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Measurement of Total Lung Capacity : A Comparison of Spiral CT and Spirometry[1]

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Purpose : To determine the potential of spiral CT as a functional imaging modality of the lung aside from its proven value in morphological depiction.

Materials and Methods : Spiral CT scan was performed in ten normal female and nine normal male adults(mean age : 39, height : 163 cm, weight : 62 kg) after single full breath-holding. Three dimensional lung images were reconstructed(minimal threshold value : −1,000 HU, maximal threshold values : −150, −250, −350, −450 HU) to obtain total lung volume(TLV) on a histogram. Total lung volume measured by spiral CT was compared with TLV obtained by spirometry.

Results : Mean TLV measured by spirometry was 5.62 L and TLV measured by CT at maximal threshold values of −150, −250, −350, and −450 HU was 5.53, 5.33, 5.15, and 4.98 L, respectively. Mean absolute differences between the modalities of 0.17 L(3%), 0.32 L(5.6%), 0.48 L(8.5%), 0.65 L(11.5%) were statistically significant($p<0.001$). Linear regression coefficients between the modalities were 0.99, 0.97, 0.95, and 0.94 and no statistically significant differences in accuracy of threshold levels in the estimation of lung volume($r=0.99$, standard error $=0.034$ L in all) were seen.

Conclusion : TLV measured by spiral CT closely approximated that measured by spirometry. Spiral CT may be useful as a means of evaluating lung function.

Index Words : Lung, volume
Lung, function
Lung, CT
Computed tomography(CT), helical technology

INTRODUCTION

In addition to its ability to depict the morphologic characteristics of the lung in great detail, computed tomography(CT) can be helpful in the evaluation of physiologic and pathologic changes of the lung. In addition to the direct visual scoring method, computer analysis of attenuation maps of lung parenchyma has been used to study diffuse lung diseases and to correlate it with pulmonary function(1−5). Few attempts to utilize CT as a functional test of the lung have been made. Wandtke et al(6). found that measurement of lung volume by CT underestimated by 34% that measured by the helium inhalation technique. Wu et al.(1) found, however, that CT was effective in predicting forced expiratory volume in 1 second and forced vital capacity using TLV measured by CT. These studies used conventional CT with multiple breath-holdings, which might have resulted in inaccurate scan location at each breath-holding state, and manually manipulated ROIs. Contrary to the scope of window width in CT volume measurement, no attempt to determine the optimal upper limit of lung attenuation has been made(1). The authors performed this study to determine whether or not the single breath-hold technique using spiral CT with fully automated ROI manipulation can narrow the difference between TLV measured by CT and spirometry and to determine the optimal upper limit of lung attenuation in measuring total lung volume.

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MATERIALS and METHODS

Eleven normal female(mean age : 41, height : 155 cm, weight : 55 kg) and nine normal male adults(mean age : 36, height : 171 cm, weight : 70 kg) practiced the technique of full breath-holding before a CT scan. Spiral CT scan was performed with GE HighSpeed Advantage (GE Medical Systems, Milwaukee, WI) with the subject in supine position and single full breath-holding state. Scan parameters used were collimation of 10 mm, pitch factor of 1, 120 kVp and 200 mAs. Images were reconstructed using a standard reconstruction algorithm with a matrix size of 512 × 512, reconstruction interval of 10 mm, and display FOV of 32 cm. The im- ages of the lung were reconstructed three dimens- ionally using a software(GE Advantage Window, Mil- waukee, WI) in volume mode with threshold range of −150 to −1,000 HU for the automatic removal of stru- ctures surrounding the lung. In the cases of incomplete removal, scalpeling of the unwanted structures was carried out in shaded surface display mode with the aid of multiplanar reformation. Lung volume on histogram was evaluated at maximal threshold values of −150, −250, −350, and −450 HU so that the results could be compared with those obtained by spirometry to determine the optimal threshold range. Spirometry(PF/Dx 1085D Breeze ; Medgraphics, St Paul, MN) was performed within one week of CT studies. Lung volume measured by CT with various threshold ranges was compared with that measured by spirometry using linear regression analysis.

RESULTS

Mean TLV measured by spirometry and CT at maximal threshold value of −150 HU was 5.62 and 5.53 L, respectively(Table 1). The mean of absolute difference between TLV obtained by spirometry and CT at maximum threshold value of −150 HU was 0.17 L(3%) which was the least mean absolute difference obtainable by the variable threshold ranges(Table 2). A progressive significant increase in mean absolute difference was noted according to the decrease in maximal threshold values(Bartletts'test, $p<0.001$) with a maximal mean absolute difference of 0.65 L(11.5%) at −450 HU. At maximal threshold of −150 HU, the mean absolute difference of 0.14 L in males was smaller than the difference of 0.20 L in females, but with a decrease in maximal threshold the values were progressively reversed so that at −450 HU, the mean absolute difference of 0.68 L in males was larger than the 0.62 L found in females.

