Sports Med 2009; 39 (4): 279-294
0112-1642/09/0004-0279/$49.95/0

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Physical Activity as a Predictor of Adolescent Body Fatness

A Systematic Review

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Abstract

Adolescent obesity has increased dramatically in several countries in recent decades; however, the contribution of physical activity level to adolescent adiposity requires clarification. This article investigates the effect of physical activity on subsequent levels of adiposity in adolescence. The methodological aspects of the studies included in this article, particularly in terms of measurement accuracy for both exposure (physical activity) and outcome (adiposity) variables, are also evaluated. Systematic searches of the literature were undertaken using online databases, including PubMed/MEDLINE, examination of citations and contacting of authors. The online databases were searched from their earliest records until 2007. Only longitudinal studies with 50 or more adolescents were included. Two independent reviewers assessed the quality of the studies using the Downs and Black checklist. Thirteen observational, five experimental and six quasi-experimental studies (without a control group) were identified. Almost all studies were carried out in high-income settings and showed protective effects of physical activity for both prevention and treatment of adolescent obesity. However, experimental studies undertaken with obese adolescents at baseline usually combined physical activity with dietary changes, making it difficult to assess the effect of physical activity itself on the treatment of obesity. Physical activity estimated from questionnaires and body mass index (BMI) were the most frequently used measures. Despite the feasibility of using these approaches in epidemiological studies, significant limitations are evident. Questionnaires are subjective and adolescents may not report physical activity level accurately. Furthermore, BMI is not an accurate measure of fatness for adolescents, as it is also associated with lean mass, hence bias may arise from its longitudinal association with physical activity level. Despite the majority of studies reviewed showing protective effects of physical activity on adiposity, particularly in individuals who are obese at baseline, the current literature on this issue is sparse and several methodological drawbacks are evident. The main limitations relate to a lack of validity in the measurements of both physical activity and body composition. Further studies are needed in order to generate evidence-based recommendations for the quantity and quality of adolescent physical activity required to prevent or treat adolescent obesity.

Adolescent obesity has increased dramatically in several countries in recent decades.[1] Currently, high rates of excessive bodyweight are observed not only in developed societies but also in low- and middle-income countries. For example, in Brazil, the prevalence of overweight more than tripled in boys aged 10–19 years (from 2.6% to 11.8%) and more than doubled in girls (from 5.8% to 15.3%) from 1975 to 1997.[2]

Obesity in adolescence is associated with a broad range of adverse health effects. First, adolescent obesity has been shown to track strongly into adulthood, and the health consequences of adulthood obesity are well established.[3] More recently, studies have demonstrated that some diseases, including elevated blood pressure, type 2 diabetes mellitus, asthma and sleep disorders, are more frequent among obese than non-obese adolescents.[4-7] Obesity is also associated with psychological disorders.[8] Thus, studies investigating the factors that play a role in the prevention or treatment of adolescent obesity are warranted.

The rapid change in the prevalence of obesity worldwide suggests that factors other than genes play an important role in the aetiology of obesity, although an interaction between these factors may occur. Fat accumulation is ultimately the result of chronic positive energy balance (energy intake > energy expenditure). In this context, physical activity, which accounts for a large part of total energy expenditure, is predicted to influence adiposity. Several cross-sectional studies have addressed this issue; however, their results are conflicting.[9-12] Such lack of consistency may arise because the association between physical activity and adiposity is highly susceptible to reverse causality (adolescents may change their physical activity level depending on the degree of adiposity). Theoretically, longitudinal studies might also be affected by reverse causality, but this bias is much less likely in randomized controlled trials. Thus, longitudinal studies are more appropriate to investigate this issue. Nonetheless, longitudinal studies performed during the period of adolescence (age 10–19 years) are rare and very heterogeneous concerning many aspects that may likewise lead to conflicting findings.

Few systematic reviews on the association between physical activity and adiposity in youth

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have been carried out and, overall, their results indicate that increased physical activity may play a role in both prevention and treatment of obesity. Not only did some reviews include only experimental studies[13,14] and one included only observational studies,[15] none of them focused exclusively on adolescents.

Physical activity can be subdivided into sleep, sedentary behaviours and motion behaviours. We carried out a systematic review of the literature with the primary aim of investigating the effect of physical activity, specifically the motion aspect, on subsequent levels of adiposity in adolescents. Our review included both observational and experimental studies. We also evaluated methodological aspects of the studies included in the review, particularly in terms of measurement accuracy of both exposure (physical activity) and outcome (adiposity) variables. This issue was not addressed in any previous review, but is critical for interpreting the results of a collation of studies using heterogeneous methods.

