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ORIGINAL ARTICLE

Main bronchial diameters in patients with very severe COPD

Gaëlle Mourissoux · Christophe Vandendries · Hélène Neveu · Antoine Scherrer · Marc Fischler

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Abstract
Purpose This retrospective study was performed in order to determine if patients with very severe chronic obstructive pulmonary disease (COPD) have larger main bronchi than patients with less severe disease.
Methods Charts of patients having had a spirometric evaluation of their COPD and a digitized thin-slice computed tomography (CT) scan between January 2004 and September 2007 were reviewed. Adequate CT scans of male patients [i.e., those allowing a multiplane reconstruction (MPR) of the upper tracheobronchial tree using a double orthogonal oblique method] were divided into two groups: group 1 [forced expiratory volume in 1 s (FEV_1) ranging from 30% to 80%] and group 2 ($FEV_1 < 30\%$).
Results Intraobserver and interobserver coefficients of repeatability were 1.79 and 2.51 mm, respectively. Median values and interquartile ranges of minimum right main bronchial diameter were 11.0 (9.6–12.7) mm versus 12.7 (10.8–13.9) mm in groups 1 (27 patients) and 2 (10 patients), respectively ($P = 0.048$); values for the minimum left main bronchial diameter were 10.7 (8.9–11.9) mm versus 11.8 (11.2–12.4) mm in groups 1 and 2, respectively ($P = 0.040$). The difference between the groups in median values of the minimum right and left main bronchial diameters was 1.2 mm. Other values were similar in both groups.
Conclusion The difference in minimum main bronchial diameters between our two groups corresponded to a difference of two or three sizes of a double-lumen tube. This difference must be taken into account for tube selection for such patients. Further studies are needed to prove that CT scan MPR can improve patients' intraoperative care.

Keywords Three-dimensional computed tomography · Double-lumen tube · Chronic obstructive pulmonary disease

G. Mourissoux · M. Fischler (✉)
Department of Anesthesiology, Hôpital Foch,
40 rue Worth, 92150 Suresnes, France
e-mail: m.fischler@hopital-foch.org

C. Vandendries · A. Scherrer
Department of Radiology, Hôpital Foch,
92150 Suresnes, France

H. Neveu
Department of Pneumology, Hôpital Foch,
92150 Suresnes, France

Introduction

Choosing the appropriate size of a double-lumen tube (DLT) is important for the safe achievement of one-lung ventilation. As the main bronchi are not completely round [1], a DLT as large as possible, i.e., one with an external diameter slightly smaller than the minimal internal main bronchial diameter, can be considered of optimal size. Pressure damage to the bronchial mucosa caused by bronchial cuff inflation would be limited [2], and auto-positive end-expiratory pressure would be decreased by optimizing gas flow during the expiratory period [3]. A large DLT also gives the best conditions for fiberoptic bronchoscopy and suctioning through the tube. On the other hand, a too-large DLT could cause bronchial rupture [4] and a too-small DLT could be advanced too deeply, obstructing the upper lobe bronchus, although it has been reported that a 35-Fr DLT can be safely used [5].

The choice of a DLT of an appropriate size remains a problem in clinical practice [6]. The choice relies generally on demographic data such as height and gender [7]. Such recommendations are generally followed, although there is little or no correlation between these variables and the measurement of the left bronchial diameter using computed tomography scan (CT scan) of the chest and multiplane reconstruction of the tracheobronchial tree [8].

Patients in our lung transplant program have very severe chronic obstructive pulmonary disease (COPD) and we had the impression that these patients had very large main bronchi. The purpose of the study was to confirm that patients with very severe COPD have larger bronchi than patients with less severe disease.

