Energy expenditure and physical activity of obese children: cross-sectional study

肥胖兒童的能量消耗與活動模式：交叉研究

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Objectives. To investigate the total daily energy expenditure and physical activity pattern of a group of obese and non-obese Hong Kong children.
Design. Cross-sectional study.
Settings. University teaching hospital, Hong Kong.
Participants. Eighteen obese children aged 6 to 17 years and 18 age- and sex-matched non-obese children in the local Hong Kong community.
Main outcome measures. Total daily energy expenditure and physical activity pattern were estimated for 3 days using heart rate monitoring. Body composition was measured by dual-energy X-ray absorptiometry.
Results. In obese children, both total fat mass and fat-free mass were greater than in non-obese children. Total daily energy expenditure and its sleep and sedentary components were higher in absolute terms (by 42%, 43%, and 126%, respectively) for obese children. When normalised for body weight, the basal metabolic rate was no different between obese and non-obese children, while the total daily energy expenditure of the obese children was significantly lower (by 22%) than that of non-obese children. When normalised for fat-free mass, the basal metabolic rate and the sedentary component of total daily energy expenditure were significantly higher for obese children. Obese children spent 12% less time asleep, but 51% more time in sedentary activity and 30% less time physically active—a ratio of active-to-sedentary waking time of 0.6 for obese children and 1.9 for non-obese children.
Conclusions. Although the basal metabolic rate may be influenced by body composition, the finding of a normal basal metabolic rate when normalised for body weight suggests that an intrinsic difference of metabolic rate is not a major contributory cause of obesity. The study pointed particularly to the potential benefit of increasing physical exercise time relative to sedentary activities to reduce the prevalence of childhood obesity. Obese and non-obese children had similar basal metabolic rates when adjusted by fat-free mass and fat mass. Obese children spent more time in sedentary activities.

目的：研究香港肥胖和非肥胖兒童每天總能量消耗與活動模式的情況。
設計：交叉研究。
安排：大學教學醫院，香港。
參與者：18名6至17歲香港本地的肥胖兒童，以及18名年齡及性別相配的非肥胖兒童。
主要結果測量：使用心率監測儀評估每天的總能量消耗和活動模式，為期3日。並用雙倍X射線吸收計測量身體組成成份。
結果：肥胖兒童的脂肪組織和無脂肪組織均比非肥胖兒童多。肥胖兒童每天的總能量消耗，及其在睡眠和靜止情況下所消耗的能量均較高(分別為42%、43%和126%)。當數據以體重標準化後，肥胖和非肥胖兒童的基礎新陳代謝率並沒有差別，而肥胖兒童每天的總能量消耗顯著低於非肥胖兒童(差距為22%)。而當數據以無脂肪組織標準化後，基礎新陳代謝率和每天總能量消耗中的靜止比重在肥胖兒童中相當高。此外，肥胖兒童的睡眠時間較非肥胖兒童少12%，靜止時間多51%，而活動時間則少30%。活動與靜止時間相比，肥胖兒童是0.6，而非肥胖兒童是1.9。
結論：雖然基礎新陳代謝率會受到身體組成成分的影響，但經體重標準化的正常基礎新陳代謝率顯示，兒童本身的新陳代謝率並不是引致肥胖的主要原因。本研究特別指出增加運動時間(相對於靜止時間)的比例，對減少兒童肥胖有潛在的好處。經無脂肪組織和脂肪組織調節後，肥胖兒童和非肥胖兒童有相近的基礎新陳代謝率，而肥胖兒童的靜止時間較多。

Key words:
Body composition;
Child;
Energy metabolism;
Exercise;
Obesity

關鍵詞：
身體組成成份；
兒童；
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Introduction

The prevalence of obesity in children and adolescents has been increasing during the past 2 decades in Hong Kong[1] as elsewhere in the developed world. This is likely to reflect changes in both diet and energy expenditure, but the pattern of such changes may differ in different communities and confirmatory data for these issues are sparse. In Hong Kong, living conditions are crowded and opportunities for sport are limited, while the attractions of television and computers, and the consequences of parental academic aspirations for their children contribute to the increase in sedentary activities.

