Metabolic And Mechanical Cost Of Sedentary And Physical Activities In Obese Children And Adolescents

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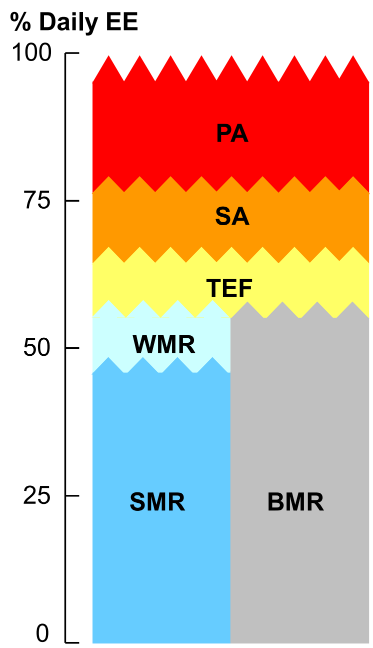
Introduction

Obesity often results from an imbalance between energy intake and energy expenditure. Daily energy intake can be determined both quantitatively and qualitatively. By contrast, estimation of daily energy expenditure in free-living conditions requires qualified personnel and sophisticated technical methods. Daily energy expenditure (EE) can be distributed between a number of interdependent factors including: basal metabolic rate (BMR) extrapolated to a 24-hour period; EE associated with alimentation (thermic effect of food, TEF); growth (in children); healing; thermoregulation (but in developed countries the effects of cold are minimized by adjustment of clothing, housing and heating, (1); and physical activity. In addition, for practical purposes the increase in EE associated with physical activities must be partitioned between sedentary behaviour and actual physical activities (Fig. 1).

Figure 1 : *Main components of daily energy expenditure (EE) (modified from (2)).*



BMR: basal metabolic rate; SMR: sleeping metabolic rate; WMR: wakefulness metabolic rate; TEF: thermic effect of food EE; SA: sedentary activity EE; PA: physical activity EE.

The objectives of this chapter are:
1) to review the influential factors on the main components of daily EE;
2) to investigate the association between mechanical parameters of walking and running gait with the obese and post-obese state in adolescents;
3) to describe the physical activity ratio corresponding to various sedentary behaviours and physical activities for children and adolescents who are obese and finally
4) to suggest methods for estimating daily energy expenditure adolescents who are obese.

Main Components Of Daily Energy Expenditure

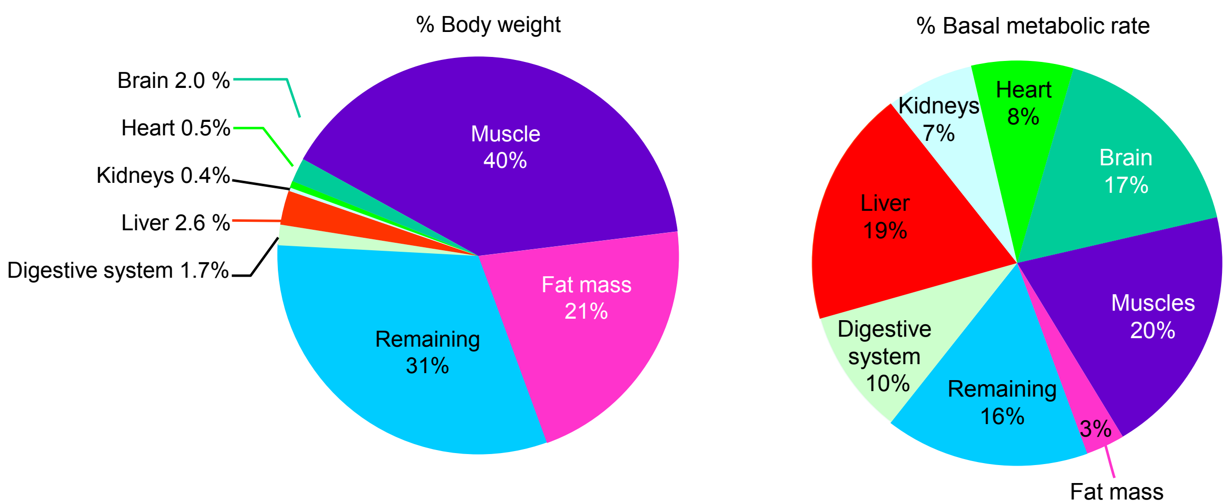
Basal metabolic rate

Basal metabolic rate (BMR) is the energy expended by the body to maintain basic physiologic functions (e.g. cellular activity and organ functions, heartbeat, muscle contraction and function, and respiration) in an individual who is awake. Due to the increased energy demands of the brain and muscle compartments when awake, the BMR is approximately 5% higher than the metabolic rate expended during sleep (the minimum level of energy expended by the body to sustain life).

BMR can be measured after a 12-hour fast while the subject is resting in a thermo-neutral and quiet environment. BMR occurs in a continuous process throughout the 24-hour daily cycle and remains relatively constant within individuals over time. It is the largest component of daily EE since it contributes, on average, 60% to daily EE, ranging from 45-50% in very active subjects to about 70% in sedentary subjects. Therefore, it depends on the mass and metabolic rate (EE · g^{-1} of tissue · min^{-1}) of tissues and organs.

However, the metabolic rate (MR) of tissues and organs is highly variable. For instance, it is about 10, 15, 20, 30, and 35 times higher in the digestive tract, liver, brain, heart, and kidney compared to resting muscle. In contrast the MR in white adipose tissue is only about 1/3 that of resting muscle (3). Consequently, while organs account for about 7% of body weight, they contribute about 60% to BMR, whereas skeletal tissues and adipose tissues account for 35-40% of BW and contribute only 18-22 % and 3-4 % to BMR, respectively (4) (Fig. 2).