1. Methods

In July 2007, the following electronic databases were searched from the earliest record: MEDLINE, SportDiscus, SCIELO, BioMed Central and PsycINFO. The reference lists from identified articles were searched manually. The first author of the articles included was contacted and questioned about other published or unpublished data. The following keywords were used: 'abdominal fat', 'abdominal obesity', 'adiposity', 'body composition', 'body fat', 'body fat distribution', 'body mass index', 'central adiposity', 'central fat', 'central fatness', 'central obesity', 'centrally distributed fat', 'centrally distributed obesity', 'fat', 'fat patterning', 'fatness', 'metabolic syndrome', 'metabolic syndrome x', 'obese', 'obesity', 'syndrome x', 'truncal fat', 'truncal obesity', 'trunk adiposity', 'trunk fat' and 'trunk obesity'. These keywords were combined with 'exercise', 'inactivity', 'motor activity', 'physical activity', 'physical exercise' or 'sports'.

Given that the aim of the present article was to assess the role of physical activity during adolescence on subsequent levels of adiposity, cross-sectional studies were excluded because of their inability to establish temporality. The following keywords were thus used: 'clinical trial', 'cohort', 'experimental', 'experimental design', 'follow-up', 'intervention', 'intervention studies', 'longitudinal', 'panel', 'prospective' and 'trial'. The keywords 'adolescence', 'adolescents', 'teenager' and 'youth' were also used in the literature search. Studies were considered if the outcome variable (adiposity) was collected when subjects were aged 10–19 years, even if the exposure (physical activity) had been measured before 10 years of age. This strategy was adopted since too few studies were carried out exclusively during adolescence. However, studies were only considered if most of the ages of the participants were within the adolescence period. Studies with fewer than 50 subjects in the sample were not considered because of the low statistical power associated with small samples.

The search resulted initially in 571 articles. After reading the titles and abstracts, 43 articles were selected, and after reading the full texts, 19 articles were included in the review. A further five articles were selected through the reference lists of these articles, and contact with experts in the area.

Two independent reviewers assessed the quality of the studies using the Downs and Black checklist.[16] In case of eventual differences between the two reviewers, the articles were re-assessed until both referees agreed with the evaluation. Because the original Downs and Black checklist is applicable to experimental designs, a modified version of the scale[17] was used to assess the quality of observational studies (table I). Therefore, questions 8, 13, 23 and 24 of this instrument were not considered for observational studies. All questions were coded as 0 (representing poor quality) or 1, with the exception of question 5, which was coded with 0, 1 or 2. Furthermore, question 27, originally coded from 0 to 5, was dichotomized into 0 or 1 (code 1 was attributed to studies that mentioned a statistical power ≥80%). The final scale ranged from 0 (poorest quality) to 24 (best quality) points for observational studies or 28 points for experimental studies.

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Table I. Quality of the studies, as defined by the Downs and Black modified scale[16]

Criteria	No. of articles	
	adequate	inadequate
1. Is the hypothesis/aim/objective of the study clearly described?	24	0
2. Are the main outcomes to be measured clearly described in the Introduction or Methods section?	24	0
3. Are the characteristics of the patients included in the study clearly described?	24	0
4. Are the interventions of interest clearly described?	24	0
5. Are the distributions of principal confounders in each group of subjects to be compared clearly described?	6	18
6. Are the main findings of the study clearly described?	24	0
7. Does the study provide estimates of the random variability in the data for the main outcomes?	24	0
8. Have all important adverse events that may be a consequence of the intervention been reported?[a]		
9. Have the characteristics of patients lost to follow-up been described?	11	13
10. Have actual probability values been reported (e.g. 0.035 rather than <0.05) for the main outcomes except where the probability value is <0.001?	17	7
11. Were the subjects asked to participate in the study representative of the entire population from which they were recruited?	8	16
12. Were those subjects who were prepared to participate representative of the entire population from which they were recruited?	10	14
13. Were the staff, places and facilities where the patients were treated representative of the treatment the majority of patients receive?[a]		
14. Was an attempt made to blind study subjects to the intervention they have received?[b]	4	20
15. Was an attempt made to blind those measuring the main outcomes of the intervention?[b]	4	20
16. If any of the results of the study were based on 'data dredging', was this made clear?	22	2
17. In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients or, in case-control studies, is the time period between the intervention and outcome the same for cases and controls?	20	4
18. Were the statistical tests used to assess the main outcomes appropriate?	21	3
19. Was compliance with the intervention/s reliable?[b]	11	13
20. Were the main outcome measures used accurate (valid and reliable)?	5	19
21. Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?	21	3
22. Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?	19	5
23. Were study subjects randomized to intervention groups?[a]		
24. Was the randomized intervention assignment concealed from both patients and healthcare staff until recruitment was complete and irrevocable?[a]		
25. Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?	18	6
26. Were losses of patients to follow-up taken into account?	9	15
27. Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is <5%?	3	21

a These questions are specific for experimental studies and, therefore, were not rated in the table.

b Observational studies were coded as 0 ('unable to determine').