Materials and methods

The Medical Research Committee of the Société de Pneumologie de Langue Française approved this retrospective study, which consisted in analyzing the medical reports of all patients with COPD having had a pulmonary function test between January 2004 and September 2007 in our institution. We selected among them those who had undergone a CT scan whatever the indication. CT scans (MX 8000 IDT 16; Philips Medical Systems, Amsterdam, the Netherlands) were performed during a normal end-inspiratory breath-hold with the following homogeneous technical parameters: collimation, 0.75×16 mm; pitch, 0.9 mm; 150 mA; 120 kV; and 15-s acquisition time. The mean dosimetry was as follows: CT dose index of 9.5 mGy and dose length product of 350 mGy/cm. Patients with previous lung surgery or with tracheobronchial tree abnormalities due to a proximal tumor were excluded. The remaining patients were categorized into two groups according to the severity of the respiratory disease based on their forced expiratory volume in 1-s (FEV_1), using the criteria of the Global Initiative for Chronic Obstructive Lung Disease: group 1 if $30\% \leq FEV_1 < 80\%$; (moderate, mild, and severe COPD) and group 2 if FEV1 $< 30\%$ (very severe COPD) [9].

Demographic parameters (i.e., age, height, and weight) which were kept for analysis were recorded for male patients (Fig. 1).

Bronchial diameters were measured when digital filmless supports with thin slices were available. Data were transferred to a standalone workstation (MX 8000; Philips Medical Systems) to reconstruct images of 1 mm thickness at intervals of 0.5 mm. On each CT scan, we performed a multiplane reconstruction (MPR) of the upper tracheobronchial tree using a double orthogonal oblique method. A coronal image of each main bronchus at its maximum diameter was obtained. A transverse plane, at 90° to the coronal image, was selected through the central portion of the bronchi to obtain a strictly orthogonal slice (Fig. 2). All the measurements were then performed with the correction of slant in the three dimensions. Cursors were used to measure the maximum and minimum internal diameters. A level of -600 UH and a width of 1200 UH were used for window settings. Minimum and maximum left main bronchial diameters (Min-LBD and Max-LBD) were measured 15 mm distally from the carina, and minimum and maximum right main bronchial diameters (Min-RBD and Max-RBD) were measured just before the origin of the upper lobe bronchus.

Statistical analysis

Descriptive statistics (median and interquartile range 25–75) were used to summarize the data. The Mann–Whitney and Fisher exact tests were used for between-group comparisons. The correlations between Min-RBD, Max-RBD, Min-LBD, Max-LBD, and FEV_1 were analyzed using Pearson correlation coefficients.

A post-hoc bilateral Mann–Whitney test with a correction for ties was used to compare the distribution of DLT diameters which would have been chosen according to the height and gender ("Slinger's rule" [7]) and those corresponding to the CT scan measurements.

To assess repeatability, the minimal and maximal right and left main bronchus diameters were measured in a randomized order on 11 randomly selected scans, yielding 44 measures from the same observer on 2 occasions and 44 measures by each of the two independent observers. Repeatability was assessed on both sets of 44 pairs of measurements using the Bland and Altman approach [10] and the repeatability coefficient was calculated accordingly. The equality of inter- and intraobserver variance was tested using a modified Levene test.

A bilateral P value of 0.05 was considered significant. The statistical package NCSS version 2007 (NCSS, Kaysville, UT, USA) was used to calculate intra- and interobserver variability. The statistical software package SPSS, version 11.5 (SPSS, Chicago, IL, USA) was used for all other analyses.

Results

Nine-hundred-and-thirty-one COPD patients performed a pulmonary function test between January 2004 and September 2007. Out of these, 203 had a thoracic CT scan, 111 of which were available on digital filmless support. Eleven patients were excluded because of previous lung surgery or tracheobronchial tree abnormalities. A CONSORT (Consolidated Standards of Reporting Trials) diagram showing the flow of studied medical reports and lung scans through each stage of the study is summarized in Fig. 1.

