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DIFFERENTIAL VITAL CAPACITY DETERMINATIONS WITH RADIOACTIVE XENON

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Differential vital capacities (right lung versus left lung) can be obtained with bronchospirometry. Radiospirometry, however, has been shown to be more reproducible and due to its noninvasive nature more acceptable by the examinee. Right lung vital capacities determined by radiospirometry were found to be statistically larger (52%) than the left lung vital capacity (48%) in 28 normal subjects (nonsmokers). The differential data of 11 smokers were not consistent with the above relationship. Vital capacities determined using radioactive xenon showed statistically significantly lower values from those determined by standard spirometry. The noninvasive nature of this technique in determining differential data (regional as well as unilateral) may allow one to locate abnormalities when standard spirometry indicates normal or abnormal pulmonary function.

The biophysical characteristics of xenon make this radioactive gas particularly useful in the evaluation of pulmonary function (*1*). The purpose of this study was to determine radiospirometrically the differential vital capacity in normal subjects. An additional objective was to compare the vital capacity determinations made by standard spirometry with those determined by the xenon technique.

MATERIALS AND METHODS

The ages of the 39 subjects ranged from 18 to 52 years, with a mean age of 26.9 years. All of the nonsmokers selected denied any history of pulmonary disease as did the smokers. Each of the 11 smokers admitted to one package of cigarettes per day.

Vital capacities were determined by the following two methods: (A) standard spirometry (Collins spirometer) (*2*) and (B) a ^{133}Xe technique with an external counting analyzer (Ohio-Nuclear Regional Pulmonary Function Analyzer).

Each subject had the following spirometric parameters determined, the results of which are shown in Tables 1 and 2: maximal midexpiratory flows and maximal breathing capacities as well as vital capacities. The best effort of at least three attempts was selected and compared with predicted values as determined from the data of Baldwin and associates and Leuallen and Fowler (*3,4*).

The technique of determining vital capacities by means of radioactive xenon in conjunction with an external counting analyzer has been reported elsewhere (*5*). Briefly, the procedure involves the use of six collimators (three collimators per chest field) which count paroximal radioactivity. The subject's lung function is analyzed during a series of 4-sec full inhalation breatholds. Each lung field is divided into three regions (upper, middle, and lower) for total of six regions. Background counts are stored initially in the analyzer followed by calibration counts accomplished by having the subjects inhale 0.25 liters of ^{133}Xe. After complete exhalation the subjects inspired to total lung capacity (TLC) from a 7-liter spirometer containing radioactive xenon gas (total radiation dose per subject = ~300 μCi). At TLC the subjects held their breath for 4 sec at which time counts were recorded.

The calculation is based upon the following where K represents the concentration of the ^{133}Xe gas used in counts per liter per 4 sec and B represents background counts. During the calibration the patient inhales 0.25 liters of xenon at concentration K. This produces a calibration count (CC).

$$CC = 0.25 \text{ liters} \cdot (K + B). \quad (1)$$

The net calibration count (NCC) is the calibration count less the room background count, or

$$NCC = 0.25\,K \quad \text{or} \quad (2)$$

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$$K = 4\,NCC. \quad (3)$$

At full inspiration, concentration K produces a vital capacity count

$$VCC = VC \cdot (K + B). \quad (4)$$

The net vital capacity count NVCC is equal to

$$VCC - B \quad \text{or} \quad VC \cdot K.$$

The vital capacity concentration is computed from the volume ratio:

$$K_v = \frac{NVCC}{TLC} = \frac{NVCC}{VC + RV} = \frac{VC \cdot K}{VC + RV}. \quad (5)$$

Eliminating K_v from Eq. 5 and solving for VC

$$VC = \frac{NVCC}{K}. \quad (6)$$

Using Eq. 3,

$$VC = \frac{NVCC}{4\,NCC}. \quad (7)$$

The vital capacity of the right or left lung is determined from the sum of the three regional vital capacities of that lung.

$$VC_R{}^* = VC_{RU} + VC_{RM} + VC_{RL}\ \text{liters}. \quad (8)$$

$$VC_L = VC_{LU} + VC_{LM} + VC_{LL}\ \text{liters}. \quad (9)$$

The vital capacity of each of the six regions using the preceding formulation can be determined as follows:

$$VC_{RU} = \frac{(VCC_{RU} - B_{RU})}{4\,NCC}\ \text{liters}. \quad (10)$$

$$VC_{RM} = \frac{(VCC_{RM} - B_{RM})}{4\,NCC}\ \text{liters}. \quad (11)$$

This method provides for the determination of three right-lung regional vital capacities, three left-lung regional vital capacities, unilateral right- and left-lung vital capacities, as well as total lung vital capacity.