2. Results

Table II presents a description and summary of the studies included in the review. Studies are presented according to the design and in alphabetical order of the first author's name. A total of five experimental,[18-22] six quasi-experimental (without control group),[23-28] and 13 observational (cohort) studies[29-41] were found and fulfilled the inclusion criteria. Only five studies exclusively included adolescents (individuals aged 10–19 years) and all but one[35] study were

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Table II. Characteristics of the studies included in the review according to design, first author's name, country, sample size, follow-up duration, weight status of the sample, definition of exposure and outcome, and main results

Study (country)	Sample size	Follow-up duration	Weight status of the sample	Definition of the exposure	Definition of the outcome	Main results
Experimental studies						
Eliakim et al.[18] (Israel)	177 individuals aged 6–16 y	3 mo	Obese	Dietary, behaviour and exercise intervention	BMI	BMI decreased in 74% of the individuals (from 26.1 ± 0.3 to 25.4 ± 0.3 kg/m^2)
Gortmaker et al.[22] (US)	1295 individuals	21 mo	General population	School-based intervention aimed to change PA and dietary habits	Combination of BMI and triciptal skinfold	Intervention was successful among girls, but not boys
Gutin et al.[19] (US)	80 adolescents aged 13–16 y	8 mo	Obese	Lifestyle intervention plus either moderate or vigorous PA	Total (DEXA) and visceral adiposity (magnetic resonance)	High- and moderate-intensity PA were similarly effective in reducing visceral and total-body adiposity
McMurray et al.[20] (US)	1140 adolescents (630 females) aged 11–14 y	8 wk	Normal	Aerobic exercise programme and education in schools	Sum of skinfold thickness	Exercise group had smaller gains in skinfold thickness than control group
Savoye et al.[21] (US)	209 individuals aged 8–16 y	1 y	Overweight	Weight management family-based programme including exercise, nutrition and behaviour modification	Change in weight, BMI and body fat estimated from Tanita, TBF 300	Individuals in the intervention group presented better indicators in all outcomes
Quasi-experimental studies						
Dao et al.[23] (France)	55 individuals aged 9–17 y	6–12 mo	Obese	Dietary and physical activity programme	Total and regional body composition determined by DEXA	Body fat decreased in both sexes and steepest declines were observed in the trunk
Reinehr et al.[24] (Germany)	75 individuals aged 7–15 y	1 y	Obese	Intervention consisted of physical exercise, nutritional course and behaviour therapy for participants and their parents	BMI	Participation in exercise groups was associated with a decrease in SD scores of BMI

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Table II. Contd

Study (country)	Sample size	Follow-up duration	Weight status of the sample	Definition of the exposure	Definition of the outcome	Main results
Reinehr et al.[25] (Germany)	170 individuals (mean age 10.5 y)	1 y	Obese	1 y of physical exercises and 3 mo of nutrition education	SD score in BMI in the third year after intervention	66% of individuals presented a reduction of SD score in BMI 3 y after the end of intervention
Sothern et al.[27] (US)	87 individuals (39 boys) aged 7–17 y	1 y	Obese	Intervention consisting of dietary restrictions, moderate-intensity PA and behaviour modification sessions	Percentage of body fat	All individuals presented better body composition indicators
Sothern et al.[26] (US)	56 individuals aged 7–17 y	1 y	Obese	Dietary restrictions and physical activities	Variation in bodyweight and percentage of body fat, estimated by skinfold thickness	Individuals had a significant decline in all outcomes after 10 wk of the programme, which was maintained at 1-y follow-up
Wong et al.[28] (Singapore)	112 adolescents	2 y	Obese	Weight control programme	BMI	Long-term weight loss was associated with increased PA after intervention
Observational studies						
Berkey et al.[29] (US)	6149 girls and 4620 boys aged 9–14 y at baseline	1 y	General population	Self-reported PA estimated by questionnaire	1-y change in BMI	PA was inversely associated with large increases in BMI in girls only
Berkey et al.[30] (US)	6767 girls and 5120 boys aged 10–15 y	1 y	General population	Self-reported PA estimated by questionnaire	1-y change in BMI	PA effects were sex-dependent and stronger in overweight than normal weight adolescents. The effect of PA on BMI was stronger than the effect of sedentary activities
Elgar et al.[31] (UK)	355 adolescents (mean age 12.3 y at baseline)	4 y	General population	Self-reported PA estimated by the Health Behaviour of School-aged Children Questionnaire	BMI	Baseline PAL was associated with BMI change, but no BMI at follow-up

