Role of physical activity in the prevention of obesity in children

MI Goran^{1*}, KD Reynolds² and CH Lindquist¹

¹*Division of Physiology and Metabolism, Department of Nutrition Sciences, School of Health Related Professions, University of Alabama at Birmingham, Birmingham, AL, USA and* ²*Department of Health Behavior, School of Public Health, University of Alabama at Birmingham, Birmingham, AL, USA*

The increasing prevalence of childhood obesity and its concomitant health risks justify widespread efforts toward prevention. Although both diet and physical activity have been emphasized as appropriate interventions, the current paper focuses on the role of physical activity in obesity prevention. Children's levels of physical activity are highly variable, and may be influenced by a multitude of factors including physiological, psychological, sociocultural and environmental determinants. Although the relationship between physical activity and obesity is controversial and the protective mechanism unclear, physical activity is hypothesized to protect individuals from the development of obesity by increasing energy expenditure and resting metabolic rate (RMR) and leading to a favourable fuel utilization. The beneficial effect of physical activity in children is supported by controlled exercise intervention programs. Several broad-based public health interventions designed to increase children's levels of physical activity have been implemented in schools, families and communities, with results suggesting promising strategies for the prevention of childhood obesity. It is likely that successful prevention of childhood obesity through physical activity promotion will involve theory-based, culturally appropriate school, family and community interventions. Through policy changes, environmental planning and educational efforts in schools and communities, increased opportunities and encouragement for physical activity can be provided.

Keywords: obesity; children; physical activity; energy expenditure; prevention

Introduction

The current increase in the prevalence of pediatric obesity has fostered a multi-disciplinary discourse on the most appropriate strategy for reducing this epidemic. While no consensus has been reached, it is likely that preventive efforts will prevail, with interventions likely to target all children at a young age. Among children, as well as adults, obesity has an etiology which is multidimensional in nature. The principle of energy balance suggests that when energy intake is higher than energy expended, weight gain is the result. Although energy intake depends solely on dietary consumption, energy expenditure is dependent on several components, with the major modifiable aspect being physical activity. Thus, both dietary and physical activity patterns have been emphasized as appropriate interventions for the prevention of obesity. However, among children, a reduction in energy intake may compromise growth and essential energy acquisition. In addition, attempts to modify the eating patterns of children may

exacerbate the risk of introducing eating disorders. Therefore, this paper focuses on the role of physical activity in the prevention of obesity among children.

Targeting children's patterns of physical activity is especially important given the argument that physical activity in childhood serves as the foundation for a lifetime of regular physical activity. Physical activity is also an ideal focus because it has many other benefits in addition to body weight regulation and improving body composition such as psychological and social well-being; moreover, even in childhood, physical activity is closely linked to other health behaviours such as smoking, diet, drug use, sexual activity and academic performance. These associations suggest that physical activity plays a role, not merely in the development of childhood obesity, but also in numerous health consequences, lifestyle patterns and psycho-social well-being.

The current paper explores the current epidemic of obesity in children, in terms of both its epidemiology and health consequences. The role of physical activity in the etiology of obesity is considered in detail, along with a comprehensive discussion of current patterns of physical activity among children. In addition, previous attempts to promote physical activity among children using well-designed behavioural interventions are reviewed. Finally, suggestions for obesity prevention through physical activity interventions are presented, and directions for future research are provided.

*Correspondence: Dr Michael I. Goran, Division of Physiology and Metabolism, Department of Nutrition Sciences, University of Alabama, Birmingham, AL 35294, USA.

Epidemiology and health consequences of pediatric obesity

Obesity (or excess body weight) currently affects 25% of children in the United States,¹ and the prevalence appears to be increasing dramatically. National data in the US from NHANES III² demonstrate that the prevalence of adolescent obesity has risen from 15% (for the period 1976–1980) to 21% (for the period 1988–1991). An analysis of secular trends clearly suggests an increase in body weight and adiposity in children.³ Between 1973 and 1994 in the US, the mean weight of a child at any given height and age increased by 0.2 kg/y, and the prevalence of overweight increased 2-fold.³

In addition to secular trends, demographic patterns appear evident regarding ethnicity and age. In local schoolchildren of Birmingham, Alabama,⁴ the prevalence of obesity (defined as a body weight > 120% ideal body weight) at age 10 y is 21% in Caucasian boys and girls, 26% in African American boys, and 38% in African American girls. The higher prevalence of obesity in African Americans, particularly among females, may explain why the mortality rate from cardiovascular disease (CVD) in African American women is 2–4 times higher than Caucasian women.^{5,6} Age also appears to be an influential factor in childhood obesity. Obesity that begins early in life persists into adulthood^{7–9} and increases the risk of obesity-related morbidity later in life.¹⁰ There are distinct periods of growth during which the risk for obesity is markedly increased: early infancy; adiposity rebound during pre-pubertal growth — the age at which body mass index (BMI) reaches a low point, occurring around the age of 5–6 y;¹¹ and, the adolescent growth phase.¹² The emergence of obesity during adolescence is of particular significance, for several reasons. First, the increasing prevalence of obesity is most apparent during this period, especially among girls.⁴ Second, obesity during adolescence, vs before adolescence, is more predictive of obesity¹³ and mortality¹⁰ later in life.

Obesity is now considered a disease of epidemic proportions with increasing prevalence worldwide.¹⁴ This general rise in obesity is likely to have long-lasting physical and mental health consequences for the population. Even during childhood, obesity is closely related to increased risk of CVD and non-insulin dependent diabetes mellitus (NIDDM),^{15–17} psycho-social concerns¹⁸ and the increased risk of some forms of cancer.^{19,20} There have been two recent studies which provide a clear indication of the epidemiological impact of childhood obesity on overall health risk. First, offspring of parents with coronary heart disease (CHD) were found to be more overweight during childhood and also developed an adverse lipid risk profile at a faster rate.²¹ Second, the incidence of NIDDM (typically thought of as an adult disease) has increased 10-fold in children in recent

years, and this increase is most apparent among obese children.²²

The increasing prevalence, numerous health risks and astounding economic costs of obesity — approximately \$100 billion per year in the US^{23,24} — clearly justify widespread efforts toward prevention. Preventive action has historically taken the form of medical intervention (for example, vaccination programs for smallpox, influenza and polio) and public health policy (for example, changes in lifestyle for control of AIDS, smoking and heart disease) and such action has demonstrated a great deal of success. Obesity is particularly dependent on preventive efforts for several reasons. First, the etiology of obesity is largely due to lifestyle factors and is thus behavioural in nature. Although recent metabolic and genetic research has deepened our understanding of the physiological aspects of body weight regulation, there is very little evidence to support the concept that the development of obesity in children is determined by acute metabolic and/or genetic defects.^{25,26} It is extremely unlikely that acute changes in the gene pool or alterations in metabolic rate have arisen and are responsible for the recent increase in obesity prevalence in the population. A more plausible explanation for the increasing prevalence of obesity relates to cultural changes accompanying societal development, such as a decreased requirement for physical activity and greater abundance and availability of food. Thus, the notion that obesity is the end-result of an interaction between a normal metabolic/genetic physiology and an obesity-promoting environment and lifestyle is gaining in acceptance.^{27,28} The relationship between obesity and lifestyle factors reflects the principle of energy balance. Weight maintenance is the result of equivalent levels of energy intake and energy expenditure. Thus, a discrepancy between energy expenditure and energy intake depends on either food intake or energy expenditure, and it is becoming clear that physical activity provides the main source of 'plasticity' in energy expenditure, even among children.^{29,30} In addition, lifestyle factors such as dietary and activity patterns are clearly susceptible to behavioural modification, and are likely targets for obesity prevention programs.

A second, yet related, reason why control of the obesity epidemic will be dependent on preventive action is that both the causes and health consequences of obesity begin early in life and track into adulthood. For example, both dietary and activity patterns responsible for the increasing prevalence of obesity are evident in childhood. Estimates indicate that only approx. 7–30% of children eat five or more fruit and vegetables per day, as recommended for cancer prevention, and that children and adolescents consume greater than the recommended 30% of calories from fat.^{31,32} Moreover, physical activity occurs less frequently and with less intensity than recommended.^{31,33} In addition, the accumulation of visceral fat begins early in life,^{34,35} and is specifically

associated with increased risk factors for NIDDM and CVD, even during childhood.^{36–38} Since risk factors and high risk behaviours are present in youth and track into adulthood, there is a compelling need to intervene to address these factors early in life.

Substantial evidence, particularly from research in heart disease epidemiology, indicates that risk factors and risk behaviours present in youth carry over, or ‘track’, into later childhood and early adulthood.^{32,39} Longitudinal evidence supporting the tracking of behaviours in children and youth is somewhat limited, particularly for the transition from youth into adulthood. However, several studies have identified the tracking of physical activity throughout life.^{40–42} Since risk factors and protective behaviours may track into adulthood, it is important to intervene early in life, to help formulate good health behaviour. Thus, targeting children early is likely to have a long-lasting effect on health behaviour that will last into adulthood, reducing disease risk for many years.

To sum up, the increasing prevalence of obesity and its concomitant impact on the quality of life have fostered awareness of the importance of prevention for the control of obesity. Consequently, a National Institute for Diabetes and Digestive and Kidney Diseases (NIDDK) task force⁴³ and the World Health Organization (WHO),¹⁴ have designated research into the prevention of obesity as their highest priority. As mentioned previously, the two major lifestyle behaviours that are clearly associated with the increased prevalence of obesity and related disease risk in children are diet⁴⁴ and physical activity.^{45,46} The remainder of this paper reviews patterns of physical activity among children and explores the role of physical activity in the etiology of obesity.