Previous studies have generally, but not always, shown that total daily energy expenditure (TDEE) is greater in absolute terms for obese children than for non-obese children.[2-5] Physical activity, an important component of TDEE, has, however, been reported to be lower or no different for obese children.[4-6] To better understand the daily energy expenditure of Hong Kong children, a study of energy expenditure in relation to daily activities among a group of obese and non-obese children was performed.

Methods

Obese children were recruited from the obesity clinic of the Prince of Wales Hospital in Hong Kong. Obesity was defined as a child's body mass index (BMI) above the age- and sex-specific international cut-off standards on the centile curves, where these BMI centile curves were defined to pass through the widely used cut-off point of 30 kg/m^2 for adult obesity at age 18.[7] This selection is almost identical to using 120% median weight-for-height as the cut-off criterion. Non-obese volunteers, matched for age, sex, and height, were recruited from nearby schools.

Body composition was measured using a high-speed fan beam dual-energy X-ray absorptiometry scanner (QDR 4500 Elite, Hologic, Inc., Waltham, US). Whole body scans (which took approximately 3 minutes) gave total fat mass (FM), lean mass, and bone mineral content.

Energy expenditure was estimated using heart rate (HR) monitoring.[4,8-10] The patient attended approximately 2 hours after a light lunch, and then rested for 20 minutes in quiet relaxing conditions. Heart rate and oxygen consumption (VO_2) were measured simultaneously at rest and during graded exercise to construct an individual HR/VO_2 calibration curve. Heart rate was measured electrocardiographically and VO_2 was measured by a cardiopulmonary exercise function analysis system (Vmax 29 SensorMedics, Yorba Linda, US) using the open-circuit method. Measurements were averaged over the last 3 minutes of each 6-minute stage. Resting stages comprised lying, sitting, and standing, while exercise stages comprised treadmill walking at 3, 4, and 5 km/hour up gradients of 0%, 3%, and 6%, respectively (Fig 1). The lowest VO_2 of the three resting states was used to derive basal metabolic rate (BMR). The mean VO_2 of the three resting states was representative of the 'resting', or sedentary state (VO_2-rest). A HR/VO_2 calibration curve was constructed for each child and was subsequently used to derive VO_2 from HR records during physical activities.

Following the calibration, ambulatory HR was monitored and recorded every waking minute for the 3 days of the study in normal free-living conditions using a HR recording meter (Polar Electro Oy, Kempele, Finland) comprising a wrist receiver and an electrode-belt transmitter, worn throughout the 3 days except when bathing or sleeping. An activity diary was kept by each child during the study.

