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Quantitative anatomy of the growing abdominal aorta in human fetuses: An anatomical, digital and statistical study

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A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
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Summary

Background: Advances in perinatal medicine have required an extensive knowledge of fetal aorto-iliac measurements. The present study was performed to compile reference data for dimensions of the abdominal aorta at varying gestational ages.

Material/Methods: Using the methods of anatomical dissection, digital-image analysis (Leica QWin Pro 16 system), and statistical analysis (Student's t-test, one-way ANOVA, post-hoc RIR Tukey test, regression analysis, and Wilcoxon signed-rank test), the growth of length (mm), proximal and distal external diameters (mm), and volume (mm^3) of the abdominal aorta in 124 (60 male, 64 female) spontaneously aborted human fetuses aged 15–34 weeks was examined.

Results: No significant male-female differences were found. The length ranged from 9.35±1.24 to 36.29±4.98 mm, according to the linear function $y=-14.596+1.519 \times Age \pm 2.639$ ($R^2=0.92$; $p<0.0001$). The proximal external diameter varied from 1.18±0.25 to 5.19±0.49 mm, according to the linear pattern $y=-2.065+0.212 \times Age \pm 0.348$ ($R^2=0.92$; $p<0.0001$). The distal external diameter increased from 1.03±0.23 to 4.92±0.46 mm, in accordance with the linear model $y=-2.097+0.203 \times Age \pm 0.351$ ($R^2=0.92$; $p<0.0001$). Both length and proximal external diameter of the abdominal aorta indicated a proportionate evolution, because the length-to-proximal external diameter ratio was stable, following the linear function $y=7.724-0.017 \times Age \pm 0.925$. The abdominal aorta volume ranged from 9.6±4.5 to 740.5±201.8 mm^3, given by the quadratic function $y=911-101 \times Age + 2.838 \times Age^2 \pm 78$ ($R^2=0.89$; $p<0.0001$).

Conclusions: There are no significant differences between males and females for morphometric parameters of the abdominal aorta. The abdominal aorta grows linearly in both length and diameters, and parabolically in volume. These detailed morphometric data of the abdominal aorta provide a database for intra-uterine echographic examinations in the early diagnosis, monitoring and management of aorto-iliac malformations.

key words: **abdominal aorta • length • external diameter • volume • human fetuses • digital-image analysis • regression analysis**

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Background

The abdominal aorta (Figure 1), the continuation of the thoracic aorta, begins at the aortic hiatus of the diaphragm at the level of T12, descends within the retroperitoneal space, and terminates as the aortic bifurcation by dividing into the right and left common iliac arteries [1]. From a strictly anatomical point of view, an appropriate terminal branch of the aorta is the median sacral artery – more developed in mammals than in man, but more conspicuous in fetuses than in adults [2]. The aortic bifurcation most commonly occurs at the level of L4, and only rarely at the levels of L5, S1, or L2 [2, 3]. However, a low aortic bifurcation is much more common than a high division, in which case the abdominal aorta tends to be longer or shorter, respectively [4].

Advances in perinatal medicine require an extensive knowledge of fetal aorto-iliac morphological data [5,10]. The normative morphometric data of the abdominal aorta in human fetuses may be helpful as a reference for future Doppler studies in the prenatal diagnosis and monitoring of congenital aortic abnormalities (eg, aneurysms, hypoplasia, atresia, agenesis, and idiopathic infantile arterial calcification) that include discordant diameters of the aorta and its great branches [11–17]. Thus, it is important to define the normal growth patterns for the abdominal aorta as early as possible, especially if the existing data on this subject are limited. Theoretical models of aortic quantitative anatomy have meticulously focused only on the length and the external diameter of the abdominal aorta [18]. To date however, the abdominal aorta volume has not been reported in human fetuses or in adults.

In order to improve the knowledge of aortic morphometric parameters, our objectives for the present study were to determine:
- age-specific reference intervals for length, proximal and distal external diameters, and volume of the abdominal aorta at different gestational ages;
- growth curves for normal development of the parameters studied.

