MEASURED VERSUS PREDICTED RESTING METABOLIC RATE IN OBESE AND NON-OBESE CHINESE SINGAPOREAN BOYS AGED 13 TO 15 YEARS

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Introduction

In Singapore, the prevalence of obesity amongst schoolchildren increased from 5.4% in 1980 to 15.1% in 1991 (Ministry of Health, 1993a). The fact that this change occurred over a relatively short period of time suggests that lifestyle factors rather than genes are responsible. The major lifestyle factors influencing obesity are physical activity and diet and recent evidence from the USA and the UK indicates that obesity is more closely related to low levels of energy expenditure than to high levels of energy intake (de Groot, 1995; Prentice and Jebb, 1995).

Daily energy expenditure encompasses three components namely, basal or resting metabolic rate (RMR), the thermic effect of feeding and the energy expended in physical activity. In most individuals RMR accounts for the majority of daily energy expenditure (Poehlman, 1989) suggesting that a low RMR may be a risk factor for future weight gain. This hypothesis has been confirmed in adult American Indians by Ravussin and colleagues (1988). Moreover, Roberts and co-workers (1988) have shown that infants with low metabolic rates at 3 months of age become overweight at 12 months whereas those with higher metabolic rates do not.

In adults, cardiovascular fitness (VO_2max) is positively related to RMR (Poehlman, 1989) and an acute bout of exercise is known to cause a transient increase in RMR (Passmore and Johnson, 1960). These findings suggest that high levels of physical activity will result in high RMR values and vice versa. Taking all of the above factors into consideration it can be speculated that the recent economic development of Singapore has lowered the physical activity levels of Singaporean schoolchildren thus in turn reducing both their energy expenditure in physical activity and their energy expenditure at rest. The overall result of these changes being an increase in the number of obese Singaporean children.

With the above hypothesis in mind the purpose the present study was to compare the RMR of obese and non-obese Chinese Singaporean boys. Additionally, this study sought to assess the agreement between RMR values predicted by 5 commonly used equations and values measured via indirect calorimetry.

Methods

Subjects: thirty-nine Chinese Singaporean boys aged 13 to 15 years were recruited for this study from one secondary school in Singapore. These boys were allocated into either an obese group or a non-obese group based on the following criteria: obese group (n=19), relative weight ≥ 120%, body mass index (BMI) > 25; non-obese group (n=20), relative weight < 120%, BMI < 25. For relative weight the Ministry of Health (1993b) weight for height charts were used which allow for a determination of percentage overweight or underweight based on a child's age, height, gender and ethnic group.

Procedures: written informed consent was obtained from both the children and their parents before the start of the study. Moreover, approval for the study was given by the School of Physical Education (SPE) Human Ethics Committee and the Testing Branch of the Ministry of Education. Prior to the study, all subjects underwent a medical examination to ensure they were free from serious illness and were fit to participate. Following this body composition and RMR were determined in the subjects as described below.

Body composition: subjects' heights were measured using a wall-mounted stadiometer (Holtain, Dyfed, Britain) to the nearest 0.1 cm. Subjects' weights were taken to the nearest 0.01 kg on an electronic weighing scale (Mettler Toledo IDL Plus, Eichfahig, Germany) in socked feet and with minimal clothing. The Quetelet Index ($kg \cdot m^{-2}$) was used as a measure of the BMI. Dual-energy X-ray absorptiometry (DXA) (Lunar DPX-L, software version 1.31, USA) was used to measure each subject's percentage body fat (%fat). Fat mass and lean body mass (LBM) were also derived from the weight and %fat measurements of the subjects. The DXA scans were performed in the Orthopaedic Diagnostic Centre at the National University Hospital.