Patterns of physical activity among children

Conceptualization of physical activity among children

Among children, as well as adults, physical activity is a highly multidimensional construct, traditionally conceptualized as ‘any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level’.⁴⁷ For children, physical activity is likely to encompass numerous behaviours such as play, chores, organized sports and exercise. Thus, exercise, defined as behaviour that is planned, structured and repetitive, and undertaken for the purpose of improving or maintaining physical fitness,⁴⁷ is only one subset of physical activity. While physical activity is considered a behaviour, physical fitness is considered an attribute.⁴⁷ Although fitness includes several attributes such as muscular strength, flexibility, balance, agility, power, speed and coordination,⁴⁷ it is typically conceptualized as cardiorespiratory endurance. Subsequently,

physical fitness is usually measured through maximal exercise tests, while physical activity is often assessed by self-report (typically through diaries and questionnaires), behavioural observations, motion sensors, heart rate monitors and use of doubly labeled water for assessing physical activity related energy expenditure over extended periods, under free living conditions. The measurement of physical activity is especially problematic among children and has been previously reviewed elsewhere.^{48,49}

Current recommendations for physical activity in children

Although it is clear that physical activity has beneficial effects on health, the optimal intensities, volumes and modalities are unclear, especially in children. In adults for example, some studies suggest that longer bouts of low intensity exercise may be more beneficial, whereas others have shown that shorter frequent bouts of high intensity exercise may have more beneficial effects on body composition.⁵⁰ There is virtually no information on children regarding the different effects of low and high intensity and frequency of activity for improving body composition and health risk. It seems likely that healthy children may benefit from an even greater volume of regular exercise than adults; that is, more than one and up to several hours per day (Recommendation of the National Association of Sport and Physical Education, 1998). Children may also benefit from training for skill development, since acquisition of essential skills is needed to promote self-efficacy, a major predictor of future free-living physical activity.⁵¹ However, there are few guidelines specific for children, especially younger children. The recommendations that do exist are variable, suggesting from 20–30 min of at least moderate intensity exercise for at least three days a week.^{52,53} A 1996 report from the Surgeon General on ‘Physical Activity and Health’, sponsored by the US Department of Health and Human Services, the Centers for Disease Control and Prevention, the National Center for Chronic Disease Prevention and Health Promotion, and the President’s Council on Physical Fitness and Sports, recommends that

*‘All people over the age of 2 years should accumulate at least 30 minutes of endurance-type physical activity, of at least moderate intensity, on most preferably all days of the week’.*⁵²

The ‘Healthy People 2000’ objectives also include children in recommendations, advocating that 30% of the population aged ≥ 6 y, perform light to moderate physical activity for 30 min on a daily basis, and 75% of those aged 6–17 y, engage in vigorous physical activity for > 20 min at least three times a week (adapted from reference 52). In addition, specific goals for children have been recommended, specifying that at least 50% of school children should participate in daily physical education in school, with at least 50% of class time devoted to being active.⁵²

Other recommendations specifically pertaining to children's levels of physical activity suggest the importance of promoting physical activity in schools and in communities. For example, the WHO recommendations¹⁴ suggest environmental modifications which facilitate everyday activities, such as walking and biking, rather than promoting specific bouts of vigorous activity. Similarly, the recommendations of the Centers for Disease Control focus on several levels of physical activity promotion for children, including policy, environment, physical education, health education, extracurricular activities, parental involvement, personnel training, health services, community programs and evaluation.⁵⁴

Epidemiology and demographics of physical activity in children

Cultural changes and advances in technology have occurred over the past few decades that have had dramatic effects on physical activity trends in the population, although there are no specific data which have documented a secular reduction in physical activity in children. Nevertheless, it is obvious that the environment in which we live is gradually changing to one which requires less and less physical activity and promotes an ever-increasing sedentary lifestyle.⁵⁵ Paradoxically, as this trend continues, we are learning more and more about the overall importance of physical activity in promoting and maintaining adequate health.⁵⁵

Previous researchers in the area of childhood physical activity have identified several general patterns of physical activity among children. First, the notion that children primarily engage in shorter bouts of physical activity, rather than prolonged exercise, is generally well-accepted.^{48,56} In addition, children appear to engage in higher levels of activity during time spent away from school, particularly on the weekends⁵⁷ and in organized programs.⁵⁸ Finally, as reviewed below, there is evidence to suggest that seasonal and geographical factors may influence children's activity levels.^{65–67}

Data on the activity levels of children, particularly pertaining to whether children are currently meeting recommendations for physical activity, are scarce. A study of a nationally representative sample of 4063 children (aged 8–16 y) during 1988–1991, showed that 20% of US children do not exercise vigorously more than twice per week.⁵⁹ Furthermore, 67% of children watch > 2 h television per day, which is particularly alarming, since television viewing appears to be linked to obesity.^{59,60} Thus, the limited amount of previous research appears to indicate that the 'Healthy People 2000' objectives mentioned previously are not being met.

Determinants of physical activity among children

In addition to identifying patterns of physical activity among children, a particularly important research goal

is to determine characteristics influential in promoting or deterring physical activity. A useful approach in understanding the multitude of factors which may influence children's physical activity patterns, modified from the classification of Kohl and Hobbs,⁶¹ considers four levels ranging in distance from the individual. These levels include the physiological, the psychological, the sociocultural and the environmental. Physiological determinants include unmodifiable biological or developmental characteristics, such as pubertal maturation, growth and aerobic fitness. Psychological determinants include personal characteristics such as motivation, self-efficacy and sense of control. Sociocultural determinants include parental and family characteristics, role models, and socio-demographic factors such as age, gender and ethnicity. Finally, ecological determinants include environmental and contextual factors, such as the availability of facilities for activity, physical safety and climate.

Interestingly, the majority of previous research exploring determinants of physical activity among children has focused on the psychological level, while broader sociocultural or ecological determinants have received little attention. Among children, physical activity patterns have been empirically linked to psychological-level characteristics such as attitudes or enjoyment of physical activity, motivation to exercise, perceived barriers (such as time, weather, or access to exercise facilities), perceived benefits of exercise, health beliefs, personal control and, particularly, self-efficacy, or the confidence to engage in a particular behaviour.^{51,61,62}

In addition to the well-researched psychological determinants, several ecological-level factors are linked to children's activity patterns, including access to facilities or equipment for physical activity, access to safe play areas, season, geographical location and climate. Several studies have shown that physical activity is positively associated with access to facilities or equipment.^{63,64} Although it seems likely that seasonal and geographical factors influence physical activity participation, there is a paucity of data to support this. The National Children and Youth Fitness Study (NCYFS) suggested that activity in children is highest in summer, then gradually drops through fall and winter, increasing again in the spring.⁶⁵ Another study assessing physical activity energy expenditure among children supports this pattern,⁶⁶ with results indicating that physical activity energy expenditure is significantly higher in spring compared to fall by approx. 100 kcal/d (independent of body composition, gender, age and geographic location). Baranowski *et al*⁶⁷ explored seasonal differences in physical activity by repeated observation measurements of physical activity in 191 children aged 3–4 y, with results indicating that physical activity varied by month of the year — a finding partially explained by the amount of time the children spent outside.⁶⁷ Although data relating to geographical

locations are lacking, the seasonal trends identified in the literature would be expected to be driven by climatic issues. One of the few geographical comparisons of children's physical activity patterns compares children living in Vermont with children living in Alabama, and reports higher physical activity energy expenditure by approx. 100 kcal/d in the Vermont children, independent of season.⁶⁶ This finding suggests that a combination of cultural and environmental differences between populations may contribute to the facilitation of physical activity through such factors such as facility availability, school policies and knowledge about physical activity.

Sociocultural factors have also received little attention, despite their potential to directly (and indirectly) influence children's activity patterns. The small amount of research on sociocultural influences of children's activity patterns has suggested several ways in which such factors exert an influence on activity among children. Role modeling may be an important influence on children's activity patterns, as children with physically active parents have been shown to be significantly more active than children with inactive parents,^{68,69} although some studies have not found a relationship between parental activity and child activity.^{63,70} In addition, parent's support has also been shown to predict physical activity for children.⁷⁰ Interestingly, however, peers and, for older children, siblings, may be even more instrumental than parents in influencing physical activity.^{69,71,72}

Other sociocultural characteristics identified as predictors of physical activity include age, ethnicity and gender. Boys appear to engage in higher levels of physical activity,^{46,69,73} report more participation in sports,⁵² and have higher levels of aerobic fitness than females.⁷⁴ Previous studies from our laboratory have suggested a minor gender difference in total energy expenditure in young children, that is detectable under some situations.⁶⁶ These gender differences are explained mainly by a lower resting energy expenditure in girls compared to boys (independent of differences in body composition, by approx. 50 kcal/d), with no difference in physical activity related energy expenditure.⁶⁶ However, gender differences in activity energy expenditure and reported physical activity become more apparent approaching puberty, because of the reported decline in physical activity in girls prior to puberty.⁶⁰

Only a few longitudinal studies have monitored physical activity during childhood growth. Saris *et al*⁷⁵ observed physical activity variables in 217 boys and 189 girls between the ages of 6–12 y. In girls, there was a tendency for a reduction in physical fitness (expressed per kilogram of body weight) by the age of 12 y. In addition, prior to puberty in girls, there is a 50% reduction in physical activity, expressed as activity energy expenditure under free-living conditions over 14 d in kcal/d and in qualitative terms, as h/d of reported physical activity.⁶⁰ The reduction in energy expenditure occurred despite a continued gain

in fat and fat-free mass that would be expected to contribute to an increased energy expenditure, and was also not associated with a concomitant reduction in energy intake. Collectively, these results suggest existence of an energy-conserving mechanism through reduced physical activity prior to puberty in girls. Alternatively, these findings could be explained by behavioural and/or environmental changes accompanying puberty. As young girls approach puberty, there may be a decrease in accessibility of structured activity and in social desirability of physical activity. This hypothesis is partially supported by the finding that 48% of high school girls do not exercise vigorously on a regular basis, compared to only 26% of high school boys.

In addition to gender, age demonstrates a relatively consistent pattern, with older children reporting less physical activity than younger children, although once again this relationship may be more pronounced among females.^{42,60} Yet, few previous studies have examined the effects of age, independent from pubertal development, suggesting a need for further research on the behavioural impact of both puberty and age.

