Developing Prediction Equation of Maximum Local Muscle Energy Metabolic Rate with Somatometric Indices

Shintaro YOKOYAMA

*Industrial Health Research, Department of Sanitary Engineering, Faculty of Engineering, Hokkaido University,
Sapporo, 060 Japan*

Maximum local energy metabolic rates of seven muscle groups have been attempted to predict with somatometric indices, which are easily measured. The predicted muscle groups were the muscles of the anterior abdominal wall (M_1), the erector spinae muscles (M_2), the muscles of the buttock (M_3), the posterior femoral muscle (M_4), the anterior femoral muscle (M_5), the posterior crural muscle (M_6), and the anterior crural muscle group (M_7). The prediction equations were constructed by using multiple regression technique. Dependent variables were energy metabolic rate Y_i (kcal/h), Y_i per BSA (m^2) and Y_i per LBM (kg) ($i=1, \dots, 7$). Independent variables were length, girth, depth, breadth and volume related to each region over the predicted muscle group.

The prediction equations could be obtained. However the accuracy of those for M_1 and M_2 was rather doubted. Adding skinfold thickness to the independent variables, the prediction equations for M_1 and M_2 were obtained as equation (10) and (11) respectively. The most valid prediction equations for M_3 - M_7 in the present study were equation (5)-(9).

Key words: Prediction Equation; Maximum Local Muscle Energy Metabolic Rate;
Somatometric Indices

INTRODUCTION

Local muscle energy metabolic rate has been determined with simultaneous measurements of total energy metabolic rate and integrated electromyograms since the introduction of the method (Yokoyama, 1980a). There are several reports concerning with the local muscle energy metabolic rates in static postures (Yokoyama, 1980b; Yokoyama, 1982; Yokoyama, Namioka and Ogata, 1982) and in periodic dynamic muscle contractions, that is, several types of human locomotion (Yokoyama, 1984). Maximum local muscle energy metabolic rates of seven muscle groups, the same as those in the present study, has been reported by the author (Yokoyama, 1983a and 1983b). If the ratio of contraction level to that of the maximum voluntary contraction (MVC) is known, maximum energy metabolic rate enables us to predict local energy

metabolic rate. The reports concerning the ratio to MVC have been presented by several authors (Kogi and Hakamada, 1962; Mondo and Scherrer, 1965; Kuroda *et al.*, 1970; Okada *et al.*, 1970; Okada, 1972 and 1975).

Local muscle energy metabolic rate is useful to evaluate physiological load both in different exercising items for a muscle group and in different muscle groups for an exercising item. It is also a valuable piece of information for the study on man and his thermal environmental system, since it affords the main source of heat generation in the human body, which is a fundamental parameter for a human thermoregulation survey. Maximum local muscle energy metabolic rate is also useful to evaluate physical fitness and to research the functional differences of muscle organ.

However, it takes a long time to determine local

muscle energy metabolic rate with the simultaneous measurements of total energy metabolic rate and integrated electromyograms. In a certain combination of exercising and resting items, the above method happened to fail to determine energy metabolic rate (Yokoyama, 1980a). It requires great care of experimental design and procedures. Accordingly, the development of prediction equation of maximum local muscle energy metabolic rate with somatometric indices, which are easily measured, is worth attempting. The purpose of this paper is to construct prediction equations of maximum energy metabolic rate of the seven muscle groups with somatometric indices.

METHODS

The subjects were seventeen Japanese healthy males, ranging in age from 20 to 30 years (mean: 23 yr.). Their physical characteristics related to whole body and skinfold thickness are summarized in Table 1. Body surface area (BSA) was calculated according to the formula of Fujimoto *et al.* (1968).

Skinfold thickness was measured by using Eiken skinfold calipers. Body density was calculated by the formula of Takasaki *et al.* (1979). Body fat percent was estimated by the formula of the Brožek *et al.* (1963). Lean body mass (LBM) was calculated by using body weight and fat percent. The other physical characteristics are shown in Table 2.

