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Comparison Of Respiratory Parameters With Lung Volume Fractions Determined By Stereological Methods In Elite Swimmers

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Abstract: The purpose of this study is to compare respiratory parameters with the lung volumes and volume ratios determined by stereological methods in elite swimmers. Research was conducted on 20 elite swimmers whose ages are from 18 to 24. Pulmonary function tests were applied to the subjects. Lung images were obtained during inspiration and expiration using high-resolution computed tomography device. Calculations were done from the images taken with Cavalieri principle which is one of stereological methods. Each lobe of the lung and the total lung volume, volume fraction and the expansion ratios were detected. The average volume of total lung of swimmers was accordingly calculated as 7508.15 ± 800.92 cm^3 during expiration and as 13292.11 ± 1256.03 cm^3 during inspiration. In comparison of respiratory parameters and lung volumes, while there was no significant difference in the volume fraction of each lobe of the lungs during expiration (p>0,05), there was a significant difference between volume ratios of Upper left and Lower right and also right and left lobes of the lung during inspiration (p<0,05). There was a significant difference between Upper left, Lower left and left lobes of the lung in expansion rates (p<0,05).

Key words: Lung Volume, Cavalieri Principle, Stereology Pulmonary Tests

INTRODUCTION

Our lungs are deceptively simple organs of respiration, noticeable only when we are breathing hard during exercise or when it becomes difficult to breathe because of pollution or disease. Many factors influence lung function—everything from premature birth to the presence of cancer (Saleeby, J.P., S. Coopersmith, 2006). The lungs having vital importance and the lung capacity have attracted the attention of many researchers and have led to new researches.

Anatomical and physiological profiles should be identified, firstly to enhance the performances of the sportsman as there is a close relationship between the structural and functional properties of the body. Thus, body components are the primary factors directly affecting the performance in all branches of sport. It is, therefore, crucial to have information on body components such as muscles, bone, fat and others in order to sustain personal and team success (Tasmektepligil, M.Y., 2009).

The volume of biological structures can be estimated by combining sectional radiological imaging techniques with the Cavalieri principle of volume estimation as described previously (Sahin, B., *et al*., 2003; Odaci, E., *et al*., 2003; Başoğlu, A., *et al*., 2007). Volume, volume fractions, surface area, surface density and cell numbers of the structures can be calculated to be close as possible as to reality using stereological methods (Gundersen, H.J.G., E.B. Jensen, 1987). The human organs do, however, vary widely in size. Several factors contribute to this variation. Factors related to growth, such as gender and physical size, are thought to influence the maximal size of an individual’s organs (Raz, N., *et al*., 1998; Sgouros, S., *et al*., 1999; Başoğlu, A., *et al*., 2007). Simply comparing the organ volumes or the volumes of lobes between two groups (i.e. control and experimental groups) will not provide reliable data. However, the volume fraction of a component within a reference volume is a simple and very widely used parameter in biomedical science (Mattfeldt, T., *et al*., 2003; Howard, C.V., M.G. Reed, 1998), which can be used to express the proportion of a phase or component within the whole structure. Hence, it is possible to use this proportion to compare the organ size and any part of an organ between the groups (Başoğlu, A., *et al*., 2007).

In the light of the above information, it was aimed to measure and to compare lung volumes and volume fractions determined by the stereological methods and respiratory parameters in elite swimmers in this study. As a result of the literature search that we done, we couldn’t detected a study that evaluated the volume changes occurring in lung and each lobe of the lung from high-resolution computed tomography images on the athletes during inspiration and expiration. Therefore, we planned to conduct this study with the idea that the volume and

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the volume fractions calculations could be a new approach in the quantitative evaluation of the volume changes of total lung and each lobe of the lung in athletes.

MATERIAL AND METHODS

Subjects:

20 male elite swimmers between the ages of 18-24 who made regular training and reached at the level of National Team were used as subjects in the research. Two subjects were excluded for various reasons. Information that the study would take place in accordance with the code of ethics was reported to Marmara University Research Ethics Committee Presidency and approval of Ethics Committee was taken to perform the study.

