Group Regressions Predicting Oxygen Consumption from Heart Rates in Japanese Male Adults

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Summary The purpose of this paper is to evaluate errors among group regressions predicting oxygen consumption \( (V_o_2) \) by heart rate (HR) method, and to obtain the fittest regression for each respective age groups and possibly a single regression for the entire subject population.

Twenty male adults participated in the study and were divided into three age groups. Body height, weight, surface area (SA), lean body mass (LBM) and body cell mass (BCM) were determined by the standard anthropometry and the measurement of \(^{40}\)K by a whole body (human) counter. At the submaximal work test, \( V_o_2 \) and HR were calculated at 4 to 6 grades of work loads on a bicycle ergometer.

All correlation coefficients of \( V_o_2 \) to HR for groups were over 0.885 \((p<0.001)\), while regression showed differences in slopes and intercepts between age groups. After correction applying indices of body composition and the ratio to resting HR (HRR), correlation coefficients of the old age group became greater, whereas correlation coefficients for the other two groups were almost unchanged when \( V_o_2 \) were corrected by SA, LBM or BCM and related to HR. The age-difference in the group regressions disappeared in the relation between \( V_o_2 \) corrected by LBM and HR. Among ten sets of relation of corrected \( V_o_2 \) and HR (or HRR), only three indicated the age-difference clearly.

These facts suggest the possibility of a single regression for all groups. Tentative regression equation for all the study-subjects showed the highest value of correlation coefficient, 0.936 \((p<0.001)\) in case that \( V_o_2 \) corrected by LBM or BCM was related to HRR.

It was concluded that the group regression should be constructed by adopting HR (for young age groups) or HRR (for old age groups) with the correction of \( V_o_2 \) by SA, LBM or BCM (for both young and old age groups). We can use additionally body weight (for only old age groups); and that a single group regression, covering an age-range up to 50 years old, is possibly applied in the relation between corrected \( V_o_2 \) by LBM or
BCM and HRR, with an error of about 25%.

Key Words  oxygen consumption, heart rate method, body composition indices, ratio to resting heart rate, group regression

The heart rate (HR) method (1) in which HR is related to oxygen consumption \( (V_{O_2}) \) or the rate of energy expenditure has been broadly used in the field survey (2–8) due to advantages for both investigators and subjects (9). This conventional HR method is based on the linearity of \( V_{O_2} \) to HR (10). But the regression equation varies individually, affected by sex, age, physical conditions, or mental and environmental factors (11–14). As a result, separate regressions are required for each subject and/or each type of muscular activity (15–19). On the other hand, the group regression has been claimed as possible (20–24) and attempts have been made to minimize such inter-individual variations in the regression of \( V_{O_2} \) or energy expenditure to HR; correcting \( V_{O_2} \) by body weight or lean body mass (25–28), applying percent of \( V_{O_2\ max} \) (24, 29–32), and adopting the ratio of HR increment to resting HR (16, 33–35). The comparison of errors by correction, however, has not been reported.

This study aimed to examine inter-group differences in the relation of \( V_{O_2} \) to HR for age groups with correction of \( V_{O_2} \) by body composition indices, and to obtain the fittest regression for each age group or all the subjects.

MATERIALS AND METHODS

Submaximal work test on bicycle ergometer. Subjects were divided into three groups according to their age (Group 1, seven male adults aged 40–47; Group 2, seven male adults aged 30–37; Group 3, six male adults aged 22–29). They were tested in autumn in our laboratory, where the room temperature stabilized around 25°C, the relative humidity ranged from 55 to 75%, and wind velocity measured by a thermal anemometer was about 0.1 m/sec without any steady direction of wind. All the subjects were instructed to fast and rest at least 2 hr to minimize effects of specific dynamic action and exercise.

Prior to the test, medical examinations consisting of blood pressure, electrocardiogram, and questionnaire were practiced, and they were judged as healthy. Also practiced was the anthropometry, including the measurement of body height, weight, and skinfold thickness (triceps, subscapular, and supra-iliac) by the method of Weiner and Lourie (36). Total body potassium \( (^{40}K) \) was evaluated in a whole body (human) counter at the University of Tokyo (37).