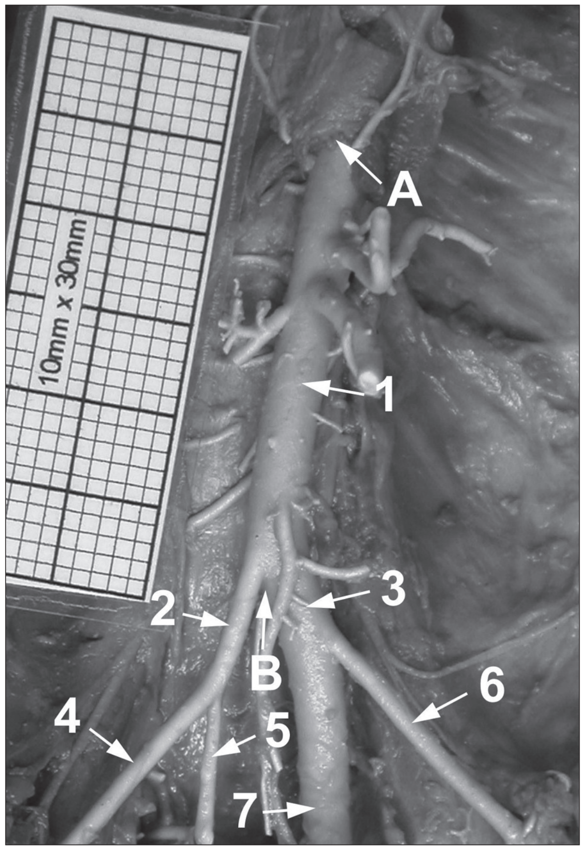

Figure 1. The abdominal aorta in a male fetus aged 26 weeks: A – aortic hiatus of the diaphragm, B – aortic bifurcation, 1 – abdominal aorta, 2 – right common iliac artery, 3 – left common iliac artery, 4 – right external iliac artery, 5 – right internal iliac artery, 6 – left external iliac artery, 7 – left internal iliac artery. This finding is showing a fetus with asymmetric common and internal iliac arteries, being atypically greater in diameters on the left side. Such arterial patterns influence some imbalance between the two umbilical arteries, but do not reflect placental maldevelopment. The extreme asymmetry in the pelvic arterial blood flow may result in single umbilical artery.

Material and Methods

The examinations were carried out on 124 human fetuses of both sexes (60 males, 64 females), which had been derived in the years 1989–2001 from spontaneous abortions or stillbirths, as a result of placental insufficiency. The sample collection was terminated in 2001 because of the legal restriction on obtaining human fetuses that was introduced in Poland at that time. All the fetuses collected in our Department were Caucasian. Legal and ethical considerations were approved by the University Research Ethics Committee (KB/217/2006). On macroscopic examination, both internal and external anatomical malformations were ruled out in all included specimens, which were diagnosed as normal. The gestational age of the fetuses collected varied from 15 to 34 weeks (Table 1). We did not have fetuses at the age of 35–39 weeks of gestation at our disposal. The fetal ages of the specimens were calculated on the basis of 2 criteria: 1) gestational age based on measurements of the crown-rump length [19], and 2) known date of the beginning of the last maternal menstrual period. The correlation between the gestational age based on the crown-rump length and that calculated by the last menstruation attained the value R=0.98 ($p<0.001$) for the whole sample. For statistical analysis, the fetuses were divided into 6 monthly groups, related to the 4^{th}–9^{th} months of gestation.