Data Collection:

Obtaining Lung Images:

Lung images of the athletes participating in the study were obtained by high-resolution computed tomography device having Multislice property of which brand name is Siemens Somatom Spirit during expiration and inspiration.

The subjects was admitted to High Resolution Computed Tomography (HRCT) device at Upine position. Starting and ending borders of cross-sectional images planning on skenogram taken to display the entire lung from apex to diaphragm were determined. After the subjects lay down to HRCT device, the subjects were wanted to inhale as much as air into the lungs and not to exhale the air until imaging finished and then their images were taken in inspiration. They were wanted to exhale all the air in their lungs in expiration. CT scan images were obtained using 1 mm slice thickness and 20 mm cross-sectional dimension on the axial plane. Computed tomography imaging process were taken using 130 Kv, 100 mAs, 1 second scan time parameters. Consecutive tomography cross-sectional series were transferred to a CD in Dicom format making the most appropriate windowing setting to show the boundaries and fissures of the lung and were pressed to the film at the same time.

Volume Estimation with Cavalieri Principle:

Cross-sectional images obtained from HRCT were transferred to ImageJ program. After images were rendered into a bunch, the boundaries of the lobes of the lung were drawn for each of the cross-section. The program automatically calculated the area of the region of which boundaries were drawn. The volume data was calculated using the field data obtained and the total cross-sectional thickness (20 mm) by the help of the formula below.

$$V = \sum_{i=1}^{m} A \times t$$

$\sum_{i=1}^{m} A$ **represents the area of each lobe, t represents the thickness of the cross section in the formula.**

Where, V is The Volume, Σa Is The Total Sectional Area Of The Structure And T Is The Space Between The Examined Sections:

As done in the previous studies, middle lobe on the right side was included to the volume of right Lower lobe (Başoğlu, A., *et al*., 2007). Thus, the volumes of four lobes of the lung were calculated separately. The total of all lobes is recorded as the total lung volume. These actions were made separately for inspiration and expiration.

Volume Fraction:

The volume fraction of a component within a reference volume is a simple and very widely used parameter in biomedical science (Tasmektepligil, M.Y., 2009; Mattfeldt, T., *et al*., 2003; Howard, C.V., M.G. Reed, 1998). Thus, it is used to express the proportion of a phase or component within the whole structure. The volume fraction of an X phase within a Y reference volume is simply expressed as follows:

$$\hat{V}v_{(X,Y)} = \frac{Volume\ of\ X\ phase\ in\ Y\ reference\ space}{Volume\ of\ Y\ reference\ space}$$

where the VV(X,Y) indicates volume fraction of X phase within the Y reference volume. Using this approach, VV (lobe,lung), VV (epidural hematoma, total brain volume) and VV (lobe, lung) can be estimated. Volume fraction ranges from 0 to 1 and is often expressed as a percentage (Howard, C.V., M.G. Reed, 1998).