Minute but progressive decrease in standard deviation and standard error of difference between TLV measured by spirometry and by CT were noted as the threshold increased, with respective minimal values of 0.11 and 0.01 at −150 HU(Table 3).

TLV in three cases measured by CT at a maximum threshold of −150 HU and in two of the three cases at −250 HU, was larger than that by spirometry, suggesting inappropriately high threshold values for optimal depiction of only the lung tissues at these ranges. However, linear regression analysis showed the highest regression coefficient(b), 0.99, and the highest coefficient of determination(r^2), 0.981, between TLV measured by spirometry(y) and by CT(x) at −150 HU (Table 4)(Fig. 1.). Subsequently decreasing coefficient values were noted with a decrease in maximal threshold values ; this suggested the more predominant exclusion of borderline pixel values of lung parenchyma relative to the inclusion of borderline extraparenchymal pixel values as the maximal threshold decreased. The highest coefficent values at −150 HU, pointed to an optimal balance between discriminatory exclusion and inclusion of the pixel values. In spite of the minute difference in coefficients, there was no statistically signifi-

Table 2. Mean Absolute TLV Difference between Spirometry and Spiral CT

	Spiral CT(Max. Threshold ; HU)			
	−150	−250	−350	−450
Female	0.20	0.32	0.46	0.62
Male	0.14	0.32	0.49	0.68
Average	0.17 (3%)	0.32 (5.6%)	0.48 (8.5%)	0.65 (11.5%)

Note. −Data indicate liter
TLV = total lung volume

Table 1. Mean Total Lung Volume(TLV) measured by Spirometry and Spiral CT

				Spirometry		Spiral CT(Max. Threshold ; HU)			
	Age	Height(cm)	Weight(kg)	*TLV%	TLV	−150	−250	−350	−450
Female(n = 10)	41	155	55	115	4.59L	4.47L	4.28L	4.13L	3.97L
Male(n = 9)	36	171	70	124	6.78L	6.71L	6.49L	6.28L	6.09L
Average	39	163	62	119	5.62L	5.53L	5.33L	5.15L	4.98L

Note. − * Percentile relative to standard according to sex, age, height, weight, and race
TLV = total lung volume

cant difference between the accuracy of the threshold levels in estimation of lung volume, as the standard error of estimate, 0.034 L, was the common value in all (Table 4).

DISCUSSION

TLV measured by CT in three patients at a maximal threshold of −150 HU, and in two of the three patients at −250 HU, was larger than that by spirometry. These readings included two females with TLV% in spirometry(percentile relative to standard, according to sex, age, height, weight, and race) of 108% and 118%(mean 115%) and one male with that of 114%(mean 124%).

The standard TLV data provided by the spirometry equipment might not be the most up-to-date nor representative of the most accurate, as evidenced by the high mean TLV% of the normal subjects in this study. The relatively lower TLV% in two of the three cases with TLV higher as measured by CT than by spirometry might suggest, then, the possible limitation of spirometry in those with poor compliance for spirometry(7). Other possible explanations may include individually variable extra- and intra-parenchymal tissue densities which may have lead to selective inclusion of extraparenchymal tissue in the three cases, perhaps pointing to the advantage of application of variable threshold ranges upon individual bases(8). Rather than

Table 3. Standard Deviation/Error of TLV Difference

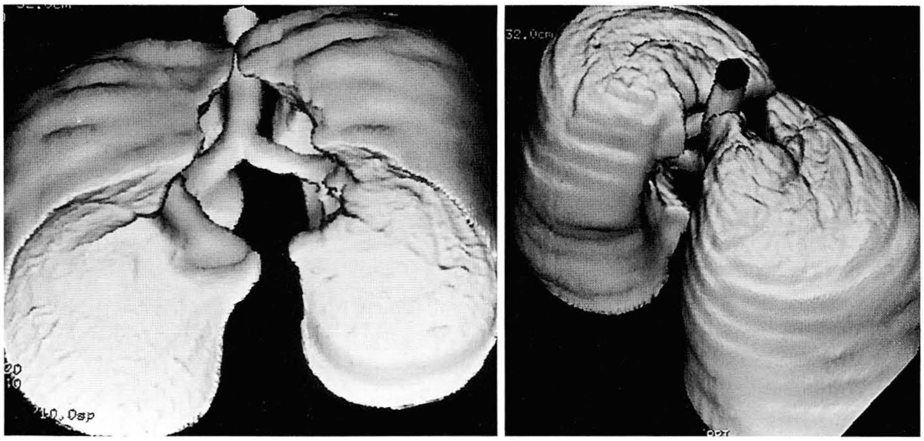
	Spiral CT(Max. Threshold ; HU)			
	−150	−250	−350	−450
Female	*0.11(0.01)	0.18(0.03)	0.20(0.04)	0.20(0.04)
Male	0.11(0.01)	0.12(0.01)	0.19(0.04)	0.20(0.04)
Average	0.11(0.01)	0.15(0.02)	0.19(0.04)	0.20(0.04)