Figure 2 : *Contribution of organs and tissues to body weight and basal metabolic rate.*



Due to lack of information on organ mass and metabolic rate in individuals, for practical purposes the main significant determinant of BMR is FFM (R^2 = 0.65-0.80). FM is a significant determinant only in individuals who are obese (R^2 < 0.04) (5)

In absolute values, BMR is higher in individuals who are obese compared to those who are lean due to higher levels of FFM and FM. However, when adjusted for body composition, BMR is not significantly different suggesting that tissue and organ metabolic rate is not significantly different between those who are obese and those who are lean. BMR expressed as per kg of FFM is significantly higher in boys than in girls, by 3% and 6% in prepubertal and pubertal subjects, respectively (6). Higher levels of BMR are observed in pubertal children due to higher proportions of skeletal glycolytic fibers (7), higher Na^+-K^+ ATPase activity (8), and changes in hormonal status (9).

Collectively, FFM, FM, age, gender, and physical activity explain 70-80% of the variance in BMR (10, 11). The remaining 20-30% may be due to genetic factors or other factors such as differences in gut flora metabolism (12).

The ability to predict BMR accurately in persons who are obese is of utmost importance for adequate dietary therapy as it provides the basis to calculate a desired level of energy deficit. The gold-standard method for the measurement of BMR is indirect calorimetry, however its regular use in clinical settings (for both diagnostic and prognostic purposes) is limited due to its complex nature, the lack of skilled staff, and the high cost of equipment. Several authors have tried to address the problem by developing equations for predicting BMR in children and adolescents on the basis of anthropometric and body composition parameters (13, 14).

The equations based on anthropometric parameters [Equation 1] or body composition [Equation 2] allow an accurate estimation of BMR in children and adolescents who are obese (10, 11):

BMR = (Gender x 213) – (Age x 28) + (Body Weight x 13) + (Stature x 434) + 355
R^2 = 0.66 and SE = 246 kcal [Equation 1]
BMR = (Gender x 217) – (Age x 26) + (FFM x 16) + (FM x 13) + 868
R^2 = 0.66 and SE = 247 kcal [Equation 2]

where Gender = 1 for males and 0 for females, BMR is expressed in kcal, Age in years, Body Weight in kg, Stature in m, FFM and FM in kg.

Thermic effect of food

The thermic effect of food includes increases in EE observed during the ingestion and digestion of food. It lasts over an extended period of at least five hours and averages 10% of energy intake. The energy expenditure associated with food ingestion is influenced primarily by the composition of the food consumed and is relatively stable over time within individuals (15). The increase in metabolic rate after food ingestion is lower for lipids and carbohydrates (3 and 5 % of energy intake, respectively, over 3-4 hour periods) than for protein (20-25 %).

Growth

Although children require additional energy for growth, the contribution of growth to total energy needs

is negligible except within the first few months of life. During the growth period energy is stored in the body as protein and lipids (5.5 and 9.5 kcal·g^{-1}, respectively). Assuming a 50-70% efficiency of energy utilization for growth (depending on the proportion of energy stored as lipids) growth would contribute 2 to 4% of daily energy requirements in adolescents despite a major growth spurt (16).
During adolescence, the relative increase in FM is 13 % in girls while the levels in boys decrease by 4 %. Adolescent boys have on average 20 kg more FFM than girls. These changes in body composition explain that EE at rest and during physical activity in boys becomes much higher than in girls at similar total BW.

Healing

Following injury or surgical procedures increased energy and protein are required by the body to support the immune response and repair. The body makes substrates readily available and in turn, resting energy expenditure rises (17).

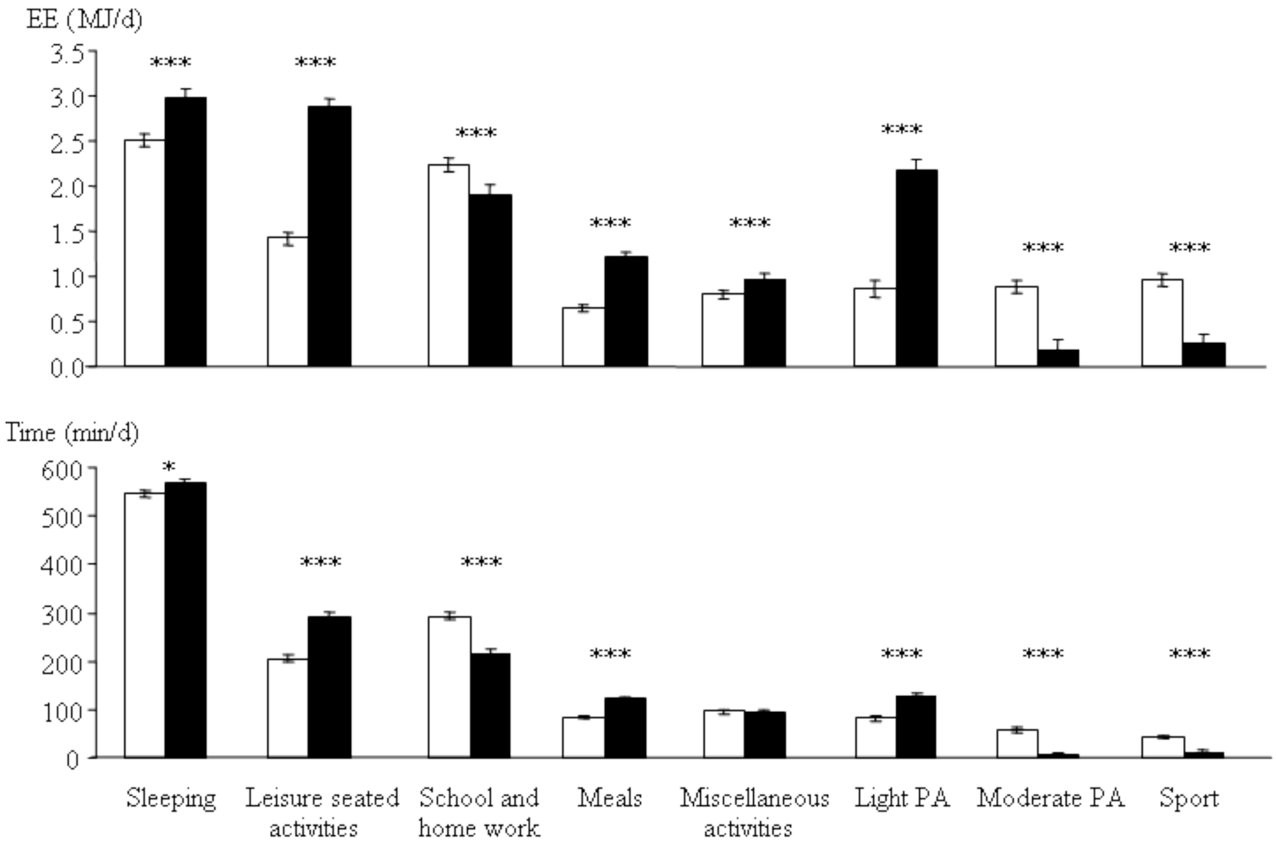
Energy expenditure during sedentary and physical activities

Because of their higher body weight including a greater FFM, children and adolescents who are obese have higher daily EE, BMR and activity energy expenditure compared to non-obese subjects (2). However, obese children are known to spend less time in physical activities and more time in sedentary activities than their age-matched counterparts (18).