Ethnicity is an additional factor presumed to influence physical activity among children, with levels being higher among Caucasian than African-American or Hispanic children, in terms of self-reported activity^{52,69,73} and physical fitness.^{76,77} According to the 1990 Youth Risk Behavior Survey, adolescent female African-American students (grades 9–12) were the least likely to be vigorously active three or more times per week.⁷⁸ We have previously shown that in African-American and Caucasian prepubertal children, free-living physical activity related energy expenditure was similar, but maximal aerobic fitness ($\dot{V}O_{2\text{ max}}$) was significantly lower in African-American children by 15%, independent of ethnic differences in body composition.⁷⁷ These data suggest that Caucasian children participated in activities of higher intensities than African-American children. In addition to physical activity and fitness, studies examining sedentary behaviour, usually measured by the limited indicator of television viewing, find higher amounts of inactivity among African-American children.⁷⁸ However, the potentially confounding influence of social class is an important caveat in the relationship between ethnicity and physical activity. It is likely that much of the statistical influence of ethnicity on physical activity could be due to the effects of social class, due to the disproportionately lower socioeconomic status (SES) of racial and ethnic minorities. The possibly underlying influence of social class is suggested by numerous studies reporting an inverse relationship between low socioeconomic background and physical activity and fitness.^{79,80} This pattern indicates a need for further research examining the influence of ethnicity on children's activity patterns, independent of confounding sociocultural characteristics such as social class background and likelihood of residing in a single-parent home.

In conclusion, physical activity is an extremely multidimensional concept among children. Although few guidelines have specifically been directed toward children and few evaluations of the compliance with such recommendations have been conducted, it appears that current levels of physical activity are inadequate. However, levels of physical activity in children are highly variable, depending on a wide range of physiological, psychological, ecological, and sociocultural factors.

Physical activity and obesity

The role of physical activity and energy expenditure in the development of obesity

The role of energy expenditure and physical activity in the development of obesity and body weight regulation, remains controversial. Although there are good examples of an inverse relationship between obesity and physical activity in children,^{81,82} and a positive relationship between obesity and physical inactivity,⁸³ some indices of physical activity (free-living activity energy expenditure) are positively related to fatness and do not predict the development of body fat in children.²⁶ In addition, although it is generally agreed that television may be related to the onset of obesity and reduced physical activity in children,^{45,59} with some prospective data suggesting that television viewing (as a marker for inactivity) in children predicts the development of obesity over time,⁸² these relationships are not supported by all prior studies.⁸⁴ Laboratory studies show that fitness and energy costs of specific activities are similar in lean and obese children after normalising for differences in body composition.^{85,86} Similar to the results for physical activity, there are some studies suggesting that a low level of energy expenditure predicts obesity,⁸⁷ and others which do not support this hypothesis.²⁶ This section briefly reviews the relationship between physical activity and energy expenditure in the development of obesity.

Physical activity is hypothesized to protect from the development of obesity through several channels. First, physical activity, by definition, results in an increase in energy expenditure due to the cost of the activity itself and is also hypothesized to increase resting metabolic rate (RMR).⁸⁸ These increases in energy expenditure are likely to decrease the likelihood of positive energy balance. However, the entire picture of energy balance must be considered, particularly the possibility that increases in one or more components of energy expenditure can result in a compensatory reduction in other components (that is, resting energy expenditure and activity energy expenditure).⁸⁹ Several examples of this exist, and have been reviewed previously.³⁰ Second, physical activity has beneficial effects on substrate metabolism,

with an increased reliance on fat, relative to carbohydrate, for fuel utilization.⁹⁰ Thus, it has been hypothesized that highly active individuals can maintain energy balance on a high fat diet.²⁵ In addition, the specific utilization of fat relative to carbohydrate may be influenced by the intensity of the exercise.⁵⁰ Unfortunately, there is a paucity of data in children relating to the influence of different exercise paradigms on substrate utilisation and energy balance. In addition to its impact on energy expenditure and metabolism, physical activity may have beneficial effects on food intake regulation, although this has also not been well studied in children.

Most studies which have examined physical activity and energy expenditure in the etiology of obesity have focused on the assessment of physical activity related energy expenditure or the impact of television viewing. However, as will be reviewed below, there are discrepant findings in the literature. Several cross-sectional studies in pre-pubertal children have shown that energy expenditure, including physical activity energy expenditure, is similar in lean vs obese children, especially after controlling for differences in body composition.^{91,92} Children of obese vs lean parents have also been examined as a model of 'pre-obesity'. One study showed that children of obese parents had a reduced energy expenditure, including physical activity energy expenditure,⁹³ whereas another study did not.⁹⁴ Other 'pre-obese' models that have been used to study the potential role of energy expenditure on the etiology of obesity include examination of ethnic groups at higher risk of obesity (for example, Mohawk Indians and African-Americans). We have previously shown that total energy expenditure was actually 8.5% higher in Mohawk compared to Caucasian children living in Vermont, because of a 37% higher physical activity-related energy expenditure in the Mohawk children.⁹⁵ In African-American children, a 14% lower resting energy expenditure was found compared with Caucasian children, adjusting for age, gender, weight, fat free mass and fat mass.⁹⁶ Among girls aged 6–16 y, lower resting energy expenditure was also found in African-Americans than Caucasians, adjusting for both body weight and lean body mass.⁹⁷ As mentioned previously, in Birmingham, Alabama, the prevalence of obesity in African-American children is almost twice that seen in Caucasian children,⁴ but there was no difference in energy expenditure components,⁹⁸ although African-American children had significantly lower levels of physical fitness.⁷⁷ There are no longitudinal data which have examined the role of decreased energy expenditure or physical activity in the development of obesity in high risk subgroups.

A major limitation for the majority of studies which have examined the role of energy expenditure in the etiology of obesity is their cross-sectional design. Because growth of individual components of body composition is likely to be a continuous process, longitudinal studies are necessary in evaluating the

rate of body fat change during the growing process. We have therefore examined whether childhood energy expenditure influences the rate of change in body fat relative to fat free mass over a four-year period. None of the components of energy expenditure were inversely related to change in fat adjusted for fat-free mass during pre-pubertal growth.²⁶

To sum up, the findings presented above illustrate an inconsistent pattern regarding the role of energy expenditure and physical activity in the etiology of obesity in children. There are several possibilities which could account for such discrepant findings. First, we have previously hypothesized that the ambiguous findings in the literature might be explained by the possibility that differences in energy expenditure and physical activity and their impact on the development of obesity are different at the various stages of maturation.²⁶ This hypothesis is supported by previous longitudinal studies in children showing that a reduced energy expenditure is shown to be a risk factor for weight gain in the first three months of life,⁸⁷ but not during the steady period of pre-pubertal growth.²⁶ Second, there could be individual differences in the impact of altered energy expenditure on the regulation of energy balance. This pattern was demonstrated in studies in which twins were challenged with under- or over-feeding.^{99,100} Thus, the impact of energy expenditure on the etiology of obesity, could vary among different sub-groups of the population (for example, boys vs girls, different ethnic groups) and could also have a differential effect within individuals at different stages of development. It is conceivable that susceptible individuals fail to compensate for periodic fluctuations in energy expenditure. Third, methodologically-related explanations can also be offered because of the complexity of the nature of physical activity and its measurement.

Finally, although physical activity-related energy expenditure is the most variable component in daily energy expenditure and therefore plays a key role in the regulation of energy balance,²⁹ there is some evidence to suggest that other more qualitative aspects of physical activity may be more important. For example, a study of 101 pre-pubertal children¹⁰¹ suggests that the time devoted to physical activity may have a more important influence on energy regulation than the daily energy cost of physical activity. After adjusting for fat free mass, gender and age, body fat mass was significantly and inversely related to physical activity in hours per week, derived by questionnaire ($r = -0.3$), but not physical activity related energy expenditure over 14 d by the doubly labeled water method.¹⁰¹ Similarly, in 49 girls aged 8–11 y, self-reported hours of physical activity at high intensity was significantly related to blood lipid levels, whereas activity energy expenditure measured by doubly labeled water was not.¹⁰² Collectively, these findings support the notion that qualitative aspects of physical activity (that is, duration and

frequency of physical activity) may be more important than physical activity related energy expenditure, in the regulation of energy balance and health. Thus, thorough characterization of physical activity using a variety of quantitative and qualitative tools is essential.

Intervention studies examining the impact of physical activity on obesity

In this section, we review intervention studies which have examined the influence of physical activity on body composition and obesity-related variables in children. A two year study in Japanese children reported reduced weight and body fat after daily, structured aerobic exercise.¹⁰³ In addition, a 15 week combined aerobic and strength training program resulted in a 3.7% decrease in body fat and an increase in fat free mass.¹⁰⁸ Interestingly, since intense physical activity interventions have previously been shown to reduce physical activity outside of the intervention,⁸⁹ it is important to examine the influence of exercise intervention on other aspects of physical activity. Only one such study has been conducted in children using an aerobic intervention. Blaak *et al*¹⁰⁴ showed that four weeks endurance training (45 min cycling, five times per week, at 50–60% of $\dot{V}O_2$ max) did not affect spontaneous physical activity outside of the intervention. Other programs have considered the impact of both physical activity and dietary modification. In a review, Bar-Or¹⁰⁷ reported a 5–20% decrease in body weight and body fat, respectively, after combined low calorie diet (LCD) and physical activity programs, ranging from 3–29 weeks in duration. Other studies using a diet plus exercise program have reported a reduction in body fat in obese children.^{108,109} The extent to which exercise intervention alone, without dietary intervention, can influence body composition and health risk in children is unclear. In a randomized and controlled study, Gutin¹¹⁰ examined the influence of four months of physical training (five days per week for 40 min per session) and detraining on body composition and health risk factors for obese children (aged 7–11 y) in the absence of any dietary intervention.¹⁰⁸ Physical activity led to significant beneficial changes in percent fat, visceral and subcutaneous abdominal adipose tissue, fasting insulin and triglycerides, and cardiac parasympathetic activity. Detraining generally led to unfavourable changes in percent fat and associated risk factors. There were no significant changes in any dietary factor.¹⁰⁸ Collectively, these studies suggest that aerobic exercise may reduce body fat in children, and can do so independent of diet intervention and changes in dietary intake.