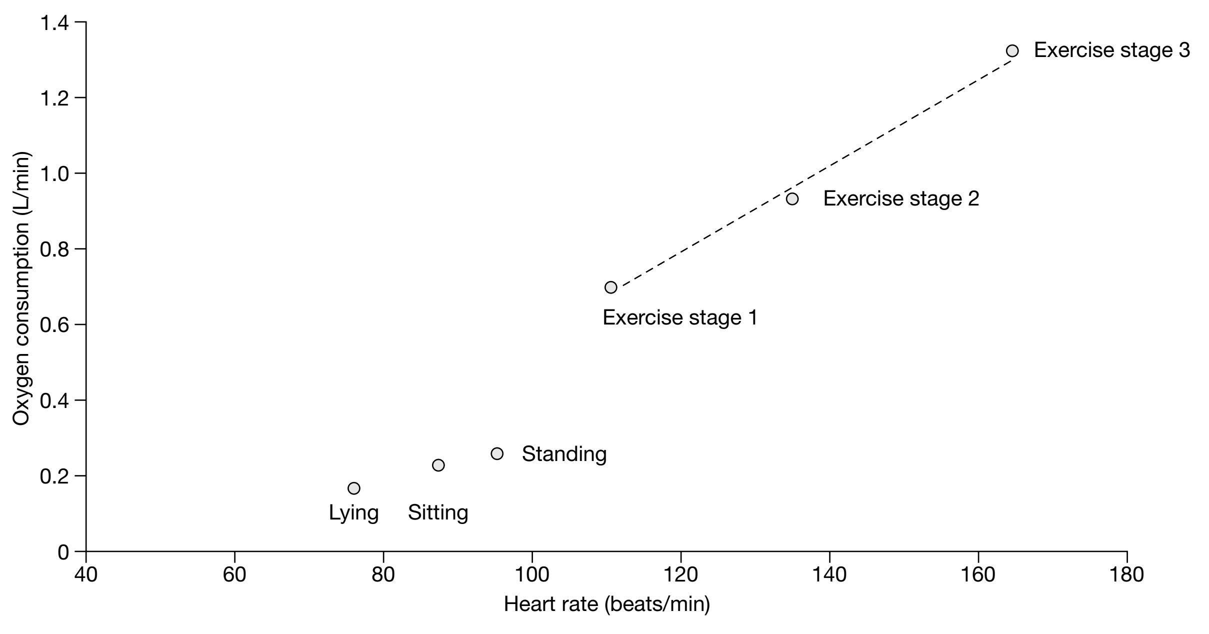

Fig 1. An example of the heart rate relative to oxygen consumption calibration curve for a 14-year-old obese girl

Diary and HR records were used to derive estimates of time and energy expended in sleeping time, in sedentary time, and in physically active time (from the three levels of activity corresponding to the three levels of predetermined HRs during graded exercise). Heart rate was used to distinguish between sedentary time (below ‘Flex HR’) and physically active time (above ‘Flex HR’)—‘Flex HR’ being the mean of the maximum of the predetermined resting state HRs and the minimum of the predetermined exercise HRs.[8] Energy expenditure was derived from VO_2 using the simplified Weir formula (20.48 kJ/L.O_2 consumed).[11] The integrals of the different levels of energy expenditure and time were collated during the 3 days and averaged to give the daily total and the component totals during sleep (EE-sleep), during sedentary activity (EE-rest), and during physical activity (EE-act).

Values are expressed as mean (standard deviation [SD]). Variables were checked for normality before comparing between obese and non-obese children. Due to the skewed distribution of the data, Mann-Whitney test was used to compare groups. The determinants of energy expenditure were assessed by backward stepwise regression model. Data of fat-free mass (FFM), FM, sex, and age were chosen to enter the model.

The study was approved by the Ethics Committee for Clinical Research of the Chinese University of Hong Kong. Informed consent was obtained in writing from a parent or guardian of each child.

Results

Eighteen obese and 18 non-obese children participated in the study. The difference in BMR and TDEE between boys and girls before and after correction for body weight or FFM were compared first. All parameters except BMR per kilogram per day were higher for boys than for girls, but the difference did not attain statistical significance. Thus, it was decided to compare the data between the obese and non-obese groups with the two sexes combined. One third were girls and two thirds were boys in each group. Table 1 shows the physical characteristics of the two groups. The obese children had significantly greater body weight, BMI, total FM, total percentage of fat, total FFM, blood pressure, resting HR, and Flex HR than the non-obese children. The mean HR/VO_2 slope was significantly steeper for the obese children (mean slope [SD], 0.019 [0.006]) than for non-obese children (mean slope [SD], 0.013 [0.006]) [P=0.010]. After correcting for body weight, the mean slope of HR/VO_2 per kilogram of body weight for obese children was similar to that for non-obese children (mean slope [SD], 0.0002 [0.0001] and 0.0003 [0.0001], respectively).

Table 2 shows that BMR, TDEE, EE-rest, and EE-sleep were all significantly higher for the obese children when measured in absolute terms. When normalised for body weight, however, BMR, EE-rest, EE-act, and EE-sleep were similar for the obese and non-obese children, while TDEE was significantly lower for the obese children. Notably, BMR and EE-rest were significantly higher for obese children when normalised for FFM.

Stepwise regression analysis showed that BMR correlated with FFM and FM as independent variables (R^2=79.8%). Basal metabolic rate increased 19.4 kcal/day per kilogram increase in FFM (95% confidence interval [CI], 11.3-27.5), and 14.7 kcal/day per kilogram increase in FM (95% CI, 5.2-24.1). Fat-free mass alone explained 72.5% of the variation in BMR while FM alone explained 62.5% of variation in BMR.

Physical activity, expressed as TDEE relative to BMR (TDEE/BMR) was 1.5 (0.3) in the obese children and 1.8 (0.5) in the non-obese children (P=0.055).