The submaximal work test was performed on a mechanically braked ergometer (Monark, Verberg, Sweden). After 10 min’s rest on a chair and 4 min’s rest on the ergometer, each subject pedalled the ergometer at a fixed pedalling speed of 50 rpm (timed with a metronome). The starting work load of 0 kpm/min was increased to 300 kpm/min after 4 min’s pedalling. As it requires at least 3 min for the steady
state (38), the work load was increased stepwise every 4 min, usually by 150 kpm, until HR of the subject reached around 150 beats/min. HR was recorded by a conventional electrocardiograph throughout the test including 10 min’s rest period on a chair. As the resting HR value, the HR in the last 2 min of resting on a chair was utilized, since the value was the lowest during the period. Expired air was collected through a low-resistance valve in a Douglas-bag during the last 2 min of each rest and the last 1 min of each work load. The volume was measured with a dry gas meter, and the oxygen and carbon dioxide concentrations were determined with an Expired Gas Monitor 1H21 (Sanei-Sokki, Tokyo, Japan). The pulmonary ventilation and $V_o_2$ were calculated in STPD (standard temperature, standard pressure, and dry).

Indices of body composition.

Body height ($H$ cm)

Body weight ($W$ kg)

Surface area (SA m$^2$): SA was calculated from the standard formula of Fujimoto, i.e.,

$$SA = W^{0.444} \times H^{0.663} \times 0.008883.$$

Lean body mass (LBM kg): LBM was calculated from skinfold thickness, i.e.,

$$LBM = W \times (5.142 - 4.570/D). \quad (39)$$

where,

$$D = \text{body density (g/ml)}$$

$$= 1.0913 - 0.00116 \times \text{(triceps skinfold mm + subscapular skinfold mm)}. \quad (40)$$

This formula was originally constructed for young Japanese male adults aged 20–29 (40). According to age-difference data on potassium content in kg of body weight for Japanese males (41), the value in the 40’s age group was slightly smaller than that in both the 20’s and 30’s age groups in which no difference was observed. Therefore, the estimated LBM value for the present group aged 40’s will be carefully collated with the body cell mass value in the Result section.

Body cell mass (BCM kg): BCM was calculated according to Moore et al. (42), from the amount of $^{40}K$, i.e.,

$$BCM = 8.33 \times ^{40}K \text{ (mmol)/1,000}.$$

RESULTS

Physical characteristics of subjects

Table 1 shows the physical characteristics of subjects by group. Group 3, the youngest group of all, is the biggest in size and has the most active portion of body,
Table 1. Physical characteristics of subjects by group.

| Group | n | Sex | Age (y)  | Height (cm) | Weight (kg) | SA (m²)a | LBM (kg)b | BCM (kg)c |
|-------|---|-----|----------|-------------|-------------|---------|----------|----------|
| 1     | 7 | M   | 43.4 ± 2.3 | 161.2 ± 5.5 | 58.6 ± 6.7 | 1.572 ± 0.087 | 49.5 ± 4.1 | 26.3 ± 2.0 |
|       |   |     |          |             |             |         |          | (84.7 ± 3.6) | (45.2 ± 3.9) |
| 2     | 7 | M   | 32.9 ± 2.9 | 162.3 ± 7.6 | 55.9 ± 5.3 | 1.547 ± 0.107 | 48.9 ± 4.4 | 28.4 ± 3.9 |
|       |   |     |          |             |             |         |          | (87.7 ± 2.6) | (50.9 ± 5.3) |
| 3     | 6 | M   | 26.0 ± 2.3 | 170.9 ± 4.2 | 60.6 ± 6.5 | 1.659 ± 0.105 | 53.3 ± 5.1 | 32.9 ± 3.4 |
|       |   |     |          |             |             |         |          | (88.0 ± 1.6) | (54.5 ± 3.8) |

Figures are mean ± standard deviation. Percent of weight is shown in parenthesis. *Surface area calculated from the standard formula of Fujimoto. b Lean body mass calculated from skinfold thickness. c Body cell mass calculated from the amount of 40K.

