significant gender differences were found ($p > 0.05$). In the examined age range the values of the external diameter of the right pulmonary artery ranged from 0.97 ± 0.24 to 2.95 ± 0.89 mm, according to the linear function $y = -0.7753 + 0.1148 x \pm 0.4580$ ($r = 0.83$; $p < 0.001$). The values of the external diameter of the left pulmonary artery ranged from 0.88 ± 0.25 to 2.63 ± 0.80 mm, in accordance with the linear relationship $y = -0.6228 + 0.1007 x \pm 0.4280$ ($r = 0.81$; $p < 0.001$). The external diameters of the right pulmonary artery were greater than those of the left pulmonary artery ($p < 0.001$). Parallel to the increase in the values of the external diameters of both the pulmonary arteries, the pulmonary artery-to-ascending aorta diameter ratio (the relative diameter of the pulmonary artery) decreased with advanced foetal age from 0.46 ± 0.10 to 0.43 ± 0.13 for the right pulmonary artery, and from 0.43 ± 0.10 to 0.39 ± 0.12 for the left one. The growth curves generated may be useful as reference data for foetal diagnosis. (Folia Morphol 2008; 67: 240–244)

Key words: external diameter, pulmonary artery, digital image--analysis

INTRODUCTION

The right and left pulmonary arteries are the remnants of the ventral part of the 6th ipsilateral aortic arches [4]. During prenatal life, both pulmonary arteries together with the ductus arteriosus form a trifurcation of the pulmonary trunk.

The majority of authors [1, 2, 10–13] emphasize that the diameter of the right pulmonary artery is greater than the left one. The linear growth in the diameter of the pulmonary arteries has been previously reported on sparse human material by anatomists [1, 8, 15] and echocardiographers [6, 7].

Based on available literature data, the objectives for the present study were to examine:

— the reference ranges of the external diameter for the pulmonary arteries at varying gestational ages;
— the growth curves for the external diameter of the pulmonary arteries versus foetal age;
— the developmental trend of the relative diameters of the pulmonary arteries (right or left pulmonary artery-to-ascending aorta diameter ratio);

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Table 1. Age and number of foetuses studied

Foetal age		Crown-rump length [mm]				Number	Sex	
Months	Weeks (Hbd-life)	Mean	SD	Min.	Max.		Male	Female
4	15	89.4	6.1	85.0	92.0	10	5	5
	16	103.7	6.1	95.0	106.0	7	3	4
5	17	114.9	8.2	111.0	121.0	6	4	2
	18	129.3	6.6	124.0	134.0	8	3	5
	19	142.7	7.7	139.0	148.0	6	3	3
	20	155.3	5.8	153.0	161.0	4	1	3
6	21	167.1	4.7	165.0	173.0	3	2	1
	22	178.1	6.9	176.0	186.0	7	4	3
	23	192.3	6.3	187.0	196.0	9	4	5
	24	202.9	5.7	199.0	207.0	11	6	5
7	25	215.2	4.8	211.0	218.0	7	5	2
	26	224.7	5.2	220.0	227.0	7	4	3
	27	234.1	4.3	231.0	237.0	4	0	4
	28	244.2	5.1	240.0	246.0	5	2	3
8	29	253.8	4.5	249.0	255.0	6	1	5
	30	262.7	3.1	260.0	264.0	6	5	1
	31	270.7	5.2	268.0	275.0	4	1	3
	32	281.4	3.7	279.0	284.0	5	4	1
9	33	290.3	6.1	286.0	293.0	9	4	5
	34	301.4	3.2	296.0	302.0	4	2	2
						Total 128	63	65

— the possible gender and syntopic (right–left) differences.

MATERIAL AND METHODS

The examinations were carried out on 128 spontaneously aborted human foetuses of both sexes (63 male, 65 female) whose ages varied from 15 to 34 weeks (Table 1). The crown-rump length (CRL) measurements were taken as a base in the determination of gestational age according to Iffy et al. tables [9]. The present study was approved by the Research Ethics Committee of the Nicolaus Copernicus University (statement of ethical approval KB/217/ /2006). Specimens that had detectable cardiovascular malformations were excluded from the examinations. Foetuses were grouped into six-monthly cohorts, from the 4th to 9th month of gestation, respectively. A catheter was introduced into the abdominal aorta and white latex LBS 3060 was pumped in under controlled pressure of 50–60 mm Hg, filling the foetal arteries. The specimens were then immersed in a 10% neutral formalin solution for 4–24 months, and then dissected under a stereoscope at a magnification of 10×, according to standard autopsy techniques. The great arterial pulmonary pathways were separated from the lungs, and the cardiovascular block removed from the chest cavity. In each foetus, the dissected pulmonary arteries with the millimetre scale were placed perpendicular to the optical lens axis, recorded afterwards using a camera Nikon Coolpix 8400 and digitalized to JPEG images. Afterwards, the images underwent angiometric analysis using digital image analysis software Leica Q Win Pro 16 (Cambridge), which estimated the original external diameters of the pulmonary arteries and the ascending aorta. The measurements were then derived by assuming that the arteries filled with latex were circular in cross section. The high degree of accuracy and high sensitivity of the digital method allows precise estimation of the diameters, to an accuracy of 0.1 mm. Because of the different sizes of the specimens studied, it was expressed for each pulmonary artery as a ratio of the ascending aorta diameter.