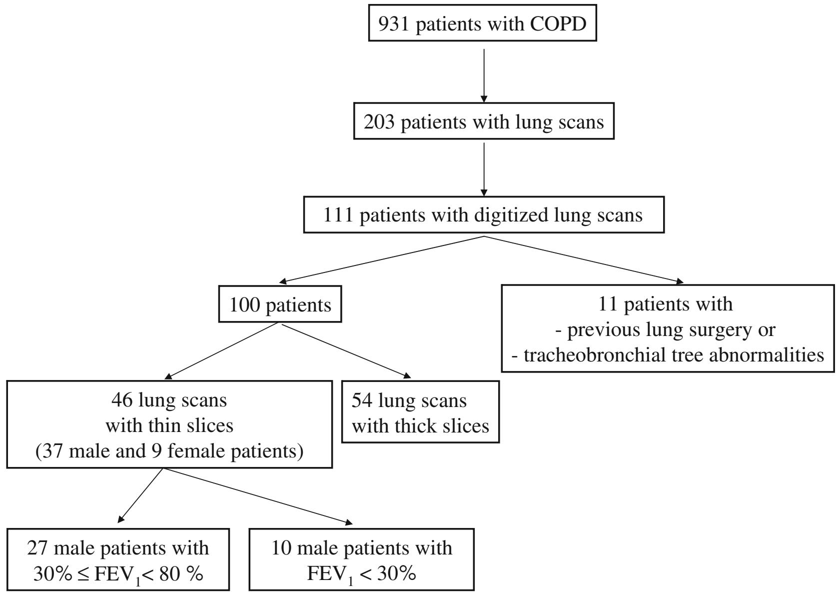

Fig. 1 CONSORT (Consolidated Standards of Reporting Trials) diagram showing the flow of studied medical reports and lung scans through each stage of the study. *COPD* chronic obstructive pulmonary disease, *FEV_1* forced expiratory volume in 1 s

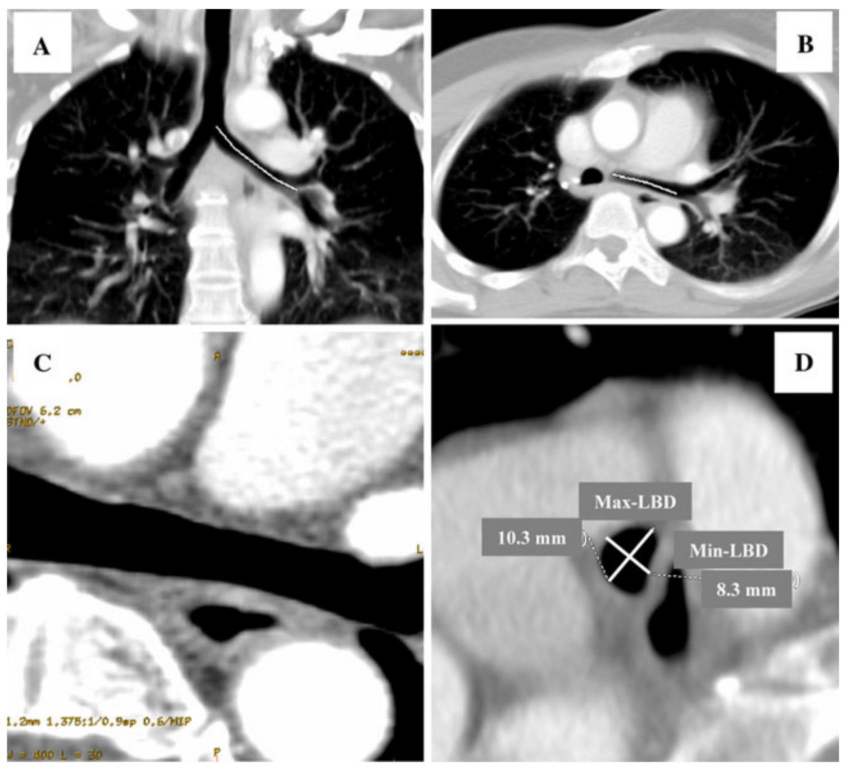

Fig. 2 Measurement of left bronchial diameters using multiplane reconstruction of the upper tracheobronchial tree with a double orthogonal oblique method. Example of the measurement of left bronchus diameters. **a**, **b** Determination of the left main bronchus major axis **c**. Longitudinal curved reconstruction of the left bronchus **d**. Sagittal oblique reconstruction perpendicular to the main axis through the mid-portion of the lumen and determination of the minimal and maximal left bronchus diameters (*Min-LBD* and *Max-LBD*, respectively)