Note. −* Standard deviation(standard error)
Data indicate liter
TLV = total lung volume

Table 4. Linear Regression Analysis of TLV : Spirometry(x), Spiral CT(y)

Coefficient	Spiral CT(Max. Threshold ; HU)			
	−150	−250	−350	−450
Regression(b)	0.99	0.97	0.95	0.94
Intercept(a)	−0.048	−0.148	−0.203	−0.305
Determination(r^2)	0.981	0.980	0.979	0.978
Correlation(r)	0.99	0.99	0.99	0.99
Standard Error	0.034	0.034	0.034	0.034

Note. −TLV = total lung volume



a b

Fig. 1. Shaded surface display of a lung reconstructed three dimensionally using threshold range of −150 to −1000HU. Anterior oblique(a) and posterior oblique(b) views show the lung free of surrounding structures.

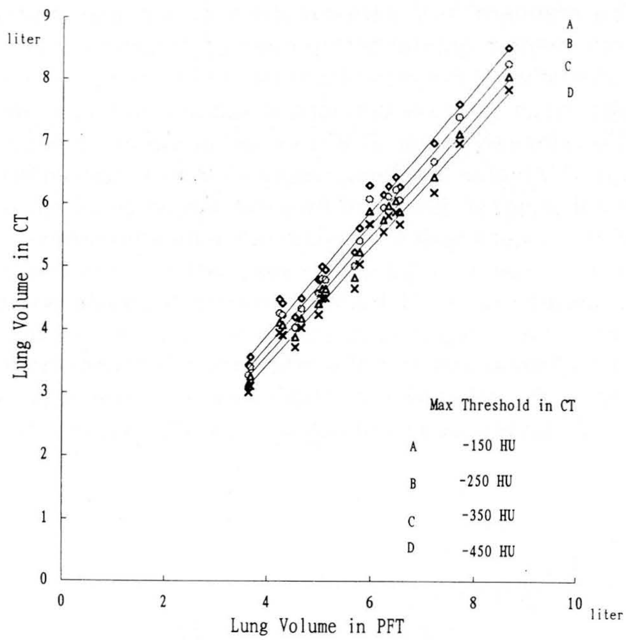


Fig. 2. Linear regression between lung volume measured by spiral CT(abscissa) at maximal threshold values of −150, −250, −350, −450 HU and by spirometry(ordinate). Correlation coefficients are displayed in Table 4.

selective inclusion in the three cases, the inclusion of extraparenchymal tissue in all cases should also be considered, as the mean difference between TLV measured by spirometry and by CT was smaller at these higher maximal thresholds. The fact that the interphase area between extra- and intra-parenchymal tissue increases with larger lung volume partly explains the larger mean TLV difference, of below −250 HU, in males than in females. The progressively increasing discrepancy between the values in male and female at a lower maximal threshold occurred due to more extraction of intraparenchymal tissue in male with larger interphase area. Conversely, the discrepancy between the mean TLV differences in male and females became reversed above −250 HU, with the smaller TLV difference in males than in females caused by the addition of more extraparenchymal tissue in males with larger interphase area. This may also explain the highest regression coefficient between TLV measured by PFT and by CT, and the smallest standard deviation of TLV differences at −150 HU. The optimal maximal threshold level may be −250 HU, since at this level there was no discrepancy between mean TLV difference in femalesad in males. However, further study, using improved scanning techniques, is needed for more definitive results.

There have been very few reports on lung volume measurements using CT. A previous study(9) on CT estimation of lung volume in children described a correlation coefficient of 0.92 between the value as determined by CT and by spirometry. One other previous study(10) in adults reported a coefficient of 0.81. These are lower values than the result of this study(r = 0.99). Apart from CT technical factors, strict adherance to patient cooperation in breath-holding practices before CT scanning and repetition of studies in some may have contributed to the result.