In addition to aerobic exercise, strength training may also influence body composition in children. In adults, strength training has many metabolically beneficial effects including increased muscle mass,^{109–111} improved insulin sensitivity,¹¹² increased

resting energy expenditure (over and above that explained by the increased muscle mass)¹¹³ and decreased body fat,¹¹⁴ specifically from the intra-abdominal region.¹¹⁵ Although there are several studies involving strength training in children, most have focused on inducing changes in strength.¹¹⁶ For example, studies have reported significant increases in strength in pre-pubescent boys and girls after isotonic strength training,^{117–120} probably due to improved motor skill coordination, increased motor unit activation, and other undetermined neurological adaptations.¹²¹ Only one study, that we are aware of, has examined the influence of strength training on energy expenditure.¹²⁰ In a study of 11 obese pre-pubertal girls, there were no significant increases in energy expenditure after a five month strength training program, despite a significant 20% improvement in upper and lower body strength.¹²⁰ Interestingly, in the same study, there was no significant increase in visceral fat after strength training, despite significant increases in subcutaneous abdominal fat mass and overall body fat mass, suggesting that strength training may retard the rate of acquisition of visceral fat mass in growing obese girls.¹²² The majority of strength training studies in children of > 8 weeks report no muscle hypertrophy in boys or girls.^{119,123,124} Thus, the data on the effects of strength training on body composition and metabolic factors related to obesity are lacking and further studies are warranted.

In conclusion, previous research on the relationship between physical activity and obesity, particularly controlled interventions, demonstrates a clear association. The success of the controlled exercise interventions in improving body composition indicates an extremely promising area for the prevention of obesity. However, further studies are required to elucidate the specific effects of different types of exercise on the key features of body weight regulation. The following section considers broad-based public health interventions, describing widespread efforts to promote physical activity in children through behaviour interventions.

Promoting physical activity through behaviour change

Targets for intervention in the prevention of obesity

A recent classification system¹²⁵ has proposed three levels of prevention activity including: a) Universal/public health prevention, which targets everyone in the population regardless of risk (for example, health promotion and education in schools and mass media campaigns); b) selective prevention, which targets sub-groups of the population with a risk of developing obesity (for example, African-Americans and adolescent females); and c) targeted prevention, which focuses on high risk individuals (for example,

overweight subjects who are not yet defined as obese). The universal/public health prevention approach is thought to be most useful and cost-effective for obesity, because the prevalence is already very high and the majority of the population is at risk.¹⁴ In addition, while benefitting the majority of the population, the universal/public health interventions would not infer additional risk on the remainder of the population. Although selective and targeted approaches to prevention are important and should limit the progression and negative consequences of obesity, we have chosen to focus on primary prevention in this review. Universal/public health prevention includes intervention activities that target behaviours and risk factors for obesity in a general population of children and adolescents, without specifically targeting those with elevated body fatness.

Previous studies using physical activity for the prevention of obesity

Several areas of behavioural intervention have utilised the universal/public health strategy for obesity prevention in children and adolescents through increased physical activity. These include family- and school-based interventions, as well as other environmental approaches to intervention. Because of our emphasis on universal/public health prevention, we have excluded studies which targeted only obese children and adolescents. We have also included studies which attempted to increase physical activity (or decrease sedentary behaviour), even if they contained intervention components for both physical activity and diet. Only outcome measures related to physical activity, aerobic fitness and body composition are presented for each study.

School-based interventions. School-based interventions have several advantages. More than 95% of children aged 5–17 y are enrolled in school, making schools an ideal setting to reach children and adolescents with health promotion and disease prevention programs.¹²⁶ Because a wide range of children and adolescents attend school, traditionally ‘hard-to-reach’ groups can also receive health promotion and disease prevention programs through this setting.¹²⁷ In addition, regular attendance at school provides health promoters with repeated access to children and enables repeated exposure to intervention activities. The school setting also provides opportunities for environmental modification which can produce long-term behaviour change well after the original intervention team has left the school. School policies can be modified, teachers and other personnel can be trained, and interventions in the physical environment can be made to support behaviour change. Schools can also provide access to the families of participating children, possibly reducing the disease risk of parents and siblings, as well as creating a home environment that is supportive of the change being produced in the recruited child.

School-based interventions, using a variety of strategies for health promotion, have been implemented. Several examples of interventions targeting some aspect of physical activity or fitness can be found in the literature. As will be described in the following paragraphs, many of these interventions have been guided by the widely-used Social Cognitive Theory (SCT), which considers three influential components: person, environment and behaviour. The physical activity-related results of several major school-based interventions will be briefly reviewed.

'Go for Health' was a theory-based intervention with physical activity components.¹²⁸ Targeting third and fourth graders (age 8–9 y), two elementary schools were assigned to the intervention condition and two elementary schools to a measurement only control condition. Physical activity components of the intervention included the implementation of a vigorous physical education curriculum. This intervention measured only physical activity inside school physical education classes, and results indicated that the percentage of physical education class time spent in moderate-to-vigorous activity increased significantly over a two year period, and the amount of time spent in physical activity was significantly higher in intervention schools compared to control schools.

'Know Your Body'^{129,130} was a school-based intervention developed by the American Health Foundation and designed to reduce the risk of CVD. The interventions included in this program are health screening, a behaviour-oriented health education curriculum for students, and parent education. Although indicators of cardiovascular risk have been evaluated in several studies,^{131–133} physical fitness outcomes have received little attention. However, early results suggested a favourable effect of the program, with aerobic fitness scores significantly increasing after two years of intervention.¹³⁰ Although measurement and assessment limitations prevent consistent results from being identified, the third study testing this intervention, a randomized trial among African-American children, yielded mixed results regarding physical activity. Although students from the intervention and control schools increased their health knowledge after a four-year period, with these gains being higher among intervention schools, there were no difference in levels of physical activity between students enrolled in the intervention and control schools. In addition, levels of physical activity among all children decreased over the four year period, consistent with the previously-discussed trend toward a reduction in children's extent of physical activity with age.

Two adaptations of the 'Know Your Body' program for international schools have been implemented, evaluated and reported in the literature. The Israeli version of the Know Your Body program included one unit on physical activity¹³⁴ and was evaluated using eight intervention and eight matched control schools. Children were recruited and pretested in the first-grade (age 6 y) and were retested after intervention

delivery in the third-grade (age 8 y). Levels of physical activity were not assessed; however, weight and height measures were collected along with additional behavioural (for example, dietary behaviour) physiological measures (for example, total cholesterol.) BMI was calculated and intervention effects were demonstrated on BMI with intervention children having lower BMI levels than control children. Another modification of the 'Know Your Body' program was developed and evaluated in Crete¹³⁵ and included units on physical fitness. Three high schools in one community were assigned to the intervention condition and two were assigned to the control condition. Students, aged 13 y at recruitment, were assessed at baseline and at one-year post-baseline. Physical activity was not assessed, but height, weight and skinfold thickness were measured for each participant. Significantly greater increases in BMI were observed in the control students, compared to intervention students at the one-year follow-up period.

In a study conducted in Australia, 30 schools were randomly assigned to one of five intervention conditions or a control condition.¹³⁶ Two of these conditions involved the implementation of a fitness program with six 30 min classroom sessions. Exercise activities were structured and teachers were offered resource packages to help with fitness instruction. A range of measures were collected including physical fitness, assessed using a 1.6 kilometer run and a Leger shuttle run, height, weight and skinfold measures. Baseline data were collected in the first term of the sixth-grade (age 11 y) and post-test data were collected in the fourth-term of that same year. Increases in endurance fitness were observed in the fitness conditions compared to controls in boys and girls. In one fitness condition, both boys and girls exhibited greater reductions in triceps skinfold measures compared to controls. No effects were observed for BMI.

Researchers at Stanford University developed the '10th Grade Study' to conduct multi-risk factor intervention for CVD among high school students in the 10th grade.¹³⁷ They designed a 20 week program, based on social cognitive theory and delivered by study staff. The classroom-based intervention focused on cardiovascular risk factors, including physical activity, and was conducted in two intervention high schools, with two matched control high schools. At two-month follow-up, physical activity knowledge gains were greater for children in the intervention condition. In addition, among students sedentary at baseline, a higher proportion reported regular exercise at follow-up. Differences favouring the intervention condition were also found for physical activity knowledge, resting heart rates, BMI, triceps skinfold thickness and subscapular skinfold thickness.

Project SPARK,¹³⁸ which was guided by social cognitive theory (SCT), used a quasi-experimental design, and randomly assigned seven elementary schools to receive physical education either *via* usual mechanisms, trained teachers, or specialized

physical education instructors. Self-reports of physical activity, Caltrac assessments of activity, measures of fitness, skinfold measurements and BMI, were monitored for two years.¹³⁸ Results indicated increased activity in the schools during physical education class in the intervention delivered by education specialists and trained teachers, compared to the usual instruction delivered by untrained teachers.¹³⁸ In addition, after two years, the girls who received the intervention from the education specialists demonstrated greater endurance in the mile run and completed more sit-ups in one minute than girls in the control condition. No fitness effects were found for boys two years after the intervention, and no improvements were found for physical activity occurring outside of the school.

One of the most extensive prevention studies ever completed for children was the school-based randomized trial entitled 'Child and Adolescent Trial for Cardiovascular Health' (CATCH).^{139–142} CATCH was a multi-site, school-based ($n = 96$ schools) intervention designed to reduce the development of CVD risk factors in ethnically-diverse 8–10 year olds, through changes in food-service, physical education curriculum, health education in the classroom, and parent involvement. Three conditions were used in CATCH: school intervention, school + family, and control. Children in treatment schools were observed to have greater levels of moderate to vigorous physical activity during physical education classes, and also reported a significantly greater physical activity in general, amounting to almost 1.5 h per week.¹⁴³

Family-based interventions. In addition to school-based intervention components aimed at promoting physical activity, evidence strongly suggests the importance of including family-based components to enhance the effectiveness of interventions.¹⁴⁴ Few intervention studies have been completed using the universal/public health approach, a family-based intervention component, and a carefully conducted evaluation of intervention effectiveness. In the paragraphs below, studies using a family-based component are reviewed.

Stolley and Fitzgibbon¹⁴⁹ conducted nutrition and exercise intervention with 65 pairs of mothers and children through a tutoring program based on the 'Know Your Body' program modules and pilot data collected by the authors. Although both dietary and activity outcomes were explored, the only significant program effect in children (also noted in mothers) was a reduction in percentage of calories from fat. Despite several methodological limitations, the study did demonstrate success in getting parent-child pairs to attend an obesity prevention program and success in modifying the behaviours of parents, who serve as role models for the children and control environmental variables that influence the children's behaviour directly.