Resting metabolic rate: this was determined using indirect calorimetry. The boys were told to avoid strenuous exercise in the 2 days prior to the test and to fast for at least 12 hours the night before the test. On the morning of the test, subjects were collected from school at 7.00 am and transported to the SPE laboratory via car. On arriving at the laboratory the boys were asked to sit quietly for at least 15 minutes before any testing began. The RMR was measured using a Sensormedics metabolic cart (Sensormedics 2900Z, USA). This metabolic cart was calibrated prior to each testing session. A half-face mask with a two-way breathing valve (2700, Hans Rudolph Inc., Kansas, USA) was fitted to each subject and connected by respiratory tubes to the metabolic cart. Testing was conducted with the boys in a sitting position for a minimum of 20 minutes or until a steady stage was achieved as indicated by dots on the computer screen attached to the metabolic cart. Oxygen consumption, carbon dioxide production and respiratory exchange ratio were measured and recorded every minute during the test and these values were averaged over the entire steady state measurement period at the end of the test as suggested by Maffeis and colleagues (1995). Finally, the measured RMR was expressed in three units as follows: (a) $kcal \cdot day^{-1}$ (b) $kcal \cdot kg^{-1} \cdot day^{-1}$ (c) $kcal \cdot kgLBM^{-1} \cdot day^{-1}$. RMR was also predicted using five commonly used equations as shown in Table 1.

Table 1: Five commonly used equations for estimating resting metabolic rate (RMR).

Source	Sex	Equation	Age (yrs)
Harris-Benedict (1919)	Male	RMR ($kcal \cdot day^{-1}$) = 66.473 + 5.003 height (cm) + 13.752 weight (kg) - 6.755 age (yrs)	Adult
FAO/WHO/UNU equation 1 (WHO, 1985)	Male	RMR ($kcal \cdot day^{-1}$) = 17.5 weight (kg) + 651	10-18
FAO/WHO/UNU equation 2 (WHO, 1985)	Male	RMR ($kcal \cdot day^{-1}$) = 16.6 weight (kg) + 77 height (m) + 572	10-18
Schofield (1985)	Male	RMR ($MJ \cdot day^{-1}$) = 0.068 weight (kg) + 0.574 height (m) 2.157	10-18
Molnar et al. (1995)	Male	RMR ($KJ \cdot day^{-1}$) = 50.9 weight (kg) + 25.3 height (cm) - 50.3 age (yrs) + 26.9	10-16

FAO = Food and Agriculture Organisation, WHO = World Health Organisation,
UNU = United Nations University

Statistical analysis: these were conducted using the SPSS (Version 6.0). Differences between obese and non-obese subjects were assessed using a t-Test for Independent samples (pooled variance) while Pearson Product Moment correlation was used to examine relationships between variables. Significance was set at the $p < 0.05$ level.

Results

The age, height and weight of the two groups of boys are shown in Table 2. There was no significant difference in the ages of the two groups but the obese boys were significantly taller (by 6.5 cm) and heavier (by 22.8 kg) than the non-obese boys.

Table 2: Age, height and weight for obese and non-obese Chinese Singaporean boys (mean ± SD).

	Obese (n = 19) Weight for Height ≥120; BMI >25	Non-obese (n=20) Weight for Height < 120 BMI <25
Age (yrs)	13.7 ± 0.4	13.5 ± 0.6
Height (cm)	169.8 ± 6.2**	163.3 ± 5.8
Weight (kg)	80.9 ± 8.8**	58.1 ± 6.9

Obese significantly different from non-obese: **$p<0.01$

The body composition variables for the two groups are shown in Table 3. For all variables the values in the obese boys were significantly higher than values in the non-obese boys. The obese boys were 14% fatter than the non-obese boys amounting to an absolute difference of 16.6 kg of fat. The obese boys also had a greater LBM than the non-obese boys (46.7 versus 41.4 kg).

Table 3: Body composition variables for obese and non-obese Chinese Singaporean boys (mean ± SD).

	Obese (n = 19)	Non-obese (n=20)
Relative weight (%)	135.8 ± 9.3**	107.6 ± 7.8
Body fat (%)	37.5 ± 3.8**	23.5 ± 4.5
Fat mass (kg)	29.9 ± 5.6**	13.3 ± 2.9
LBM (kg)	46.7 ± 4.1**	41.4 ± 5.9
BMI ($kg{\cdot}m^{-2}$)	28.0 ± 1.9**	21.7 ± 1.7

Obese significantly different from non-obese: **$p<0.01$

Table 4 shows the RMR values of the two groups of boys expressed in three different ways. The obese boys expended significantly more energy than the non-obese boys when values were expressed in absolute terms ($kcal{\cdot}day^{-1}$) but significantly less energy than the non-obese boys when values were expressed relative to body weight ($kcal{\cdot}kg^{-1}{\cdot}day^{-1}$). When values were expressed relative to LBM ($kcal{\cdot}kgLBM^{-1}{\cdot}day^{-1}$) there were no significant differences between the two groups.