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Table II. Contd

Study (country)	Sample size	Follow-up duration	Weight status of the sample	Definition of the exposure	Definition of the outcome	Main results
Heelan et al.[32] (US)	320 individuals aged 10.2 ± 0.7 y	6 mo	General population	Active commuting to and from school estimated from the self-administered PA checklist	BMI and body fat determined by skinfold thickness	Significant positive correlation between active commuting and overweight was observed
Kettaneh et al.[33] (France)	436 individuals aged 8–18 y	2 y	General population	Self-reported and parent-assisted PA estimated from the Kriska's modifiable activity questionnaire	BMI, sum of skinfold thickness and waist circumference	A decline in PAL during the follow-up period was associated with lower adiposity in girls, but not boys
Kimm et al.[34] (US)	2379 girls followed up from age 9/10–18/19 y	9 y	General population	Self-reported PA estimated from the Habitual Activity Questionnaires	BMI and sum of skinfold thickness	Active girls had smaller gains in both outcomes than inactive ones
Mo-suwan et al.[35] (Thailand)	2252 schoolchildren aged 5–16 y at baseline	5 y	General population	Exercise level compared with other individuals of the same age, as reported by the parents	BMI	Lower level of exercise was associated with increases in BMI
Mundt et al.[36] (Canada)	208 individuals aged 8–19 y	Maximum of 7 y; median of 5 y	General population	Self-reported PA estimated from the PA Questionnaire for Children or Adolescents	Fat mass determined by DEXA	PAL was negatively associated with fat mass accumulation in boys, but not girls
Must et al.[37] (US)	173 pre-menarcheal girls aged 8–12 y followed up until 4 y post-menarche	7.5 y (average)	General population	Self-reported PA estimated from questionnaire	Percentage of body fat estimated from bioelectrical impedance and BMI	PA was negatively associated with percentage of body fat only among those who had at least one parent overweight
O'Loughlin et al.[38] (Canada)	2951 schoolchildren aged 9–12 y at baseline	1 or 2 y	General population	Self-reported PA estimated from questionnaire	BMI	Highest decile of change in BMI was more frequent among those with low levels of physical activity

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Table II. Contd

Study (country)	Sample size	Follow-up duration	Weight status of the sample	Definition of the exposure	Definition of the outcome	Main results
Rosenberg et al.[39] (US)	1083 students from the fourth grade of seven elementary schools	2y	General population	Self-reported active commuting estimated from questionnaire	BMI and skinfold thickness	Active commuting to school over 2y was not associated with BMI change or overweight status
Stice et al.[40] (US)	496 girls aged 11–15y	4y	General population	Self-reported PA estimated from the Past Year Leisure Physical Activity Scale	BMI	No association between past year PAL and BMI increases was observed
Wardle et al.[41] (UK)	2727 students aged 11–12y at baseline	5y	General population	Self-reported and teacher-reported number of physical education classes per wk	BMI and waist circumference	Higher levels of physical education classes were associated with lower gains in adiposity in boys

BMI = body mass index; **DEXA** = dual-energy x-ray absorptiometry; **PA** = physical activity; **PAL** = PA level; **SD** = standard deviation.

undertaken in high-income countries. Sample sizes ranged from 55[23] to 11 887,[30] and follow-up duration was as short as 3 months[18] and as long as 9 years.[34] Table I describes the methodological quality of the articles according to the Downs and Black checklist. Figure 1 presents potential confounders considered by the studies reviewed.

2.1 Measuring the Exposure: Physical Activity

In the 24 studies revised here, physical activity was both measured and promoted in the intervention studies in a variety of different ways.

2.1.1 Experimental and Quasi-Experimental Studies

All experimental and quasi-experimental studies included components other than a physical activity programme in the intervention (table II). For example, Gutin et al.[19] assigned participants to one of the following three groups: (i) 1 hour of lifestyle education every 2 weeks (which served as a control condition because it was offered to all groups); (ii) lifestyle intervention plus moderate physical activities (55–60% of peak oxygen uptake [$\dot{V}O_{2peak}$]); and (iii) lifestyle intervention plus high-intensity physical activities (75–80% $\dot{V}O_{2peak}$). Energy expenditure for each session was held at approximately 250 kcal/session; therefore, the training duration was related to physical activity intensity. However, individuals of the high-intensity group performed the exercises at a heart rate (154 beats/min) significantly lower than that prescribed (167 beats/min), and the attendance rate was low for both physical training groups (~54%).