Table 2. Correlation coefficients matrix of body indices for all the subjects.

| Weight | -0.172 |
| SAa    | -0.406* |
| LBMb   | -0.374 |
| BCMc   | -0.704*** |
| Age    | 0.846*** |
| Weight | 0.940*** |
| SA     | 0.754*** |
| LBM    | 0.759*** |

*a Surface area, b lean body mass, c body cell mass. * p<0.05, ** p<0.01, *** p<0.001.

Fig. 1. Relation between BCM and LBM by group. Regressions for Group 1 (----), 2 (-----), and 3 (----) are shown. By analysis of covariance (ANACOVA), intercept for Group 1 was significantly different from that for Group 3 or the group in which Groups 2 and 3 were combined.
judged from the ratio of LBM or BCM to weight. Correlation coefficients matrix of body composition indices for all the subjects is presented in Table 2. Age inversely correlated with all the indices, but significant correlation coefficients were found for SA and BCM. Other indices (Weight, SA, LBM, BCM) positively correlated with each other. In regression analyses of BCM to LBM, Group 1 significantly differed from Group 3 or the group in which Groups 2 and 3 were combined on the intercept, but not on the slope (Fig. 1).

Relations of $V_o_2$ and HR

Group regressions of $V_o_2$ to HR were computed for each group (Table 3). All regressions showed high correlation coefficients (all $p<0.001$). Difference of slopes and intercepts were tested by the analysis of covariance (ANACOVA). As shown in Table 3, slope differed between Groups 1 and 2. When comparing the groups with almost identical slope values, a significant difference was detected between Groups 2 and 3 on the intercept value. These facts indicated the difficulty of making a single regression of $V_o_2$ to HR for all the subjects.

In the next analysis, $V_o_2$ and HR were corrected, adopting body composition indices for $V_o_2$ and the ratio to resting HR (HRR) for HR. Thus obtained values of correlation coefficients are shown in Table 4, with coefficients of variation (%) at the mean HR or HRR. In the group regression of $V_o_2$ to HR or HRR, none of the changes of correlation coefficient due to correction of $V_o_2$ by body composition indices was statistically significant. But it should be noted that correlation coefficient for old age group (Group 1) changed from 0.885 to over 0.920 in cases where HRR was applied instead of HR. For the young age group (Group 3), correlation coefficient became greater when $V_o_2$ was corrected by SA, LBM or BCM and related to HR. Group regressions for Group 2 showed almost no change in correlation coefficient, excluding one case in which $V_o_2$ corrected by weight was related to HRR.

Difference among group regressions after correction of $V_o_2$ and HR was compiled in Table 5. Group regressions explicitly differed between age groups in the

| Group | Slope | Difference* | Intercept | Difference* | $r$  |
|-------|-------|-------------|-----------|-------------|-----|
| 1     | 0.141 |             | -0.673    |             | 0.885 |
| 2     | 0.170 | *           | -1.001    | **          | 0.964 |
| 3     | 0.167 |             | -0.837    |             | 0.942 |

*Difference was tested by analysis of covariance (ANACOVA), and the difference of intercept was tested when the slopes did not show statistical significant difference. 
* $p<0.05$, ** $p<0.01$, — not significant.

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Table 4. Correlation coefficients and coefficients of variation in corrected group regressions.