Figure 2 shows the average daily time spent in sleeping, sedentary activities (rest), and non-sedentary (physical) activities. Obese children spent 12% less time asleep, 51% more time in sedentary activities, and 30% less time in physical activity than non-obese children. The ratio of physically active-to-sedentary waking time was 0.6 (0.4) for the obese children compared with 1.9 (2.2) for the non-obese children (P=0.021).

Discussion

Energy expenditure was measured using HR monitoring, with reference to individually predetermined HR/VO_2 relationships. The method has been well validated against

Table 1. Physical characteristics of obese and non-obese children

Physical characteristic	Obese children, n=18 Mean (SD)	Non-obese children, n=18 Mean (SD)	P value
Age (years)	13.4 (2.9)	12.8 (3.2)	NS*
Height (cm)	159.5 (13.4)	156.2 (17.4)	NS
Weight (kg)	85.5 (21.5)	46.7 (15.1)	<0.0005
Body mass index	32.9 (4.3)	18.5 (3.1)	<0.0005
Total fat mass (kg)	33.6 (9.1)	10.6 (4.7)	<0.0005
Total percentage of fat (%)	38.8 (5.2)	23.2 (7.9)	<0.0005
Total fat-free mass (kg)	54.6 (14.0)	37.3 (14.3)	0.002
Systolic blood pressure (mm Hg)	126.1 (13.1)	103.7 (8.4)	<0.0005
Diastolic blood pressure (mm Hg)	75.6 (10.4)	67.5 (9.9)	0.023
Resting heart rate (beats per min)	92.4 (10.2)	83.4 (10.4)	0.014
Flex heart rate	107.8 (10.0)	94.2 (9.5)	<0.0005

* NS not significant

Table 2. Basal metabolic rate, total daily energy expenditure, and sleeping, sedentary, and exercising energy expenditure for obese and non-obese children

	Obese children, n=18 Mean (SD)	Non-obese children, n=18 Mean (SD)	P value
BMR* (kcal/day)	1467 (475)	899 (323)	<0.0005
BMR (kcal/kg/day)	17.1 (3.8)	18.8 (4.6)	NS**
BMR (kcal/kg ffm†/day)	27.5 (6.3)	22.1 (5.1)	0.029
TDEE‡ (kcal/day)	2183 (791)	1540 (528)	0.008
TDEE (kcal/kg/day)	25.5 (6.6)	32.6 (9.0)	0.023
TDEE (kcal/kg ffm/day)	40.3 (10.6)	38.2 (9.1)	NS
EE-rest§ (kcal/day)	612 (265)	271 (149)	<0.0005
EE-rest (kcal/kg/day)	6.9 (1.9)	5.6 (2.7)	NS
EE-rest (kcal/kg ffm/day)	11.1 (3.1)	6.6 (3.1)	<0.0005
EE-act‖ (kcal/day)	966 (579)	845 (462)	NS
EE-act (kcal/kg/day)	11.6 (6.4)	18.4 (10.4)	0.056
EE-act (kcal/kg ffm/day)	17.7 (10.0)	21.5 (11.5)	NS
EE-sleep¶ (kcal/day)	605 (218)	424 (199)	0.015
EE-sleep (kcal/kg/day)	7.0 (2.0)	8.6 (2.7)	NS
EE-sleep (kcal/kg ffm/day)	11.4 (3.3)	10.2 (3.0)	NS

* BMR basal metabolic rate
† ffm fat-free mass
‡ TDEE total daily energy expenditure
§ EE-rest energy expenditure during sedentary activity
‖ EE-act energy expenditure during physical activity
¶ EE-sleep energy expenditure during sleep
** NS not significant