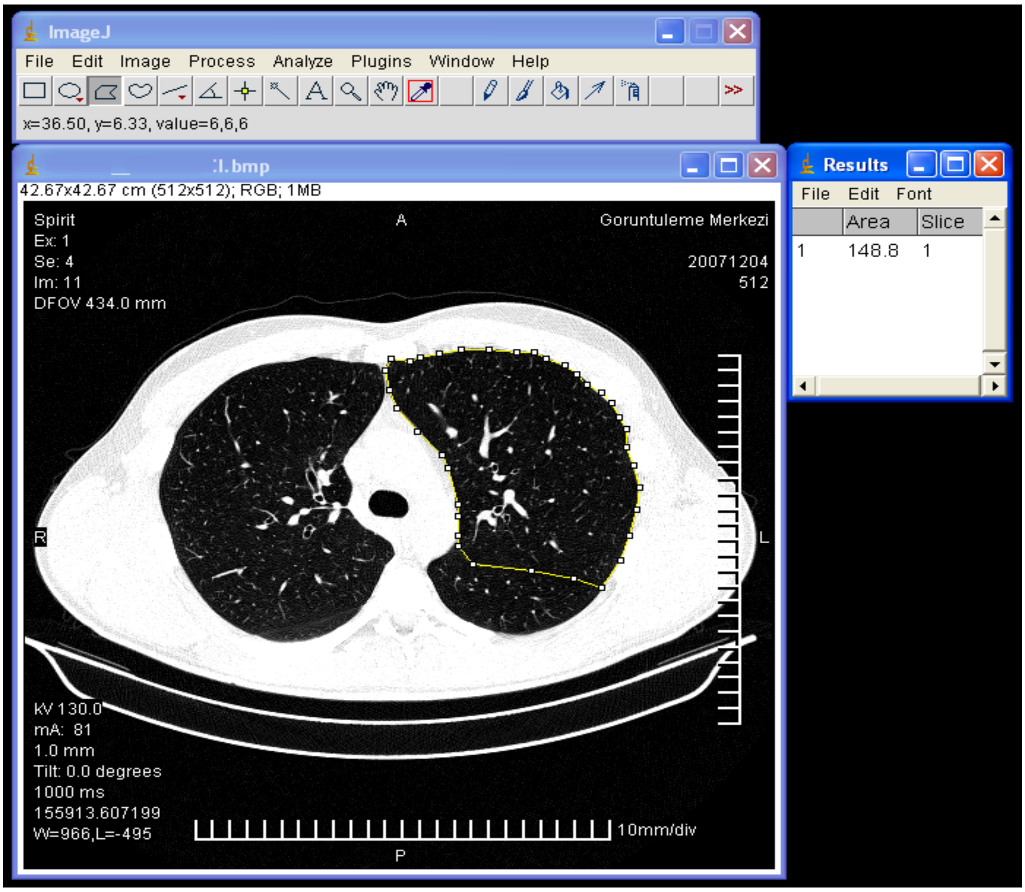

Fig. 1: A cross-sectional view obtained from lung tomography of one individual on horizontal plane. Circularization of one lobe and calculation of the area value using ImageJ program.

Calculation of Expansion Rates:

The expansion rate of each lobe, right and left lungs and all lung in expiration were calculated with the help of the following formula:

Expansion rate =(inspiration volume×100)/expiration volume)-100

The coefficient error (CE) of stereological estimations was determined using the formula reported by Gundersen and Jensen (Gundersen, H.J.G., E.B. Jensen, 1987). All calculations and other related data were obtained as a spread sheet sing Microsoft Excel. After the initial setup and preparation of the formulae, the point counts, formulae and other data were entered for each subject and the final data obtained automatically.

Statistical Analysis:

SPSS version 15.0 statistical package program was used to process the data. Before statistical procedures, Kolmogorov-Smirnov test (K-S test) was used to determine the level of the normal distribution of the data, Asymptotic approaches (based probability) was used for K-S test as the significance approach and the significance level was set at $p \leq$ 0.05.Because of the fact that some of the features didn't show a normal distribution, Wilcoxon rank scores sign test in the comparison inside the groups were applied. The relationship between respiratory parameters and lung volumes were determined with the Spearman-Pearson correlation analysis..

Results:

It was detected that mean age was 19.44 ± 1.94 years, the average height was 182.50 ± 7.36 cm and the average of the body weight was 71.77 ± 10.80 kg of swimmers participating in the study. Additionally, the average percentage of body fat and Body mass index were calculated as 11.78 ± 1.57 and 22.53 kg/m2, respectively.

In the case of the expiration and inspiration, the largest volume was detected in right Lower lobe and left Lower lobe among all of the lung lobes. In general, it was observed that right lobe volume had a larger value than left lobe volume in both of the lung maneuvers.

Table 1: The mean respiratory parameters of the subjects

Respiratory Variables	N	Minimum	Maximum	Mean	Std. Deviation
VC (lt)	18	4,58	6,76	5,62	,59
VC (%)	18	85,00	135,00	108,27	15,69
MVV (lt/dak)	18	169,00	222,00	193,61	13,52
MVV (%)	18	91,00	193,00	141,88	29,72
FVC (lt)	18	4,46	6,53	5,53	,61
FVC(%)	18	91,00	120,00	106,94	8,30
FEV1 (lt)	18	3,58	5,62	4,65	,63
FEV %	18	88,00	125,00	106,38	10,87
FEV1 / FVC	18	68,20	97,70	85,77	6,90
PEF	18	6,25	11,74	9,20	1,45
PEF %	18	63,00	116,00	98,22	13,42

Table 2: Volume values of lung lobes in expiration (cm^3).