The arterial bed was filled with white latex LBS 3060 through a Steri-Cath catheter (diameter of 0.5–1 mm), which was introduced by lumbar access into the abdominal aorta. The fetal arteries were filled under an automatically controlled pressure of 50–60 mm Hg, using a SEP 11S syringe infusion pump (Ascor S.A., Medical Equipment, Warsaw 2001). All specimens were immersed in 10% neutral buffered formalin solution for 4–24 months for preservation, and then dissected under 10-power magnification using a stereoscope with Huygens ocular. Each fetus was dissected to expose its abdominal aorta. The optical axis of the objective lens was oriented vertically to the abdominal aorta *in situ* with a millimeter scale, then the aorto-iliac segment was recorded using a Nikon Coolpix 8400 camera, and digitalized to TIFF images (Figure 1). Next, digital pictures of the abdominal

Table 1. Age, number and sex of fetuses studied.

Fetal age*		Crown-rump length (mm)					Sex	
Months	Weeks	Mean	SD	Min	Max	Number	Male	Female
4	15	89.4	6.1	85.0	92.0	9	4	5
	16	103.7	6.1	95.0	106.0	7	3	4
5	17	114.9	8.2	111.0	121.0	5	3	2
	18	129.3	6.6	124.0	134.0	8	3	5
	19	142.7	7.7	139.0	148.0	9	5	4
	20	155.3	5.8	153.0	161.0	2	0	2
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	4	2	2
8	29	253.8	4.5	249.0	255.0	6	1	5
	30	262.7	3.1	260.0	264.0	6	3	3
	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	7	4	3
	34	301.4	3.2	296.0	302.0	4	2	2
Total						**124**	**60**	**64**

* For anatomists the most objective information for establishing fetal ages is the crown-rump length, when compared to the known data of the beginning of the last maternal menstrual period. The gestational age based on the crown-rump length and that calculated by the last menstruation was highly correlated (R=0.98, p<0.001).

aorta were assessed using digital image analysis (Leica QWin Pro 16, Cambridge), which semi-automatically estimated its length, external diameter and volume. Diameter measurements were derived by assuming that the filled abdominal aorta was circular in cross section [2,20]. In order to calculate the arterial volume based on the analysis of images showing only 2-dimensional information, it was assumed that each vessel of varying diameter can be organized into a great number of small irregular cylinders with both varying diameter and height [21]. The sum of volumes of such cylinders approximating the vessel was given in mm^3 as the abdominal aorta volume. Because the volume did not represent a derived parameter, this study provides direct volumetric measurements, instead of deduced, extrapolated data obtained through a series of indirect measurements of the length and external diameters of the abdominal aorta. Furthermore, the abdominal aorta length constituted the length of the flexible cylinder axis.

For each fetus the following 4 parameters of the abdominal aorta were assessed:

1. length in mm, measured on its anterior aspect, corresponding to the distance from the anterior-superior border of the aortic hiatus of the diaphragm to the aortic bifurcation;
2. proximal external diameter in mm, measured immediately below the aortic hiatus;
3. distal external diameter in mm, measured at the level of the aortic bifurcation;
4. volume in mm^3.

In a continuous effort to minimize measurement and observer bias, all the measurements were performed by 1 researcher (M. Sz.). Each measurement was repeated 3 times under the same conditions but at a different time, and then averaged. The differences between the repeated measurements, as the intra-observer variation, were evaluated by the Wilcoxon signed-rank test. The length, proximal and distal external diameters, and volume of the abdominal aorta were correlated to fetal age in order to establish their growth patterns. The relative growth of the abdominal aorta was expressed as the length-to-proximal external diameter ratio.

Table 2. Block scheme of the statistical analysis of morphometric parameters of the abdominal aorta.