* R = right; L = left; U = upper; M = middle; L = lower.

TABLE 1. THE PHYSICAL AND FUNCTIONAL CHARACTERISTICS OF THE NONSMOKERS AND VITAL CAPACITY DETERMINATIONS

									Xenon vital capacity			
Number	Age	Sex	Height (cm)	BSA (m^2)	MMF (liters/sec)	MBC (% pred)	Spir.* V.C. (ml)	Xenon V.C. (ml)	Left lung (ml)	% of total	Right lung (ml)	% of total
1	27	M	197	2.18	6.30	163	6,370	5,670	2,270	40	3,400	60
2	27	M	186	2.16	5.50	148	5,520	4,970	2,480	50	2,490	50
3	20	F	164	1.62	4.10	171	3,370	2,910	1,420	49	1,490	51
4	25	M	163	1.66	2.20	96	4,790	3,670	1,760	48	1,910	52
5	26	F	165	1.70	5.40	147	3,990	2,970	1,350	45	1,620	55
6	30	M	176	1.88	3.25	111	4,420	2,880	1,460	51	1,420	49
7	21	F	158	1.50	3.40	129	3,860	3,020	1,420	47	1,600	53
8	30	M	165	1.70	5.90	148	5,190	3,680	1,760	48	1,920	52
9	26	M	180	2.06	5.20	116	5,690	5,130	2,360	46	2,770	54
10	18	M	180	1.86	3.60	113	4,990	3,610	1,790	50	1,820	50
11	23	M	180	1.86	6.10	174	4,840	4,600	2,170	47	2,430	53
12	23	M	185	2.00	5.00	112	5,100	4,950	2,620	53	2,330	47
13	26	M	180	1.96	6.00	116	4,090	4,520	2,270	50	2,250	50
14	28	M	180	2.02	3.20	97	5,330	4,390	2,070	47	2,320	53
15	22	F	170	1.84	3.90	120	4,540	4,090	1,970	48	2,120	52
16	23	F	168	1.62	3.50	101	3,400	2,660	1,230	46	1,430	54
17	27	M	170	1.66	4.00	124	5,540	4,380	2,130	49	2,250	51
18	26	M	178	1.94	4.30	108	5,510	4,940	2,390	48	2,550	52
19	41	M	165	1.78	4.30	98	3,960	3,350	1,630	49	1,720	51
20	27	M	178	1.94	5.84	148	5,510	4,550	2,260	50	2,290	50
21	26	M	190	2.16	5.30	158	6,390	5,050	2,360	47	2,690	53
22	28	M	183	2.06	8.10	134	6,460	4,280	2,130	50	2,150	50
23	34	M	178	2.00	4.50		5,874	4,660	2,290	49	2,370	51
24	26	F	164	1.46	3.50		2,777	2,410	1,180	49	1,230	51
25	30	M	168	1.64	3.20	109	4,517	3,920	1,940	50	1,980	50
26	24	F	158	1.50	3.36		3,350	2,660	1,240	48	1,360	52
27	38	M	180	2.04	4.50	80	4,305	3,660	1,940	53	1,720	47
28	23	F	158	1.50	3.06		3,640	2,020	990	49	1,030	51
Mean							4,761.4	3,914.3	1,888.6	48.4	2,023.6	51.6
s.d.							1,002.05	959.41	455.33	2.50	534.32	2.50

* Spirometric vital capacity (ml).

