日本人体育専攻男子大学生における身体計測値からの 肺残気量予測式の検討

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Examination of anthropometric measurements for estimations of
pulmonary residual volume among physical education major Japanese college male students

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抄 録

水中体重計量法により身体密度から体脂肪量を推定する際に用いられる肺残気量(RV)を身体各部の計測値から予測するための重回帰式の作成を試みた。被験者は、比較的身体トレーニングレベルの高い順天堂大学体育学部男子学生40名(年齢18—26歳)である。9種類の形態計測値, RV実測値, 肺活量(VC)が, それぞれの被験者ごとに求められた。Wherry-Doolittle test selection methodにより, RV予測に貢献する項目の選択と, それらによる重回帰式を検討した。その結果, 以下の3種類の式を作成した。

(1) $RV = 35.451(X1) - 37.870(X2) + 8.344(X5) + 6.142(X10) - 6029.4$ ($R = 0.533$, $SEE = 231.0\text{ml}$)

(2) $RV = 34.986(X1) - 31.544(X2) + 10.228(X5) - 4476.5$ ($R = 0.491$, $SEE = 237.8\text{ml}$)

(3) $RV = 25.073(X1) - 12.393(X2) - 2146.5$ ($R = 0.370$, $SEE = 253.6\text{ml}$)

ただし, RV: 予測される肺残気量(ml), X1: 身長(cm), X2: 体重(kg), X5: 胸厚(mm), X10:

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首囲 (mm).

これらの回帰式による RV の予測能力は必ずしも高いとは言えない。しかしながら, RV の実測値を得ないで体脂肪推定が行われる場面において, しばしば便宜的に用いられてきた RV 推測値(肺活量の割合や単なる一定値)の利用の不確かさに比較すれば, 予測の誤差平均と誤差分散を約30%小さくすることが認められた。

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Abstract

The purpose of the present study was to derive several regression equations based on anthropometric measurements to estimate pulmonary residual volume (RV) and to ascertain their applicability in the calculation of body density (BD). Subjects were forty male physical education major students (18—26 years old). Nine anthropometric measurements, actual RV, vital capacity (VC), and BD using the conventional underwater weighing method were made on each subject. Four measurements (height, weight, chest width, and neck circumference) were selected by Wherry-Doolittle test selection method. The formulas using these measurements were as follows;

- (1) $RV = 35.451 (X1) - 37.870 (X2) + 8.344 (X5) + 6.142 (X10) - 6029.4$ (R=0.533, SEE=231.0 ml)
- (2) $RV = 34.986 (X1) - 31.544 (X2) + 10.228 (X5) + 4476.5$ (R=0.491, SEE=237.8 ml)
- (3) $RV = 25.073 (X1) - 12.393 (X2) - 2146.5$ (R=0.370, SEE=253.6 ml)

Where RV: predicted RV (ml), X1: height (cm), X2: weight (kg), X5: chest width (mm), and X10: neck circumference (mm).

Mean absolute differences between BDs obtained by using the actual and the predicted RVs were 0.00309g/cm³ (using above formula (1)), 0.00488 g/cm³ (a value of 24% of VC), and 0.00417 g/cm³ (a constant of 1300 ml), respectively.

It was suggested that the extent of the potential error to predict RV from anthropometric measurements could be reduced as compared with the other easy predictions such as fractions of VC or a constant of 1300 ml.

Introduction

Body density (BD) of humans has been measured using an underwater weighing technique based on the Archimedean principle to evaluate percentage of body fat. In this type of research, pulmonary residual volume (RV) must be measured to remove its buoyancy when the BD is calculated. Although several methods to measure the RV have been developed, they require special knowledge, techniques, and devices. Furthermore, these conditions are not always satisfactory anywhere. Therefore, a simplified estimation of 24% of the vital capacity (VC) or a constant value of 1300 ml for adult male have been used to calculate the BD occasionally (Wilmore¹⁵⁾). Considering a large individual variation of the RV (Behnke and Wilmore²¹⁾) and a poor relation between the VC and the RV (Wilmore and Behnke¹⁶⁾), the validity of the calculated BD using these simplified estimations must be questionable. Developing new methods to estimate the RV more simply and more accurately are desired accordingly. Several regression equations to predict RV from only height and age have been reported. However, there were scarcely any attempt to increase accuracy of prediction using several anthropometric measurements in the regression equations.