Volume Regions	N	Minimum	Maximum	Mean	Std. Deviation
Left Upper Volume	18	1048,05	2035,67	1579,63	248,82
Left Lower Volume	18	1397,52	2521,83	1990,74	308,67
Left total lobe	18	2820,37	4557,49	3570,37	460,40
Right Upper Volume	18	1184,92	1648,52	1358,16	154,84
Right Lower Volume	18	1893,78	3050,13	2619,97	422,34
Right total lobe	18	3091,22	4474,41	3978,14	420,13
Lung Volume	18	5946,13	8914,38	7508,15	800,92

Table 3: Volume values of lung lobes in inspiration (cm^3).

Volume Regions	N	Minimum	Maximum	Mean	Std. Deviation
Left Upper Volume	18	2545,55	3513,90	2840,42	245,23
Left Lower Volume	18	2913,48	4625,78	3521,62	489,90
Left total lobe	18	5639,13	8139,68	6362,05	669,88
Right UpperVolume	18	1961,47	2865,95	2389,76	222,87
Right Lower Volume	18	3675,63	5991,21	4540,28	650,33
Right total lobe	18	6233,17	8409,38	6930,05	617,22
Lung Volume	18	11872,30	16549,07	13292,11	1256,03

Table 4: The correlation between respiratory parameters and lung volumes

	Expiration	Inspiration
FVC (lt)	-0,092	-0,026
FVC (%)	-0,160	0,108
FEV1	-0,007	-0,051
FEV (%)	-0,093	0,001
FEV1 / FVC	-0,098	-0,156
PEF	-0,084	-0,239
PEF (%)	-0,281	-0,340
VC (lt)	-0,161	-0,245
VC (%)	-0,290	-0,079
MVV	0,180	0,407
MVV (%)	0,013	0,081

* Significant at the level of 0,05

Table 5: Statistical analysis of lung volumes in expiration and inspiration

Lung Lobes	N	Minimum	Maximum	Mean	Std. Dev.	P
ExVolUpLeft	18	1048,05	2035,67	1579,63	248,82	0,00
InVolUpLeft	18	2545,55	3513,90	2840,42	245,23	
ExVolUpRight	18	1184,92	1648,52	1358,16	154,84	0,00
InVolUpRight	18	1961,47	2865,95	2389,76	222,87	
ExVolLowLeft	18	1397,52	2521,83	1990,74	308,67	0,00
InVolLowLeft	18	2913,48	4625,78	3521,62	489,90	
ExVolLowRight	18	1893,78	3050,13	2619,97	422,34	0,00
InVolLowRight	18	3675,63	5991,21	4540,28	650,33	
ExVolTotalLung	18	5946,13	8914,38	7508,15	800,92	0,00
InVolTotalLung	18	11872,30	16549,07	13292,11	1256,03	

ExVolUpLeft: Expiration volume Upper left lobe InVolLowRight: Inspiration volume Lower right lobe In general, when the table is analyzed, the average volume difference between both of the lung lobes in expiration and inspiration in swimmers was seen to be statistically significant ($p<0.05$).

There was no significant relationship at the level of 0,01 or 0,05 in any of respiratory parameters of expiration and inspiration lung volumes in the correlation analysis between the values of the respiratory parameters and lung volumes.

Table 6: Comparison of volumes of right and left lungs

	N	Minimum	Maximum	Mean	Std. Dev.	P
ExVolLeftLung	18	2820,37	4557,49	3570,37	460,40	
InVolLeftLung	18	5639,13	8139,68	6362,05	669,88	0,00
ExVolRightLung	18	3091,22	4474,41	3978,14	420,13	
InVolRightLung	18	6233,17	8409,38	6930,05	617,21	0,00

In lung volumes obtained from stereological calculation, it was found that mean of left lobe volume was 3570,37±460,40 cm^3 in expiration and 6362,05±669,88 cm^3 in inspiration. This difference between expiration and inspiration was found statistically significant ($p < 0,05$). Difference in volume of the right lung lobe was found statistically significant as in the left lobe ($p < 0,05$).