Daily EE and energy expenditures associated with usual sedentary and physical activities were assessed in 50 non-obese adolescents, and 27 obese adolescents aged 14.0 ± 0.3 y (2). As expected, BMI, FFM and FM were higher in obese subjects: 34.1 *vs* 18.8 kg·m^{-2}, 52.4 *vs* 39.9 kg, and 43.1 *vs* 19.7 kg, respectively. Excess weight was composed of 27 % FFM and 73 % FM, on average. Sleeping and sedentary activity EE, were 19% higher in those who were obese compared to those who were non-obese but similar after adjustment for body composition. Energy expenditure during walking at the same speeds on a treadmill in whole-body calorimeters was 81% higher in those who were obese compared to those who were non-obese. After adjustment for body weight, it was still 25% higher ($P<0.001$), probably because of greater difficulty of walking observed in severely obese subjects (19-21).

DEE in free-living conditions were 2.26 MJ higher in those who were obese compared to those who were non-obese (Fig. 3, $P < 0.001$)**.** After adjustment for body composition, sleeping, sedentary activities and daily energy expenditures were not significantly different between obese and non-obese subjects, but energy expenditure associated with physical activities was 61 % lower in obese adolescents ($P<0.001$) in spite of the higher energy cost of physical activities. In fact, the obese adolescents spent 47 min·d^{-1} more at light physical activities (slow walking and housework) and 53 min·d^{-1} less at moderate physical activities (walking at a normal speed and recreational activities) than the non-obese subjects (22).

Figure 3. *Least-squares mean (± SE) energy expenditure (EE) of and time devoted to the main activities by non-obese (□; n = 50) and obese (■; n = 27) adolescents in free-living conditions. Significant effects of obesity: *P < 0.05, ***P < 0.001.*



*Significant effects of obesity: *P < 0.05, ***P < 0.001.*

The inter-individual variability in EE was high and gender dependent in obese adolescents. After adjustment for differences in FFM, it averaged ± 10.1 % in boys and ± 12.4 % in girls for EE during sedentary activities in standardized conditions (whole-body calorimeter). Similarly, after adjustment for body weight, the inter-individual variability in EE during walking at 5 km $\cdot h^{-1}$ on a treadmill was ± 21.3 % in boys and ± 12.9 % in girls (22), which suggests differences in walking efficiency.

Effects of reduction of obesity on energy expenditure

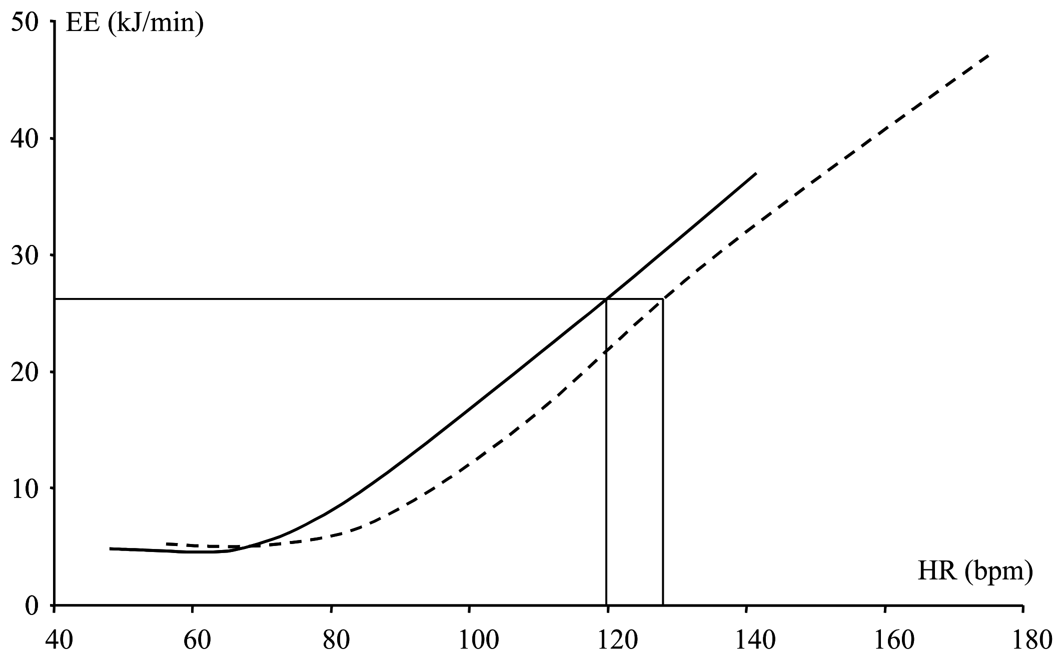
The major objectives of weight reduction programs are: 1) to decrease FM in order to reduce metabolic disorders which predispose obese adolescents to metabolic complications and severe morbidities such as hypertension, cardiovascular diseases and diabetes; 2) to enhance skills, physical capacities, pleasure and motivation to practice physical activities; 3) to preserve or increase FFM in order to enhance daily EE and improve long-term weight regulation; and 4) to change food and behaviour in order to improve energy balance. All programmes should aim to increase well-being, encourage social integration and promote mental blossoming which are mandatory conditions to maintain a long-term effect.

