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Tracheo-bronchial angles in the human fetus – an anatomical, digital, and statistical study

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Background: Both the advancement of visual techniques and intensive progress in perinatal medicine result in performing airway management in the fetus and neonate affected by life-threatening malformations. This study aimed to examine the 3 tracheo-bronchial angles, including the right and left bronchial angles, and the interbronchial angle, in the fetus at various gestational ages.

Material/Methods: Using methods of anatomical dissection, digital image analysis with an adequate program (NIS-Elements BR 3.0, Nikon), and statistics, values of the two bronchial angles and their sum as the interbronchial angle were semi-automatically measured in 73 human fetuses at the age of 14–25 weeks, derived from spontaneous abortions and stillbirths.

Results: No male-female differences between the parameters studied were found. The 3 fetal tracheo-bronchial angles were found to be independent of age. The right bronchial angle ranged from 11.4° to 41.8°, and averaged 26.9±7.0° for the whole analyzed sample. The values of left bronchial angle varied from 24.8° to 64.8°, with the overall mean of 46.2±8.0°. As a consequence, the interbronchial angle totalled 36.2–96.6°, and averaged 73.1±12.7°.

Conclusions: The tracheo-bronchial angles change independently of sex and fetal age. The left bronchial angle is wider than the right one. Values of the 3 tracheo-bronchial angles are unpredictable since their regression curves of best fit with relation to fetal age cannot be modelled. Both of the 2 bronchial angles and the interbronchial angle are of great relevance in the location of inhaled foreign bodies, and in the diagnosis cardiac diseases and mediastinal abnormalities.

Key words: **right bronchial angle • left bronchial angle • interbronchial angle • digital-image analysis • regression analysis • human fetuses**

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Background

The advancement of visual techniques implemented in perinatal medical care enables surgeons and anesthesiologists to perform airway management and to detect, monitor, and surgically treat life-threatening anomalies of the fetal tracheo-bronchial tree [1–11]. Thus, the tracheo-bronchial angles in the human fetus are of increasing relevance in perinatal medicine to determine both normal and pathological criteria adapted to anatomical particularities of the fetal tracheo-bronchial tree [11–13].

The angle of tracheal bifurcation refers to both the interbronchial angle, measured between the central axes of the right and left main bronchi, and the subcarinal angle, measured along the inferior borders of the 2 main bronchi [13–16]. As presented in helical CT images [17], the interbronchial angle is somewhat wider than the subcarinal one. The tracheal bifurcation angle was found to vary from 40° to 99°, on average 60–65° [18–21]. Interestingly enough, in Indian population the subcarinal angle was considerably smaller, and averaged 53.54° in fetuses with CRL of 131–200 mm, 62.98° in neonates, 58.58° in children aged 1–10 years, and 54.56° in teenagers [22]. Since the deviation of the left main bronchus from the vertical is considerably greater than that of the right main bronchus, the left bronchial angle is much larger than the right one [9,22,23].

To date, the radiographic and anatomical literature has mainly focused on the tracheal bifurcation angle in neonates, children, and adults [12,15,16,18–22], and to some extent on the fetus [9], mainly based on very subjective methods with the use of protractors and goniometers. Another serious limitation of most radiographic studies is the lack of standardization with respect to the phase of respiration, type of projection, degree of rotation, or posture [13,17,23]. In fact, the angle of tracheal bifurcation tends to decrease by up to 9° between inspiration and expiration alone [13].

The present autopsy study is the first in the medical literature to highlight the fetal tracheo-bronchial angles with the help of objective and repeatable digital image analysis, using an adequate program of NIS-Elements BR 3.0 (Nikon). To supplement the missing information on the fetal tracheo-bronchial angles, in this study we aimed to investigate:
- values of the right and left bronchial angles, and their sum as the interbronchial angle at varying gestational ages; and
- possible both male-female and age-related differences between the studied parameters.

Material and Methods

The study sample consisted of 73 human fetuses of both sexes (39 males and 34 females) at the age of 14–25 weeks of gestation (Table 1), which had been derived from spontaneous abortions and stillbirths, and never intubated. In no case was the cause of fetal death related to congenital cardiovascular

Table 1. Distribution of fetuses studied.