Nader¹⁴⁶ conducted a novel study in which 12–15 elementary schools were assigned to a treatment or

control condition. Families with a fifth- or sixth-grade (10–11 y) child were then recruited from each school to participate in a family-based intervention held at local schools. Families participated in three months of weekly sessions and nine months of monthly to bi-monthly maintenance sessions. Based on social learning theory, each group session involved an exercise segment, separate child and adult education segments, a family behaviour management segment and a snack segment. Results showed that adults and children in the experimental condition gained more knowledge regarding skills needed to exercise than families in the control condition. However, no differences were observed for reported physical activity or in fitness tests between the conditions, although differences favouring the intervention were found in adults and children for blood pressure.

Environmental and Policy Approaches. Policy and environmental changes are potentially important components of obesity prevention efforts.¹⁴⁶ These approaches might be considered 'passive' and do not require substantial individual behaviour change to produce increased physical activity. King *et al*¹⁴⁶ has provided an excellent compilation of changes in policy and environment that might lead to community-wide increases in physical activity. For children and adolescents, the provision of athletic equipment, the building of play areas and athletic facilities, the provision of light for night time activities, the provision of safe environments for exercise, and access to sidewalks and bike paths, are likely to facilitate and promote physical activity among children. In addition, coalitions might be organized at the local level to influence school and community decision-making and increasing the availability of the resources noted above. Even policy and environmental efforts targeted at adults might influence the activity levels of children including the promotion of physical activity in the workplace, leading to increased activity among the parents and perhaps a more active home environment. Critical to the success of these environmental efforts will be the creation of overarching national, state and local plans to create environments more conducive to physical activity. In addition, crucial steps can be taken in the schools including the training of educators to deliver physical activity programs, the institutionalization of programs such as SPARK¹³⁸ or CATCH, which have been demonstrated to be effective, and the integration of physical activity into other school activities.

Children and adolescents spend large amounts of time watching television. As reviewed above, television viewing may be related to obesity and reduced physical activity in children. Thus, the mass media may be an important arena for environmental modifications promoting physical activity in children and adolescents. Despite the potential for media interventions, relatively little work has been undertaken to

develop and test mass media interventions to increase physical activity. An evaluation of a television campaign conducted in Australia to increase physical activity showed elevated activity for adults, but not for children.¹⁴⁷ Studies have also used the mass media in combination with school-based activities, for the prevention of smoking in adolescents. Little corresponding work has been undertaken with physical activity, although the combined media and school approach may be effective at reaching children and adolescents. A novel approach involving mass media is the use of Media Advocacy,¹⁴⁸ which requires the active involvement of interested community members in the promotion of a health issue, using the media as an aid. For example, interested individuals might form coalitions to promote exercise by structuring media events and using health data creatively to foster community awareness and action.

To sum up, preventive action taken to reduce obesity through increased physical activity appears to be an encouraging area. Interventions targeting schools, families, communities and environmental factors may play a major role in reducing the prevalence of pediatric obesity. However, despite the evidence that the causes of obesity are environmental, there are relatively few intervention studies targeting policy and physical environmental strategies. Individual-level interventions have received the majority of research attention, attempting to foster change in children's attitudes, knowledge and self-efficacy. Yet numerous barriers to physical activity exist at several levels, such as the familial, community and environmental. Appropriate strategies to increase physical activity should target broader determinants of children's physical activity patterns.

Conclusions

Summary and recommendations

This review has considered in detail the potential ability of physical activity interventions to reduce the prevalence of pediatric obesity. As discussed in the previous section, the most effective strategies for promoting physical activity in children are likely to be theory based and involve school and community interventions as well as significant family involvement. In addition, in order to achieve the goal of preventing pediatric obesity, there is a clear need to design programs that are culturally relevant and appropriate for the diversity of school-aged children regarding factors such as ethnicity, gender, age, region and SES. Clearly, these efforts will require concerted attempts among various partnerships, including government, school education boards, parents, educators, industry and trade organisations, professional organisations, and the mass media. The end result of this collaboration could include the development and universal provision of comprehensive physical and health

education curricula, changes in the school and community environment that promote enjoyable and safe physical activity before, during, and after school, the involvement of the family, and the training of personnel.

In addition to the primary goal of increasing the frequency and enjoyment of physical activity, recommended interventions should also incorporate the goal of improving muscular strength and physical fitness. Improving muscular strength may be important because the effect of prolonged inactivity during periods of muscular growth may be detrimental to overall skeletal development. Interventions designed to increase physical fitness are particularly important because epidemiological data indicate that low fitness is a powerful precursor of mortality in adults. For example, moderate levels of physical fitness exhibit a protective effect against the influence of factors contributing to mortality such as smoking, hypertension and hypercholesterolemia.⁷³ It is currently unknown whether aerobic capacity or physical activity patterns in children would affect long-term adult health outcomes, but given the argument that patterns of physical activity and fitness formed during childhood extend into adulthood (see discussion in an earlier section), physical fitness and activity are likely to have direct and indirect health consequences later on in life.

A number of recommendations can be made regarding the universal/public health approach to obesity prevention, beginning with school-based approaches. The school-based primary prevention studies have demonstrated some success in the modification of self-reported and observed physical activity and changes in body composition. The majority of school-based interventions have relied on a theoretical approach when promoting physical activity among children. As reviewed in the preceding section, SCT has been widely used to develop school-based interventions utilizing physical activity. SCT and other theories provide guidance for intervention developers and also lead to the most effective intervention strategies. The continued use of theory-based approaches should aid in the development of additional effective interventions for children and adolescents. In addition to designing interventions based on a strong theoretical framework, studies should also incorporate improved methodology. The consistent application of strong design and measurement principles will be needed in future research so that conclusive decisions can be made about the effectiveness of intervention approaches at producing increased physical activity and improvements in body composition in children and adolescents.

As mentioned previously, ideal interventions should target increased physical activity in families, as well as schools. This approach remains attractive since it provides another avenue for intervention with children, provides environmental changes at home that will support increased physical activity among

the children, and could provide access to other family members for physical activity intervention. Despite the barriers which exist to mounting effective family-based interventions, new and innovative intervention models should be attempted with families to increase their participation and the effectiveness of the interventions. These models will need to integrate exercise into the ongoing life of the family, including existing recreational activities, as well as work activities around the home. It is likely that family interventions will prove to be most effective when they are integrated with school- and community-level programs, helping to embed physical activity into an overall lifestyle pattern for the family.

Novel environmental approaches described in detail by King *et al*¹⁴⁷ and reviewed in the previous section of this paper, have been under-utilized as a tool to increase physical activity among children and adolescents. Since many of these approaches are passive, and do not require direct intervention to change individuals' knowledge, attitudes and skills, they may reach many people at low cost and may provide enduring changes in physical activity. As a result, communities should continue to examine and enact policy and environmental changes that will promote physical activity. The implementation of policy and environmental changes will require a coordinated effort that is supported at the national, state and local levels. Federal government agencies, state departments of education or health, and major private organizations might provide the necessary leadership to foster policy and environmental change. The efforts of these organizations will also require grass roots support, perhaps *via* coalitions formed to promote physical activity in the local community. Media advocacy can also play a role in effecting policy change by increasing awareness of the need for restructuring our local environments to support physical activity. Mass media approaches, along with other types of environmental modifications, may be most effective when used in conjunction with school and family interventions.

Directions for future research

Although this review has discussed in detail the role of physical activity in obesity prevention among children, there are several gaps in the literature. First, attention to the variability in children's activity patterns is warranted. In particular, further research is needed to determine habitual physical activity patterns of children of different ethnic and cultural groups, as well as to find culturally-appropriate ways to educate and motivate children to adopt regular physical activity patterns. Attention to ethnic and cultural differences in children also includes physiological components. In particular, the long-term relationship between physical activity and/or aerobic fitness and risk of obesity and other chronic diseases has yet to be determined in different ethnic groups. Similarly,

studies exploring differences in the influence of physical activity on food intake regulation and substrate and energy metabolism, and the subsequent susceptibility to obesity is needed. In addition, although guidelines for children's appropriate levels of physical activity are available, empirical evidence of whether children are meeting such recommendations is needed. A related suggestion for future research is an exploration of the optimal intensity, frequency, duration and mode of exercise among children, including the impact of exercise on physical fitness and other obesity-related factors. Additional behavioural interventions should be examined with improved outcome measures to examine different approaches for promoting physical activity in schools, families and communities.

Recommendations

It is clear that promoting physical activity in children will have a crucial role in the life-long prevention of obesity. However this is not as straightforward as it would appear, as the successful promotion of physical activity is complex and will require knowledge and incorporation of physiological, environmental, behavioural, cultural, legislative and financial factors. Because childhood is a time for 'free play', children should be encouraged to participate in spontaneous physical activity which is well-integrated into daily life, rather than being directed towards regimented exercise programs. The physical education curriculum, in particular, should promote skills essential for developing physical activity patterns and instill a general appreciation for physical activity later in the adult years. A realistic approach to the prevention of obesity would be to have schools, families and communities provide an atmosphere that encourages a physically active existence in combination with sound nutritional practices. This atmosphere can be achieved by having parents and teachers serve as role models themselves by participating regularly in physical activity and by providing ample opportunity for 'active free play' instead of encouraging sedentary activities (such as watching television). Undoubtedly, the promotion of physical activity in children will require significant resources, major policy changes, environmental planning and educational efforts in schools and communities. Novel solutions must be developed to overcome the numerous barriers to promotion of physical activity. The impetus to make these changes on a broad societal level is not currently evident. However, rising levels of obesity and the consequent results for morbidity and mortality may provide some motivation for change.

Acknowledgements

This study was supported by the United States Department of Agriculture (95-37200-1643), and the

National Institute of Child Health and Development
(R29 HD 32668; RO1 HD/HL 33064).