Table 4: Resting metabolic rate (RMR) for obese and non-obese Chinese Singaporean boys (mean ± SD).

	Obese (n = 19)	Non-obese (n=20)
RMR (kcal·day^{-1})	1889.1 ± 308.1**	1528.8 ± 174.1
RMR (kcal·kg^{-1}·day^{-1})	23.4 ± 2.9**	26.5 ± 3.0
RMR (kcal·kgLBM^{-1}·day^{-1})	40.4 ± 4.8	37.4 ± 5.1

Obese significantly different from non-obese: **p<0.01

Table 5 shows correlations between RMR (kcal·day^{-1}) and various body composition variables for the obese and non-obese boys separately and pooled together (n=39). When RMR was correlated with weight, LBM and fat mass for the pooled values of the two groups correlation coefficients of 0.76, 0.63 and 0.68 respectively were found (all significant at p<0.01) indicating modest to high correlations.

Table 5: Pearson Product Moment correlation coefficients between RMR (kcal·day^{-1}) and body composition variables for obese and non-obese Chinese Singaporean boys.

	RMR (kcal·day^{-1})		
	Obese (n=19)	Non-obese (n=20)	Combined (n=39)
Relative weight (%)	0.31	0.54*	0.67**
BMI (kg·m^{-2})	0.45	0.61**	0.71**
Weight (kg)	0.60**	0.57**	0.76**
Fat mass (kg)	0.43	0.37	0.68**
LBM (kg)	0.66**	0.45	0.63**

Significant correlation: *p<0.05; **p<0.01

A comparison between measured values for RMR and values predicted by 5 commonly used equations is shown in Table 6. Student t-Tests revealed that RMR was significantly overestimated by both Food and Agriculture Organisation/World Health Organisation/United Nations University (FAO/WHO/UNU) equations and by Schofield's (1985) equation. The magnitude of this overestimation was approximately 9%. No significant differences were noted between the measured values and those predicted by the Harris-Benedict (1919) equation and the equation of Molnar and colleagues (1995). Correlation coefficients (not shown) between the measured and predicted values for the obese boys and for the non-obese boys ranged from 0.53 to 0.60. Although all of these relationships were significant they indicate only modest correlation.

Table 6: Measured RMR values ($kcal \cdot day^{-1}$) for obese and non-obese Chinese Singaporean boys compared to values predicted via five commonly used equations.

	Obese (n = 19)		Non-obese (n=20)	
	RMR ($kcal \cdot day^{-1}$) Mean ± SD (Range)	% error from measured value	RMR ($kcal \cdot day^{-1}$) Mean ± SD (Range)	% error from measured value
Measured RMR	1889 ± 308 (1409 - 2755)	-	1529 ± 174 (1248 - 1907)	-
Harris-Benedict (1919)	1935 ± 146 (1727 - 2275)	+2.4	1592 ± 118 (1312 - 1749)	+4.1
FAO/WHO/UNU equation 1 (WHO, 1985)	2066 ± 153 (1847 - 2415)	+9.4**	1668 ± 121 (1403 - 1855)	+9.1**
FAO/WHO/UNU equation 2 (WHO, 1985)	2045 ± 148 (1867 - 2386)	+8.3*	1663 ± 118 (1399 - 1841)	+8.8**
Schofield (1985)	2054 ± 149 (1842 - 2395)	+8.8**	1678 ± 118 (1412 - 1854)	+9.8**
Molnar et al. (1995)	1845 ± 138 (1644 - 2165)	-2.3	1533 ± 110 (1267 - 1674)	+0.3