| Y      | X       | Group |
|--------|---------|-------|
|        |         | 1     | 2     | 3     |
| $V_{O_2}$ | HR     | 0.885 | 0.964 | 0.942 |
|        |         | (33.8)| (18.7)| (22.6)|
| $V_{O_2}$/Weight | HR     | 0.867 | 0.956 | 0.937 |
|        |         | (37.2)| (21.1)| (24.9)|
| $V_{O_2}$/SA$^a$ | HR     | 0.872 | 0.960 | 0.943 |
|        |         | (35.9)| (19.7)| (23.1)|
| $V_{O_2}$/LBM$^b$ | HR     | 0.876 | 0.955 | 0.943 |
|        |         | (35.7)| (21.0)| (23.5)|
| $V_{O_2}$/BCM$^c$ | HR     | 0.899 | 0.940 | 0.946 |
|        |         | (32.5)| (24.5)| (22.1)|
| $V_{O_2}$ | HRR$^d$ | 0.924 | 0.950 | 0.948 |
|        |         | (26.9)| (21.3)| (20.9)|
| $V_{O_2}$/Weight | HRR    | 0.935 | 0.967 | 0.922 |
|        |         | (26.6)| (18.4)| (27.5)|
| $V_{O_2}$/SA  | HRR    | 0.920 | 0.961 | 0.939 |
|        |         | (28.7)| (19.6)| (23.8)|
| $V_{O_2}$/LBM  | HRR    | 0.929 | 0.960 | 0.926 |
|        |         | (27.5)| (20.0)| (26.6)|
| $V_{O_2}$/BCM  | HRR    | 0.929 | 0.954 | 0.929 |
|        |         | (27.4)| (21.6)| (26.4)|

Figures in parenthesis indicate coefficient of variation (%) at the mean HR (or HRR).

*Surface area, blean body mass, cbody cell mass, dHR ratio to resting HR.

following cases; $V_{O_2}$ was related to HRR, $V_{O_2}$/Weight was related to HRR, $V_{O_2}$/SA was related to HRR, and $V_{O_2}$/BCM was related to HR. On the contrary, the age-difference disappeared when $V_{O_2}$ was corrected by LBM and related to HR.

Next, regressions for all the subjects were calculated. Figure 2 presents the best correlated regression ($r=0.936$, $p<0.001$), in which $V_{O_2}$ corrected by LBM was related to HRR. Almost the same correlation coefficient was found in the relation of $V_{O_2}$/BCM to HRR (data were not shown as a figure). In both cases, coefficient of variation at the mean HRR (144.5) was 25.7%.

DISCUSSION

Individual differences in the relation of $V_{O_2}$ to HR has been claimed (11–14). But for mass observation of energy expenditure in the field, group regression for the relation is desirable, and the size of errors when using group regression must be known. On the one hand, with the change of R.Q., $V_{O_2}$ cannot be converted into

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Table 5. Difference among corrected group regressions.

| (Y)       | HR (X) Slope | Intercept | HRR (X) Slope | Intercept |
|-----------|--------------|-----------|---------------|-----------|
| $V_{O_2}$ | *            |           | *             |           |
| Group 1   |              |           |               |           |
| Group 2   |              |           |               |           |
| Group 3   |              |           |               |           |
| $V_{O_2}/W^a$ |              |           | **            |           |
| Group 1   |              |           |               |           |
| Group 2   |              |           |               |           |
| Group 3   |              |           |               |           |
| $V_{O_2}/SA^b$ | *           |           | *             |           |
| Group 1   |              |           |               |           |
| Group 2   |              |           |               |           |
| Group 3   |              |           |               |           |
| $V_{O_2}/LBM^c$ |              |           | *             |           |
| Group 1   |              |           |               |           |
| Group 2   |              |           |               |           |
| Group 3   |              |           |               |           |
| $V_{O_2}/BCM^d$ |              |           | *             |           |
| Group 1   |              |           |               |           |
| Group 2   |              |           |               |           |
| Group 3   |              |           |               |           |

* Body weight, $^a$ surface area, $^c$ lean body mass, $^d$ body cell mass. * $p<0.05$, ** $p<0.01$, — not significant. Difference of intercept was tested when the slopes did not show statistical significant difference.

energy expenditure by only multiplying a single coefficient. However, most of the costs of daily activities fall within the range of submaximal work, in which R.Q. is known to be rather stable. In the present study the value of R.Q. fluctuated slightly,
Fig. 2. Relationship between oxygen consumption ($V_{O_2}$) per kg of lean body mass (LBM) per min and the heart rate ratio to resting one (HRR). Solid line, regression equation; broken line, 95% confidence limit at estimation by the equation.

and thus $V_{O_2}$ was judged to be utilized as a substitute for energy expenditure.