For each individual, the five following measurements and calculations were made:

1 — external diameter of the ascending aorta (at the level of the aortic valve annulus);
2–3 — external diameters of the both pulmonary arteries (at their origins);
4–5 — relative diameters of the pulmonary arteries, expressed as the left or right pulmonary artery-to-ascending aorta diameter ratio.

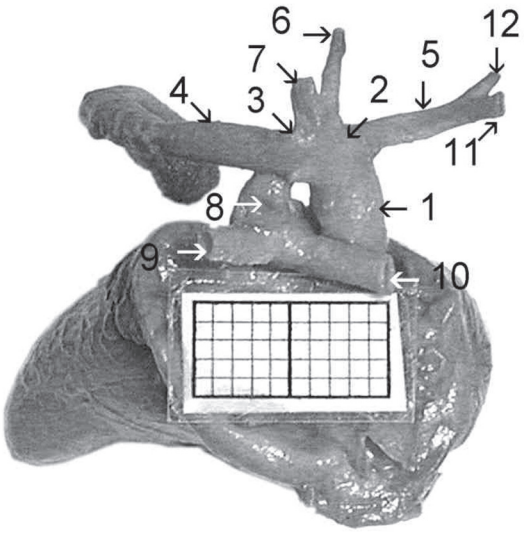

Figure 1. The great arteries of the foetal heart in a male foetus aged 23 weeks: 1 — ascending aorta, 2 — aortic arch, 3 — aortic isthmus, 4 — thoracic aorta, 5 — brachiocephalic trunk, 6 — left common carotid artery, 7 — left subclavian artery, 8 — ductus arteriosus, 9 — right pulmonary artery, 10 — left pulmonary artery, 11 — right subclavian artery, 12 — right common carotid artery.

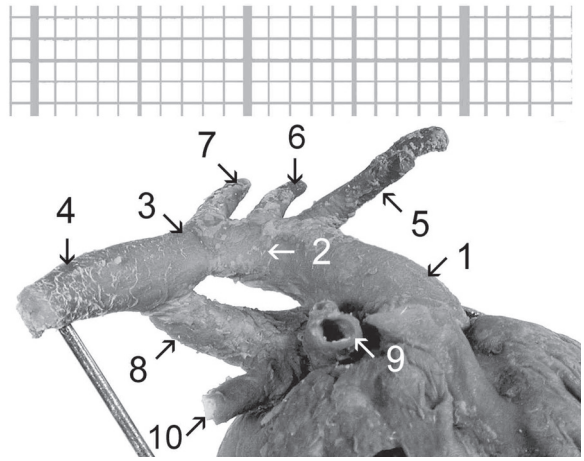

Figure 2. The great arteries of the foetal heart in a female foetus aged 27 weeks: 1 — ascending aorta, 2 — aortic arch, 3 — aortic isthmus, 4 — thoracic aorta, 5 — brachiocephalic trunk, 6 — left common carotid artery, 7 — left subclavian artery, 8 — ductus arteriosus, 9 — left pulmonary artery, 10 — right pulmonary artery.

The external diameters of the pulmonary arteries were correlated to foetal age to establish the dynamics of their growth. The results obtained were analyzed by two-way ANOVA test for unpaired data and post-hoc intergroup comparisons were performed using RIR Tukey test. Regression analysis was introduced to derive the line of best fit for the plot for each diameter of the right or left pulmonary arteries versus gestational age. Correlation coefficients (r) of pulmonary artery diameters with foetal age were estimated. Differences were considered significant at $p < 0.05$.