Savoye et al.[21] randomly assigned overweight individuals to either a control group (receiving traditional clinical weight management counselling) or a 12-month weight management group, which received a family-based programme involving exercise, nutrition and behaviour modification. The exercises consisted of aerobic activities performed at 65–85% of the age-adjusted maximal heart rate for twice a week (50 minutes each session) during the first 6 months and 100 minutes per month for the last 6 months.

The intervention proposed by Reinehr et al.[25] was based on 1 year of physical exercise, nutrition

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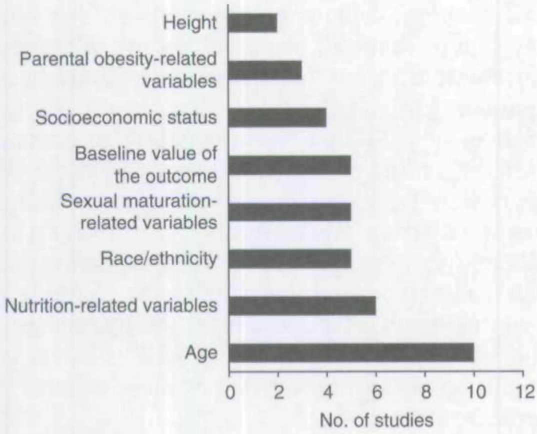

Fig. 1. Potential confounders considered in the observational studies reviewed.

education and behaviour therapy for children and parents separately (first 3 months) and individual psychological care of the child and its family. Twenty of the 75 participants dropped out during the study, but training session attendance among those who remained in the study was >90%.

Sothern et al.[26] also proposed an intervention with three main branches: nutrition, physical exercises and behaviour modification. The exercise was of moderate intensity (45–55% of maximal oxygen uptake [$\dot{V}O_{2max}$]) and the frequency and duration of the sessions varied according to the degree of obesity, although no specific information for these variables was provided. Ninety-three percent of individuals completed the acute phase (10–20 weeks) of intervention and 62.5% completed the 1-year programme. Mean attendance during the acute phase was 91% with 57% for the remaining phase.

2.1.2 Observational Studies

All observational studies estimated physical activity level by questionnaires (table II). Most of the questionnaires were self-reported, with the remainder completed by parents[33,35] or teachers.[41]

2.2 Measuring the Outcome: Adiposity

Adiposity was also measured in a variety of different ways in the 24 different studies.

2.2.1 Experimental and Quasi-Experimental Studies

Most of the studies included more than one method to estimate adiposity. Body mass index (BMI) or change in this variable during the follow-up period was the most frequently used outcome.[18,21,24,25,28] One study defined obesity based on both BMI and triciptal skinfold thickness.[22] Percentage of body fat derived by either skinfold thickness[26,27] or bioelectrical impedance[21] was another outcome frequently used in the studies. Dual-energy x-ray absorptiometry (DEXA) was used in two studies[19,23] and MRI in one study.[19]

2.2.2 Observational Studies

Observational and experimental/quasi-experimental studies used similar methods to estimate adiposity. Virtually all observational studies used BMI as a measure of adiposity (table II), with six of the 13 studies using only this method. Skinfold thickness measurements and bioelectrical impedance as well as circumferences were also used in some studies. One study[36] used DEXA.

2.3 Effects of Physical Activity on Adiposity Measures

2.3.1 Experimental and Quasi-Experimental Studies

All studies showed favourable effects of the intervention on adiposity level of adolescents. However, it should be highlighted that all interventions included other exposures besides physical activity (e.g. dietary change). Thus, it is difficult to assess the independent impact of physical activity on adiposity. One school-based intervention decreased obesity only among girls,[22] while the remaining studies found comparable results of the intervention among both sexes.

One experimental study measured total body composition by DEXA and visceral adipose tissue and subcutaneous abdominal tissue by MRI.[19] Based on efficacy analyses adjusted for potential confounders and baseline values, the authors showed a significant decline in the following outcomes after 8 months of physical training: visceral adipose tissue ($-42.0 \pm 9.3\,cm^3$), subcutaneous abdominal adipose tissue ($-69.7 \pm 55.9\,cm^3$),

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and percentage of body fat (−3.57±0.80%). The efficacy analyses included only those participants who attended at least 40% of intervention sessions. However, the intent-to-treat analyses (i.e. effectiveness analysis) showed no association of the intervention with either of the outcomes. Furthermore, the authors highlighted that there was no evidence that the high-intensity physical training was more efficacious than the moderate-intensity training, although no analyses for this association were shown.