Table 1 Mean values, standard deviation (S.D.) and coefficients of variation (C.V.) [—] of somatometric parameters related to whole body and skinfold thickness.

Item	Mean	S.D.	C.V.	Symbol
Stature [cm]	171.0	5.7	0.033	
Weight [kg]	65.0	6.2	0.095	
Body surface area [m ²]	1.713	0.101	0.059	BSA
Skinfold thickness [mm]				
1) Chest	7.3	3.3	0.452	S ₁
2) Iliac	17.2	11.7	0.680	S ₂
3) Abdomen	10.4	6.3	0.605	S ₃
4) Subscapula	11.1	4.0	0.360	S ₄
5) Triceps	8.5	5.7	0.671	S ₅
6) Thigh	6.6	2.0	0.303	S ₆
Body density [g/ml]	1.075	0.012	0.012	
Body fat [%]	10.95	5.06	0.462	
Lean body mass [kg]	57.8	5.7	0.099	LBM

Table 2 Mean values, standard deviation (S.D.) and coefficients of variation (C.V.) [—] of somatometric parameters of length(l), girth(g), depth(d), and breadth(b) related to each muscle group.

Muscle Group	Item	Mean	S.D.	C.V.[—]
1) M. of the Ant. Abdominal Wall	l ₁ ; Length of interasternale to symphision [cm]	32.8	4.6	0.140
	g ₁ ; Girth of waist [cm]	75.3	4.3	0.057
2) Erector Spinae M.	l ₂ ; Length of cervicale to lumbale [cm]	45.3	3.5	0.077
	g ₂ ; Girth of chest [cm]	89.1	4.8	0.054
3) M. of the Buttock	g ₃ ; Girth of buttock [cm]	90.4	3.6	0.040
	d ₁ ; Depth of buttock [cm]	21.6	1.1	0.051
	b ₁ ; Crista iliac breadth [cm]	23.5	1.6	0.068
4) Post. Femoral M.	l ₃ ; Length of iliospinale to tibiale [cm]	49.2	3.0	0.061
5) Ant. Femoral M.	g ₄ ; Girth of thigh (max)[cm]	53.2	2.6	0.049
	g ₅ ; Girth of thigh (min)[cm]	38.4	2.8	0.073
6) Post. Crural M.	l ₄ ; Length of tibiale to sphyron [cm]	35.4	2.4	0.068
7) Ant. Crural M.	g ₆ ; Girth of calf [cm]	36.9	1.3	0.035
	g ₇ ; Girth of ankle [cm]	21.8	0.8	0.037

Maximum local energy metabolic rate in seven muscle groups, which were the muscles of the anterior abdominal wall (M_1), the erector spinae muscles (M_2), the muscles of the buttock (M_3), the posterior femoral muscle (M_4), the anterior femoral muscle (M_5), the posterior crural muscle (M_6) and the anterior crural muscle group (M_7) were determined according to Yokoyama (1983a). Total energy metabolic rates and integrated bipolar surface electromyograms of the seven muscle groups were simultaneously measured during fifteen or sixteen static contraction conditions in each subject. The measurements of the electromyograms were also performed during the maximum voluntary contraction (MVC). Though total energy metabolic rate during an exercising item was three times of that during a resting one, the sum of energy metabolic rates of internal organs during exercising was the same as that during resting (Lehmann, 1953). Janský (1964) reported that when the maximum metabolic rate was generated in the human body, it increased to about ten times of basal metabolic rate (BMR). It was achieved mainly by muscle organs and the sum of metabolic rate except that of muscle increased to only two times of BMR at most. By means of multiple regression analysis it was disclosed that the present muscle groups had a significant effect on the total energy metabolic rate in static postures (Yokoyama, 1976). Therefore under the condition that the metabolic changes are restricted to the above seven muscle groups, the total energy metabolic rate during k th item H_k (kcal/h) can be expressed as equation (1).