Severe energy restrictions in adolescents resulted in significant decreases in FM and FFM (23), which may slow down growth and induce reductions in energy expenditure, favouring subsequent body weight regain. On the contrary, physical training, without energy restriction preserved FFM or allowed increases in FFM, physical capacities and energy expenditures, but with a lower reduction in FM (24, 25). Weight reduction programs offer the possibility to combine medical, psychological and physical therapy, nutritional education and dietetic follow-up, and adapted progressive physical training.

A study following this model was conducted with 26 obese adolescents (12 boys and 14 girls), aged 12-16 years, over a 9-months period. Body weight loss averaged 18.4 kg (- 20 %) in boys, including 18.0 kg FM (- 51 %) but only 0.4 kg FFM (- 0.7 %). Mean BMI decrease was 8.1 and 6.3 kg/m² (s.e.m.: 0.38 kg/m^2) in boys and girls respectively. Body weight loss averaged 15.6 kg (- 17 %), including 12.5 kg FM (- 31 %) and 3.2 kg FFM (- 6 %). EE was affected by weight loss. BMR, sleeping EE, and sedentary EE were significantly lower at the end of the 9-month weight reduction program, both in absolute values (-8.3, -14.0, and -14.0%, respectively; $p< 0.001$) and after adjustment for FFM (-6.3, -12.6, and -11.7%, respectively; $p<0.001$). The energy cost of walking at the same speeds also decreased significantly (-24% and -22% in boys and girls, respectively), even after adjustment for BW (-17.6% in boys; $p<0.004$). As a consequence, with the same activity program, daily EE was significantly lower (11.67 vs. 13.96 MJ/d; $p<0.001$) after the weight reduction period, even after adjustment for FFM (11.84 vs. 13.76 MJ/d; $p<0.001$) (26).

The weight reduction program, also resulted in a continuous increase in walking speed during the 9-month period: +2.9 $km.h^{-1}$ in boys and +1.8 $km.h^{-1}$ in girls. The working capacity of arms and legs was increased threefold. Cardiovascular capacities improved: heart rate decreased 11-18 beats per minute (bpm) during sleep and sedentary activities, and 20-25 bpm during walking at 4-5 and 6 $km.h^{-1}$ (Fig. 3, (26).

***Figure 4**. Relationship between heart rate (HR) and energy expenditure (EE) as measured by whole-body calorimetry, before (- - -) and after (—) the weight-reduction program (mean values of all subjects) (26).*



During the 4-month period following the weight reduction program, 12 of the 26 adolescents maintained their body weight, while 10 others gained 6.6 kg body weight, including 5.8 kg FFM (27).

The results of this study confirm and demonstrate that a multidisciplinary weight reduction program in a specialized institution induces numerous beneficial effects in obese adolescents, but reductions in EE were observed, especially during sleep and sedentary activities (which account for about 80 % daily EE). These phenomena contribute to the frequent FM and body weight regains after a weight reduction program.

In addition, for adolescents who are obese and limited in their functional capacity by impaired exercise performance, it is optimal to devise a form of physical activity which promotes considerable EE. This should ideally promote substantial fat oxidation with the minimal subjective perception of effort and exercise intensity, which could ultimately allow a better tolerance and adherence to physical activity protocols. Previous studies, suggest that adolescents who are obese exhibited maximal fat oxidation rates at 41% V'O2max, which corresponded to 58% HRmax (28). Similarly, walking entails the advantages of enhancing fat utilization over cycling at an intensity requiring similar EE (29). It should be noted however, that in children who are obese, walking and jogging may be associated with joint pain and as such, non-weight bearing activity (e.g. cycling or walking in a swimming pool) may be initially preferable.

Physical Activity Ratio For Various Sedentary And Physical Activities

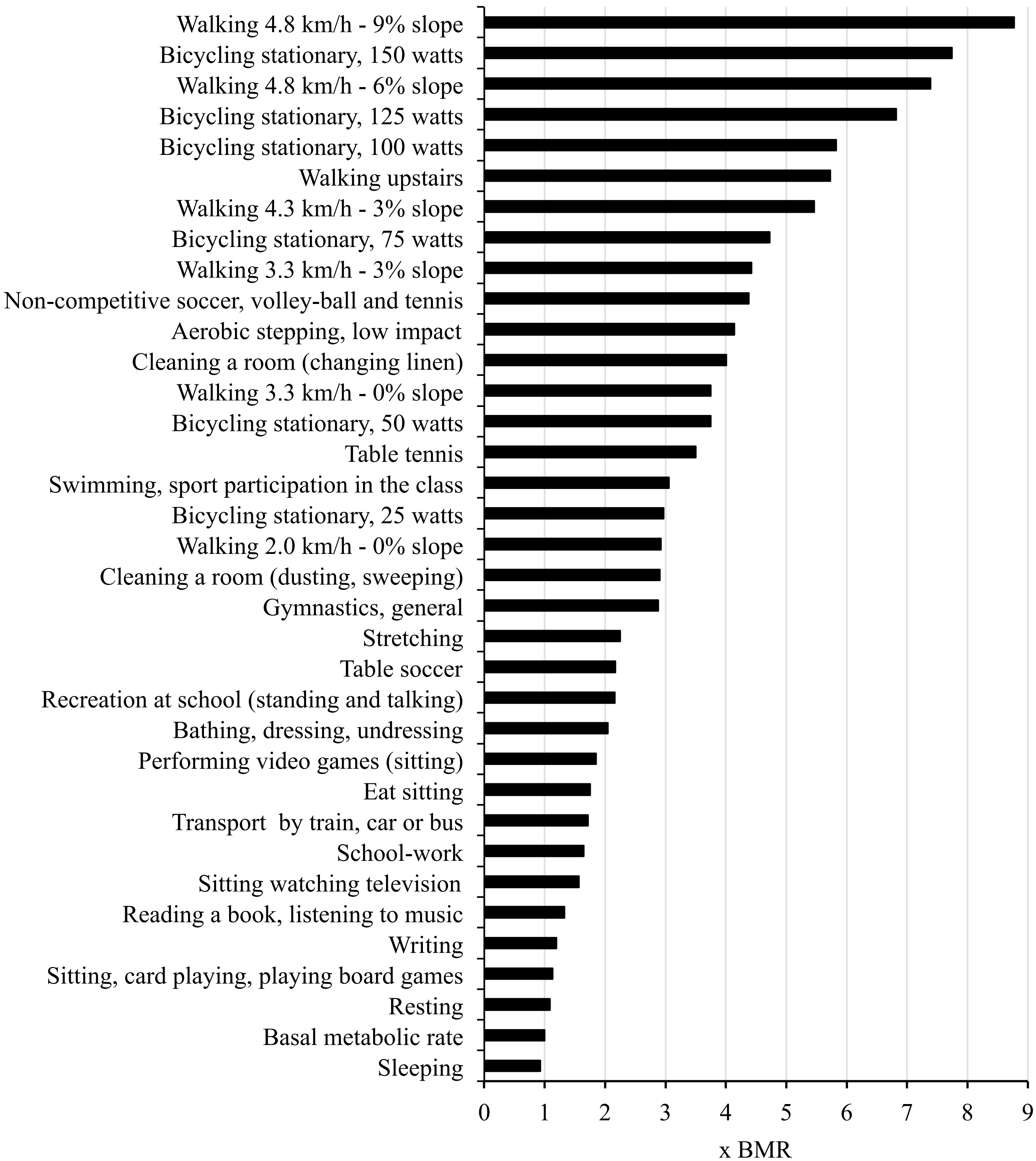
Professionals caring for children and adolescents who are obese need information on the type, energy cost and duration of their usual physical activities in order to prescribe appropriate individual dietary treatments and activity guidelines.