References

- 1 Troiano RP, Flegal KM, Kuzmarski RJ. Overweight prevalence and trends for children and adolescents. *Arch Pediatr Adolesc Med* 1995; **149**: 1085–1091.
- 2 Center for Disease Control. Prevalence of overweight among adolescents—United States, 1988–91 *Morb Mortal Weekly Rep* 1994; **44**: 818–821.
- 3 Freedman DS, Srinivasan SR, Valdez RA, Williamson DF, Berenson GS. Secular increases in relative weight and adiposity among children over two decades: the Bogalusa Heart Study. *Pediatrics* 1997; **99**: 420–426.
- 4 Figueroa-Colon R, Franklin FA, Lee JY, Aldridge R, Alexander L. Prevalence of obesity with increased blood pressure in elementary school-aged children *J South Med Assoc* 1997; **90**: 806–813.
- 5 Morrison JA, Payne G, Barton BA, Khoury PR, Crawford P. Mother-daughter correlations of obesity and cardiovascular disease risk factors in black and white households: The NHLBI Growth and Health Study. *Am J Public Health* 1994; **84**: 1761–1767.
- 6 The NHLBI Growth and Health Study Research Group. Obesity and Cardiovascular Disease risk factors in black and white girls: The NHLBI Growth and Health study. *Am J Public Health* 1992; **82**: 1613–1620.
- 7 Charney E, Goodman HC, MacBride M, Lyon B, Pratt B. Childhood antecedent of adult obesity: Do chubby infants become obese adults? *N Engl J Med* 1976; **295**: 6–9.
- 8 Stark D, Atkins E, Wolff DH, Douglas JWB. Longitudinal study of obesity in the National Survey of Health and Development. *BMJ* 1981; **283**: 12–17.
- 9 Abraham S, Collins C, Nordsieck M. Relationship of child weight status to morbidity in adults. *Public Health Rep* 1970; **86**: 273–284.
- 10 Must A, Jacques PF, Dallal GE, Bajema CJ, Dietz WH. Long-term morbidity and mortality of overweight adolescents: a follow-up of the Harvard Growth Study of 1922 to 1935. *New Engl J Med* 1992; **327**: 1350–1355.
- 11 Whitaker RC, Pepe MS, Wright JA, Seidel KD, Dietz WH. Early adiposity rebound and the risk of adult obesity. *Pediatrics* 1998; **101**: e5.
- 12 Dietz WH. Critical periods in childhood for the development of obesity *Am J Clin Nutr* 1994; **59**: 955–959.
- 13 Whitaker RC, Wright JA, Pepe MS, Seidel KD, Dietz W. Predicting obesity in young adulthood from childhood and parental obesity *N Engl J Med* 1997; **337**: 869–873.
- 14 Report of a World Health Organization Consultation on Obesity. *Obesity: Preventing and managing the global epidemic*. WHO: Geneva, 1997. WHO/NUT/NCD/98.1.
- 15 Hubert HA. Obesity as an independent risk factor for cardiovascular disease. A 26 year follow up of participants in the Framingham heart study. *Circulation* 1983; **67**: 968.
- 16 Després J-P, Moorjani S, Lupien PJ, Tremblay A, Nadeau A, Bouchard C. Regional distribution of body fat, plasma lipoproteins, and cardiovascular disease. *Arteriosclerosis* 1990; **10**: 497–511.
- 17 Björntorp P. Abdominal fat distribution and disease: An overview of epidemiological Data. *Ann Med* 1992; **24**: 15–18.
- 18 Neumark-Aztainer D, Story M, French SA, Hannan PJ, Resnick MD, Blum R. Psychosocial concerns and health-compromising behaviors among overweight and nonoverweight adolescents. *Obes Res* 1997; **5**: 237–249.
- 19 Ballard-Barbash R. Anthropometry and breast cancer: body size—a moving target. *Cancer* 1994; **74** (Suppl): 1090–1100.
- 20 Huang Z, Hankinson SE, Colditz GA, Stampfer MJ, Hunter DJ, Manson JE, Hennekens CH, Rosner B, Speizer FE, Willett WC. Dual effects of weight and weight gain on breast cancer risk. *JAMA* 1997; **278**: 1407–1411.
- 21 Bao W, Srinivasan SR, Valdez R, Greenlund KJ, Wattigney WA, Berenson GS. Longitudinal changes in cardiovascular risk from childhood to young adulthood in offspring of parents with coronary heart disease. *JAMA* 1997; **278**: 1749–1754.
- 22 Pinhas-Hamiel O, Dolan LM, Daniels SR, Standiford D, Khoury PR, Zeitler P. Increased incidence of non-insulin-dependent diabetes mellitus among adolescents. *J Pediatr* 1996; **128**: 608–615.
- 23 Quesenberry CP, Caan B, Jacobson A. Obesity, health service use, and health care costs among members of a Health Maintenance Organization. *Arch Int Med* 1998; **158**: 466–472.
- 24 Wolf AA, Colditz GA. Current estimates of the economic cost of obesity in the United States. *Obes Res* 1998; **6**: 97–106.
- 25 Hill JO, Peters JC. Environmental contributions to the obesity epidemic. *Science* 1998; **280**: 1371–1374.
- 26 Goran MI, Shewchuk R, Gower BA, Nagy TR, Carpenter WH, Johnson R. Longitudinal changes in fatness in white children: No effect of childhood energy expenditure. *Am J Clin Nutr* 1998; **67**: 309–316.
- 27 Ravussin E, Swinburn BA. Pathophysiology of obesity. *Lancet* 1992; **340**: 404–412.
- 28 Hill JO, Pagliassotti MJ, Peters JC. In: Bouchard, C (eds). *Genetic determinants of obesity*. CRC Press, Inc: Boca Raton, 1994, 35–48.
- 29 Goran MI. Variation in total energy expenditure in humans. *Obes Res* 1995; **3**: 59–66.
- 30 Goran MI, Poehlman ET, Johnson RK. Energy requirements across the life span: new findings based on measurement of total energy expenditure with doubly labeled water. *Nutr Res* 1995; **15**: 115–150.
- 31 Kann L, Warren CW, Harris WA, Collins JL, Williams BI, Ross JG, Kolbe LJ. Youth Risk Behavior Surveillance—United States, 1995. *J School Health* 1996; **66**: 377.
- 32 Berenson GS, Wattigney WA, Bao W, Srinivasan SR, Radhakrishnamurthy B. Rationale to study the early natural history of heart disease: the Bogalusa Heart Study. *Am J Med Sci* 1995; **310**: s22–s28.
- 33 Sallis JF, McKenzie TL, Alcaraz JE. Habitual physical activity and health-related physical fitness in fourth-grade children. *Am J Dis Child* 1993; **147**: 890–896.
- 34 Goran MI, Nagy TR, Treuth MT, Trowbridge C, Dezenberg C, McGloin A, Gower BA. Visceral fat in Caucasian and African-American pre-pubertal children *Am J Clin Nutr* 1997; **65**: 1703–1709.
- 35 Fox K, Peters D, Armstrong N, Sharpe P, Bell M. Abdominal fat deposition in 11-year-old children *Int J Obes* 1993; **17**: 11–16.
- 36 Caprio S, Hyman LD, McCarthy S, Lange R, Bronson M, Tamborlane WV. Fat distribution and cardiovascular risk factors in obese adolescent girls: Importance of the intraabdominal fat depot. *Am J Clin Nutr* 1996; **64**: 12–17.
- 37 Caprio S, Hyman LD, Limb C, McCarthy S, Lange R, Sherwin RS, Shulman G, Tamborlane WV. Central adiposity and its metabolic correlates in obese adolescent girls. *Am J Physiol* 1995; **269**: E118–E126.
- 38 Gower BA, Nagy TR, Trowbridge CA, Dezenberg C, Goran MI. Fat distribution and insulin response in pre-pubertal African American and Caucasian children. *Am J Clin Nutr* 1997; **67**: 821–827.
- 39 Bao W, Srinivasan SR, Wattigney WA, Berenson GS. Persistence of multiple cardiovascular risk clustering related to syndrome X from childhood to young adults. *Arch Intern Med* 1994; **154**: 1842–1848.
- 40 Malina RM. Tracking of physical activity and physical fitness across the lifespan. *Res Q Exerc Sport* 1996; **67**: S48–S57.