Spiral CT with its fast scanning ability, makes possible lung volume measurement during a single full breath-holding, thereby minimizing error caused by changes in scan location due to multiple breath-holding. However, the speed of scanning in spiral CT is still not the most desirable for optimal depiction of lung volume, as the minimum scan duration of 1 second limits the maximum number of scans during a single breath-holding to 30. (It was the authors experience that 30 seconds was more or less the safest duration of a full breath-holding for all patients positioned within the CT gantry.) High resolution CT would ultimately lead to more accurate lung volume measurement but a smaller section thickness of as little as 1 mm would require much more than 30 seconds for completely scanning entire lungs. With scan thickness limited to 1 cm due to breath-holding limitations, the most important issue, then, is partial volume averaging between lung parenchyma and extraparenchymal tissue. It is therefore expected that some parenchymal lung tissue would be lost if maximal threshold value was inadvertently set too low in order to exclude extraparenchymal tissue and conversely, some extraparenchymal tissues would be included if the threshold was set too high in order to include lung tissue. Smaller collimation, higher pitch factor, and an overlapped reconstruction interval combined with smaller FOV and bone algorithm may lead a to better result. Further improvement may also occur if the patients are positioned identically during both CT scanning and spirometry.

In summary, total lung volume measured by spiral CT approximated the values measured by spirometry especially at higher upper limits of lung attenuation, thus pointing to the potential role of CT as a valuable means of evaluating lung function, aside from its already proven value in morphological depiction. An upper limit of −250 HU appeared to be the ideal level for optimal inclusion of intraparenchymal and exclusion of extraparenchymal tissue. Faster scanning, higher resolution, and the application of a variable threshold range upon individual bases may lead to more accurate results.

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전폐 용적의 측정 : 나선형 CT와 폐활량 검사와의 비교[1]

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목 적 : 폐의 기능적 검사방법으로서의 나선형 전산화 단층촬영술의 유용성을 평가하고자 하였다.

대상 및 방법 : 19명의 건강한 성인 폐를 단일 심흡기 상태에서 나선형 전산화 단층촬영하였다. 삼차원적 폐영상을 재구성(최저 한계치 : −1,000 HU, 최고 한계치 : −150, −250, −350, −450 HU)하여 전폐용량을 측정하였으며 그 결과를 폐활량검사상의 전폐용량과 비교하였다.

결 과 : 폐활량검사상의 평균 전폐용량과 최고 한계치 −150, −250, −350, −450 HU시 전산화 단층촬영상의 평균 전폐용량은 각 5.62, 5.53, 5.33, 5.15, 4.98 L였고 두 검사방법 간의 절대 차이의 평균은 0.17(3%), 0.32(5.6%), 0.48(8.5%), 0.65(11.5%) L였다. 두 검사간의 회귀분석에 의한 회귀계수는 각 0.99, 0.97, 0.95, 0.94였고 각 CT 감쇄 한계치에서 측정한 폐용량에 있어서 통계적으로 유의한 정확도의 차이는 없었다.

결 론 : 나선형 전산화 단층촬영으로 측정한 전폐용량은 폐활량검사상의 결과와 근접하였다. 나선형 전산화 단층촬영술은 폐기능의 평가에 유용한 방법으로 사용될 가능성이 있다.

1996년도 추계 진단방사선과 전공의 연수교육 안내

제　　목 : 1996년 10월 20일
장　　소 : 인촌강당(고려대학교내)
주　　제 : 복부 질환의 영상진단
등 록 비 : 10,000원

시 간	연 제	연 사
09 : 00－09 : 40	국소간질환의 감별진단	최병인(서울의대)
09 : 40－10 : 10	폐쇄성 황달 환자의 영상진단	이문규(울산의대)
10 : 10－10 : 40	담낭 질환의 영상진단	이동호(경희의대)
10 : 40－11 : 00	휴 식	
11 : 00－11 : 30	췌장염의 영상진단	변재영(가톨릭의대)
11 : 30－12 : 00	췌장암의 영상진단	강형근(전남의대)
12 : 00－12 : 30	기타 췌장 종양의 영상진단	이원재(삼성의료원)
12 : 30－13 : 30	점 심	
13 : 30－14 : 00	복막/후복막강 질환의 영상진단	박철민(고려의대)
14 : 00－14 : 30	부신 질환의 영상진단	백승연(이화의대)
14 : 30－15 : 00	비장 질환의 영상진단	조온구(한양의대)
15 : 00－15 : 20	휴 식	
15 : 20－15 : 50	위장 질환의 영상진단	조준식(충남의대)
15 : 50－16 : 20	대장 질환의 영상진단	김기황(연세의대)
16 : 20－16 : 50	단순 복부 X－선 진단	한준구(서울의대)