Fetal age		Crown-rump length (mm)				Number	Sex	
Months	Weeks	Mean	SD	Min.	Max		Male	Female
4	14	79.5	4.3	76.0	81.0	2	1	1
	15	89.3	0.0	89.3	89.3	1	1	0
	16	103.1	6.3	96.0	108.0	2	1	1
5	17	114.0	7.3	110.0	123.0	9	5	4
	18	129.5	6.8	124.0	136.0	10	5	5
	19	141.9	5.9	138.0	149.0	7	4	3
	20	155.0	5.2	152.0	162.0	13	7	6
6	21	166.4	4.9	165.0	174.0	11	6	5
	22	178.9	7.2	175.0	185.0	5	2	3
	23	192.9	7.2	187.0	195.0	6	3	3
	24	201.4	4.2	199.0	204.0	5	3	2
7	25	214.8	4.7	212.0	217.0	2	1	1
Total						73	39	34

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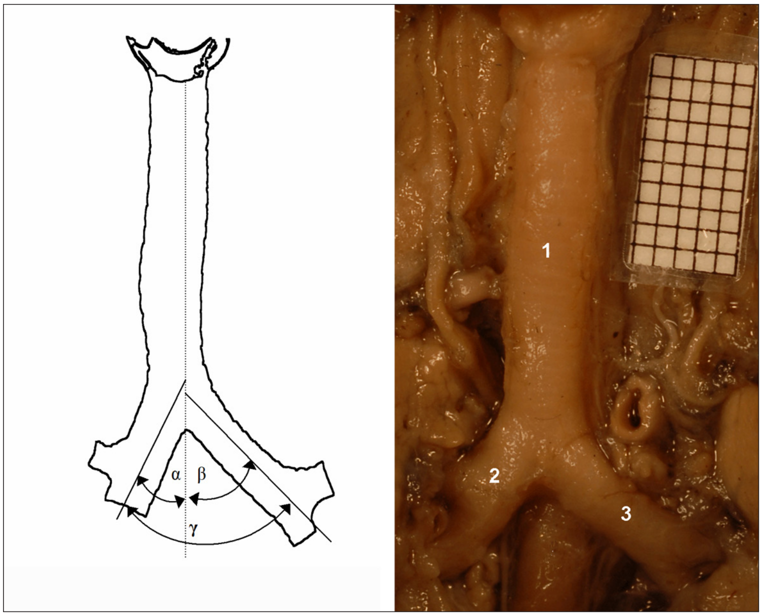

Figure 1. Tracheo-bronchial angles in a male fetus aged 19 weeks: 1 – trachea, 2 – right main bronchus, 3 – left main bronchus, α – right bronchial angle, β – left bronchial angle, γ – tracheal bifurcation angle.

or laryngeo-tracheal anomalies. The series included fetuses, which were only the outcome of causes of placental insufficiency. Gestational ages were estimated by the crown – rump length [24]. The research was consistent with the rules of the Research Ethics Committee of our university (KB 189/2011).

After opening the thorax through sternotomy, the heart and its great vessels were dissected with the use of microsurgical instruments, and then removed from the mediastinum. Thus, the trachea and main bronchi with no conspicuous anomalies were visualized in the posterior mediastinum.

In every fetus, the trachea and 2 main bronchi, *in situ* with a millimeter scale, were placed perpendicularly to the optical lens axis, recorded using a Nikon D200 camera, and digitalized to TIFF images. Afterward, digital pictures of the trachea and main bronchi (Figure 1) were subjected to digital image analysis, using an adequate computer program (NIS-Elements BR 3.0, Nikon). First, in each picture, the following 3 borderlines were consistently reproduced, as follows: the central axis of the right main bronchus, the central axis of the left main bronchus, and the vertical passing through the inferior point of tracheal bifurcation. After that, the 3 variables of tracheal bifurcation angle were precisely defined and assessed.

1. α – right bronchial angle (in degrees), computed between the central axis of the right main bronchus and the vertical passing through the inferior point of tracheal bifurcation;
2. β – left bronchial angle (in degrees), computed between the central axis of the left main bronchus and the vertical passing through the inferior point of tracheal bifurcation; and
3. γ – interbronchial (tracheal bifurcation) angle (in degrees), computed as the angle of intersection between the 2 central axes of the right and left main bronchi.