Significantly different from measured value: *$p<0.05$; **$p<0.01$

Discussion

The initial purpose of this study was to compare RMR values between obese and non-obese Chinese Singaporean boys. Based on the research cited earlier (Ravussin et al. 1988; Roberts et al. 1988) obese boys were predicted to have lower RMR values than non-obese boys. The present study shows that this is not necessarily the case and the difference between RMR values depends very much on the units of expression (Table 4). Obese boys have higher RMR values in absolute terms ($kcal \cdot day^{-1}$) but lower RMR values per unit of body mass ($kcal \cdot kg^{-1} \cdot day^{-1}$) and there is no difference between the two groups when values are expressed per unit of LBM ($kcal \cdot kgLBM^{-1} \cdot day^{-1}$). Although at first surprising, these findings can perhaps be explained with reference to the studies of Bandini and colleagues (1990) and Ravussin and co-workers (1988). The former study examined RMR in obese and non-obese adolescents and found that RMR is not reduced in already obese individuals and daily energy expenditure is in fact higher in already obese individuals than it is in non-obese individuals. Moreover, although Ravussin and co-workers (1988) did show a trend for individuals with low RMR values to experience future weight gain they also found that subsequent to weight gain RMR is elevated in these same individuals. Therefore, it may be that the obese boys in the present study follow the same pattern and that obesity development is characterised by a low RMR in the early stages and a normal, or even high, RMR following weight gain.

Correlations between RMR and body composition variables (Table 5) for all 39 subjects pooled together showed that weight was most highly correlated to RMR ($r=0.76$, $p<0.01$) while the correlation between LBM and RMR was moderate ($r=0.63$, $p<0.01$). This finding differs from the studies of Bandini and colleagues (1990) and Molnar and co-workers (1995) both of whom found LBM to be the best predictor of RMR as suggested by Ravussin and Bogardus (1992) in their review on energy expenditure and obesity. The explanation usually given for the high correlation between LBM and RMR is that LBM represents the active body tissue and it is this tissue which directly determines RMR. In the present study, although the correlation between LBM and RMR was lower than that between weight and RMR it was still significant ($p<0.01$). Perhaps the incongruity between the findings of the present study and those of the studies cited above is due to differences in the subject groups i.e. a greater weight range and/or a lower LBM range in the subjects of the present study, either of which would affect the correlations.

The second purpose of this study was to compare measured RMR with values predicted by five commonly used equations. This is an important area of research for the following reasons: 1) RMR assessment forms a major component of obesity related research, 2) it is easier to predict RMR than to measure it directly especially when studies are being conducted with large sample sizes, 3) most RMR equations currently in use have been generated from RMR measurements made under thermoneutral conditions and therefore they may not be valid for use in Singapore and 4) to the authors' knowledge no research has yet been conducted validating RMR equations in obese and non-obese Singaporean children.

Three of the five RMR equations in the present study were found to overestimate RMR (FAO/WHO/UNU equations 1 and 2 and Schofield's (1985) equation). These findings are in line with the trend observed in other studies showing that the RMR of people living in the tropics (e.g. Malaysia, Indonesia, Philippines, India etc.) is lower than that of people living in more temperate climates (for a brief review see Henry and Rees, 1991). Moreover, these findings confirm those of Henry and Rees (1991) that the current FAO/WHO/UNU predictive equations overestimate the RMR of people living in the tropics by 8% since the average overestimation in the present study by these same equations was 9%.

There were no significant differences between measured RMR values and values predicted by either the Harris-Benedict (1919) equation or the equation of Molnar and colleagues (1995). The Harris-Benedict (1919) equation is probably the most widely used equation for estimating energy requirements and although this equation was generated from adult data it is commonly used to estimate RMR in adolescents (Dietz and colleagues, 1991). The equations of Molnar and colleagues (1995) were developed from Hungarian children in whom RMR was also overestimated when the FAO/WHO/UNU equations were used. Comparing the Harris-Benedict (1919) equation with that of Molnar and colleagues (1995) the equation of the latter group appears to be the better predictor of RMR for the subjects in the present study (Table 6).

Conclusion

This study has shown that obese Chinese Singaporean boys have a higher RMR than non-obese Chinese Singaporean boys when values are expressed in absolute terms ($kcal \cdot day^{-1}$) but a lower RMR when values are expressed per unit of body mass ($kcal \cdot kg^{-1} \cdot day^{-1}$). Furthermore, when values are expressed per unit of LBM ($kcal \cdot kgLBM^{-1} \cdot day^{-1}$) there is no significant difference between groups. This confirms the findings of earlier studies in other ethnic groups (e.g. Bandini et al. 1990). This study has also demonstrated that the FAO/WHO/UNU equations for RMR (WHO, 1985) and Schofield's (1985) equation, overestimate RMR in Chinese Singaporean boys by approximately 9%. However, RMR predictions by the recent equation of Molnar and colleagues (1995) were not found to differ significantly from measured values and this equation appears to be the most accurate of those examined here.

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