Table 1. Means(M) and standard deviations(SD) of the measurements, and the correlation coefficients(r) between various anthropometric measurements and the actual residual volume (RV). It is noted that the correlation coefficient between VC and the actual RV indicated an extremely low value.

		r	M	SD
Actual RV	(ml)	—	1384.0	273.0
Height	(cm)	.333*	174.6	6.3
Weight	(kg)	.100	68.3	7.2
Vital capacity	(ml)	.137	5119.0	649.6
Chest diameter	(mm)	.124	282.8	16.8
Chest width	(mm)	.188	186.5	13.5
Bideltoid diameter	(mm)	.124	462.9	15.1
Biacromial diameter	(mm)	.047	414.2	15.0
Neck circumference	(mm)	.268	367.2	15.0
Shoulder circumference	(mm)	-.034	1129.2	55.5
Chest circumference	(mm)	.190	911.4	42.2

* $p < 0.05$

The purpose of the present study was to derive the several regression equations based on anthropometric measurements to estimate the RV and to ascertain their applicability for calculations of the BD. The extent of the potential error inherent in using the constant average value, the fraction of the VC, and the predicted RV using regression equations in the present study were evaluated.

Methods

Subjects

Subjects were 40 male physical education major students of Juntendo University, ranging in age from 18 to 26 years. They had performed about one hour of physical fitness training five days per week which included jogging, sprint and weight training. The physical characteristics of these subjects are shown in Table 1.

Procedures

1) Vital capacity and residual volume measurements

Vital capacities were determined by use of a Collins 9-liter spirometer according to the procedures outlined by Kory et al.¹⁰⁾ Residual volumes were determined out of the water by the closed circuit, helium dilution method modified from Meneely et al.¹¹⁾ Although RV and underwater weighing determinations were administered separately, the same postural positions (sitting) were used for both (Pollock et al.¹⁴⁾).

2) Anthropometric measurements

Nine measurements including weight and height which were thought to have some relations to RV were measured. Four testers who were sufficiently trained prior to the present study, performed all of the anthropometric measurements. Two independent anthropometric measurements were taken for each

subject. Whenever the difference between the two independent measurements for any one site exceeded 1% of the initial value, a third measurement was taken. A mean of the two measurements was accepted as the representative value for each site. When a third measurement was necessary, the mean of the two closest measurements was accepted as the representative value (Wilmore and Behnke¹⁷⁾). Height was measured with the subject standing to the nearest 1 mm. Circumferences were measured with a cloth tape to the nearest 1 mm. Diameters and widths were measured with a sliding scale to the nearest 1 mm.

The anatomical landmarks for the selected sites were almost the same as those used by Behnke¹⁾ and Wilmore and Behnke¹⁷⁾.

- a) Chest diameter: at the fifth to sixth ribs, at arm abducted about 45 degrees to vertical axis.
- b) Chest width: Nipple line at mid-tidal volume.
- c) Bideloid diameter: Distance between the outermost protrusions of the shoulder with the anthropometer making only light contact with the skin.
- d) Biacromial diameter: Distance between the most lateral projections of the acromial processes with the elbows next to the body and the hands resting on the thighs.
- e) Neck circumference: Just inferior to the larynx.
- f) Shoulder circumference: Laterally, at the maximal protrusion of the deltoid muscles and anteriorly, at the articular prominence of the sternum and second rib.
- g) Chest circumference: Nipple line at mid-tidal volume.

3) Underwater weighings

Body density was obtained for each subject by the underwater weighing method. The underwater weighings were conducted in a circular tank (120 cm in diameter, 150 cm in height). Underwater weight of each subject was derived by means of transducer (KYOWA, LU-10KE) connected by a steel wire to a metal cradle. The transducer output was amplified by a strain amplifier (KYOWA, DPM-602B) and recorded on a penoscilloscope. A minimum of ten consecutive determinations was performed for each subject. The selection of the representative underwater weight was made according to the method by Wilmore and Behnke¹⁷⁾.

Data analysis

Body density and percent of body fat were calculated for each subject by each of four different approaches, using: 1) the actually measured RV (actual RV); 2) estimated RVs using the regression equations in the present study; 3) a fraction of VC to estimate the RV (24% of VC); and 4) a constant assumed average value (1300 ml) (Wilmore¹⁵⁾).