We did not evaluate the subcarinal angle because of its irregular outlines.

In a continuous attempt to minimize measurement and observer bias, all measurements were controlled by 1 researcher (M.D). The 3 repeated semi-automatic measurements were taken for each variable and averaged to minimize intra-observer variation. The differences between the repeated measurements, as the intra-observer variation, were evaluated by one-way ANOVA test for paired data and post-hoc Bonferroni test. The data obtained were checked for normality of distribution using the Kolmogorov-Smirnov test and for homogeneity of variance with the use of Levene's test. As the first step in the statistical analysis, the t-test was used to examine the influence of sex on the values of the parameters studied. Since the fetuses were not equally distributed with relation to gestational age, to examine sex differences we tested possible differences between the following 9 age groups: 14–16, 17, 18, 19, 20, 21, 22, 23, and 24–25 weeks. Next, we tested possible sex differences for the whole sample, without taking into account age. To examine the relationship between values of every tracheo-bronchial angle and fetal age, the Kruskal-Wallis test was used. The values of 3 tracheo-bronchial angles were plotted against fetal age in weeks to establish their growth dynamics. We attempted to introduce both linear and nonlinear regression analysis to derive the possible curve of best fit for each angle studied against gestational age. Differences were considered significant at $P<0.05$.

Results

No statistically significant differences were found in the evaluation of intra-observer reproducibility of the 3 tracheo-bronchial

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Table 2. The three tracheo-bronchial angles in human fetuses.

Gestational age [weeks]	n	Right bronchial angle [deg]		Left bronchial angle [deg]		Interbronchial angle [deg]	
		Mean	SD	Mean	SD	Mean	SD
14	2	30.04	3.20	49.03	2.31	79.07	0.89
15	1	32.25		58.04		90.29	
16	2	32.99	10.76	38.74	1.65	71.73	9.11
17	9	30.20	7.48	47.90	6.83	78.10	11.99
18	10	26.31	3.87	46.05	5.86	72.36	9.07
19	7	27.59	5.83	50.70	3.90	78.30	8.81
20	13	22.86	7.15	42.31	11.54	65.17	15.38
21	11	27.80	6.18	45.50	5.47	73.29	9.40
22	5	24.78	6.95	46.65	8.59	71.42	15.15
23	6	25.16	7.78	44.50	9.50	69.67	15.03
24	5	27.75	9.71	51.97	8.35	79.73	10.00
25	2	29.53	14.01	41.10	5.02	70.63	8.99

angles ($P>0.05$, the one-way ANOVA test for paired data, and post-hoc Bonferroni test). Obviously, inter-observer variability was not assessed, since all measurements had been done by 1 observer. The morphometric values obtained were characterized by normality of distribution (the Kolmogorov-Smirnov test) and homogeneity of variance (Levene's test). As a consequence, all the quantitative variables were expressed as the mean ± standard deviation. The statistical analysis showed no male-female differences for the 3 tracheo-bronchial angles ($P>0.05$, t-test), so the numerical data without regard to sex are presented in Table 2.

The statistical analysis showed that values of the 3 tracheo-bronchial angles evolved independently of fetal age ($P>0.05$, Kruskal-Wallis test). The right bronchial angle (Figure 2) ranged from 11.4° to 41.8°, with its overall mean of 26.9±7.0°. Throughout analyzed period, the values of left bronchial angle (Figure 3) varied from 24.8° to 64.8°, and averaged 46.2±8.0°. As a consequence, the interbronchial angle totalled from 36.2° to 96.6°. The overall mean of the interbronchial angle averaged 73.1±12.7° (Figure 4).

The regression curves of best fit for every tracheo-bronchial angle against fetal age could not be modelled because of great inter-individual variability of their values at varying gestational ages. Instead, Figure 5 summarizes only the developmental trend of the 3 tracheo-bronchial angles during the analyzed period.