- 41 Pate RR, Baranowski T, Dowda M, Trost SG. Tracking of physical activity in young children. *Med Sci Sport Exer* 1996; **28**: 92–96.
- 42 Sallis JF, Berry CC, Broyles SL, McKenzie TL, Nader PR. Variability and tracking of physical activity over 2 yr in young children. *Med Sci Sport Exer* 1995; **27**: 1042–1049.
- 43 The National Task Force on the Prevention and Treatment of Obesity. Towards prevention of obesity: research directions. *Obes Res* 1994; **2**: 571–584.
- 44 Gortmaker SL, Dietz WH, Cheung LWY. Inactivity, diet and the fattening of America *J Am Diet Assoc* 1990; **90**: 1247–1252.
- 45 Dietz WH, Gortmaker SL. Do we fatten our children at the television set? Obesity and television viewing in children and adolescents. *Pediatrics* 1985; **75**: 807–812.
- 46 Deheeger M, Cachera-Rolland MF, Fontvieille AM. Physical activity and body composition in 10 year old french children: linkage with nutritional intake? *Int J Obes* 1997; **21**: 372–379.
- 47 Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise and physical fitness. *Public Health Rep* 1985; **100**: 125–131.
- 48 Saris WH. Habitual physical activity in children: methodology and findings in health and disease. *Med Sci Sport Exer* 1986; **18**: 253–263.
- 49 Goran MI. Measurement issues related to studies of childhood obesity: Assessment of body composition, body fat distribution, physical activity and food intake. *Pediatrics* 1998; **101**: 505–518.
- 50 Hunter GR, Weinsier RL, Bamman MM, Larson DE. A role for high intensity exercise on energy balance and weight control. *Int J Obes* 1998; **22**: 489–493.
- 51 Reynolds K, Killen JD, Beyson SW, Maron DJ, Taylor CB, Maccoby N, Farquhar JW. Psychosocial predictors of physical activity in adolescents. *Prev Med* 1990; **19**: 541–551.
- 52 *Physical Activity and Health: A report from the Surgeon General*. US Dept of Health and Human Services: Atlanta, 1996.
- 53 Sallis JF, Patrick K. Physical activity guidelines for adolescents: consensus statement *Pediatr Exerc Sci* 1994; **6**: 302–314.
- 54 Centers for Disease Control and Prevention. Guidelines for school and community programs to promote lifelong physical activity among young people *Morb Mortal Weekly Rep* 1997; **46**, 1–36.
- 55 Haskell W. Physical activity, sport and health: Toward the next century. *Res Q Exerc Sport* 1996; **67**: 37–47.
- 56 Bailey RC, Olson J, Pepper SL, Porszasz, J, Barstow, TJ, Cooper, DM. The level and tempo of children's physical activities: an observational study. *Med Sci Sport Exer* 1995; **27**: 1033–1041.
- 57 Shephard RJ, Jequier JC, Lavalley H, LaBarre R, Rajic M. Habitual physical activity: effects of sex, milieu, season and required activity. *J Sports Med Phys Fitness* 1980; **20**: 55–66.
- 58 Ross JG, Dotson CO, Gilbert GG, Katx SJ. After physical education: Physical activity outside of school physical education programs. *J Phys Educ Recr Dance* 1985; **56**: 35–39.
- 59 Andersen RE, Crespo CJ, Bartlett SJ, Cheskin LJ, Pratt M. Relationship of physical activity and television watching with body weight and level of fatness among children. *JAMA* 1998; **279**: 938–942.
- 60 Goran MI, Gower BA, Nagy TR, Johnson R. Developmental changes in energy expenditure and physical activity in children: Evidence for a decline in physical activity in girls prior to puberty. *Pediatrics* 1998; **101**: 887–891.
- 61 Kohl HW, Hobbs KE. Development of physical activity behaviors among children and adolescents. *Pediatrics* 1998; **101**: 549–554.
- 62 Anonymous. Gender differences in physical activity and determinants of physical activity in rural fifth grade children. *J School Health* 1996; **66**: 145–150.
- 63 Garcia AW, Norton-Broda MA, Frenn M, Coviak C, Pender NJ, Ronos DL. Gender and developmental differences in exercise beliefs among youth and prediction of their behavior. *J School Health* 1995; **65**: 213–219.
- 64 Zakarian JM, Hovell MF, Hofstetter CR, Sallis JF, Jeating KJ. Correlates of vigorous exercise in a predominantly low SES and minority high school population. *Prev Med* 1994; **23**: 314–321.
- 65 Ross JG, Pate, RR. The National Children and Youth Fitness study. *J Phys Educ Recr Dance* 1987; **58**: 51–56.
- 66 Goran MI, Nagy TR, Gower BA, Mazariegos M, Solomons N, Hood V, Johnson R. *Am J Clin Nutr* 1998; **68**: 675–682.
- 67 Baranowski T, Thompson WO, Durant RH, Baranowski J, Puhl J. Observations on physical activity in physical locations: age, gender, ethnicity and month effects. *Res Q Exerc Sport* 1993; **64**: 127–133.
- 68 Moore LL, Lombardi DA, White MJ, Campbell JL, Oliveria SA, Ellison RC. Influence of parents' physical activity levels on activity levels of young children. *J Pediatr* 1991; **118**: 215–219.
- 69 Anderssen N, Wold B. Parental and peer influences on leisure-time physical activity in young adolescents. *Res Q Exerc Sport* 1992; **63**: 341–348.
- 70 Sallis JF, Alcaraz JE, McKenzie TL, Hovell MF, Kolody B, Nader PR. Parental behavior in relation to physical activity and fitness in 9-year-old children. *Am J Dis Child* 1992; **146**: 1383–1388.
- 71 Stucky-Ropp RC, DiLorenzo TM. Determinants of exercise in children. *Prev Med* 1993; **22**: 880–889.
- 72 Perusse L, Tremblay A, Leblanc C, Bouchard C. Genetic and environmental influences on level of habitual physical activity and exercise participation. *Am J Epidemiol* 1986; **129**: 1012–1020.
- 73 Pate RR, Heath GW, Dowda M, Trost SG. Associations between physical activity and other health behaviors in a representative sample of US adolescents. *Am J Public Health* 1996; **86**: 1577–1581.
- 74 VandenBergh MF, DeMan SA, Witterman JC, Hofman A, Trouerbach WT. Physical activity, calcium intake and bone mineral content in children in The Netherlands. *J Epidemiol Commun H* 1995; **49**: 299–304.
- 75 Saris WHM, Elvers JWH, van't Hof MA, Binkorst RA. In: (Rutenfranz J, Mocellin R Klimt F eds) *Children and Exercise XII*. Human Kinetics Publishers, Inc: Champaign, 1986, 121–130.
- 76 Pivarnik JM, Bray MS, Hergenroeder AC, Hill RB, Wong WW. Ethnicity affects aerobic fitness in US adolescent girls. *Med Sci Sport Exer* 1995; **27**: 1635–1638.
- 77 Trowbridge C, Gower BA, Nagy TR, Goran MI. Aerobic fitness in African American and Caucasian children. *Am J Physiol* 1997; **273**: E809–E814.
- 78 DiPietro L, Caspersen CJ. National estimates of physical activity among white and black Americans. *Med Sci Sport Exer* 1991; **23**: S105.
- 79 Allison KR. Predictors of inactivity: An analysis of the Ontario Health Survey. *Can J Public Health* 1996; **87**: 354–358.
- 80 Epstein LH, Paluch RA, Coleman KJ, Vito D, Anderson K. Determinants of physical activity in obese children assessed by accelerometer and self-report. *Med Sci Sport Exer* 1996; **28**: 1157–1164.
- 81 Stunkard A, Pestka J. The physical activity of obese girls. *Am J Dis Child* 1962; **103**: 116–121.
- 82 Gortmaker SL, Must A, Sobol AM, Peterson K, Colditz GA, Dietz WH. Television viewing as a cause of increasing obesity among children in the United States, 1986–1990. *Arch Pediatr Adolesc Med* 1996; **150**: 356–362.
- 83 Maffei C, Zaffanello M, Schutz Y. Relationship between physical inactivity and adiposity in prepubertal boys. *J Pediatr* 1997; **131**: 288–292.

- 84 Robinson TN, Hammer LD, Killen JD, Kraemer HC, Wilson DM, Hayward C, Barr Taylor C. Does television viewing increase obesity and reduce physical activity? Cross-sectional and longitudinal analyses among adolescent girls. *Pediatrics* 1993; **91**: 273–280.
- 85 Maffei C, Schutz Y, Schena F, Zaffanello M, Pinelli L. Energy expenditure during walking and running in obese and nonobese prepubertal children *J Pediatr* 1993; **123**: 193–199.
- 86 Maffei C, Schena F, Zaffanello M, Zocante L, Schutz Y, Pinelli, L. Maximal aerobic power during running and cycling in obese and non-obese children. *Acta Paediatr* 1994; **83**: 113–116.
- 87 Roberts SB, Savage J, Coward WA, Chew B, Lucas A. Energy expenditure and intake in infants born to lean and overweight mothers. *N Engl J Med* 1988; **318**: 461–466.
- 88 Poehlman ET. A review: exercise and its influence on resting energy metabolism in man. *Med Sci Sport Exer* 1989; **21**: 515–525.
- 89 Goran MI, Poehlman ET. Endurance training does not enhance total energy expenditure in healthy elderly persons. *Am J Physiol* 1992; **263**: E950–E957.
- 90 Almras N, Lavalle N, Desprs J-P, Bouchard C, Tremblay A. Exercise and energy intake: Effect of substrate oxidation. *Physiol Behav* 1995; **57**: 995–1000.
- 91 DeLany JP, Harsha DW, Kime J, Kumler J, Melancon L, Bray GA. Energy expenditure in lean and obese pre-pubertal children. *Obes Res* 1995; **3**: S67–S72.
- 92 Treuth MS, Figueroa-Colon R, Hunter GR, Weinsier RL, Butte NF, Goran MI. Energy expenditure and physical fitness in overweight vs non-overweight prepubertal girls. *Int J Obes* 1998; **22**: 440–447.
- 93 Griffiths M, Payne PR. Energy expenditure in small children of obese and non-obese parents. *Nature* 1976; **260**: 698–700.
- 94 Goran MI, Carpenter WH, McGloin A, Johnson R, Hardin M, Weinsier RL. Energy expenditure in children of lean and obese parents. *Am J Physiol* 1995; **268**: E917–E924.
- 95 Goran MI, Kaskoun MC, Martinez C, Kelly B, Carpenter WH, Hood VL. Energy expenditure and body fat distribution in Mohawk Indian children. *Pediatrics* 1995; **95**: 89–95.
- 96 Kaplan AS, Zemel BS, Stallings VA. Differences in resting energy expenditure in prepubertal black children and white children. *J Pediatr* 1996; **129**: 643–647.
- 97 Morrison JA, Alfaro MP, Khoury P, Thornton BB, Daniels SR. Determinants of resting energy expenditure in young black girls and young white girls. *J Pediatr* 1996; **5**: 637–642.
- 98 Sun M, Gower BA, Nagy TR, Trowbridge CA, Dezenberg C, Goran MI. Total, resting and physical activity related energy expenditure are similar in Caucasian and African-American children. *Am J Physiol* 1997; **274**: E232–E237.
- 99 Bouchard C, Tremblay A, Desprs JP, Nadeau A, Lupien PJ, Theriault G, Dussault J, Moorjani S, Pinault S, Fournier G. The response to long-term overfeeding in identical twins. *N Engl J Med* 1990; **322**: 1477–1482.
- 100 Bouchard C. Individual differences in the response to regular exercise. *Int J Obes* 1995; **19**: S5–S8.
- 101 Goran MI, Hunter G, Nagy TR, Johnson R. Physical activity related energy expenditure and fat mass in young children. *Int J Obes* 1997; **21**: 171–178.
- 102 Craig SB, Bandini LG, Lichenstein AM, Scafer EJ, Dietz WH. The impact of physical activity on lipids, lipoproteins and blood pressure in pre-adolescent girls *Pediatrics* 1996; **98**: 389–395.
- 103 Sasaki J, Shindo M, Tanaka H, Ando M, Arakawa K. A long-term aerobic exercise program decreases the obesity index and increases the high density lipoprotein cholesterol concentration in obese children. *Int J Obes* 1987; **11**: 339–345.
- 104 Blaak EE, Westerterp KR, Bar-Or O, Wouters LJM, Saris WHM. Total energy expenditure and spontaneous activity in relation to training in obese boys. *Am J Clin Nutr* 1992; **55**: 777–782.
- 105 Bar-Or O. *Pediatric sports medicine for the practitioner*. Springer Verlag: New York, 1983.
- 106 Epstein LH, Valoski A, Wing RR, McCurley MA. Ten-year follow-up of behavioral, family-based treatment for obese children. *JAMA* 1990; **264**: 2519–2523.
- 107 Reybrouck T, Vinckx J, Van den Berghe G, Vanderschueren Lodeweyckx M. Exercise therapy and hypocaloric diet in the treatment of obese children and adolescents *Acta Paediatr Scand* 1990; **79**: 84–89.
- 108 Gutin B. Role of exercise interaction in improving body fat distribution and risk profile in children. *Am J Hum Biol* 1999 (in press).
- 109 Yarasheski KE, Zachwieja JJ, Bier DM. Acute effects of resistance exercise on muscle protein synthesis rate in young and elderly men and women. *Am J Physiol Endocrinol Metab* 1993; **265**: E210–E214.
- 110 Treuth MS, Ryan RE, Pratley RE, Rubin MA, Miller JP, Nicklas BJ, Sorkin J, Harman SM, Goldberg AP, Hurley BF. Effects of strength training on total and regional body composition in older men. *J Appl Physiol* 1994; **77**: 614–620.
- 111 Fiatarone MA, O'Neill EF, Ryan ND, Clements KM, Solares GR, Nelson ME, Roberts SB, Kehayias JJ, Lipsitz LA, Evans WJ. Exercise training and nutritional supplementation for physical frailty in very elderly people. *New Engl J Med* 1994; **330**: 1769–1775.
- 112 Miller, JP, Pratley, RE, Goldberg, AP, Gordon P, Rubin M, Treuth MS, Ryan AS, Hurley BF. Strength training increases insulin action in healthy 50- to 65-year old men. *J Appl Physiol* 1994; **77**: 1122–1127.
- 113 Melby C, Scholl C, Edwards G, Bullough R. Effect of acute resistance exercise on postexercise energy expenditure and resting metabolic rate. *J Appl Physiol* 1993; **75**: 1847–1853.
- 114 Campbell WW, Crim MC, Young VR, Evans WJ. Increased energy requirements and changes in body composition with resistance training in older adults. *Am J Clin Nutr* 1994; **60**: 167–175.
- 115 Treuth MS, Hunter GR, Kekes-Szabo T, Weinsier RL, Goran MI, Berland L. Strength training reduces intra-abdominal adipose tissue in older women. *J Appl Physiol* 1995; **78**: 1425–1431.
- 116 Blimkie CHR. Resistance training during preadolescence: Issues and controversies. *Sports Med* 1993; **15**: 389–407.
- 117 Blanksby B, Gregor J. Anthropometric, strength and physiological changes in male and female swimmers with progressive resistance training. *Aust J Sport Sci* 1981; **2**: 3–6.
- 118 Ozmun JC, Mikesky AE, Surburg PR. Neuromuscular adaptations during prepubescent strength training. *Med Sci Sport Exer* 1991; **23**: S32.
- 119 Ramsay JA, Blimkie CJR, Smith K, Garner S, MacDougall JD, Sale DG. Strength training effects in prepubescent boys. *Med Sci Sports Exerc* 1990; **22**: 605–614.
- 120 Treuth MS, Hunter GR, Pichon C, Figueroa-Colon R, Goran MI. Fitness and energy expenditure after strength training in obese prepubertal girls. *Med Sci Sport Exer* 1998; **30**: 1130–1136.
- 121 Resnicow K. School-based obesity prevention. *Ann NY Acad Sci* 1993; **699**: 154–166.
- 122 Treuth MS, Hunter GR, Figueroa-Colon R, Goran MI. Effects of strength on intra-abdominal adipose tissue in obese pre-pubertal girls. *Int J Obes* 1999 (in press).
- 123 Siegel JA, Camaione DN, Manfredi TG. The effects of upper body resistance training on prepubescent children. *Pediatr Exerc Sci* 1989; **1**: 145–154.
- 124 Weltman A, Janney C, Rians CB, Strand K, Berg B, Tippitt S, Wise J, Cahill BR, Katch FI. The effects of hydraulic resistance strength training in pre-pubertal males. *Med Sci Sport Exer* 1986; **18**: 629–638.
- 125 US Institute of Medicine. *Reducing risks for mental disorders: frontiers for preventive intervention research*. National Academy Press: Washington, 1994. Report of the Committee on Prevention of Medical Disorders Division,