Considering Buskirk's proposition (Buskirk⁵⁾), the gastrointestinal gas was considered to be a volume of 100 ml to calculate the BD. The revised formula of Brožek et al.⁴⁾ was used to compute percent fat from the BD.

Results

Relationships between residual volume and anthropometric measurements

A selection of items which contribute to estimate the RV and derivations of the multiple regression equations from anthropometric measurements were made using Wherry-Doolittle test selection method (Clarke and Clarke⁷⁾). This method provides a process for solving the problem of variable selection. This method allows to select the variables in order of their importance; multiple correlation coefficients are computed cumulatively after each variable is added to the equation. When the multiple correlation

coefficients fail to increase appreciably, the process stops. After the multiple correlation is completed, the process may be continued to compute a multiple regression equation.

Intercorrelations of ten measurements and the actual RV were calculated. The criterion was the actual RV, and mean and standard deviation (SD) of these measurements were 1384.6 ml and 273 ml respectively. Table 1 shows the means and SDs of the measurements and the correlation coefficients(r) between the actual RV and the other measurements. No measurements except height ($r=0.333$, $p<0.05$) were found to have significant correlation with the actual RV. It is noted that the correlation coefficient between VC and the actual RV indicated an extremely low value ($r=0.137$). Four measurements (Height, Weight, Chest width and Neck circumference) were selected by Wherry-Doolittle method. Multiple regression equations using these measurements were as follows;

$$RV=35.451 (X1) - 37.870 (X2) + 8.344 (X5) + 6.142 (X10) - 6029.4 \quad (R=0.533, SEE=231.0 \text{ ml}) \dots (1)$$

$$RV=34.986 (X1) - 31.544 (X2) + 10.228 (X5) - 4476.5 \quad (R=0.491, SEE=237.8 \text{ ml}) \dots (2)$$

$$RV=25.073 (X1) - 12.393 (X2) - 2146.5 \quad (R=0.370, SEE=253.6 \text{ ml}) \dots (3)$$

where RV: predicted RV (ml), X1: height (cm), X2: weight (kg), X5: chest width (mm), X10: neck circumference (mm), R: multiple correlation coefficient, and SEE: standard error of estimation.

Differences between actual and predicted residual volumes

Figure 1 shows the histograms of the difference between the actual and the predicted RV when using the formula (1) (A) and (2) (B), a fraction of VC (VC 24%) (C), and a constant (1300 ml) (D), respectively. When the predicted RVs were obtained by using the regression equations, the mean absolute differences

Fig. 1 Histogram of predicted residual volume (RV) difference from actual RV. Predicted RVs were obtained by using four anthropometric measurements (A), three measurements (B), a fraction of vital capacity (24% of VC) (C), and a constant of 1300 ml (D).

between the actual and the predicted RVs were 177.5 ± 130.0 ml (formula (1)) and 182.2 ± 143.1 ml (formula (2)). Meanwhile, when using the fraction of VC and the constant, the mean absolute differences were 282.8 ± 177.6 ml (VC 24%) and 242.0 ± 152.0 ml (the constant of 1300 ml), respectively. Therefore, in the present study it was indicated that the mean differences between the actual and the predicted RVs using the formula (1) were reduced to 63% of those found by using the value of 24% of the VC.

Comparison of body densities obtained by using actual and several predicted residual volumes

The extent of the potential error inherent in using the several predicted RVs was confirmed as described above. Subsequently, when these predicted RVs were used to calculate the BD, the effects of these potential errors to calculate the BD by underwater weighing method were studied. Mean and SD of the BD obtained by using the actual RV (actual BD) were 1.08223 g/cm^3 and 0.00931 g/cm^3 , respectively.

Figure 2 shows relations between the BDs obtained by using the actual RVs (abscissa; actual BD) and the predicted RVs (ordinate; predicted BD). The predicted RVs were obtained as follows; derived from formula (1) (A), using formula (2) (B), 24% of the VC (C), and the constant of 1300 ml (D). Correlation

Fig. 2 Relationships between body densities (BDs) obtained by using actual RV (abscissa) and predicted RV (ordinate). RVs were predicted as follows; derived from regression equation using four anthropometric measurements (A), using three measurements (B), 24% of VC (C), and the constant of 1300 ml (D).