Discussion

The present study describes a cross-sectional interpretation of the 3 tracheo-bronchial angles based on the evidence from 73 fetuses at ages of 14–25 weeks. Thus, it is rather a populational perspective than a true representation of growth in itself. The main limitation of this study is a relatively narrow gestational age, ranging from 14 to 25 weeks. Apart from this, our results suffer from lack of inter-observer variability because all numerical data have been controlled by 1 researcher. Fortunately, the adequate digital program of NIS-Elements BR 3.0 (Nikon) appears to compensate for that disadvantage due to precise semi-automatic evaluation of the 3 tracheo-bronchial angles in digital pictures.

The medical literature on the tracheal bifurcation angle offers many discrepancies between reported values [9] with relation to sex- [17,22,25] and age-dependent [13,15,16,18] differences. As reported by Karabulut [17], the 4 tracheo-bronchial angles (right and left bronchial, interbronchial and subcarinal) were significantly greater in females than males. Similarly, according to Kamel et al. [13], the subcarinal angle in adults ranged from 36° to 121° in men, and from 47° to 115° in women, with overall means of 76±20°, and 81±20° respectively, without any correlation with age. This remains contradictory to most of the previous studies, which reported the tracheal bifurcation angle to be independent of sex [12,13,18–20,25], and to our findings in the material under examination. To our

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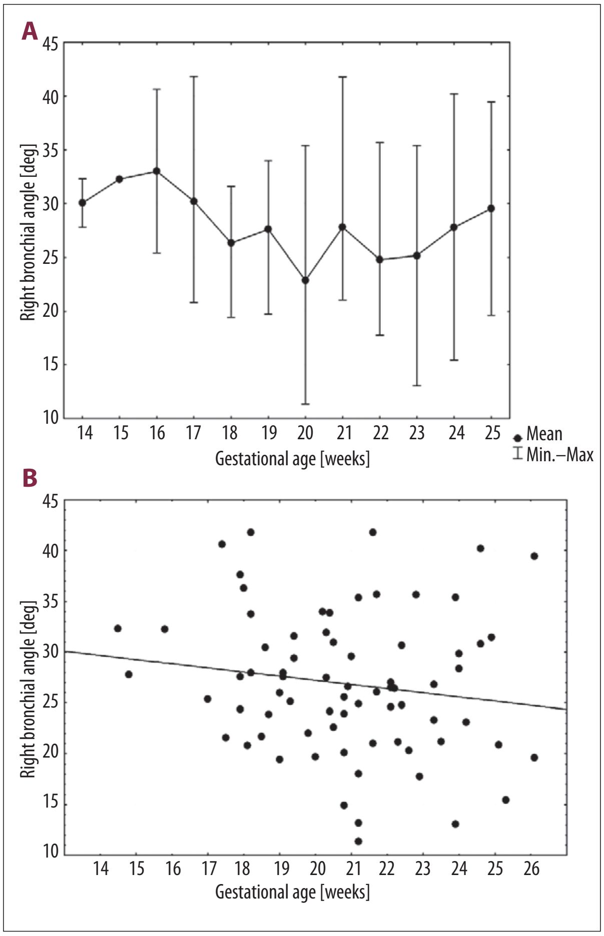

Figure 2. Right bronchial angle with means and standard deviations (**A**), and all individual results (**B**) in human fetuses *vs.* fetal age.