2.3.2 Observational Studies

All but two studies[39,40] showed significant inverse associations of physical activity with body composition or BMI, although the magnitude of the association was markedly different between studies. Some studies suggest that the effect of physical activity on these outcomes depended on sex,[29,36] ethnicity[34] and baseline BMI.[30] For example, Berkey et al.[29] showed that active girls had smaller gains in BMI (−0.0284; $p=0.046$) over a 1-year period. Among boys, this difference was not significant, despite similarity in the strength and direction of the effect (coefficient = −0.0261; $p=0.094$). In contrast, Mundt et al.[36] showed that physical activity was associated with reduced increments in fat mass (measured by DEXA) in boys but not girls.

2.4 Prevention versus Treatment Effects

2.4.1 Experimental and Quasi-Experimental Studies

The evidence that physical activity prevents adolescence obesity is very limited, since only two experimental studies on normal weight individuals were located[20,22] and one of them found no effect of the intervention on boys.[22] The remaining experimental and quasi-experimental studies were carried out with either overweight or obese individuals at baseline and showed positive effects of the intervention.[18,19,21,23-28] Overall, the results were consistent regardless of the method used to estimate adiposity. However, McMurray et al.[20] found no differences in the BMI changes among four groups studied (educational intervention, exercise intervention, educational plus exercise interventions, and control group). In contrast, the sum of skinfolds increased less in the exercise intervention groups than in the control and education-only groups ($p<0.001$).

It is very difficult to draw confident conclusions regarding the actual effects of physical activity from these studies because the interventions also focused on other aspects, for example diet. Therefore, although there is some evidence that physical activity is important in the prevention and treatment of adolescence obesity, the real impact of physical activity, as well as the type, frequency and duration that is most beneficial, remains unknown.

2.4.2 Observational Studies

Observational studies demonstrated that physical activity might play a role in the prevention of fat accumulation in normal-weight subjects. For example, Kimm et al.[34] demonstrated a clear dose-response effect of physical activity practice on skinfold thicknesses: girls who were more active from ages 9–19 years had smaller gains in skinfold thicknesses throughout adolescence. However, although most studies estimated physical activity from questionnaires, there are numerous differences between these instruments. Some of them estimated only leisure-time physical activities, while others measured all-domain activities. They also used a variety of cut-off points and units of measures (metabolic equivalents, minutes of physical activity and kilocalories spent per week, etc.). Another pitfall of questionnaires concerns their subjectivity. Therefore, the relative importance of type, frequency and duration of physical activities for preventing or treating obesity is also unknown.

2.5 Measuring Potential Confounders

All observational studies adjusted their analyses for potential confounders. Figure 1 shows the factors most frequently considered as confounders and the number of studies that included them in analyses. The figure does not show sex as a potential confounder, but most of the studies performed analyses stratified by this variable. Confounders not included in the figure, but

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considered by at least one study, were smoking habits,[34] hours of television viewing, number of parents,[31] compensatory behaviours (i.e. vomiting for weight-control purposes, laxative abuse and diuretic abuse), depressive symptoms[40] and school.[38]

Table I describes the methodological quality of the articles, as defined by the Downs and Black modified scale. The average quality score of the observational studies was 16.4/24 (standard deviation [SD] 2.1; median 17; range 12–19) and of the experimental studies was 17.2/28 (SD = 2.7; median = 18.0; range 14–21).

3. Discussion

This review focused on the role of physical activity (or lack of activity) on subsequent levels of adiposity with the latter, at least, being investigated during adolescence. Despite most of the articles reviewed showing protective effects of physical activity against adiposity, several limitations are evident in the literature. Although the longitudinal relationship between these variables is of most importance, few studies on this subject (particularly experimental studies) could be located. Furthermore, there are virtually no relevant studies from low- or middle-income countries. This result was expected, given the fact that longitudinal studies are very expensive and time consuming. It is plausible that the physiological effects of a specific physical activity will have similar effects on body composition regardless of the population and setting. However, different activities are practised in low- and middle-income country populations compared with those of high-income countries (e.g. leisure-time vs travel or subsistence activity).[42-45] Therefore it is important to assess the effectiveness of different activity patterns on changes in body composition. The only study undertaken outside high-income countries from Thailand[35] showed similar results (i.e. an increase in BMI was associated with lower levels of exercise); however, many populations and settings still remain unexplored.