Thirty-seven thoracic CT scans were analyzed, 27 in group 1 (moderate, mild, and severe COPD) with a median FEV_1 of 47% (41%–55%) and 10 in group 2 (very severe COPD) with a median FEV_1 of 21% (15.5%–26.7%) ($P = 0.0001$) (Table 1). Age differed statistically significantly between the groups [72 (60–78) years in group 1 and 59 (59–68) years in group 2; $P = 0.01$], while height and weight were comparable (Table 1).

There was no significant correlation between Min-RBD, Max-RBD, Min-LBD, Max-LBD, and FEV_1 (Fig. 3).

The right main bronchus showed a minimal diameter that was lower in group 1 than in group 2 [11.0 (9.6–12.7) mm vs. 12.7 (10.8–13.9); $P = 0.048$], while its maximal diameter was similar in the two groups. The left main bronchus showed a minimal diameter that was lower in group 1 than in group 2 [10.7 (8.9–11.9) mm vs. 11.8

Table 1 Demographic characteristics and FEV_1 measurements

	Group 1 (30% ≤ FEV_1 < 80%) (n = 27)	Group 2 (FEV_1 < 30%) (n = 10)	P value
Age (years)	72 (60–78)	59 (59–68)	0.01
Height (cm)	171 (169–178)	171 (167.5–179)	0.77
Weight (kg)	78 (67–89)	68.5 (59.7–78.2)	0.12
FEV_1 (%)	47 (41–55)	21 (15.5–26.7)	0.0001

Data are medians and interquartile ranges or numbers

FEV_1 forced expiratory volume in 1 s

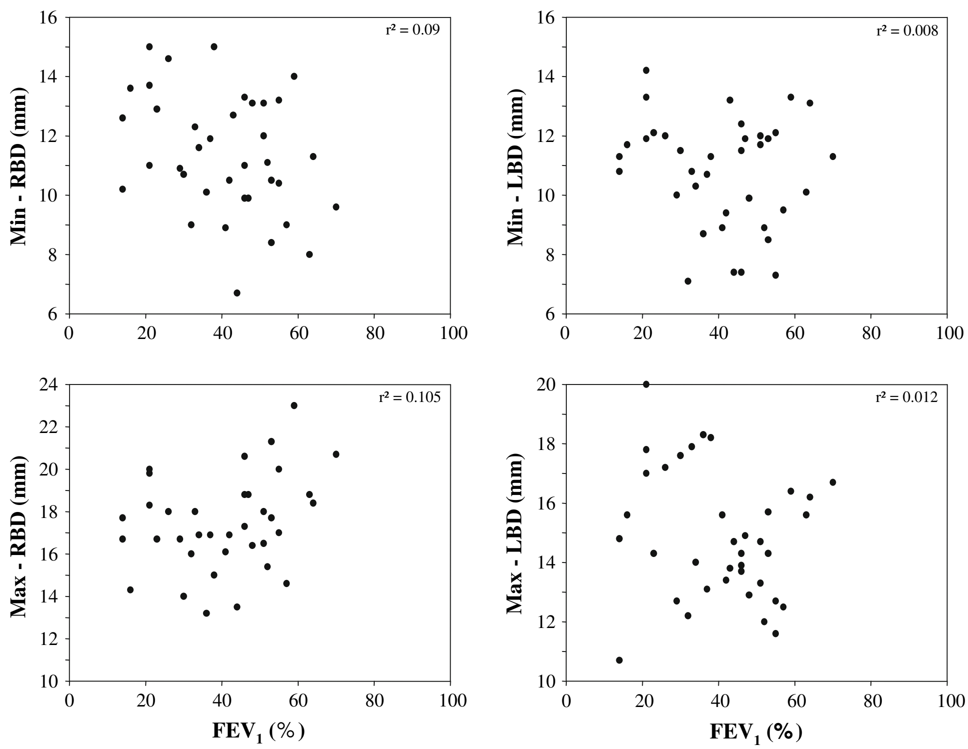

Fig. 3 Relation between Min-RBD, Max-RBD, Min-LBD, Max-LBD, and FEV_1. *Min-RBD* minimal right main bronchus diameter, *Max-RBD* maximal right main bronchus diameter, *Min-LBD* minimal left main bronchus diameter, *Max-LBD* maximal left main bronchus diameter