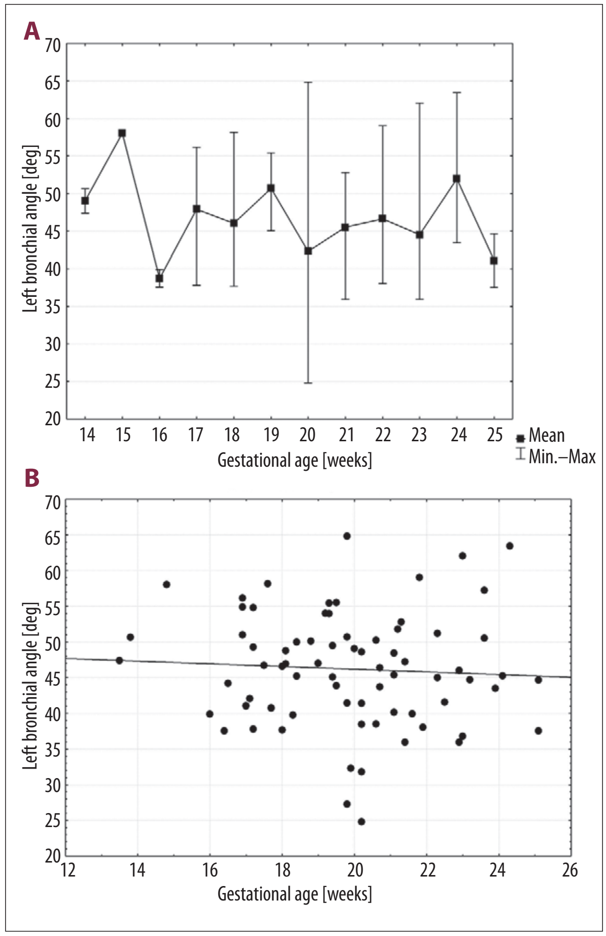

Figure 3. Left bronchial angle with means and standard deviations (**A**), and all individual results (**B**) in human fetuses *vs.* fetal age.

knowledge, the significantly greater tracheo-bronchial angles in females may partly have resulted from obesity of the examined women, positively correlated with the tracheal bifurcation angle [17].

Most authors have agreed that, irrespective of sex and age, the right bronchial angle was smaller than the left one [9,12,13,15,16,19–21,25,26]. According to Harjeet et al. [9], in the 3 groups of fetuses with CRL of 61–130 mm, 131–200 mm, and 201–270 mm, the left bronchial angles were consequently wider than the right ones, and averaged 32.17±6.98° *vs.* 17.37±7.77°, 33.79±8.57° *vs.* 19.75±8.73°, and 34.74±3.67° *vs.* 20.54±1.86°, respectively. In the material under examination, the right and left bronchial angles correlated with the literature data, ranging from 11.4° to 41.8°, with the mean of 26.9±7.0° on the right, and from 24.8° to 64.8° with the mean of 46.2±8.0° on the left, with no effect of age or sex. As reported by Jit and Jit [22], in neonates, infants, and children, the right bronchial angle was always smaller than the left [25]. However, Tahir et al. [23] noticed the right main bronchus deviates significantly less from the vertical on chest radiograms in children over 3 years when compared to younger children (25° *vs.* 28°). This may have been influenced by a greater proportion of upright chest radiograms in older children and a greater proportion of supine chest radiograms in younger children.

A radiographic study by Harjeet et al. [9] revealed an insignificant increase in the subcarinal angle with age from 49.53±12.10° in fetuses with CRL of 61–130 mm, through 53.54±16.17° in fetuses with CRL of 131–200 mm, up to 55.27±3.66° in fetuses with CRL of 201–270 mm. Although in the present study the interbronchial angle attained much larger values than the afore-mentioned subcarinal angle, varying widely from 36.2° to 96.6° to average 73.1±12.7°, there were no statistical differences with age, in keeping with Karabulut's helical CT studies [17]. Of note, in the present study the values of fetal tracheo-bronchial angles were unpredictable in particular individuals. In fact, regression curves of best fit for every tracheo-bronchial angle against fetal age could not be computed. In patients aged 17–85 years [17], the mean interbronchial

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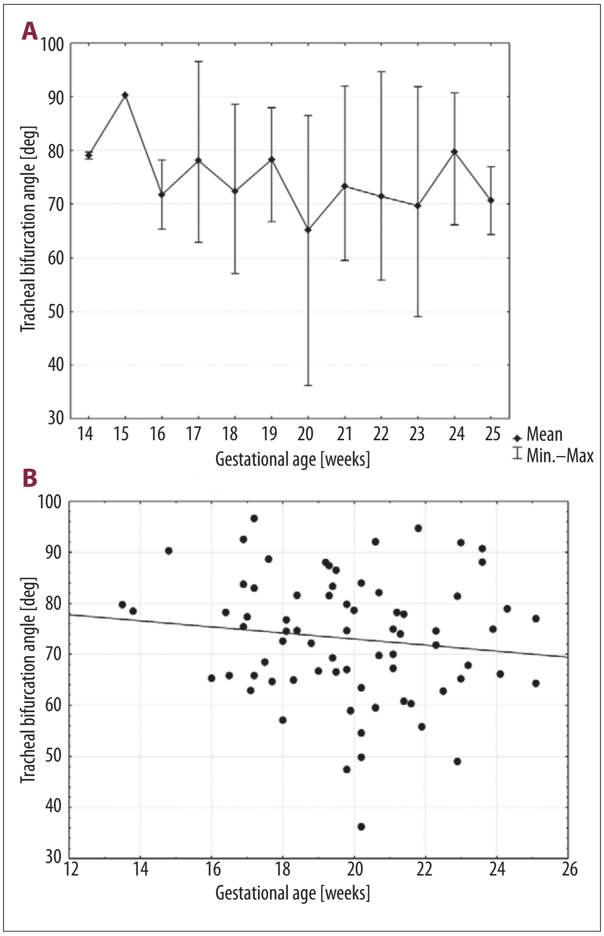