Volume Fraction

Table 7: Volume Fraction of Lung Lobes in Expiration (%)

	N	Minimum	Maximum	Mean	Std. Dev.
Upper Left Ratio	18	17,46	23,61	20,82	2,14
Lower Left Ratio	18	21,95	30,39	26,36	2,77
Left Lung	18	44,29	51,77	47,18	2,18
Upper Right Ratio	18	14,65	21,80	18,20	2,86
Lower Right Ratio	18	29,41	37,91	34,54	2,60
Right Lung	18	48,23	55,71	52,75	2,13

The fraction of Upper and Lower left lobes to total lung volume in expiration were found 20,82±2,14 % and 26,36±2,17 %, respectively. The Fraction of Upper and Lower right lobes to total lung in expiration were detected 18,20±2,86 % and 34,54±2,60 %, respectively. When looked at the fraction of the right and left total lobes to total lung volume in expiration, mean of left and right lobe volume fraction were detected as 47,18±2,18 % and 52,75±2,13 %, respectively.

Table 8: Volume Fraction of Lung Lobes in Inspiration (%)

	N	Minimum	Maximum	Mean	Std. Dev.
Upper Left Ratio	18	19,74	23,29	21,42	1,37
Lower Left Ratio	18	24,46	29,35	26,42	1,53
Left Lung	18	44,65	49,20	47,85	1,10
Upper Right Ratio	18	14,45	21,79	18,13	2,47
Lower Right Ratio	18	30,52	36,34	34,03	2,04
Right Lung	18	50,80	55,35	52,15	1,09

The mean of fraction of Upper and Lower left lobes to total lung volume in inspiration were calculated as 21,42±1,37 % and 26,42±1,53 % of the subjects participated in this study, respectively. According to the fraction of volumes, the mean volume fraction of Upper and Lower right lobes in inspiration were detected 18,13±2,47 % and 34,03±2,04 %, respectively. Mean of left and right lobe volume fraction to total lung volume were calculated as 47,85±1,10 % and 52,16±1,09 % in inspiration, respectively.

Expansion Ratios:

Table 9: Expansion Ratios of Lung Lobes

	Minimum	Maximum	Mean Dif. (cm^3)	Mean	Std. Deviation	P
Upper Left	60,81	172,99	1260,79	83,76	32,49	0,024
Lower Left	64,41	135,07	1530,89	78,10	16,35	0,031
UpperRight	47,07	106,46	1031,6	76,90	15,21	0,888
Lower Right	52,99	118,23	1920,32	75,59	25,24	0,293

The difference between inspiratory and expiratory volumes was recorded as expansion ratio in per cent. Accordingly, the mean expansion ratio of Upper and Lower left lobes were found as 83,76±32,49 % and 78,10±16,35 %, respectively. In the right lobe, the expansion ratio of Upper and Lower lobes were obtained as 76,90±15,21 % and 75,59±25,24 % as results, respectively.

Table 10: Expansion Ratios of Lung (%)

	Minimum	Maximum	Mean Dif. (cm^3)	Mean	Std. Deviation	P
Right Lung	55,27	107,54	2951,91	75,53	19,24	
Left Lung	66,88	111,79	2791,68	79,31	15,13	0,145
Total Lung	61,10	108,87	5738,95	78,00	16,18	

Expansion ratio values between right and left lungs of swimmers participated in the study were not found statistically significant ($p > 0.05$).

Discussion:

With research, training programs applied regularly were detected to have positive effect on respiratory, circulatory and blood parameters physiologically. Lung volumes and capacities of athletes has been a subject of curiosity for scientists and respiratory measurements were made (Somal, M.S., *et al*. 1998). Swimming is a sport with which almost all the muscle groups run actively. Therefore, benefit of muscles from O_2 was at the highest level in swimmers. The current state of lung function has an important role in the performance of swimmers (Katch, V.L., *et al*., 2000; Kesavachandran, C., *et al*., 2001; De, A.K., 1979).