Table 2. Mean absolute differences and ranges of difference between BDs obtained by using the actual and the predicted RVs.

Prediction	Mean absolute difference	Difference range	
		max	min
Formula 1)	0.00309	0.00926	0.00024
Formula 2)	0.00371	0.02045	0.00001
24% of VC	0.00488	0.01293	0.00380
Constant of 1300 ml	0.00417	0.01055	0.00089

coefficients between the actual and predicted BDs were 0.915 (A), 0.907 (B), 0.846 (C), and 0.873 (D), respectively. Mean absolute differences and ranges of deviation from the actual BD indicated in Fig. 2 were shown in Table 2. As a matter of course, when using the formula derived in the present study the extent of the potential error was reduced largely as compared with the other predictions.

Discussion

Validity of the device measuring RV which was using the closed circuit helium dilution method used in the present study have been examined. Meneely et al.¹¹⁾ reported that the reproducibility or objectivity was so high that the mean difference was 1.4% and standard error was 0.08% when measuring the dead space. The authors of the present study also examined the reproducibility and objectivity of this device (Yoshigi et al.¹⁸⁾). In consequence, the objectivity of the device was so high that the mean difference was less than 1.87% when measuring the dead space. And repeated measurements of the RV for five subjects indicated only slight variations of measurements in each subject. Namely, coefficient of variance was 4—5% on the average (Nigorikawa et al.¹²⁾).

The maximal expiration required the lung volume to RV can profoundly affected by many factors such as posture, fatigue, respiratory resistance, and various external stimuli (Christie⁶⁾; Craig and Ware⁸⁾; Girandola et al.⁹⁾). It is suggested that the RV would be influenced by factors due to the uncertainty of voluntary activities. Therefore, in the present study, the experiments were performed under fully controlled conditions to minimize the influence of these factors on the measurements. Moreover, well trained subjects who could exhale fully under any condition were used.

The measurements of RV require special knowleges, techniques and devices. Moreover, these conditions are not always prepared. Therefore, attempts have been made to develop methods to estimate the RV more simply and more accurately. One of those methods commonly in use is to estimate the RV from the easily obtained measure of the VC. Namely, a fraction of the VC has been used instead of using RV which was actually measured. Generally the fraction is estimated by using 24% of the VC for males and 28% for the females (Wilmore¹⁵⁾). However, poor relations between the RV and the VC of the same subject have been reported (Wilmore and Behnke¹⁶⁾; Yoshigi et al.¹⁸⁾). Therefore, the validity of the calculated BD using simplified estimation should be questionable. As shown in Table 1, the correlation coefficient(*r*) between the RV and the VC was 0.137. It was only height that indicated a statistically significant relation to the actual RV (*r*=0.336, *p*<0.05) in the present study. Therefore, it would be suggested that height is the most valied one out of the measurement used in this study when the RV should be estimated from one item.

One of the purposes of the present study was to derive several regression equations based on anthropometric measurements to estimate the RV more accurately than the simplified methods which have been commonly used. As shown in the results, multiple correlation coefficients(R) using the formula (1) and (2) were 0.533 and 0.491 respectively. Therefore, when using the formula (1), mean of the absolute difference between predicted and actual value of RV were reduced about 30%. Furthermore, when these formulas were used to calculate BD, mean absolute differences between BDs obtained by using the actual and the predicted RVs were 0.00309 g/cm³ and 0.00371 g/cm³, respectively. These values were calculated for 1.2% and 1.4% of body fat. On the other hand, the absolute differences using the value of 24% of VC and the constant of 1300 ml were 0.00488 g/cm³ and 0.00417 g/cm³ respectively. When the BD was calculated using the formula (1), the accuracy increased by 0.00179 g/cm³ on the average as compared with using the value of 24% of VC. This increment of accuracy induced the mean value of body fat by only 0.7%. Considering the homogeneous nature of subjects belonging to a physically trained group, this value of 0.7% body fat would be a significant value.

It is well known that the RV varies with such factors as age, sex, and pulmonary disorders. Moreover, the subjects of our experiments possessed the homogeneous nature as described above. Therefore, care should be taken to use the formulas presented in this study.

Anyway, it may be suggested that the extent of the potential error to predict RV from anthropometric measurements could be reduced as compared with the other easy predictions such as fractions of VC or a constant value of 1300 ml.

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