ASSESSMENT OF BRONCHIAL WALL THICKNESS IN SECONDARY CHILDHOOD AND ADULTS (12-19 YEARS OLD) COMPARISON WITH THEORETICAL MODELS

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Abstract

A thickened bronchial wall is the morphological substratum of most diseases of the airway. Theoretical and clinical models of bronchial morphometry have so far focused on bronchial lumen diameter, and bronchial length and angles, mainly assessed from bronchial casts. However, these models do not provide information on bronchial wall thickness. This article reports in vivo values of cross-sectional wall area, lumen area, wall thickness and lumen diameter in ten healthy subjects as assessed by multi-detector computed tomography.Measured lumen diameters and homothety ratios were compared with theoretical values obtained from previously published studies, and no difference was found when considering dichotomic division of the bronchial tree. Multi-detector computed tomography measurements of bronchial morphometric parameters may help to improve our knowledge of bronchial anatomy in vivo, our understanding of the pathophysiology of bronchial diseases and the evaluation of pharmacological effects on the bronchial wall.

Keywords: bronchial anatomy; human; image processing; in vivo; MDCT; morphometry.

Introduction: Many current knowledge of lung physiology in human is mainly based on pulmonary function and relies on pulmonary functional tests (PFTs). However, many physiological parameters (resistance of the conducting airway tree, dynamics of flow through bronchi and responsiveness to various physiological or therapeutic events) depend on the geometric properties of bronchi . The study of the extra- and intraorgan vessels of the bronchus of the lungs and histological features was carried out on 30 troupes of children aged 8 years of birth to 12 years old and adults (19 years old)who died from injuries or diseases not associated with the pathology of the lung or heart.

In vivo conducting airway morphometry has seldom been reported so far, due to the difficulty of imaging complex threedimensional (3D) structures. Morphometric studies of the bronchial tree have previously been performed in a small number of cadavers of different species .Some of these models describe airway length and diameter as a decreasing function of the order of generation, predicting the mean bronchial length and diameter of each generation as a function of trachea length and diameter .Nevertheless, due to the method used, no information could be obtained on bronchial wall thickness. In addition, few studies have assessed bronchial morphometric parameters *in vivo*. Sauret et al. (2002) and Tawhai et al. (2004) recently focused on bronchial length, diameter or angulations assessed on human bronchial casts and *in vivo* on ovine and human bronchial trees using multi-detector computed tomography (MDCT) 3D imaging. These parameters are fundamental to simulate flow and inhaled particle transport. Bronchial wall thickness (WT), however, has still not been fully evaluated, and WT changes may be a substantial indicator of the efficiency of inhaled treatments and in various pathological processes (Boser et al. 2005; Montaudon et al. 2007a). The evaluation of bronchial WT could benefit from recent MDCT developments that help to obtain isotropic images of bronchi in any reconstructed plane. For this purpose, 3D software packages enabling *in vivo* measurements of cross-sectional wall area (WA) and cross-sectional lumen area (LA) of any visible bronchus on MDCT have been developed (Palagyi et al. 2005; Brillet et al. 2007) and validated (Montaudon et al. 2007b).The aims of our study were (1) to measure bronchial lumen diameter (LD) obtained by 3D quantitative thinsection CT in a population of adult healthy subjects, (2) to compare these measurements with values predicted by various theoretical models and (3) to provide a range of normal values for bronchial WA, LA, WT and LD for a given generation

MATERIALS AND METHODS

Subjects

Experiments and research were conducted at the Republican Center for Pathological Anatomy.

The study of the extra- and intraorgan vessels of the bronchus of the lungs and histological features was carried out on 30 troupes of children aged 8 years of birth to 12 years old and adults (19 years old)who died from injuries or diseases not associated with the pathology of the lung or heart.

Using an eyepiece-micrometer of MOV X15, the diameter of the bronchi, the thickness of the shells was measured, the development coefficient of muscle plate and elastic structures in the own plate of the mucous membrane was calculated. MDCT scans of ten subjects (nine males and one female) were prospectively used to carry out this study. Scans were obtained from healthy subjects referred to exclude parenchymal blebs before scuba diving. None of them presented a clinical history of thoracic disease, abnormal MDCT findings (including bronchial dilatation) or abnormal PFT results. Mean subject age was 39.2 (range 8-12) years.