$$H_k = M_{k1} + \dots + M_{ki} + \dots + M_{k7} + B_i \quad (1)$$

where M_{ki} : energy metabolic rate in i th muscle group at k th item; B_i : energy metabolic rate in organs other than those in the seven muscle groups (kcal/h). Since B_i was considered to reflect adequately the basal metabolic rate (Yokoyama and Yoshida, 1982; Yokoyama and Ogino, 1983), it would be called quasi-basal metabolic rate. The ratio of contraction level to MVC (p_{ki}) during k th

item in i th muscle group could be determined with electromyograms during all items (m_{ki} ; $k=1, \dots, n$; $i=1, \dots, 7$) and MVC (m_{imax} ; $i=1, \dots, 7$).

$$p_{ki} = m_{ki} / m_{imax} \quad (2)$$

$$M_{ki} = Y_i p_{ki} \quad (3)$$

where Y_i is the maximum energy metabolic rate in i th muscle groups. Therefore equation (1) is rewritten as equation (4).

$$H_k = Y_1 p_{k1} + \dots + Y_i p_{ki} + \dots + Y_7 p_{k7} + B_i \quad (4)$$

The simultaneous equations derived from (4) ($k=1, \dots, n$) are obtained for each subject. By solving the simultaneous equations, Y_i ($i=1, \dots, 7$) and B_i can be determined. The present exercising and resting items are the same as those in the previous reports (Yokoyama, 1983a and 1983b). The solution methods of Y_i and B_i are according to our previous reports (Yokoyama, Namioka and Ogata, 1982; Yokoyama, 1983a and 1983b).

Maximum local muscle energy metabolic rate was attempted to predict with somatometric indices which were related to length, girth, depth, breadth and volume. The prediction equations were constructed by using multiple regression technique. Dependent variables were energy metabolic rate Y_i ($i=1, \dots, 7$) (kcal/h). Furthermore, Y_i per body surface area (BSA) (m^2) (Y_i/BSA) (kcal/ m^2 h) and Y_i per lean body mass (LBM) (kg) (Y_i/LBM) (kcal/kg h) were selected to dependent variables. Independent variables related to length, girth, depth and breadth in each muscle group are shown in Table 2. The independent variable of v of each region of each muscle group was calculated according to the equation with length (l), girth (g) and skinfold thickness (s) as seen in Table 3. The values of v in six muscle groups except M_3 mean imaginary volumes, excluded skin and cutaneous fat when each region is assumed to be cylindrical form. The v_3 for M_3 is not imaginary volume but imaginary cross sectional area excluded skin and cutaneous fat, when the girth of buttock is assumed to be circumference.

The calculation of the multiple regression analysis

Table 3 Mean values, standard deviation (S.D.) and coefficients of variation (C.V.) [—] of independent variables of volume (v) related to each muscle group.

Muscle Group	Item	Mean	S.D.	C.V.
1) M. of the Ant. Abdominal Wall	$v_1 = l_1[g_1/2\pi - (S_3/2)/10]^2$	4,358.03	957.48	0.220
2) Erector Spinae M.	$v_2 = l_2[g_2/2\pi - (S_4/2)/10]^2$	8,498.07	1,610.11	0.189
3) M. of the Buttock	$v_3 = l_3[g_3/2\pi - (S_2/2)/10]^2$	207.44	16.30	0.079
4) Post Femoral M.	$v_4 = l_4[g_4/2\pi - (S_6/2)/10]^2$	66.31	7.26	0.109
5) Ant Femoral M.	$v_5 = l_5[g_5/2\pi - (S_6/2)/10]^2$	33.58	5.54	0.165
6) Post Crural M.	$v_6 = l_6[g_6/2\pi - (S_6/2)/10]^2$	34.56	2.48	0.072
7) Ant Crural M.	$v_7 = l_7[g_7/2\pi - (S_6/2)/10]^2$	12.07	0.87	0.072

is was performed with SPSS (Statistical Package for the Social Science) on HITAC M-200H in Hokkaido Computing Center.

RESULTS

Table 4 summarizes the means, standard deviations and coefficients of variation of the maximum energy metabolic rates of the seven muscle groups in voluntary sustained contraction.