- 126 Kann L, Collins JL, Collins-Pateman B, Leavy-Small M, Ross JG, Kolbe LJ. The school health policies and programs study (SHPPS): rationale for a nationwide status report on school health programs. *J School Health* 1995; **65**: 294.
- 127 Kirby D, DiClemente RJ. In: (DiClemente RJ, Peterson JL eds) *Preventing AIDS: Theories and methods of behavioral intervention*. Plenum Publishing Corporation: New York, 1994, 117–139.
- 128 Parcel GS, Simons-Morton DG, O'Hara NM, Baranowski T, Wilson B. School promotion of healthful diet and physical activity: Impact on learning outcomes and self-reported behavior. *Health Educ Q* 1989; **16**: 181–199.
- 129 Williams CL, Carter BJ, Eng A. The know your body program: a developmental approach to health education and disease prevention. *Prev Med* 1980; **9**: 371–383.
- 130 Bush P, Zuckerman AE, Taggart VS, Theiss PK, Peleg EO, Smith SA. Cardiovascular risk factor prevention in black school children: The 'Know your body' evaluation project. *Health Educ Q* 1989; **16**: 215–227.
- 131 Walter HJ. Primary prevention of chronic disease among children: The school-based Know Your Body intervention trials. *Health Educ Q* 1989; **16**: 201–214.
- 132 Walter HJ, Hofman A, Vaughan RD, Wynder EL. Modification of risk factors for coronary heart disease: Five-year results of school-based intervention trial. *N Engl J Med* 1988; **318**: 1093–1100.
- 133 Resnicow K, Cohn L, Reinhardt J, Cross D, Futterman R, Kirschner E, Wynder EL. A three-year evaluation of the Know Your Body program in inner-city schoolchildren. *Health Educ Q* 1992; **19**: 463–480.
- 134 Tamir D, Feurstein A, Brunner S, Halfon ST, Reshef A, Palti H. Primary prevention of cardiovascular diseases in childhood: Changes in serum total cholesterol, high density lipoprotein, and body mass index after 2 years of intervention in Jerusalem schoolchildren age 7–9 years. *Prev Med* 1990; **19**: 22–30.
- 135 Lionis C, Kafatos A, Vlachonikolis J, Vakaki M, Tzortzi M, Petraki A. The effects of a health education intervention program among Cretan adolescents. *Prev Med* 1991; **20**: 685–699.
- 136 Vandongen R, Jenner DA, Thompson C, Taggart AC, Spickett EE, Burke V, Beilin LJ, Milligan FA, Dunbar DL. A controlled evaluation of a fitness and nutrition intervention program on cardiovascular health in 10- to 12- year-old children. *Prev Med* 1995; **24**: 9–22.
- 137 Killen JD, Telch MJ, Robinson TN, Maccoby N, Taylor CB, Farquhar JW. Cardiovascular disease risk reduction for tenth graders: A multiple-factor school-based approach. *JAMA* 1988; **260**: 1728–1733.
- 138 Sallis JF, McKenzie TL, Alcaraz JE, Kolody B, Faucette N, Hovell MF. The effects of a 2-year physical education program (SPARK) on physical activity and fitness in elementary school students. *Am J Public Health* 1997; **87**: 1328–1334.
- 139 Luepker RV, Perry CL, McKinlay SM, Nader PR, Parcel GS, Stone EJ, Webber LS. Outcomes of a field trial to improve children's dietary patterns and physical activity: the Child and Adolescent Trial for Cardiovascular Health (CATCH). *JAMA* 1996; **275**: 768–776.
- 140 Perry CL, Parcel GS, Stone EJ, Nader PR, McKinlay SM, Luepker RV, Webber LS. The child and adolescent trial for cardiovascular health (CATCH): Overview of the intervention program and evaluation methods. *Cardiovasc Risk Factors* 1992; **2**: 36–44.
- 141 Perry CL, Sellers DE, Johnson C, Pederson S, Bachman KJ, Parcel GS, Stone EJ, Luepker RV, Wu M, Nader PR, Cook K. The Child and Adolescent Trial for Cardiovascular Health (CATCH): Intervention, implementation and feasibility for elementary schools in the United States. *Health Educ Behav* 1997; **24**: 716–735.
- 142 Stone EJ, Osganian SK, McKinlay SM, Wu M, Webber LS, Luepker RV, Perry CL, Parcel GS, Elder JP. Operational design and quality control in the CATCH multicenter trial. *Prev Med* 1996; **25**: 384–399.
- 143 McKenzie TL, Nader PR, Strikmiller PK, Yang M, Stone EJ, Perry CL, Taylor WC, Epping JN, Feldman HA, Luepker RV, Kelder SH. School physical education: effect of the Child and Adolescent Trial for Cardiovascular Health. *Prev Med* 1996; **25**: 423–431.
- 144 Perry CL, Luepker RV, Murray DM, Kurth CL, Mullis R, Crockett S, Jacobs DR. Parent involvement with children's health promotion: The Minnesota Home Team. *Am J Public Health* 1988; **78**: 1156–1160.
- 145 Nader PR. The role of the family in obesity prevention and treatment *Ann NY Acad Sci* 1993; **699**: 147–153.
- 146 King AC, Jeffery RW, Fridinger F, Dusenbury L, Provence S, Hedlund SA, Spangler K. Environmental and policy approaches to cardiovascular disease prevention through physical activity: Issues and opportunities. *Health Educ Q* 1995; **22**: 499–511.
- 147 Owen N, Bauman A, Booth M, Oldenburg B, Magnus S. Serial mass-media campaigns to promote physical activity: Reinforcing or redundant? *Am J Public Health* 1995; **85**: 244–248.
- 148 Wallack L, Dorfman L. Media advocacy: A strategy for advancing policy and promoting health. *Health Educ Q* 1996; **23**: 293–317.
- 149 Stolley MR, Fitzgibbon ML. Effects of an obesity prevention program on the eating behavior of African American mothers and daughters. *Health Educ Behav* 1997; **24**: 152–164.