In clinical practice the questionnaire is the most common method used to estimate the physical activity level of subjects (30). From this, sedentary and physical activity recalls can be converted to daily EE using the factorial method with previously determined metabolic equivalents (MET) (31). It should be noted, that the Compendium values were obtained mainly from studies in normal-weight adults and the authors defined the MET as the ratio of work metabolic rate to a standard resting metabolic rate of 1.0 $kcal.kg^{-1}\cdot h^{-1}$ ($4.184\ kJ\cdot kg^{-1}\cdot h^{-1}$).

On the basis of previous studies (2, 32, 33), the measured energy cost of walking at $3.5\ km\cdot h^{-1}$ was on average 16% higher than the predicted MET EE (31). In addition, for all physical activities, including walking or body movements, considered in this study, the energy expenditure were on average 15-35% higher than that predicted by MET (31).

These data suggest the use of the appropriate Physical Activity Ratios (PARs) values (PAR = EE of activity ($kcal\cdot min^{-1}$) / BMR ($kcal\cdot min^{-1}$)) to determine daily energy expenditure by the factorial method in adolescents who are obese. These PARs values (2, 32, 33) allow more precision in the estimation of daily energy expenditure of obese who are obese when using the factorial method (Fig. 5).

Figure 5. *Physical activity ratios (PAR) corresponding to various sedentary and physical activities (modified from (2, 32, 33)*



All values are mean ± SD; PAR: Physical activity ratio = PAR = EE of activity (kcal·min^{-1}) / BMR (kcal·min^{-1}).

Estimation Of Daily Energy Expenditure

Daily energy expenditure of subjects is often evaluated from subjects' diaries or recalls during the previous weeks (26). The activities reported are then evaluated for frequency, duration, and intensity to evaluate mean daily energy expenditure (kcal). The latter can be calculated by using the following equation:

$$\text{Daily EE} = \sum_{1}^{N} (\text{BMR} \cdot \text{PAR} \cdot \text{duration}) \qquad \text{[Equation 3]}$$

where N corresponds to the number of activities, BMR (Equation 1 and 2) is expressed in $\text{kcal} \cdot \text{min}^{-1}$, PAR (Table 1) is a dimensionless measure, and duration of activity in min.

On this basis, a boy (14 y, body weight 93 kg, height 1.62 m) has a predicted basal metabolic rate of 1.46 ($\text{kcal} \cdot \text{min}^{-1}$, Eq. 1)). If he sleeps for 540 min (PAR: 0.93), dresses for 60 min (PAR: 2.05), eats for 120 min (PAR: 1.75), stays at school for 420 min (PAR: 1.65), watches television for 180 min (PAR: 1.57), walks for 60 min (PAR: 5.46) and cycles for 60 min (PAR: 3.75), his daily energy expenditure can be estimated to 3441 $\text{kcal} \cdot \text{day}^{-1}$.

Mechanical Cost Of Walking And Running

In normal-weight subjects

It has been suggested that children who are obese experience a greater mechanical cost during standing and walking. In particular greater loading of the lower limb joints is observed compared to those of normal weight and such, persistent loading may predispose the child to pathological gait patterns.