Fetal age [months]	n=124	Lenght (mm) (mean ±SD)	Proximal external diameter (mm) (mean ±SD)	Distal external diameter (mm) (mean ±SD)	Volume (mm^3) (mean ±SD)
4	16	9.35±1.24 ↓ (p<0.001)	1.18±0.25 ↓ (p<0.001)	1.03±0.23 ↓ (p<0.01)	9.6±4.5 ↓ (p<0.001)
5	24	13.07±1.98 ↓ (p<0.001)	1.94±0.32 ↓ (p<0.001)	1.75±0.32 ↓ (p<0.001)	36.8±18.0 ↓ (p<0.001)
6	30	20.32±2.52 ↓ (p<0.001)	2.79±0.35 ↓ (p<0.001)	2.55±0.35 ↓ (p<0.01)	116.4±38.8 ↓ (p<0.001)
7	22	24.16±2.95 ↓ (p<0.001)	3.31±0.51 ↓ (p<0.01)	3.02±0.50 ↓ (p<0.001)	196.9±73.2 ↓ (p<0.001)
8	21	32.26±3.72 ↓ (p<0.05)	4.37±0.50 ↓ (p<0.01)	4.05±0.48 ↓ (p<0.01)	456.3±136.4 ↓ (p<0.001)
9	11	36.29±4.98	5.19±0.49	4.92±0.46	740.5±201.8

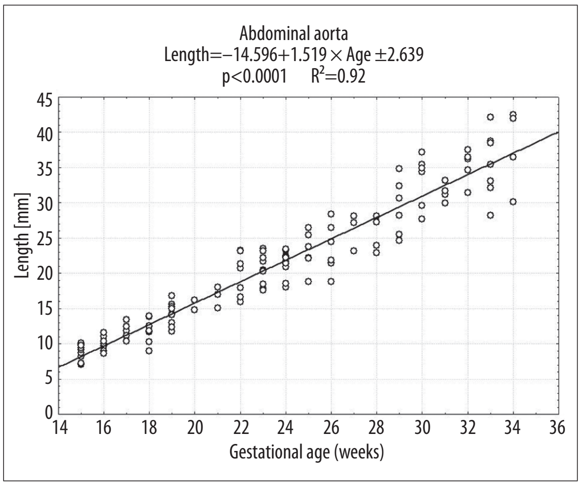

Figure 2. Regression line for length of the abdominal aorta *vs.* gestational age.

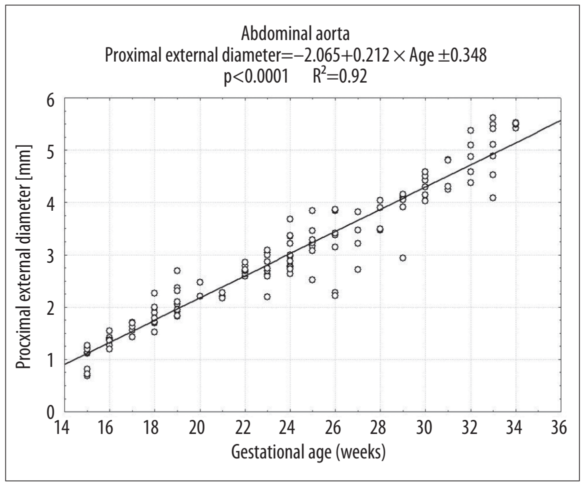

Figure 3. Regression line for proximal external diameter of the abdominal aorta *vs.* gestational age.

As the first step in the statistical analysis, Student's t-test was used to examine the influence of sex on the values of the parameters studied. To test whether the different variables significantly changed with age, the one-way ANOVA test for unpaired data and post-hoc RIR Tukey test were used.

Linear and nonlinear regression analysis was used to derive the line of best fit for each morphometric feature of the abdominal aorta and gestational age. Coefficients of determination (R^2) between the parameters and fetal age were estimated. Differences were considered significant at $p<0.05$.

Results

No significant differences were found in the evaluation of intra-observer reproducibility of the abdominal aorta measurements.

There were no significant differences in the 4 studied parameters of the abdominal aorta according to sex. Therefore, the statistical analysis of morphometric values has been summarized in Table 2, irrespective of sex. On the contrary, the growth curves of best fit for the plot for each parameter studied against gestational age were statistically significant ($p<0.0001$).