Figure 4. Tracheal bifurcation angle with means and standard deviations (**A**), and all individual results (**B**) in human fetuses *vs.* fetal age.

and subcarinal angles averaged 77±13° (range 49–109°) and 73±16° (range 34–107°). Furthermore, with relation to the subcarinal angle, the interbronchial angle was greater, smaller, or equal in 67%, 28%, and 5% of individuals, respectively.

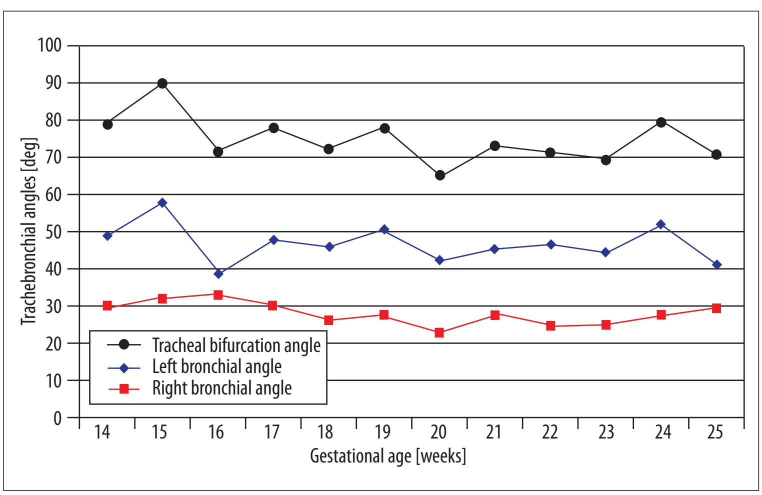

Figure 5. Developmental trend of the tracheo-bronchial angles in the human fetus.

After presenting the morphometric analysis of tracheo-bronchial angles, we would like to highlight some resultant clinical aspects. The subcarinal and interbronchial angles were found to correlate positively with the size of the left atrium of the heart [17,25,27]. The tracheal bifurcation angle may be widened due to cardiac disease (left atrial enlargement, cardiomegaly, and pericardial effusion) and mediastinal abnormalities (subcarinal masses) [12,17,25]. However, the angle of tracheal bifurcation may be reduced after pulmonary lobectomy and lobar collapse [28]. Furthermore, there was a weak inverse correlation between the shape of thorax and the tracheal bifurcation angle [17,25,26]. Thus, as the thorax was shorter and wider, the angle of tracheal bifurcation increased.

Both major anatomical [18] and clinical textbooks [29] support that inhaled foreign bodies are more likely (70%) to enter the right main bronchus than the left because the former is wider and steeper, slightly deviating from the midline of the trachea [12,13,16,19–21,30]. Some authors [31,32] emphasized the greater airflow through the right lung, and the left position of the carina. Tahir et al. [23] stated that in 66% of children, especially under age 1 year, the carina was positioned to the left of the midline of the trachea. Furthermore, Kamel et al. [13] found the carina to be situated on the left in up to 81.4% of individuals. The left-sided carina is reported to increase the “catchment area” of the right main bronchus [23].

Conclusions

1. The tracheo-bronchial angles change independently of sex and fetal age.
2. The left bronchial angle is wider than the right.
3. Values of the 3 tracheo-bronchial angles are unpredictable because their regression curves of best fit with relation to fetal age cannot be modelled.

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4. The 2 bronchial angles and the interbronchial angle are of great relevance in the location of inhaled foreign bodies, and in the diagnosis cardiac diseases and mediastinal abnormalities.

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