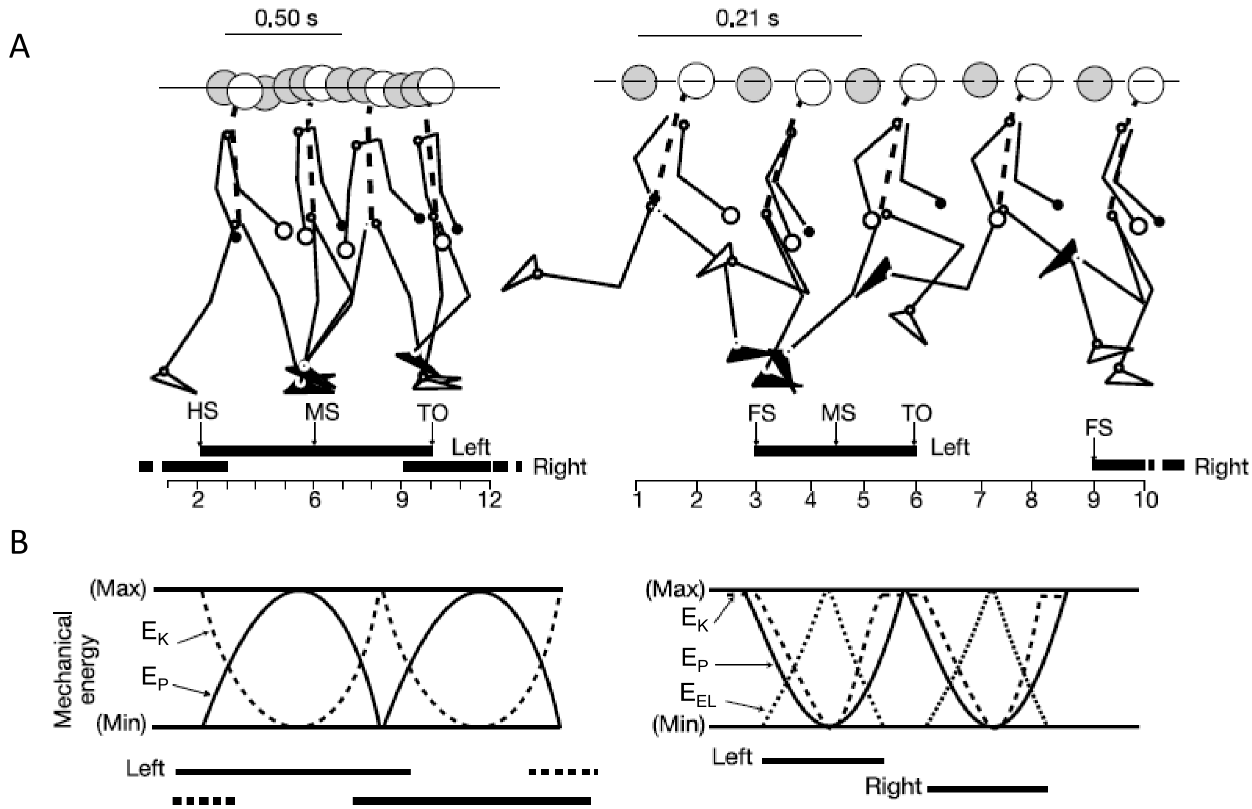
Generally, human locomotion is characterized by two principal gaits, walking and running. The basic features of the two modes of progression are the same: each step presents one phase of stance and one of swing, but then they differ, as the leg controllers have two separate modes of operation for walking and running. The timing of the events in the cycles are different, the stance of each foot being longer in walking and shorter in running, whilst the swing shows the opposite trend. In walking there is always at least one foot on the ground, while in running there is a period during which both feet are off the ground, and the amplitudes of the contractions of the flexor and the extensor muscles during the two phases of the step are different.

The mechanical energy changes (i.e. the work) required to maintain the overall motion have received considerable attention because they affect the metabolic EE. Total work (W_{TOT}) is defined as $W_{INT}+W_{EXT}$ where the work done to raise and accelerate the body centre of mass within the environment is the external work (W_{EXT}) and the work associated with the acceleration of body segments (mainly limbs) with respect to the body centre of mass is the internal work (W_{INT}) (34, 35). The W_{INT} tends to be an increasing function of speed (34), stride frequency (35), segment mass and duty factor (36) and constitutes 25 - 40% of W_{TOT} in humans (34).

The ratio between W_{TOT} and EE yields the efficiency $\eta = W_{TOT} \cdot EE^{-1} \cdot 100$, where W_{TOT} and EE must be expressed in the same units (J, $J \cdot m^{-1}$ or $J \cdot m^{-1} \cdot kg^{-1}$), therefore efficiency is a dimensionless measure, expressed in percentage (34). In normal-weight adolescents η increased from 15 to 21 % when the walking speed increased from 0.75 to 1.50 $m \cdot s^{-1}$ (21).

Despite legged locomotion being the result of the coordinated actions of dozens of muscles, many of them being bi-articular, exerting force via tendons and producing the movement of a multitude of bones and body segments, each gait can be described by a model which helps understand the overall mechanics of the progression along the ground. More specifically, the model elucidate for each gait the interplay among the three fundamental energies associated to the body centre of mass, namely the potential energy (E_P, $m \cdot g \cdot h$), the kinetic energy (E_K, $0.5\ m \cdot v^{-2}$), and the elastic energy (E_{EL}), where g is acceleration due to gravity (9.81 $m \cdot s^{-2}$), m is body weight (37), h is the vertical coordinate above an arbitrary reference level (m) and v is the speed ($m \cdot s^{-1}$) of the body centre of mass.
Then W_{EXT} can be expressed as $W_{EXT} = \Delta E_P + \Delta E_K$

Figure 6*: Comparisons of walking and running mechanics (modified from Bramble and Lieberman (38)).*



A. Kinematics of walking (left) and running (right). During walking, the centre of mass are lowest near toe-off (TO) and highest at mid-stance (MS) where the leg is relatively straight. During running, the head and centre of mass are highest during the aerial phase and lowest at MS, when the hip, knee and ankle are flexed; the trunk is also more inclined and the elbow more flexed.

B. Biomechanical contrasts between human gaits. During walking, an inverted pendulum mechanism exchanges forward kinetic energy (E_K) for gravitational potential energy (E_P) between heelstrike (HS) and MS; the exchange is reversed between MS and TO. During running, a mass-spring mechanism causes E_P and E_K to be in phase, with both energies declining rapidly to minima between footstrike (FS) and MS. Leg tendons and ligaments partially convert decreases in E_P and E_K to elastic energy (E_{EL}) during the first half of the stance, which is subsequently released through recoil between MS and TO.

Walking has been classically described by an inverted pendulum (Fig. 6, (39)). In those models potential energy (E_P) and kinetic energy (E_K) continuously exchange, resulting in a total mechanical energy (TE, where TE is the sum of E_P and E_K) with a smaller change over the stride with respect to the two components taken separately. Such a mechanism minimizes the net energy needed to drive the moving system. The energy recovery is a parameter which aims at quantifying the ability to save mechanical energy by using a pendulum-like model. While in ideal (straight) pendulums the energy exchange is complete (energy recovery is 100%), the path of the centre of mass of the body in walking resembles the motion of an inverted pendulum (40), with losses associated both with the deviation from an ideal system and with the transition from one (inverted) swing to the next (35). The energy recovery is moderately high (up to 60%) and depends on stride length (41) and walking speed (42). While recent literature has suggested some elastic energy contribution to walking mechanics, through elastic energy storage and release in the Achilles tendon (43) and possibly through the bending of the arch of the foot (44), the pendulum-like model still explains most of the energy interplay within the stride.