The values of the abdominal aorta length increased from 9.35±1.24 mm for the 4-month group to 36.29±4.98 mm for the 9-month group. With regard to fetal age in weeks, the length of the abdominal aorta (Figure 2) followed the first-degree polynomial (linear) function $y=-14.596+1.519 \times Age \pm 2.639$ ($R^2=0.92$).

The statistical analysis revealed significant differences between the proximal and distal external diameters of the abdominal aorta; the former was found to be greater than the latter ($p<0.01$). The proximal external diameter of the abdominal aorta varied from 1.18±0.25 to 5.19±0.49 mm for the groups of 4 and 9 months, respectively. The proximal external diameter was dependent on fetal age (Figure 3), given by the first-degree polynomial (linear) function $y=-2.065+0.212 \times Age \pm 0.348$ ($R^2=0.92$). The values for

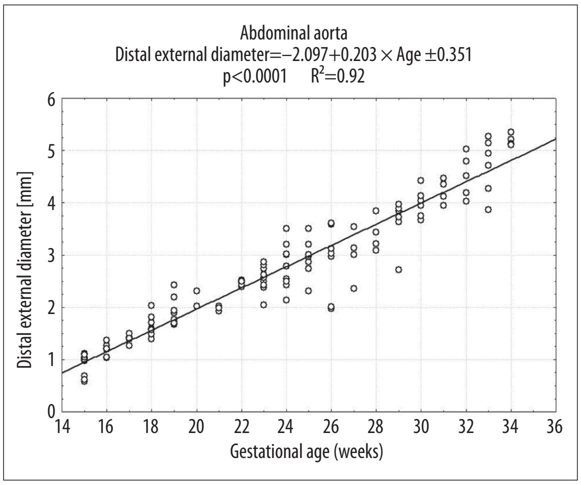

Figure 4. Regression line for distal external diameter of the abdominal aorta *vs.* gestational age.

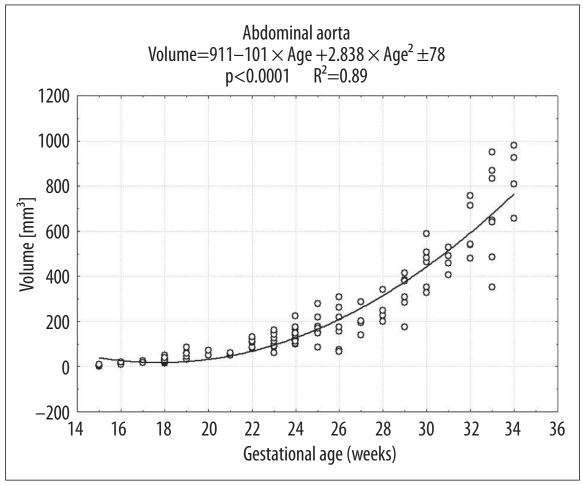

Figure 6. Regression line for volume of the abdominal aorta *vs.* gestational age.

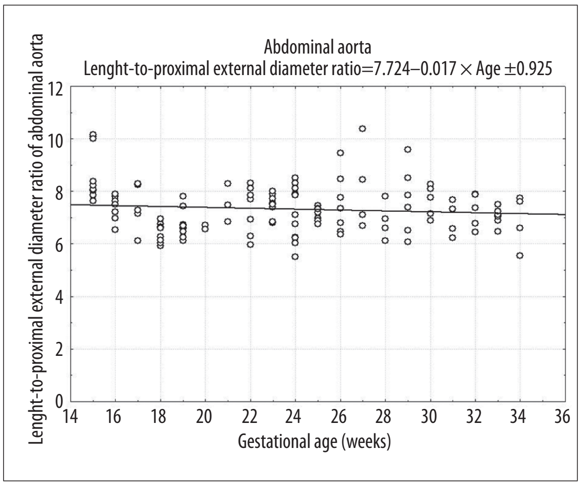

Figure 5. Regression line for length-to-proximal external diameter ratio of the abdominal aorta *vs.* gestational age.

distal external diameter of the abdominal aorta increased from 1.03±0.23 to 4.92±0.46 mm for groups of fetuses at 4 and 9 months of gestation, respectively. The numerical data show that the distal external diameter of the abdominal aorta as a function of fetal age in weeks (Figure 4) was expressed by the first-degree polynomial (linear) regression y=–2.097+0.203 × Age ±0.351 (R^2=0.92).