According to respiratory parameters emerged in our study, vital capacity and mean of percentage values were found 5,62±0,69 lt and 108,27±15,69 %, respectively. As a result of FVC measurements, it was detected that FVC was 5,53±0,61 lt, its percentage value was 106,94±8,30, FEV_1 was 4,65±0,63 lt, mean of FEV percentage was 106,38±10,87 and FEV_1 / FVC was 85,77±6,90. Finally, PEF (9.20 ± 1.45 - 98.22 ± 13.42%) and MVV (193.61 ± 13.52 to 141.88 ± 29.72) values were measured. When researches on swimmers are examined, respiratory parameters emerged in our study shows close to those on these researches (Armour, J., *et al*., 1993; Başbuğ, G., 2004; Bonnier, M.N., *et al*., 2007; Mckay, E.E., *et al*., 1983; Pedersen, L., *et al*., 2008).

Today, it is observed that Cavalieri Principle, an objective method of volume calculation, is frequently applied on images obtained by radiologic studies in clinical practices (Ochs, M., 2006 Ochs, M., 2006; Roberts, N., *et al*., 2000; Yan, X., *et al*., 2003; Markowitz, Z., *et al*., 2005; Canan, S., *et al*., 2002). Chest X-ray and HRCT methods were compared in order to ensure proper image on tissues not united like lung (162). It was seen in many literatures that images obtained by HRCT would be useful to reach sharper results in imaging the total lung clearly and assessments of common lung diseases (Başoğlu, A., *et al*., 2007; Angus, G.E., W.M. Thurlbeck, 1972; Hsia, C.C.W., 2006; Jong, P.A., *et al*., 2003; Sajjad, Z., 2008).

Results emerged in measurements that we done in line of these information were presented in tables. Images were taken and volumes were calculated of each lobes of the lung, two left lobes and two right lobes, in inspiration and expiration

The means of the total lung volume of the swimmers during expiration and inspiration were calculated as 7508.15 cm3 and 13292.11 cm3, respectively. The results obtained are important because there is no possibility to compare with another literature or branch. However, as it is known, lung volume values of swimmers are larger than other branches and thus, we can say their lung volumes could be larger also. As we know, swimming is an important resistance sport that it is based on aerobic metabolism and anaerobic metabolisms takes role intensely. We think that the lungs are provided to be larger due to the fact that the starting age for sport is early, they are exposed to a pressure like water in their trainings and respiratory system organs work as a whole.

The average volume ratio of left and right lungs to total lung volume were found as 47,18 % and 52,75 %, respectively. In expiration, left lobe was seen smaller than right lobe in the lung. It can be said that formation of left lobe from three structures can be factor in the occurrence of this difference.

Results emerged with the calculations of lung volume and volume ratios couldn’t compare due to the fact that there was no similar studies in the present literature that we can search. Because the studies in the literature covered comparison of two different imaging methods or study results of patients having health problems (COPD - cancer - tumor, etc.) in their lungs (Markowitz, Z., *et al*., 2005; Rami, M., *et al*., 2012; Ochs, M., *et al*., 2004). We think that our study done upon this will take place in the literature as the first study carried out on calculation of lung volumes of the athletes by stereological methods.

Stereological methods were often used to calculate volumes of muscle tissue in athletes. Sağlam (2003) calculated the volume of m. quadriceps femoris in 19 professional soccer players on CT images using the method of Cavalieri in his study and calculating the volume of the quadriceps femoris, Kabadayı (2005) calculated m. Triceps brachii muscle volume in basketball and soccer players with and without active disabilities by stereological methods (Sağlam, E., 2003; Ghanbarzadeh, M., *et al*., 2012; Kabadayı, M., 2005).

In our study, it can be considered that this information can be used as a tool for selection of talented athletes for endurance performance and also for the assessment of general health status of the athletes at the beginning of training periods in case the results obtained are supported by new studies.

It was concluded that the lung volume can be calculated accurately and effectively using the principle of Cavalieri on HRCT images with this study. It is thought that it would be possible to be able to monitor changes in the volume of each lobe in the lung with the help of proposed method.

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