The best study design for testing the hypothesis that physical activity prevents excessive fat accumulation is randomized field trials. However, virtually all available data regarding the prevention of fat accumulation through increased physical activity derive from observational studies, and several biases are therefore of concern. For example, high rates of loss of follow-up and refusal to participate are observed in the reviewed literature, which may lead to an overestimation of the actual effects of physical activity. All but two[20,22] of the experimental (randomized intervention) and quasi-experimental studies reviewed were carried out in individuals overweight/obese at baseline. Although all of these studies suggested favourable effects of the intervention on adiposity levels, such studies are very heterogeneous regarding both exposure and outcome, and their results must be interpreted with caution. First, none of the studies verified the effect of physical activity itself on adiposity levels. Interventions usually consisted of a combination of factors such as change in dietary habits, behaviour and physical activity levels.[18,21,23,25,27,28] Thus, the results are likely to be a consequence of an interaction between these variables. Secondly, there were noticeable differences in terms of baseline body composition, duration of the intervention, and number of subjects included in the study, which all may affect the results.

An important methodological aspect to be considered is the decision of adjusting or not for the baseline value of the outcome. One should consider that physical activity practice may have different consequences on later body composition depending on the current nutritional status of the individual. In order to address this issue, one of the possibilities is to adjust the association between physical activity and later body composition by baseline values of the outcome variable. An alternative approach is to test interactions between the variables. Both approaches were rarely used in the reviewed studies.

Regardless of the design of the study, a further important limitation relates to the measurement of both physical activity and body composition. Despite the recognized importance of these variables for patterns of morbidity and mortality worldwide, accurate determination of physical activity and body composition in large-scale

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studies remains a challenge. A non-systematic error in the measurement of any of these variables would underestimate the effect of physical activity; however, the effect of a systematic error is unknown.

The optimum technique for assessing fat mass is the multi-component model, although deuterium dilution is also considered to have high accuracy.[46] MRI is also considered a gold standard for adipose tissue quantity and distribution, though it should be noted that adipose tissue is not equal to fat mass, hence reducing comparability across studies. DEXA is often described as an accurate objective technique; however, bias is systematically associated with factors such as sex, body size and obesity status.[47,48]

In this context, we found that BMI was the most frequently used outcome measure (18 out of 24 studies reviewed). It has been shown that for a given value of BMI, a wide range of fatness is observed in children.[49] The limitation of BMI is much more evident if the aim is to investigate its association with physical activity. Physical activity can increase lean mass as well as decrease fat.[50] However, BMI does not distinguish between these two compartments and, therefore, either stability or even increase in this index may actually correspond to favourable changes in body composition. In fact, the lack of association between physical activity and BMI in boys observed in some studies[29,33] may be related to this issue. Nonetheless, one should note that studies that used BMI and another method to estimate adiposity (i.e. bioelectrical impedance, skinfold thickness or circumferences) usually found similar effects of physical activity regardless of the outcome measurement. For example, Savoye et al.[21] showed an effect of comparable magnitude ($p<0.001$) of physical activity on BMI and percentage of body fat derived from a body fat analyser (Tanita, TBF 300).

Skinfold thickness was another frequently used outcome measure. This approach at least measures one component of adiposity directly, but may not reflect deeper fat depots,[51] which are most strongly associated with health outcomes.[52] Furthermore, published equations have been shown to be inaccurate. However, the majority of adolescent fat mass is subcutaneous rather than intra-abdominal, hence raw skinfold data provide valuable information about energy stores. Raw data expressed as standard deviations are frequently based on reference data that may not be appropriate for contemporary populations;[53,54] however, ranking within the population is likely to be accurate.

Some studies, with noticeably lower numbers of participants, have used more sophisticated methods such as DEXA. In addition to the limitations in accuracy discussed above, their results are frequently converted into percentage of body fat. However, percentage of body fat has been criticized because it is both statistically and conceptually problematical.[54-56] For example, percentage fat is the inverse of percentage lean mass, hence the actual body component associated with other variables remains unclear. Proposed alternatives, such as adjusting body fat to body size (as kg/m^2, for example), have not yet been associated with physical activity in longitudinal studies; however, in cross-sectional studies, both fat mass and lean mass adjusted for height have been associated with physical activity level.[57]

Similar lack of validity is also evident in the measurement of physical activity. The gold standards for estimating physical activity in children and adolescents have been claimed to be direct observation, double-labelled water or indirect calorimetry.[58] None of the studies used any of these methods. Instead, most studies estimated physical activity by questionnaires. Although questionnaires have some advantages over other methods, they are very subjective. Collecting valid data through questionnaires depends on the reliability of the interviewee in reporting accurately the practice of physical activities over a determined period of time. This is particularly problematic with children and adolescents, given their low ability to record their activities. Furthermore, physical activities in these ages are generally characterized by irregular bouts of short duration and varied intensity activities, making it even more difficult to obtain accurate data.