Both length and external diameters of the abdominal aorta were found to rise proportionately, because they had the same growth rate through the analyzed fetal ages. This fact is illustrated in Figure 5, in which the length-to-proximal external diameter ratio of the abdominal aorta, plotted against gestational age, was relatively stable according to the linear function y=7.724–0.017 x Age ±0.925.

The present study revealed that the volume of the abdominal aorta ranged from 9.6±4.5 to 740.5±201.8 mm^3 for fetuses aged 4 and 9 months, respectively. The volumetric growth of the abdominal aorta (Figure 6) modeled the second-degree polynomial (quadratic) function y=911–101 × Age +2.838 × Age^2 ±78 (R^2=0.89).

Discussion

The present study constitutes the continuation of our previous morphometric studies on the normal evolution of the ascending aorta [22], aortic arch [23], and thoracic aorta [24], which provided both detailed normative ranges and growth patterns for these aortic segments during gestation. Because the existing data on the abdominal aorta have been precisely focused on its length and diameters only [18], the present study provides reference values and growth patterns for length, external diameters and volume of the abdominal aorta in human fetuses. The fetal sample could be considered as normal, because the aortas were not affected by:

- multiple coarctations or calcifications,
- anatomical variations that may have involved the major visceral branches, both unpaired (celiac trunk, superior and inferior mesenteric arteries) and paired (renal arteries), and
- hypoplasia typical of classical aortic coarctation.

In fact, the subjects might potentially have smaller aortic size due to placental insufficiency. However, they could not suffer from intrauterine growth retardation, because the correlation between the gestational age based on the crown-rump length and that calculated by the last menstruation reached the value R=0.98 (p<0.001) for the whole sample. The aortic root diameter was reported to remain normal in most cases of intra-uterine growth retardation [25]. The lack of such quantitative information in the medical literature concerning the abdominal aorta has limited discussion on this subject. Furthermore, neither tissue shrinkage related to neutral buffered formalin fixation nor the 50–60 mm Hg filling pressure significantly influenced the measurements of the abdominal aorta *in situ*, the wall of which was mainly composed of elastic connective tissue. The autopsy findings of Szpinda [21] showed only 0.5–1% shrinkage in elastic fetal arteries *in situ*, which had been filled with latex, and then immersed in 10% neutral buffered formalin solution for 4–24 months.

All the parameters measured could be considered as exact and clearly definable. The aortic hiatus of the diaphragm is an oblique structure, dividing the aorta in an oblique manner, as it passed from the mediastinum into the retroperitoneal space. Consequently, the length on its anterior aspect was different from the length as measured on its posterior aspect. For this reason, the length was always measured on the anterior aspect of the abdominal aorta.

No significant male-female differences for any of the abdominal aorta parameters were revealed in our series, in keeping with previous studies concerning the remaining aortic segments in fetuses [21–24] and children [26]. In contrast to our study, in adolescents and adults, both the aortic length and diameters were found to be greater in males than females of the same age, and these differences even increased with advanced age [27]. On the other hand, according to Yahel and Arensburg [28], the abdominal aorta length was reported to be similar in both sexes, and constituted about 32.4–43.2% of the descending aorta length. According to the medical literature [29,30], the abdominal aorta length closely correlates with body length and stature.

Of note, in the present study several transformations were computed concerning either aortic length or diameter *vs.* gestational age, but a simple linear function turned out to be the best growth model. Such findings are compatible with those of previous autopsy studies from early pregnancy [31], or from the second trimester to childhood [32], that revealed the linear growth in diameter of the great vessels.