RESULTS

During the second childhood, the diameter of the main bronchus increases to 4430 ± 67 microns with a thickness of 1475 ± 41 microns. The mucous membrane consisting of epithelium, its own and muscle records, is 215 ± 7.5 microns. A multi -row attendant epithelium with a height of 29.7 ± 0.9 microns, which is essential compared to the previous juice of research changes. Own plate with the thickness of MKM is formed by a loose connective tissue, where together with fibroblasts, obese, plasma cells, lymphocytes are detected longitudinally and obliquely oriented bundles of elastic and collagen fibers. In the membranous part where the folds are formed, powerful bundles of longitudinal elastic fibers are found. The muscle plate, as in the previous periods, is thin almost throughout the entire bundles has a relatively powerful longitudinal fibrous-elastic weight. Using Boyden's modified classification, the division of the Table 2 provides comparisons per generation between bronchial tree was found as follows: trachea gave two measured LD and HR and theoretical LD and HR values daughter branches, B1-10 (main bronchus) in ten subjects. averaged over subjects.In the right lung, B1-10 bifurcated in B1-3 and B4-10 in cation, a significant difference was found between measured ten subjects. B1-3 trifurcated in B1, B2 and B3 in eight and expected LD when using Mauroy's equation but not subjects, bifurcated in B1-2 and B3 in one subject, and when using Weibel's one. By contrast, using Boyden's bifurcated in B1a + 3 and B1b + 2 in one subject, so this classification downwards from segmental bronchi, no patient did not have a segmental bronchus for the apical difference was found. No difference was also found when segment of the right upper lobe. B4-10 bifurcated in B4-5 comparing measured HR and theoretical HR whatever the and B6-10 in eight subjects, and trifurcated in B4-5, B6 and ordering of generations used, except for the 0.79 value of B7-10 in two subjects. B4-5 always bifurcated in B4 and B5. HR and Boyden's classification.B6-10 bifurcated in B6 and B7-10 in all subjects ($n = 8$). B6 Plots show that LD was underestimated up to generabifurcated in nine cases and trifurcated in one case. In ten tion 8 of Weibel's classification, and up to generation 6 of subjects, B7-10 gave B7 and B8-10 and the latter bifurcated Boyden's classification (Fig. 2). LD of downwards generations

Table 1 Comparison of lumen diameters and homothety ratios assessed by MDCT in each subject against the theoretical results based on Weibel's and Boyden's models

Subject	No. of bronchi	Generation no. (W)	LD_m vs. LD_t (W)	LD_m vs. LD_t (M)	HR_m vs. HR_t (0.79)	HR_m vs. HR_t (0.85)
1	156	10	0.016	< 0.001	NS	NS

2	246	12	0.029	< 0.001	NS	NS
3	288	12	0.02	< 0.001	NS	NS
4	339	13	NS (Wr)	< 0.001 (Wr)	NS	NS
5	257	12	0.04	< 0.001	NS	NS
6	185	13	NS	< 0.001	NS	NS
7	289	10	< 0.001	< 0.001	NS	NS
8	271	14	NS	< 0.001	NS	NS
9	199	10	0.02	< 0.001	NS	NS
10	338	13	NS (Wr)	0.001 (Wr)	NS	NS

Subject	No. of bronchi	Generation no. (B)	LD_m vs. LD_t (W)	LD_m vs. LD_t (M)	HR_m vs. HR_t (0.79)	HR_m vs. HR_t (0.85)
1	156	7	NS (Wr)	NS (Wr)	NS (Wr)	NS (Wr)
2	246	8	NS (Wr)	0.043 (Wr)	NS (Wr)	NS (Wr)
3	288	10	NS (Wr)	NS (Wr)	NS (Wr)	NS (Wr)
4	339	9	NS (Wr)	0.028 (Wr)	NS (Wr)	NS (Wr)
5	257	10	NS (Wr)	NS (Wr)	NS (Wr)	NS (Wr)
6	185	9	NS (Wr)	NS (Wr)	NS (Wr)	NS (Wr)
7	289	9	NS (Wr)	0.028 (Wr)	NS (Wr)	NS (Wr)
8	271	12	NS	NS	0.038	NS
9	199	8	NS (Wr)	0.043 (Wr)	NS	NS
10	338	9	NS (Wr)	NS (Wr)	NS	NS