In contrast to walking, during running, potential energy (E_P) and kinetic energy (E_K) change in phase during the stride (thus no exchange between E_P and E_K occurs during ground contact). In this gait elastic energy (E_{EL}) has a crucial role in exchanging with the sum of the other two energy types. Part of the total mechanical energy (TE) of the system during the flight phase is transformed into elastic energy (E_{EL}) during the first half of the contact phase, via tendon stretch. In the second half of the phase a consistent part of the stored energy is given back to the system via tendon recoil, in the preparation for the next stride.

While W_{EXT} is a reliable estimate of the mechanical work done by muscles in walking, the values obtained for running overestimate muscle work because of the inherent inability to take elastic energy (E_{EL}) into account. In fact, part of the decrease and increase of total mechanical energy (TE) in running are not caused by the eccentric and concentric contractions of muscle, but by tendon stretch and recoil, respectively.

Effects of obesity on mechanical cost of walking and running

In individuals who are obese the mass distribution is different from that of non-obese subjects, the thigh dimension being generally increased in disproportion to the general increase of the rest of the body. External work of walking was higher in obese, but after adjustment for body weight, the external work was not significantly different between obese and non-obese adolescents; consequently the efficiency (η) was on average 23 % lower in obese than in non-obese adolescents, and the difference decreased from 30 to 20 % when the walking speed increased (21). The mechanical walking pattern differs between obese and non-obese adolescents, in particular a greater mediolateral center of mass displacement is greater and associated with greater step widths, especially at the lowest speeds, probably due to reduced postural stability. It did not induce a greater external work (W_{EXT}) as measured in the study. The greater net energy cost of walking in obese subjects may be partially explained by the increased step-to-step transition cost (i.e., the internal work occurring during the double contact phase) associated with wide gait.

Gushue *et al*. (45) proposed that overweight children have altered knee joint kinematics due to higher peak knee adduction moments (73-100% higher than normal weight children). The authors proposed that gait adaptation may increase medial compartment loading of the lower limbs and contribute to the development of varus/valgus deformities and osteoarthritic wear and tear. This assertion was supported by Davids et al (46) who demonstrated that the dynamic gait deviations seen in obese children resulted in pathologic compressive forces in the medial compartment on the knee. High joint loading across the medial tibiofemoral compartment is believed to play an important role in the pathogenesis of articular injury and osteoarthritis of the knee ((47, 48, 49., 50). Similarly, shearing forces at the hip and a reduced femoral neck anteversion angle may lead to the development of slipped upper femoral epiphysis(51, 52). It is reasonable to assert that excess adiposity increases the energy cost of movement and can contributed to biomechanical inefficiency and postural instability. McGraw and colleagues (2000) and Colne et al.,(20, 53) found that those who were obese spent significantly longer in the dual stance phase of gait compared to those who were lean. Obesity was also associated with greater postural sway and slower preferred gait cadence when compared to normal weight participants. Postural instability in the medio-lateral plane are corrected by stabilizing responses occurring mainly around the hip (20). These responses can influence a slower progression of gait as reported by Colne et al. (20, 53).

Additionally, the external work (W_{EXT}) and the net energy cost of running and efficiency (η) in obese and normal-weight adolescents and adults running at 8 $km.h^{-1}$ (Taboga et al.2012) were independent of body mass of the subjects. Elastic tissues of obese subjects seem to adapt (e.g. by thickening) to the increased mass of the body, thus maintaining their ability to store elastic energy, at least at 2.2 ms^{-1} speed, at the same level as in the lean subjects.

Effects of reduction of obesity on mechanical cost of walking

After a 3-month multidisciplinary weight reduction program, adolescents who were obese lost on average 6 % of body mass, 15 % of FM without significant changes in lean body mass (54). After weight loss, the net metabolic cost of walking at 1.25 $m{\cdot}s^{-1}$, decreased in association with the biomechanical parameters of walking: stride length increased by 3.5 %;lateral leg swing and the variation of the medio-lateral kinetic energy decreased by 18 % and variation in potential energy by 6 %. Consequently the net energy cost of walking, adjusted for body mass, decreased by 9 %, whereas the external work (Wext) did not vary significantly.

The decrease in the net energy cost of walking were correlated with the decreases in body weight, FM and percent of gynoid mass, but not with the lateral leg swing after weight loss. The main determinant was the decrease in body weight, which in turn reduced the leg muscle work required to raise and accelerate the center of mass as well as to support body weight and maintain body equilibrium (55) during walking.

Indeed, as vertical motions allow a pendulum-like exchange between potential and kinetic energy, weight-reduced individuals could reduce the potential energy available (hence vertical motions) because of the decrease in medio-lateral kinetic energy fluctuations. The reduction in FM in the gynoid region, independently of the decrease in total body FM, is related to the decrease in net cost of walking (55).

Reductions in hip and knee moments proportional to weight loss have also been observed following bariatric procedures (56).

Practical Applications

High cardiorespiratory fitness during childhood and adolescence has been associated with a lower percentage of body fat and a healthier cardiovascular profile (57, 58), while childhood adiposity is associated with an unfavourable lipid profile (59). Studies of the available evidence (60) indicated that increased physical activity and decreased sedentary behaviour protect against weight gain in childhood and adolescence.

From a public health perspective, the focus should be on preventing of weight gain and regain after weight loss (61, 62). Physical activity is recognized as a major component of the management of overweight or obesity. The importance or magnitude of the beneficial effects of physical activity in this context differs according to the outcome examined. Physical activity appears essential for weight maintenance after diet-induced weight loss, rather than for weight loss per se. It is also important for the preservation of fat-free mass during weight loss. Physical activity has beneficial effects on fitness and reducing obesity-related complications, such as cardiovascular diseases and diabetes. Most data suggest that total volume of physical activity, rather than its intensity, is important for managing weight.

Amount of physical activity needed to prevent obesity

There is no definite consensus on the amount of physical activity required to prevent weight gain at the population level, and the shape of the dozen the amount is not clear. This is a complex issue, especially in view of the difficulty of matching energy intake with energy expenditure in times of readily available food and low levels of habitual physical activity (61, 62).