Table 2 Bronchial diameters

	Group 1 (30% ≤ FEV_1 < 80%) (n = 27)	Group 2 (FEV_1 < 30%) (n = 10)	P value
Min-RBD (mm)	11.0 (9.6–12.7)	12.7 (10.8–13.9)	0.05
Max-RBD (mm)	17.3 (16.1–18.8)	17.2 (16.1–18.7)	0.65
Min-LBD (mm)	10.7 (8.9–11.9)	11.8 (11.2–12.4)	0.04
Max-LBD (mm)	14.3 (13.1–15.7)	16.3 (13.9–17.7)	0.15

Results are expressed as medians and interquartile ranges

Min-RBD minimal right main bronchus diameter, *Max-RBD* maximal right main bronchus diameter, *Min-LBD* minimal left main bronchus diameter, *Max-LBD* maximal left main bronchus diameter

(11.2–12.4); $P = 0.040$], while its maximal diameter was similar in the two groups (Table 2).

The difference between the median values of the minimum right and left main bronchial diameters was 1.2 mm [10.7 (9.1–12.0) mm in group 1 and 11.9 (11.0–13.3) mm in group 2].

There was a significant difference ($P = 0.02$) between the clinical ("Slinger's rule" [7]) and the CT scan approaches, larger diameters being determined by the latter method. Overestimation by Slinger's rule may be more frequent ($P = 0.065$) in the milder forms of COPD than in the most severe ones (Table 3).

On the 11 randomly selected CT scans, the intraobserver coefficient of repeatability was 1.79 mm and the interobserver coefficient was 2.51 mm. Intra- and interobserver variance were found not to be significantly different ($P = 0.22$).

Discussion

The minimal internal diameters of the main right and left bronchi vary with the severity of COPD. This variation is about 1.2 mm, leading to a difference of two or three sizes for DLTs depending on the manufacturer [11]. In view of the possible severe complications related to the use of a DLT of inappropriate size, the choice of the DLT based on minimal main bronchial diameter CT scan measurement with MPR has to be considered.

Bronchial dimensions are not constant. The LBD is smaller in female than in male patients [8, 12] and smaller in Asians than in Caucasians [13]. The right main bronchus is approximately 5 mm shorter in Japanese patients compared to that in the average American patient [14]. Moreover, some pathologies influence tracheobronchial dimensions through remodeling. For example, in cystic fibrosis, airway wall thickness and wall area measured on chest CT scans differ with the severity of the disease [15]. Airway wall area is larger in patients suffering from asthma than in control subjects [16] and is positively correlated with the duration and clinical severity of the disease [17]. Our study demonstrates that the minimal right and left main bronchial diameters are greater in patients with very severe COPD than in patients with less severe disease.

Anesthesiologists are looking for a simple method of bronchial diameter measurement, and particularly of LBD because of the greater use of left DLTs. Direct measurement of the LBD on a chest radiograph is possible in approximately 50% of cases [18], increasing to 69% by using a filmless digital system [19]. This limitation has led to the indirect evaluation of the LBD, using simple demographic parameters (i.e., conventional height-based and gender-based selection) [7] or the tracheal diameter measured from the preoperative posterior-anterior chest radiograph [20, 21]. Finally, direct measurement of the LBD on conventional chest CT scans without reconstruction cannot be recommended, because measuring airway

Table 3 Choice of double-lumen tube (DLT) diameter (Fr) according to either the clinical approach (“Slinger’s rule” [7]) or the computed tomography (CT) scan approach