Group regressions obtained in this study showed greater correlation coefficients, over 0.885 in any age groups (Table 3). Bradfield et al. (17) studied 22 sedentary young men and calculated energy expenditure from HR, and showed coefficient of variation of energy expenditure at the mean HR (90 beats/min) being 27.6%. This figure is comparable with our results though the coefficients of variation varied among age groups. This may be due to the sample size to some extent, but the large coefficient of variation for old age group indicates that there is a tendency for individual variations in the physiological function becoming larger with aging. The correlation coefficient for Group 1 became greater, accordingly the coefficient of variation decreased, when HRR was used instead of HR (Table 4). However, this result is not in agreement with that by Datta and Ramanathan (34), in which correlation coefficients between $V_{O_2}$ and HR or HRR were 0.88 and 0.70, respectively. The cause of disagreement may be the different method in measuring HR, including resting HR (35). Sato et al. (30) reported that it remained unclarified whether or not, HRR was superior to HR for making group regression, in spite of their previous results showing that the influence of air temperature on HR was
decreased when HRR was applied. In all the group regressions using HR (Table 4), correlation coefficients for Group 1 were far smaller than those for the other two groups, while the values of correlation coefficients were close, though still smaller, to other two groups' values when HRR was used. Thus, HRR seems more useful than HR for group regression, especially for old age groups.

It may not be easily concluded which is the best body composition index for correction of $V_{O_2}$, as the values of correlation coefficients and coefficients of variation were similar for each group in both cases when HR and HRR were used (Table 4). This may have been caused by the fact that body composition indices correlated highly with each other (Table 2), and this problem may be able to be solved by increasing the number of samples. On the other hand, the difference of group regressions (Table 5), which is expected to be caused by the difference of age or those of factors accompanied with age, did not appear when group regressions were made between $V_{O_2}$/LBM and HR. In other words, the relation of $V_{O_2}$ per active portion of body to HR was independent of age. This fact may have assured the superiority of LBM as a correcting factor of $V_{O_2}$ as had been claimed by other researchers (25, 26). The BCM, index of active portion of body as well as LBM, did not significantly diminish the age-difference in the relation between $V_{O_2}$ and HR (Table 5). Berg (4) used BCM in his article, in which the relation of $V_{O_2}$/BCM to HR showed individual differences. No comments were given about the reason why he applied BCM for the correction of $V_{O_2}$ and the cause of the difference, however, that difference may be due to the subjects, children with cerebral palsy. The suitability of applying BCM as a correction of $V_{O_2}$ should be further investigated, because BCM has another problem that the value calculated from the amount of $^{40}$K by the human counter was greater than that calculated from the formula of Burmeister and Bingert (43) about 6.5 kg for our subjects, although those two values were well correlated ($r=0.84$, $p<0.001$). In the field situation, it is not feasible to measure BCM by the human counter, so we could determine the skinfold thickness to estimate LBM, and correct $V_{O_2}$ by LBM to make group regressions. Nevertheless, it is also problematic to estimate LBM from skinfold values, since measuring skinfold involves an error to a considerable extent (44), and the estimation of body density from skinfold values is established only for young adults aged 20-29 as already mentioned. In the present analysis, the relation of BCM and LBM in the old age group was different from that in other age groups (Fig. 1). Thus our feeling is that it continues to be a matter of debate, which is more reliable for correcting $V_{O_2}$ between LBM and BCM.

Finally the error of a single regression between $V_{O_2}$/LBM or BCM and HRR for all the study-subjects was a little smaller than that reported by Bradfield et al. (17). They studied only a group of young males, while our result was obtained from subjects with wide age ranges. This has encouraged us to attain a single group regression by correcting $V_{O_2}$ with body composition indices.

Concerning other factors affecting the relation of $V_{O_2}$ to HR intra-individually, which may cause differences between individuals or groups, studies concerning the
effect of meal and exercise have just begun (45–47). We should examine them further to estimate human energy expenditure for recommending energy intake (48) and for evaluating the fitness of the people (49) as well.

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