Prediction equation of maximum energy metabolic rate of each muscle group have been attempted to establish by using multiple regression analysis technique. Dependent variables were energy metabolic rate Y_i ($i=1, \dots, 7$) (kcal/h), Y_i per body surface area (BSA) (m^2) (Y_i/BSA) (kcal/ m^2 h) and Y_i per lean body mass (LBM) (kg) (Y_i/LBM) (kcal/kg h). In the first step, the independent variables were selected from length and girth items in six muscle groups except the muscles of the buttock (M_3) and from girth, depth and breadth items in M_3 , seen in Table 2. Table 5 shows a part of the results of the above multiple regression analysis. Almost multiple correlation coefficients (R) in Table 5 were not so high. Especially those of the muscles of the anterior abdominal wall (M_1), the erector spinae muscles (M_2) and the posterior femoral muscle group (M_4) were very low. Among them, the equations for the muscles of the buttock (M_3) and the anterior crural muscle group (M_7), which had fairly high R, are shown as equation (5) and (6), respectively.

Table 4 Mean values, standard deviations (S.D.) [kcal/h] and coefficients of variation (C.V.) [—] of the predicted maximum energy metabolic rate in voluntary sustained contraction.

Muscle Group	No.	Mean [kcal/h]	S.D. [kcal/h]	C.V. [—]
Y_1 ; Ant. M. of the Abdominal wall.	(17)	355.36	232.19	0.653
Y_2 ; M. Erector Spinae	(17)	255.19	187.58	0.735
Y_3 ; M. of the Buttock	(16)	180.76	130.81	0.723
Y_4 ; Post. Femoral M.	(17)	90.40	63.95	0.707
Y_5 ; Ant. Femoral M.	(17)	289.50	185.46	0.641
Y_6 ; Post. Crural M.	(17)	121.28	82.57	0.681
Y_7 ; Ant. Crural M.	(12)	38.58	16.47	0.427

$$Y_3 = -62.86g_3 + 9.16d_1 + 52.54b_1 - 312.65 \quad (R=0.752) \quad (5)$$

$$(Y_7/BSA) = 3.27g_6 - 9.63g_7 + 110.69 \quad (R=0.685) \quad (6)$$

Since equations for the other five muscle groups had lower R, another item v_i ($i=1, \dots, 7$) as shown in Table 3, which was considered to relate to volume of each region over the predicted muscle group, was added to independent variables. The multiple correlation coefficients of prediction equations are summarized in Table 6. Table 6 shows that equations for M_1 and M_2 have low R regardless of the kind of dependent variable. The most valid prediction equations for Y_4 - Y_6 in this study are as follows.

$$(Y_4/LBM) = -0.521_4 - 2.66g_4 + 2.19g_5 + 0.02v_4 - 0.03v_5 + 59.16 \quad (R=0.703) \quad (7)$$

$$Y_5 = -11.471_5 - 52.16g_4 + 149.92g_5 + 0.77v_4$$

Table 5 Comparison of multiple correlation coefficient (R) between equation Y_1 [kcal/h], (Y_1/BSA) [kcal/m²h] and (Y_1/LBM) [kcal/kg h] with length(l), girth(g), depth(d) and breadth(b).

Muscle Group	Y_1 [kcal/h]	(Y_1/BSA) [kcal/m ² h]	(Y_1/LBM) [kcal/kg h]	Independent Variable
1) M. of the Ant. Abdominal Wall	0.309	0.324	0.333	l_1, g_1
2) Erector Spinae M.	0.389	0.357	0.337	l_2
3) M. of the Buttock	0.752	0.754	0.711	g_3, d_1, b_1
4) Post. Femoral M.	0.382	0.369	0.396	l_3, g_4, g_5
5) Ant. Femoral M.	0.519	0.518	0.487	l_3, g_4, g_5
6) Post. Cxuxal M.	0.424	0.440	0.440	l_4, g_6, g_7
7) Ant. Crural M.	0.654	0.685	0.656	g_6, g_7

$$-1.77v_5 - 1706.50 \quad (R=0.594) \quad (8)$$

$$(Y_6/LBM) = 2.491_6 - 3.21g_6 + 13.59g_7 + 0.06v_6 - 0.37v_7 - 178.04 \quad (R=0.617) \quad (9)$$