For each subject, values are *P*-values from comparisons between mean measured values and theoretical values per generation.
No. of bronchi: number of assessable bronchi; Generation no. (W): number of generations assessed using Weibel's model; Generation no. (B): number of generations assessed using Boyden's classification; LD_m: measured lumen diameter; LD_t: theoretical lumen diameter; HR_m: measured homothety ratio; HR_t: theoretical homothety ratio according to Weibel's study (0.79) and to Mauroy's study (0.85). Comparisons were achieved using paired *t*-test or Wilcoxon rank-sum test (Wr).

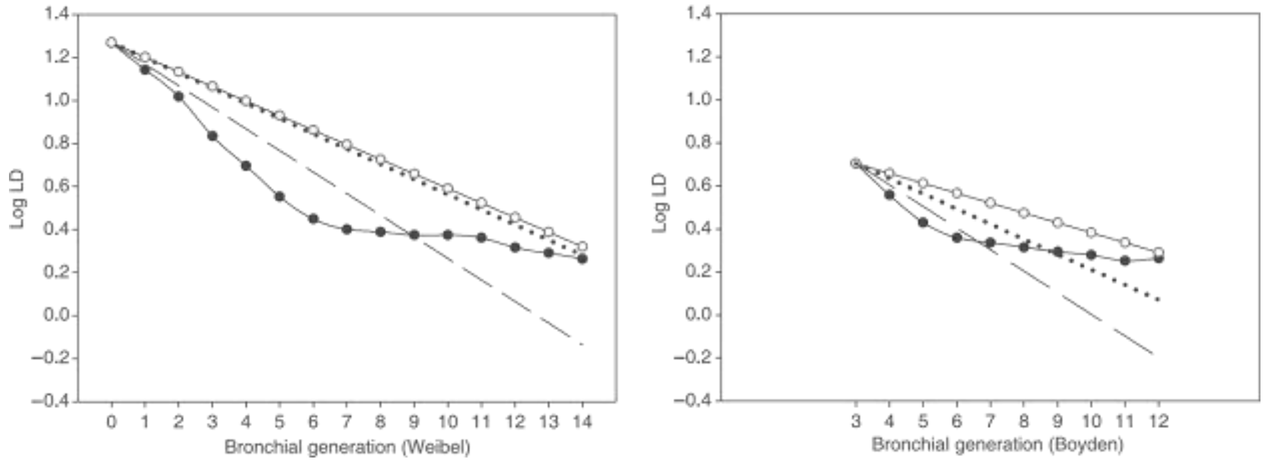

Fig. 2 Plots of mean lumen diameter over all subjects on a logarithmic scale (log LD) against bronchial generations according to Weibel's model (left graph) and Boyden's classification (right graph). Black circles: log of measured LD; open circles: log of theoretical LD calculated with the mean measured HR; dashed line: log of theoretical LD calculated using an HR value of 0.79 (Weibel); dotted line: log of theoretical LD calculated using an HR value of 0.85 (Mauroy).