TABLE 2. THE PHYSICAL AND FUNCTIONAL CHARACTERISTICS OF THE SMOKERS AND VITAL CAPACITY DETERMINATIONS

									Xenon vital capacity			
Number	Age	Sex	Height (cm)	BSA (m^2)	MMF (liters/sec)	MBC (% pred)	Spir.* V.C. (ml)	Xenon V.C. (ml)	Left lung (ml)	% of total	Right lung (ml)	% of total
1	25	M	178	1.96	3.20	110	5,220	5,410	2,380	44	3,030	56
2	27	M	175	2.04	2.50	111	4,940	3,770	1,900	50	1,870	50
3	22	M	175	1.84	3.50	124	5,430	4,500	2,170	48	2,330	52
4	21	M	180	2.06	4.70	104	4,690	3,240	1,670	52	1,570	48
5	23	F	174	1.62	3.80	154	4,190	3,250	1,630	50	1,620	50
6	25	F	158	1.88	3.20	125	2,960	2,850	1,230	43	1,620	57
7	38	M	178	2.02	4.40	98	4,742	3,660	1,840	50	1,820	50
8	24	M	186	2.18	4.40	112	6,400	5,910	3,100	52	2,810	48
9	23	F	168	1.58	3.40		3,215	2,330	1,100	47	1,230	53
10	23	M	180	2.04	2.70		5,070	3,960	1,990	50	1,970	50
11	52	M	178	2.04	2.94		4,358	3,350	1,710	51	1,640	49
Mean							4,655.9	3,839.1	1,883.6	48.8	1,955.5	51.2
s.d.							973.56	1,069.84	547.98	3.03	552.31	3.03

* Spirometric vital capacity (ml).

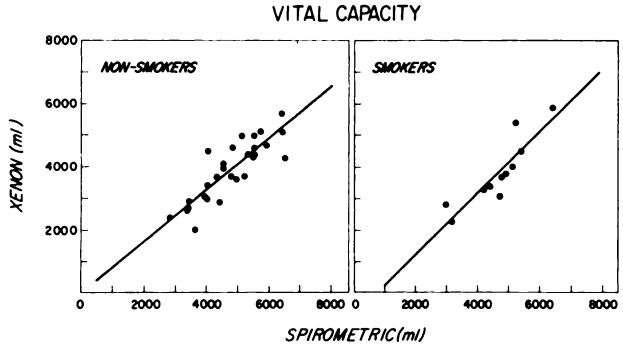

FIG. 1. Vital capacity determined by spirometry and xenon technique. Equation of regression line for nonsmokers is $Y = 24.24 + 0.82\ X$ and for smokers is $Y = 717.62 + 0.98\ X$. Y represents vital capacity determined by xenon technique. X represents vital capacity determined by Collins 9-liter spirometer.

RESULTS

The vital capacity by both radioactive xenon and spirometry as well as the physical and functional characteristics of the 28 nonsmokers and 11 smokers are presented in Tables 1 and 2, respectively. The average vital capacity for the nonsmokers by spirometry is 4,761.4 ml with a standard deviation of 1,002.05 ml in contrast with an average vital capacity with xenon of 3,914.3 ml with a standard deviation of 959.4 ml (Table 1). This difference is statistically significant ($p < 0.001$) and is highly correlated ($r = 0.85$).

The vital capacity for the smokers by the two techniques is shown in Table 2 and the statistically significant difference between the two techniques is the same as for the nonsmoker ($p < 0.001$). However, vital capacity by both techniques for the smokers is, on the average, approximately 100 ml less than for the nonsmokers. In only 2 of the 39 cases studied did the vital capacity determination by xenon exceed that by spirometry.

The data for unilateral lung vital capacity as determined by xenon are shown in the last four columns of each of the tables. As can be seen, the volume mean and percent mean are larger for the right lung versus the left lung for the nonsmokers and smokers. The larger right side vital capacity for the nonsmokers is statistically significant. The data regarding the smokers show an average larger right side vital capacity but the difference is not statistically significant. Of interest is the fact that 7 of the 11 smokers have left side vital capacity equal to or greater than the right side whereas 9 of the 28 nonsmokers showed this reversal.