Our findings indicate that during the study period the abdominal aorta length varied from 9.35±1.24 to 36.29±4.98 mm, given by the linear model y=−14.596+1.519 × Age ±2.639. Also, Özgüner and Sulak [18] reported the values of aortic length, showing a proportionate evolution with gestational age. According to these authors, the abdominal aorta length varied from 10.42±1.09 mm in the first trimester (9–12 weeks), through 17.55±3.8 mm in the second trimester (13–25 weeks), and 32.73±4.3 mm in the third trimester (26–37 weeks) to 42.91±1.9 mm in full-term fetuses (38–40 weeks). Thus, the regression equation for the abdominal aorta length, modeled as a linear function of gestational age in terms of weeks, was y=−5.254+1.207 × Age ±1.273. When comparing the 2 linear models, the expected growth velocity for length, expressed by the age coefficient, was more dynamic in the material under examination (1.519 mm per week) than in Özgüner and Sulak's autopsy study (1.207 mm per week). Furthermore, Hirata [33] proved that during a 6-7-month period, the growth of the abdominal aorta length was more intensive than that of the ascending and thoracic aortas, whereas during a 7–8-month period proportions of each subdivision were stable.

In our sample, external diameter of the abdominal aorta decreased regularly from proximal to distal along its length, attributed to a decrease in flow volume as blood was supplied to abdominal organs [34,35]. In the material under examination, the proximal and distal external diameters of the abdominal aorta increased proportionately from 1.18±0.25 to 5.19±0.49 mm, and from 1.03±0.23 to 4.92±0.46 mm, respectively, with the lines of best fit as follows: y=−2.065+0.212 × Age ±0.348 and y=−2.097+0.203 × Age ±0.351. According to these models, external diameters of the abdominal aorta increased every week by 0.212 mm at its origin, and by 0.203 mm at its bifurcation. Özgüner and Sulak [18] reported that external diameters at the origin of the abdominal aorta in the following trimesters reached the following values: 1.20±0.2 mm, 2.85±0.7 mm and 5.77±0.8 mm, and in full-terms fetuses as much as 8.28±0.7 mm, being described by the linear regression y=−1.816+0.246 × Age ±0.306 (R=0.98). Furthermore, external diameters at the aortic bifurcation attained the following values: 1.12±0.2 mm, 2.37±0.6 mm, 4.50±0.4 mm and 6.26±0.66 mm, respectively, according to the linear model y=−1.026+0.179 × Age ±0.244 (R=0.97). Having compared regression coefficients, the growth dynamics presented by these authors were found to be faster in relation to the proximal external diameter (0.246 mm per week), and slower in relation to the distal external diameter (0.179 mm per week), than results obtained in the present study (ie, 0.212 and 0.203 mm per week, respectively).

In the material under examination, the distal external diameter of the abdominal aorta turned out to be very interesting when correlated with those of the common, external and internal iliac arteries, which had previously been studied in the same fetuses [4,36,37]. Although no laterality differences for external diameters within the whole group were observed, a strong trend towards greater external diameters was found on the right side: for the common (63.7%), external (71%), and internal (65.3%) iliac arteries. The external diameters of the internal iliac arteries were found to be nearly 50% greater than external diameters of the external iliac arteries. As predominant vessels, the internal iliac arteries supply pelvic organs, and then continue as the umbilical arteries to reach the placenta. Because fetal pelvic organs need more blood supply than the lower limbs, and the umbilical arteries are the direct continuation of the internal iliac arteries, the diameters of the internal iliac arteries are greater than those of the external iliac arteries [2,18,38,39].

As indicated in Figure 5, having correlated length of the abdominal aorta with its proximal external diameter, we found a proportionate evolution. Because these 2 parameters grew all the time at the same rhythm, the abdominal aorta length-to-proximal external diameter ratio was relatively stable, according to the linear function y=7.724–0.017 × Age ±0.925.