Table 5 and 6 show that prediction equations for M_1 and M_2 with dependent variables of l , g and v (shown in Table 2 and 3) fail to predict maximum local muscle energy metabolic rate. Y_1 and Y_2 showed to be inversely proportional to skinfold thickness in each region, whereas Y_3 - Y_7 did not always bear linear relationship to skinfold thickness in Table 1. Therefore skinfold thickness S_i ($i=1, \dots, 6$) were added to the dependent variables in the equations for M_1 and M_2 . The results are summarized as follows.

$$(Y_1/LBM) = 2.551_1 + 2.31g_1 - 0.02v_1 - 0.29S_2 - 0.38S_3 - 150.24 \quad (R=0.655) \quad (10)$$

$$Y_2 = 107.861_2 - 100.54g_2 - 0.49v_2 - 51.99S_4 - 8864.94 \quad (R=0.675) \quad (11)$$

DISCUSSION

The sample number and the coefficient of variation of each muscle group in the present study were

Table 6 Comparison of multiple correlation coefficient (R) between equation Y_1 [kcal/h], (Y_1/BSA) [kcal/m²h] and (Y_1/LBM) [kcal/kg h] with length(l), girth(g), depth(d), breadth(b) and volume(v).

Muscle Group	Y_1 [kcal/h]	(Y_1/BSA) [kcal/m ² h]	(Y_1/LBM) [kcal/kg h]	Independent Variable
1) M. of the Ant. Abdominal Wall	0.309	0.324	0.340	l_1, g_1, v_1
2) Erector Spinae M.	0.425	0.394	0.374	l_2, g_2, v_2
3) M. of the Buttock	0.752	0.745	0.711	g_3, d_1, b_1
4) Post. Femoral M.	0.702	0.696	0.703	l_3, g_4, g_5, v_4, v_5
5) Ant. Femoral M.	0.591	0.594	0.568	l_3, g_4, g_5, v_4, v_5
6) Post. Crural M.	0.603	0.613	0.617	l_4, g_6, g_7, v_6, v_7
7) Ant. Crural M.	0.654	0.685	0.659	l_4, g_6, g_7

greater than those in previous reports (Yokoyama, 1983a and 1983b). Therefore the present data in Table 4 were suitable for accomplishment of prediction equation of each maximum muscle energy metabolic rate up to date.

As is evident from Table 5, there were wide variations in accuracy of the prediction equations with length (l) and girth (g). The prediction equations for M_3 and M_7 had higher multiple correlation coefficients (R) than those for the other muscle groups. On the contrary, the values of R for M_1 , M_2 and M_4 were very low. However, that for M_4 with l , g and volume (v), is improved, whereas those for M_1 and M_2 are doubted as seen in Table 6. M_1 and M_2 are superficial muscle groups in whole trunk region, of which volume forms a small percentage of v_1 and v_2 . On the other hand, M_4 is composed of superficial and deep muscles, of which volume comprises a large percentage of v_4 and v_5 together with M_5 . M_6 also accounts for high percentages of v_6 and v_7 . Though R of the equation (Y_6/LBM) with l and g alone was 0.440, R with l , g and v increased to 0.617

as seen in Table 6 and equation (9).

In Table 5 and 6, prediction equations with independent variable of (Y_1/BSA) or (Y_1/LBM), which are widely adopted as normalized indices in whole body energy metabolic rate, did not always have higher multiple correlation coefficient than that of Y_1 . It is considered to constitute a characteristic feature of local muscle energy metabolic rate, which is related to individual muscle organ having a functional difference from each other.

However, the proportions (R^2) in the present prediction equations (5)-(11) were 0.566 at most, which were considered to be of not so high a value. Accordingly, further investigations are necessary for establishment of high accuracy prediction equation. At this time, selecting simple measurable physiological indices to the independent variables becomes a problem of utmost importance.

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