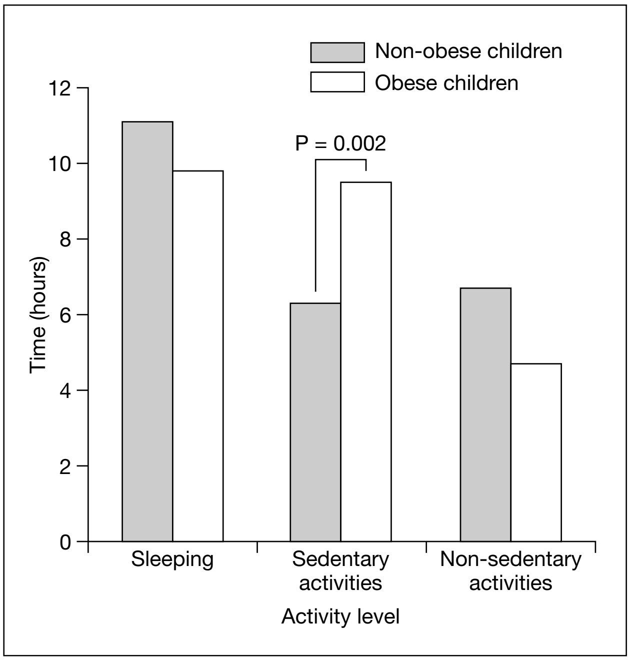

Fig 2. Daily hours spent in different activities

calorimetric[8,9] and doubly-labelled water techniques,[10] and has the advantage of being practically convenient and relatively inexpensive, although it cannot distinguish between physical and emotional contributions to HR. Average daily energy expenditure under normal free-living conditions was calculated from the integral of VO_2 corresponding to monitored HRs as previously related to VO_2 under different resting and exercising conditions.

For practical reasons it was only possible to use afternoon sessions for calibration and the children were therefore not tested for the BMR assessment. Dimmed lights and soft music were used to relax the children during the calibration for resting activities to obtain a VO_2 value close to BMR. Maffeis et al[12] compared BMR and postprandial metabolic rate for obese and non-obese children. These researchers demonstrated that the postprandial metabolic rate was approximately 10% higher than the BMR, due to the meal-induced thermogenesis effect. In this study, the lowest resting VO_2 value during the HR/VO_2 calibration test was used for the calculation of BMR.

Predictably, the obese children had greater body weight, BMI, and total FM than the non-obese children. Their average resting HR was also higher. During the resting states, the lowest average HR was observed in both groups in the lying position. Although both groups had similar HRs in the lying position, obese children had higher average resting HRs when sitting (P=0.01) and standing (P=0.023).

The slope of HR/VO_2 was steeper in obese children than in non-obese children, which indicates that obese children consumed more oxygen for the same workload level than did non-obese children. This can contribute to the larger amount of FFM and FM for obese children. As expected, when VO_2 was corrected for body weight, the slope of HR/VO_2 per kg of body weight for obese children flattened. However, this may also be explained by the difference in body composition. Obese children have a higher percentage of FM and relatively less FFM per kg of body weight than their non-obese counterparts, where FM consumed less oxygen than FFM.

Fat-free mass is well known to correlate with BMR. It was not until recently, however, that FM was also found to consume oxygen and significantly affects BMR.[13,14] Our results support this finding, since after correcting for FFM, the BMR of obese children was still significantly higher than that of non-obese children. This indicates that besides FFM, greater FM in obese children may result in a higher BMR than in non-obese children. From the regression analysis model, FM alone explained 62.5% of variation in BMR. In addition, whole-body protein turnover is an important energy-requiring process which contributes to approximately 20% of BMR.[15] A higher whole-body protein turnover rate has been demonstrated in obese children.[16]

Apart from FFM and FM, it has been reported that boys have a higher BMR than girls.[13,14] It was also found that the absolute BMR and TDEE for obese and non-obese boys, even corrected for body weight or FFM, were higher than those for obese and non-obese girls—although the difference did not attain statistical significance except for BMR per kilogram per day (P=0.027). This could be attributed to the small number of study subjects.

In this study, the pubertal stage of the children was not assessed. Nevertheless, Molnar and Schutz[14] reported that although the absolute value of resting metabolic rate increases as puberty advances, there were no significant changes of BMR normalised for FFM and FM with the advance of puberty.

Conclusions

This study showed that, firstly, obese children had higher BMR and TDEE than non-obese children. After adjustment for FFM and FM, the difference of BMR between obese and non-obese children disappeared. This implies that an inherent difference of metabolic rate may not be an important cause of obesity. Secondly, obese children spent more time in sedentary activities than non-obese children did. Whether the lower activity level for obese children is the cause or the consequence of obesity cannot be elucidated by this cross-sectional study.

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