RESULTS

The source pictures of the pulmonary arteries and the ascending aorta are presented in Figures 1 and 2. The values of the diameters examined were similar in both genders ($p > 0.05$). For this reason, the obtained morphometric results, without regard to sex, have been presented in Table 2. Several transformations concerning the external diameters of the pulmonary

Table 2. The block scheme of the statistical analysis of the external diameters of the pulmonary arteries

Foetal age (months)	n	Right pulmonary artery				Left pulmonary artery			
		Diameter [mm]		Relative diameter		Diameter [mm]		Relative diameter	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
4	17	0.93^A	0.40	0.46	0.10	0.88^B	0.25	0.43	0.10
		↓ ($p > 0.05$)		↓ ($p < 0.01$)		↓ ($p > 0.05$)		↓ ($p < 0.01$)	
5	24	1.19^A	0.18	0.41	0.07	1.09^B	0.14	0.38	0.06
		↓ ($p < 0.01$)		↓ ($p < 0.01$)		↓ ($p < 0.01$)		↓ ($p < 0.01$)	
6	30	2.05^A	0.40	0.52	0.07	1.87^B	0.37	0.47	0.07
		↓ ($p > 0.05$)		↓ ($p < 0.01$)		↓ ($p > 0.05$)		↓ ($p < 0.01$)	
7	23	2.32^A	0.43	0.48	0.11	2.10^B	0.48	0.43	0.10
		↓ ($p > 0.05$)		↓ ($p < 0.01$)		↓ ($p > 0.05$)		↓ ($p < 0.01$)	
8	21	2.62^A	0.53	0.43	0.09	2.35^B	0.48	0.39	0.08
		↓ ($p < 0.01$)		↓ ($p > 0.05$)		↓ ($p < 0.01$)		↓ ($p > 0.05$)	
9	13	2.95^A	0.89	0.43	0.13	2.63^B	0.80	0.39	0.12

The means for external diameters of the right and left pulmonary arteries, marked by different letters A and B in the rows, differ significantly: $p < 0.001$

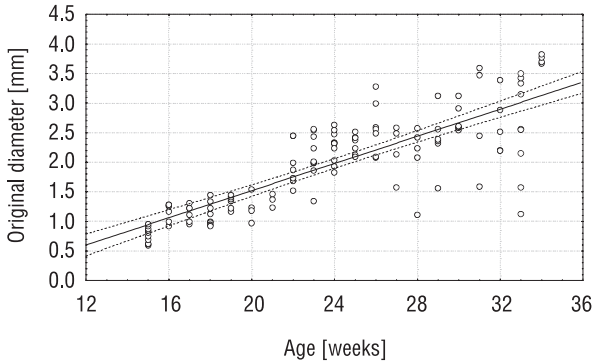

Figure 3. Regression line for the external diameter (y) of the right pulmonary artery versus foetal age (x); $y = -0.7753 + 0.1148\ x \pm \pm 0.4580$ ($r = 0.83$; $p < 0.001$).

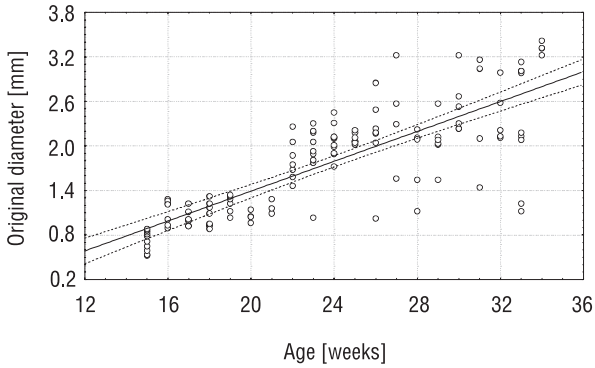

Figure 4. Regression line for the external diameter (y) of the left pulmonary artery versus foetal age (x); $y = -0.6228 + 0.1007\ x \pm \pm 0.4280$ ($r = 0.81$; $p < 0.001$).

arteries against foetal age were generated, but it was proven to be a linear correlation, being best described as a straight line. During prenatal development, the external diameters of both pulmonary arteries increased proportionally with advanced foetal age. The values of the external diameter of the right pulmonary artery ranged from 0.97 ± 0.24 to 2.95 ± 0.89 mm for groups of 4 and 9 months of gestation, respectively. The growth of the right pulmonary artery diameter followed the linear function $y = -0.7753 + + 0.1148\ x \pm 0.4580$ (Fig. 3). The values of the external diameter of the left pulmonary artery ranged from 0.88 ± 0.25 mm for the 4-month group to 2.63 ± ± 0.80 mm for the 9-month group. The external diameter of the left pulmonary artery was dependent on foetal age, according to the linear function $y = -0.6228 + 0.1007\ x \pm 0.4280$ (Fig. 4). Positive correlation coefficients between external diameters of the pulmonary arteries and foetal age were statistically significant ($p < 0.001$) and reached the following values: $r = 0.83$ for the right pulmonary artery, and $r = 0.81$ for the left pulmonary artery.