Table 2 Comparison of mean lumen diameters and mean homothety ratios assessed by MDCT versus those calculated using Weibels and Boyden's models

Generation (W)	No. of bronchi	LD_m (mm)	LD_t (W) (mm)	LD_t (M) (mm)	HR_m	HR_t (0.79)	HR_t (0.85)
0	10	18.55	18.55	18.55			
1	20	13.89	14.72	15.77	0.75	0.79	0.85
2	40	10.42	11.68	13.40	0.75	0.79	0.85
3	92	6.82	9.27	11.39	0.65	0.79	0.85
4	190	4.96	7.36	9.68	0.73	0.79	0.85
5	366	3.56	5.84	8.23	0.72	0.79	0.85
6	538	2.81	4.64	7.00	0.79	0.79	0.85
7	500	2.52	3.68	5.95	0.90	0.79	0.85
8	357	2.45	2.92	5.05	0.97	0.79	0.85
9	219	2.36	2.32	4.30	0.97	0.79	0.85
10	107	2.37	1.84	3.65	1.00	0.79	0.85
11	66	2.30	1.46	3.10	0.97	0.79	0.85
12	49	2.07	1.16	2.64	0.90	0.79	0.85
13	12	1.95	0.92	2.24	0.94	0.79	0.85
14	2	1.84	0.73	1.91	0.94	0.79	0.85
P			NS (Wr)	< 0.001		NS	NS

Generation (B)	No. of bronchi	LD_m (mm)	LD_t (W) (mm)	LD_t (M) (mm)	HR_m	HR_t (0.79)	HR_t (0.85)
0	10	18.55					
1	20	13.89					
2	149	8.22					
3	197	5.06	5.06	5.06			
4	392	3.60	4.02	4.30	0.71	0.79	0.85
5	634	2.69	3.19	3.66	0.75	0.79	0.85
6	631	2.28	2.53	3.11	0.85	0.79	0.85
7	365	2.16	2.01	2.64	0.95	0.79	0.85
8	116	2.06	1.59	2.25	0.95	0.79	0.85
9	38	1.96	1.27	1.91	0.95	0.79	0.85
10	12	1.90	1.00	1.62	0.97	0.79	0.85
11	2	1.78	0.80	1.38	0.94	0.79	0.85
12	2	1.84	0.63	1.17	1.03	0.79	0.85
P			NS	NS		0.02	NS

For each generation, values are number of assessable bronchi (No. of bronchi), mean lumen diameter measured on MDCT scans per subject and averaged over subjects (LD_m), mean theoretical lumen diameter calculated from trachea diameter using Weibel's equation [LD_t (W)] and Mauroy's homothety ratio [LD_t (M)], homothety ratio measured on MDCT scans (HR_m) and theoretical homothety ratio calculated using Weibel's study [HR_t (0.79)] or Mauroy's study [HR_t (0.85)].

DISCUSSION

In this study we used a post-processing software package, previously validated for accuracy *in vitro* and *in vivo* (Montaudon et al. 2007b), for measuring bronchial morphometric parameters on 1-mm MDCT scans. We have compared our measurements with those calculated from theoretical models of bronchial anatomy and provided bronchial WA, LA, WT and LD values according to bronchial generation in healthy adults. When comparing mean HR per generation versus theoretical values for each subject, no statistical difference was found (Table 1). However, when comparing mean measured LD with expected LD, differences were found in all cases when using a 0.85 value for HR and in six of ten with a 0.79 value for HR (Table 1). These differences are likely to be the consequence of a non-strictly dichotomic division of bronchi up to segmental bronchi. This hypothesis is strengthened by the fact that the number of subjects with differences diminishes when considering a more dichotomic classification of bronchial divisions (Boyden's classification).

By contrast, differences were found between measured and expected LD values using Mauroy's equation applied to Weibel's classification, but no difference when using Boyden's classification (Table 2). We believe this difference may be related to the equation used to predict theoretical values: the trachea LD directly influences LD of all other generations so its measurement must be made with great care. Trachea LD diminishes regularly from its origin to its bifurcation.

CONCLUSION

We have compared bronchial morphometry in healthy adults(19 years old) with 8-12 years old children performed using a validated software package and 1-mm MDCT section images against those obtained from theoretical models. From 8 to 12 years of life, with the same microscopic structure of the layers of the upper and lower and lower segmental bronchi, the thickness of each of the layers is larger in the upper novel, which, apparently, is due to the features of gas exchange and microcirculatory channel Despite being valid when studying a population, Weibel's equation applied to individuals may induce an error when determining LD of bronchi from the tracheal diameter. This error is probably due to anatomical variations in bronchial division upward from the segmental level.

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