Group 1 ($30\% \leq FEV_1 < 80\%$) ($n = 27$)			Group 2 ($FEV_1 < 30\%$) ($n = 10$)		
Patient number	Clinical approach (“Slinger’s rule” [7])	CT scan approach	Patient number	Clinical approach (“Slinger’s rule” [7])	CT scan approach
1	37	32	1	37	41
2	39	28	2	39	35
3	39	28	3	39	41
4	39	28	4	39	41
5	39	32	5	39	41
6	39	32	6	41	41
7	39	32	7	41	41
8	39	39	8	41	41
9	39	41	9	41	41
10	39	41	10	41	41
11	39	41			
12	39	41			
13	41	28			
14	41	28			
15	41	32			
16	41	35			
17	41	37			
18	41	41			
19	41	41			
20	41	41			
21	41	41			
22	41	41			
23	41	41			
24	41	41			
25	41	41			
26	41	41			
27	41	41			

lumens when they are not perpendicular to the scanning plane may lead to significant errors, overestimating internal diameter when the angle is larger than 90° [22, 23]. For all these reasons, Olivier et al. [8] recommended direct radiology measurement using MPR chest CT scan as the only reliable method for determining the size of the left main bronchus. They have reported that the relationship between bronchial diameters and biometric characteristics is poor or absent and that the estimated LBD values from tracheal widths are within 1 mm from the measured one in only 40% of the cases, making this approximation not very useful in clinical practice [8]. The present study reports values of the minimal LBD 1 mm lower than those reported by Olivier et al.: 11 $\pm$ 1.8 versus 12 $\pm$ 2.0 mm in males and 9.5 $\pm$ 1.1 versus 10.5 $\pm$ 2.0 in females [8]. These variations can be explained because we systematically measured the minimal diameter and not the anteroposterior one, which represents the minimal diameter in only 75% of cases [8].

Chronic obstructive pulmonary disease (COPD) consists of parenchymal destruction associated with small airway disease with degenerated cartilage and perichondrial fibrosis [24]. This probably explains why most radiological studies have focused on small bronchi which have, in comparison with those of controls, thicker walls and narrower lumens in patients with mild COPD [25, 26]. Hasegawa et al. [27] have pointed out that airflow limitation is closely related to the airway dimensions from the third- to the sixth-generation bronchi. Furthermore, the correlation coefficients between expiratory flow measurements and airway luminal areas obtained at expiratory CT are higher than those obtained at inspiratory CT [28]. Few studies have focused on the dimensions of larger bronchi in COPD patients. The right upper lobe, a structure usually sliced in cross section and large enough to be accurately measured, has been studied by Nakano et al. [29], who have reported that the airway wall of this bronchus is thicker and that its luminal area is smaller in patients who have more severe airflow obstruction. More recently, Ohara et al. [30] showed that airway measurements of the basal segment bronchus correlated well with those of the apical bronchus. Our results show that the minimal main right and left bronchial diameters are not linearly related to FEV_1 but are greater in patients with very severe COPD ($FEV_1 < 30\%$) than in less severely affected patients. Several hypotheses may be put forward. First, the role of tracheobronchomalacia, frequently seen in COPD patients [31] has to be considered. It generally results from weakness of the tracheal or main bronchial walls and leads to tracheal and main bronchial narrowing during both quiet exhalation and forceful expiratory efforts [32]. Bronchial wall weakness may also lead to bronchial deformation increasing inspiratory-measured bronchial diameter. Second, airflow obstruction in very severe COPD causes hyperinflation and increases inspiratory muscle work [9] leading to inspiratory bronchial deformation.

In conclusion, this study confirms our impression that patients with very severe COPD have larger bronchi than patients with less severe disease. The difference in the median values of Min-RBD and Min-LBD was 1.2 mm, which corresponds to a difference of two or three sizes of a DLT; this difference should be taken into account in DLT selection for such patients, as demonstrated by the comparison between the clinical ("Slinger's rule" [7]) and the CT scan approaches. Further studies are needed to prove that CT scans can improve patients' intraoperative care, as stated by Iwamoto et al. [33] in their report of a patient having suffered from hypoxia during one-lung ventilation due to a tracheal bronchus.

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