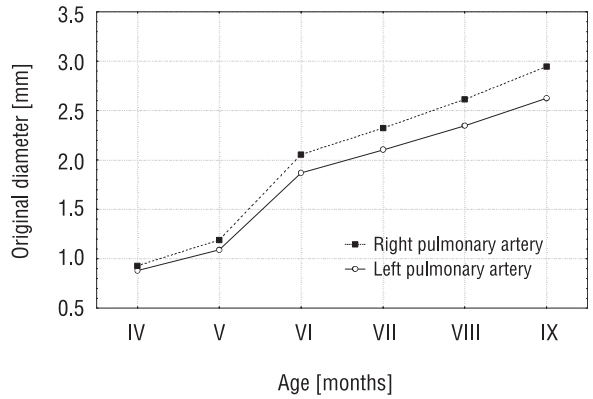

Figure 5. The predominance of the right pulmonary artery.

The statistical analysis revealed the syntopic differences of both pulmonary arteries. The external diameters of the right pulmonary artery were greater ($p < 0.001$) than those of the left one (Fig. 5).

Despite an increase in the values of the external diameters, the relative diameters of the pulmonary arteries (right or left pulmonary artery-to-ascending aorta diameter ratio) decreased with advanced foetal age (Table 2).

In the examined age range, the relative diameters of the right or left pulmonary arteries decreased from 0.46 ± 0.10 to 0.43 ± 0.13, and from 0.43 ± ± 0.10 to 0.39 ± 0.12, respectively.

DISCUSSION

Reference data for normal growth of the external diameters of the pulmonary arteries are scarce on human material. In this autopsy study, a Leica Q Win 16 Pro digital image analysis system was used to provide precise, objective measurements.

Some authors [1, 8, 15] have suggested that external diameters of the pulmonary arteries increase proportionally during gestation. Moreover, echocardiographic measurements of the internal diameters of the pulmonary arteries [6] confirm a linear increase according to the following models: $y = -0.0287 + 0.01257\ x$ ($r = 0.8816$) for the right, and $y = -0.043 + 0.01326\ x$ ($r = 0.8910$) for the left. Therefore, the present autopsy findings concerning the external diameters of the pulmonary arteries are compatible with those of a previous study *in utero* concerning the internal diameters of the pulmonary arteries. In the material under examination, the external diameters of the right and left pulmonary arteries increased proportionally. It was found that values for the right pulmonary artery diameter ranged from 0.97 ± 0.24 to 2.95 ± 0.89 mm, according to the linear model $y = -0.7753 + 0.1148\ x \pm 0.4580$ ($r = 0.83$;

$p < 0.001$). During the study period, the left pulmonary artery diameter progressed from 0.88 ± 0.25 to $2.63 \pm \pm 0.80$ mm, according to the model $y = -0.6228 + + 0.1007\ x \pm 0.4280$ ($r = 0.81$; $p < 0.001$).

In all age ranges the external diameters of the right pulmonary artery were greater than those of the left. In this respect, the present results are in close accordance with the majority of authors [3, 5, 7, 10, 12]. Castillo et al. [3] indicated that in foetuses aged 13–20 weeks, the right pulmonary artery diameter ranged from 1.2 to 2.5 mm, whereas the left pulmonary artery diameter was significantly smaller, and varied from 0.9 to 2.18 mm. Although, as reported by Tan et al. [14], in premature infants there was no difference in the diameter between the right and left pulmonary arteries ($p = 0.254$) in the same specimen. Moreover, the mean diameters both the pulmonary arteries were greater in infants with patent ductus arteriosus (PDA) compared to those without PDA. Hornberger et al. [7] reported that values of the pulmonary artery diameters were normal even in foetuses with mild and severe tetralogy of Fallot.

In spite of an increase in the external diameters of the pulmonary arteries, in the material under examination, a decrease in their relative diameters was found. The relative diameters decreased from 0.46 ± 0.10 to 0.43 ± 0.13 and from 0.43 ± 0.10 to 0.39 ± 0.12 for the right and left pulmonary arteries, respectively. Until now, there has been no information concerning the relative diameters of the pulmonary arteries - something which has been addressed by this study.

The present findings demonstrated the lack of statistically differences in the external diameters of the pulmonary arteries during prenatal life.

A particular strength of this study is the large number of normal specimens used to generate the growth curves. Moreover, the relative diameters of the pulmonary arteries in foetuses have not previously been reported in professional literature. There is no doubt that the results obtained in this study may be useful in clinical evaluation of the developing pulmonary arteries.

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