The U.S. Department of Health and Human Services 2008 Physical Activity Guidelines for Americans (63) recommend that children and teens be physically active for at least 60 minutes on most, if not all, days, including:

Aerobic: Most of the 60 or more minutes a day should be either moderate- or vigorous-intensity aerobic physical activity (running, hopping, skipping, jumping rope, swimming, dancing, and bicycling are all examples of aerobic activities), and should include vigorous-intensity physical activity at least 3 days a week. Aerobic activities increase cardiorespiratory fitness.

Muscle-strengthening: As part of their 60 or more minutes of daily physical activity, children and adolescents should include muscle-strengthening physical activity on at least 3 days of the week. Muscle-strengthening activities can be unstructured and part of play, such as playing on playground equipment, climbing trees, and playing tug-of-war. Or these activities can be structured, such as lifting weights or working with resistance bands.

Bone-strengthening: As part of their 60 or more minutes of daily physical activity, children and adolescents should include bone-strengthening physical activity on at least 3 days of the week. Produce a force on the bones that promotes bone growth and strength. This force is commonly produced by impact with the ground. Running, jumping rope, basketball, tennis, and hopscotch are all examples of bone strengthening activities.

It is important to encourage young people to participate in physical activities that are appropriate for their age, that are enjoyable, and that offer variety.

Amount of physical activity needed to weight loss

The amount of physical activity needed to weight loss is related to negative balance between daily energy intake and daily energy expenditure. Energy intake can be calculated as 1.2 or 1.3 times basal metabolic rate (32). While, energy expenditure can be calculated as suggested previously. As well as physical activity must to consider the following suggestions:

Endurance exercise

Frequency: For moderate-intensity activities, accumulate at least up to 60 $min \cdot d^{-1}$ in bouts of at least 15 min each, at least 20–30 $min \cdot d^{-1}$ or more of vigorous-intensity activities, an equivalent combination of moderate and vigorous activity.

Intensity: On a scale of 0 to 10 for level of physical exertion, 5 to 6 for moderate-intensity and 7 to 8 for vigorous intensity. It has been demonstrated in adolescents that fat oxidation is at a maximum during moderately intense physical activity (50% $V'O_2$peak, 65% maximum heart rate, ~130 bpm) (29) walking speed 5 $km \cdot h^{-1}$. However, short bouts (30-60 s) at 100% VO2peak or 100% heart rate favours improvements also on aerobic power (64).

Duration: For moderate-intensity activities, accumulate at least 45 $min \cdot d^{-1}$ in bouts of at least 15 min each of continuous activity for vigorous-intensity activities.

Type: Any modality that does not impose excessive orthopaedic stress; walking or running is the most common type of activity. Stationary cycle exercise may be advantageous for those with limited tolerance for weight bearing activity.

Muscle-strengthening

Frequency: At least 2 $d \cdot w^{-1}$.
Intensity: Between moderate- (5–6) and vigorous- (7–8) intensity on a scale of 0 to 10.
Type: Progressive weight training program or weight bearing calisthenics (8–10 exercises involving the major muscle groups of 8–12 repetitions each), stair climbing, and other strengthening activities that use the major muscle groups.

Flexibility

Frequency: At least 4 $d \cdot w^{-1}$.
Intensity: Moderate (5–6) intensity on a scale of 0 to 10.
Type: Any activities that maintain or increase flexibility using sustained stretches for each major muscle group and static rather than ballistic movements.

The progression of activities should be individual and tailored to tolerance and preference; a conservative approach may be necessary for the most deconditioned and physically limited obese children and adolescents. Obese children and adolescents should exceed the recommended minimum amounts of physical activity if they desire to improve their fitness.

Amount of physical activity needed to preventing weight regain

While consensus is lacking on the amount of physical activity needed to prevent weight regain, there is an indication that children and adolescents would need 60 or more minutes of daily of physical activity needed to prevent weight regain, there intense activity, to avoid regaining weight (65, 66). This physical activity also can be done in smaller chunks of time over the day. Engage in more than 1 h of daily physical activity promoting walking or cycling to school, suggesting activities that involve parents or friends and promote even small amounts of moderate to vigorous activities. Particularly promote enjoyable and fun activities.

As well, discourage sedentary behaviour remain a simple ways to increase physical activity.

Conclusion

Daily energy expenditure, basal metabolic rate and energy expenditure corresponding to the various sedentary and physical activities are significantly higher in the obese than in the non-obese adolescents, but none except walking was significantly different after adjustment for FFM or BW. The mechanical walking pattern differs between adolescents who are obese compared to lean peers. In particular a greater mediolateral center of mass displacement is greater and associated with greater step widths, especially at the lowest speeds, probably due to reduced postural stability. The greater net energy cost of walking in obese subjects may be partially explained by the increased step-to-step transition cost (i.e., the internal work occurring during the double contact phase) associated with wide gait. Increased energy costs and greater joint loading may predispose the developing musculoskeletal system of children and adolescents who are obese to injury and abnormal development. In addition, these factors may influence the child's interest or affinity to being physically active.

Children who are obese spent more time at light physical activities but much less time at moderate and sports activities than did the non-obese subjects. The energy expenditure for sports activities did not differ significantly, which indicates that the obese subjects engaged in less intense activities. Consequently, the energy expenditure of the obese subjects for moderate and sports activities amounted to 20% and 25% of those of the non-obese subjects, respectively.

A multidisciplinary weight-reduction program has numerous beneficial effects but induces reduction in energy expenditures during sleeping and sedentary activities. These decreases do not result only from the reductions in FM and FFM, but probably also from the reductions in size and metabolic rate of organs associated with the energy deficit. These phenomena explain the frequent FM and body weight regains. It is therefore essential for the adolescents to follow scrupulously the dietary recommendations and to practice daily moderate physical activities to maintain the beneficial effects of the weight reduction program. In addition, it is recommended that age-appropriate and enjoyable physical activity which promotes substantial fat oxidation be prescribed. Such activity might be tolerated better in this cohort and might improve adherence to physical activity protocols. Previous studies, suggest that obese adolescents exhibited maximal fat oxidation rates at 41% V’O2max, which corresponded to 58% HRmax. Finally, walking enhances fat utilization over cycling (at an intensity requiring similar EE) though such weight-bearing activity may initially be uncomfortable in those who are severely obese.

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