An alternative to overcome these shortcomings would be the application of more

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objective measures of physical activity, such as motion sensors to determine physical activity level. Such techniques have been shown to be valid and reliable in young populations, with no evidence of high reactivity.[59] However, our review did not identify any studies using these approaches. Possible reasons for this finding are the high costs associated with the use of such devices in large-scale studies, or the limited feasibility of assessing physical activity over long time periods using these instruments. The costs and the storage capacity of recent accelerometer models have changed favourably and it is possible that in the near future these devices will be used in epidemiological studies.

Experimental and quasi-experimental studies usually focused on aerobic activities lasting at least 30 minutes and performed at least twice a week. Gutin et al.[19] verified the effect of different intensities on body composition and concluded that either high- or moderate-intensity activities impacted on body composition similarly. However, these authors highlighted important limitations such as the low rate of attendance at the exercise sessions, and the inability to perform the exercises in the target heart rate zone, which might have compromised the results. In this context, based on our review, the current recommendation of 60 min/day of physical activities practice on most days of the week to prevent/treat adolescent obesity[60] lacks evidence. In fact, this recommendation has been criticized for the same reason in other studies.[61]

Some methodological aspects of our review should be highlighted. Several studies on the association between physical activity and body composition were cross-sectional, and thus were not included in this review. Although cross-sectional studies are valuable for addressing various research questions, they are unable to establish temporality of the association between the exposure and outcome under study (physical activity and adiposity levels), which was the objective of our review. Therefore, our review only included prospective studies, since they are less likely to be affected by reverse causation than cross-sectional studies. Studies with fewer than 50 participants were excluded due to the lack of statistical power associated with such a low number of individuals. Furthermore, we were interested in the effectiveness (i.e. intent-to-treat analysis) rather than efficacy of physical activity, whereas smaller studies usually carry out only efficacy analyses. However, it should be noted that small-sized studies usually allow for more sophisticated measures of both physical activity and adiposity, and their results can represent valuable pilot data requiring confirmation in larger samples.

The likelihood of publication bias in our review must be considered. If studies with inconclusive results or indicating an unexpected association (i.e. unfavourable effects of physical activity on adiposity) were not located but do exist, then the beneficial effects of physical activity on adiposity would be overestimated. In order to decrease the likelihood of this bias, several strategies of the literature search were adopted and the authors of the articles included were asked about other studies (either published or unpublished) on the same topic. Finally, we assessed the methodological quality of the studies using a modified version of the Downs and Black Scale.[16] Such a scale has been used in other reviews.[17,62-64] Overall, results from studies with higher scores were similar to those with lower scores.

Although it is important to have an indicator of the quality of the studies included in the review, some limitations of the Downs and Black Scale itself must be pointed out. Firstly, some criteria (e.g. numbers 14, 15 and 19) are not applicable to observational studies and were coded as 0 (thus, rated as 'inadequate'). Secondly, the absence of some items of the scale in an article might be a reflection of factors other than solely poorer methodological quality. For example, it is reasonable to believe that authors from studies with small sample sizes are under greater editorial pressure to discuss the power of analyses than authors from larger studies. In fact, several large studies were rated as inadequate in criteria number 20 because sample size calculations were not presented. Some items of the scale are vague and difficult to evaluate. For example, regarding criteria number 19, there is no widely acceptable rate of desired compliance. Likewise, some studies did

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not clearly indicate the compliance rate with the intervention. Therefore, we decided to rate all studies as adequate for this item, as this is also recommended in the original article reporting the scale, being relevant whenever misclassification error is likely to bias the association to the null.[16]

4. Conclusions

This article focused on the longitudinal association between physical activity and adiposity in adolescence. Most studies showed protective effects of physical activity against adiposity, mainly in individuals who were obese at baseline. Nonetheless, few studies, in particular experimental ones, are available and several methodological drawbacks are evident. The main limitations relate to a lack of validity in the measurement of both physical activity and body composition. Thus, based on the current available data, we conclude that the literature offers only limited support for a causal link between physical activity and adiposity in adolescence. Further studies are needed in order to generate evidence-based recommendations for the quantity and quality of adolescent physical activity to prevent and treat adolescent obesity.

Acknowledgements

Felipe F. Reichert thanks the National Council of Technological and Scientific Development (CNPq) for supporting him with an academic scholarship during the writing of the manuscript. No other sources of funding were used to assist in the preparation of this review. The authors do not have any conflicts of interest that are relevant to the contents of this manuscript.

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