DISCUSSION

The use of radioactive xenon to determine the ventilation-perfusion relationships in pulmonary embolic disease, bronchial asthma, and chronic obstructive lung disease has been reported elsewhere (*6–10*). One of the purposes of this study was to compare vital capacity determined by radioactive xenon versus that obtained by standard spirometry. In the 28 normal subjects studied (nonsmokers) and in the 11 cigarette smokers, it was found that the xenon method persistently gave a statistically significant lower value than spirometry. The relationship between the two methods is shown in Fig. 1. In other words, by knowing the spirometric vital capacity in an individual, one could predict the xenon vital capacity determination and vice versa. This can be done by multiplying the spirometric vital capacity by a factor of 0.82.

The explanation for the statistically significant dif-

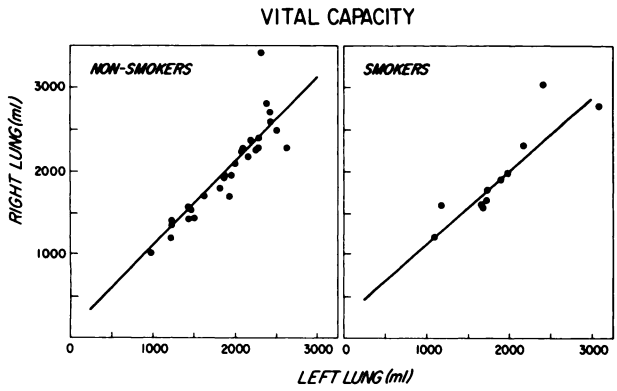

FIG. 2. Differential vital capacity determined by xenon technique. Equation of regression line for nonsmokers is Y = 49.85 + 1.05 X and for smokers is Y = 264.95 + 0.90 X. Y represents right lung vital capacity and X represents left lung vital capacity.

ference between the two techniques may be a combination of several factors. Xenon is slightly soluble in blood with a Bunsen solubility coefficient of 0.84 (*1*) which may allow some xenon to cross the alveolar membrane and pass into the bloodstream during the time the counts are being recorded. The positioning of the patient with his back held as closely as possible to the collimators may restrict the subject from taking a maximal vital capacity. During spirometric evaluation there is no restriction to movement of the subject's thoracic cage. The inherent mechanical characteristics of the Pulmonary Function Analyzer (absence of a motor blower and the presence of higher resistance valves) may be the most significant factor for the observed difference between the two methods.

The data comparing the unilateral lung vital capacities reveal that the right lung represents 52% of the total vital capacity and the left lung represents 48% of the total capacity. Figure 2 shows the differential vital capacity lung curves for the nonsmokers and smokers. This finding is in agreement with Miörner who studied 38 normal volunteers between the ages of 18 and 49 years with radiospirometry and observed that the right lung represented 53% of the total function (*11*). Svanberg and Arborelius had noted similar findings with bronchospirometry (*12,13*). As previously noted, it may be of some importance that this right-to-left lung relationship was not well maintained among the smokers. Although it is beyond the scope of this paper, further radiospirometric analysis of regional ventilation in the smokers may be performed to identify areas of decreased ventilation when overall pulmonary function by standard spirometry is normal.

Prior to the introduction of radioactive gases by Knipping (*14*), the only technique for obtaining unilateral pulmonary data was by means of bronchospirometry. The relative advantages and disadvantages of radiospirometry versus bronchospirometry have been reviewed by Miörner (*11*). His analysis of cumulative data has established radiospirometry as a diagnostic method upon which valid and reproducible measurements of pulmonary function can be made. Bronchospirometry is an invasive technique requiring significant technical skill and an obliging patient. Accumulated mucous secondary to intubation may adversely affect ventilation and thereby adversely affect the results. The interested reader is referred to an excellent review of over 1,000 examinations and the associated problems (*15*). The noninvasive nature of radioactive xenon analysis makes this method more acceptable to the individual being examined. In addition, dynamic as well as static ventilation-perfusion information can be obtained in the approximate 15 min that the entire study requires. Radiospirometry has been shown to be more reproducible than bronchospirometry both with duplicate determinations in the same investigation and on repeated determinations (*11*). A major advantage of the xenon technique is the ability to measure unilateral and regional vital capacities. Also, other unilateral and regional data, such as washout times, are obtained. The detection of early lung disease with radioactive xenon on a regional or unilateral basis when standard spirometric studies are normal adds greatly to the clinical application of the procedure.

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