To date, data concerning the abdominal aorta volume during gestation has been scant in the quantitative anatomical medical literature. The abdominal aorta volume calculated from 2-D measurements using digital analysis is considered as precise and objective [21]. Of note, our results showed that the best fit correlation between the abdominal aorta volume and gestational age was the second-degree polynomial (quadratic) function $y=911-101 \times Age+2.838 \times Age^2 \pm 78$. In our series, the abdominal aorta volume increased 77-fold from 9.6±4.5 to 740.5±201.8 mm^3. To date however, there have been no comparative data in the medical literature concerning volume of the abdominal aorta.

Basing on our previous findings [22–24], we indicated that there was also observed a proportionate growth of the abdominal aorta in relation to the remaining aortic segments, as length and volume of the abdominal aorta were correlated to those of the ascending aorta, aortic arch, and thoracic aorta. The 4 following aortic segments (ie, the ascending aorta, aortic arch, thoracic aorta and abdominal aorta) increased in a proportionate fashion in relation to each other, being expressed as 5:7:22:16 for their lengths, and

4.8:6:15:9.6 for their volumes, respectively. The abdominal aorta length was responsible for 42.6–42.8% of the descending aorta length, closely corresponding with results obtained by Yahel and Arensburg [28]. The proportionate evolution of each aortic subdivision throughout gestation appeared to remain different from fetuses aged 6–7 months from Hirata's autopsy study [33], the abdominal aortas of which grew more intensively.

Having presented the normal growth of the abdominal aorta during gestation, we would like to stress the importance of the measurements, because the reader should be provided with relevant data, so as to distinguish abnormal from normal fetal development. Nowadays, the advancing resolution capabilities of ultrasound devices lead to an increase in *in utero* diagnostic examinations [5,6,9]. Thus, in fetuses, neonates and infants, the following arterial malformations can be expected at the level of the abdominal aorta: abdominal aortic aneurysms, abdominal aortic hypoplasia, abdominal aortic atresia, infrarenal abdominal aortic agenesis, and idiopathic infantile calcification. Abdominal aortic aneurysms are usually associated with infection, trauma (eg, umbilical artery catheterization), arteritis (Takayasu, Kawasaki, Cogan and Behcet), collagen vascular disease (Ehlers-Danlos syndrome, Marfan syndrome, mucopolysaccharidoses, homocystinuria), or can be idiopathic in nature [13,40]. Abdominal aortic hypoplasia is frequently associated with other forms of restriction to aortic flow, most commonly in cases of classical coarctation [15,17]. The localized segmental narrowing of the abdominal aorta (ie, abdominal coarctation) accounts for less than 2% all aortic coarctations [11]. Abdominal aortic atresia refers to conditions that can cause either a severe decrease or absence of aortic flux. Neonates with abdominal aortic atresia need to be evaluated for associated underlying syndromes or diseases [16]. In turn, infrarenal abdominal aortic agenesis is characterized by the absence of aortic tissue in its topography and the presence of hypertrophic lumbar arteries [12]. Idiopathic infantile arterial calcification is related to widespread calcification and stenosis of elastic arteries (eg, abdominal aorta and iliac arteries) being characterized by smaller external and internal diameters [14].

To summarize, using the normograms, especially for external diameters, constructed in the present study, the severe congenital anomalies of the abdominal aorta can be detected, monitored and treated in the intrauterine or newborn periods. Although the volumetric growth is considered to be the most characteristic and valuable parameter of every dimensional arrangement of structures [21,41], abdominal aortic volume determination is not relevant in clinical and echographic settings, because echographists need to determine only the length and diameters of the abdominal aorta.

Conclusions

1. There are no significant differences between sexes for morphometric parameters of the abdominal aorta.
2. The abdominal aorta grows linearly in length and diameters, and parabolically in volume.
3. Detailed morphometric data of the abdominal aorta provide a database for intra-uterine echographic examination in the early diagnosis, monitoring and management of aorto-iliac malformations.

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