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Original research

BMI is a misleading proxy for adiposity in longitudinal studies with adolescent males: The Australian LOOK study

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ABSTRACT

Objectives: Despite evidence suggesting caution, employment of body mass index (BMI, kg m^{-2}) as a proxy for percentage of body fat (PFat) in longitudinal studies of children and adolescents remains commonplace. Our objective was to test the validity of change in BMI as a proxy for change in PFat measured by dual-energy X-ray absorptiometry (DXA) during adolescence.
Design: Longitudinal study.
Methods: Healthy, predominantly Australian youth of mainly Caucasian background (131 females and 115 males) underwent repeated measures at 12.0 (SD 0.3) and 16.0 (SD 0.3) years for height, weight and PFat (DXA).
Results: There was no significant difference in the percentage changes in BMI and PFat for the females ($\beta = 2.45$, standard error (SE) = 1.39, 95% confidence interval (CI) = [−0.27; 5.17]) with their mean BMI increasing 15% as their mean PFat increased 18%. However, for the males, while their mean BMI also increased 15%, their mean PFat was reduced 25%; this change being highly significant ($\beta = -42.25$, SE = 2.23, 95% CI = [−46.22, −38.27]).
Conclusions: While change in BMI is likely to be a rough proxy for change in PFat measured by DXA in longitudinal studies of adolescent females, this is not the case for adolescent males, where increased BMI is likely to correspond with decreased PFat. Consequently, inferences from longitudinal studies of adolescents which have assumed that an increase in BMI (or BMI Z-scores or percentiles) represents an increase in adiposity require reconsideration.

1. Introduction

With its convenience and simplicity, body mass index (BMI, body mass (kg)·ht $(m)^{-2}$) is widely employed in children and adolescents as an indicator of adiposity, despite its inability to distinguish fat and lean mass. BMI classified by age is a common means of classifying the adiposity of children, based on the findings that BMI or BMI derived variables are significantly associated with the percentage of body fat (PFat, fat mass × body $mass^{-1}$ × 100) of a child at the between-child (cross-sectional or population) level. However the curvilinear relationship between BMI and PFat with increasing age complicates this relationship,[1] as do maturation, race and gender.[2] For example in a sample of children whose BMI ranked in the lowest third, higher BMI is not generally indicative of higher PFat, and this is more pronounced in males.[1] The latter study suggested that BMI can only be considered a reasonable proxy for PFat in childhood cross-sectional (population) data when BMI falls within the top 50% for males and 70% for females.

The limitations of BMI become even more pronounced at the within-child (longitudinal) level. Previous reports[1,3,4] have indicated that during growth in pre-adolescents, increases in mean BMI are not necessarily accompanied by increases in mean PFat. Indeed, in adolescent males, increased BMI or BMI percentiles may even be accompanied by a decrease in PFat,[1,3] indicating the increase in BMI to be due to increased lean mass. Consequently, reports based on the assumption that increased BMI represents increased PFat are likely to be misleading. Nonetheless, workers in many longitudinal studies involving children and adolescents continue to make this assumption, and there are probably two contributing reasons. Firstly, BMI is widely published, and its measurement easy, inexpensive and non-invasive, avoiding x-rays as used in dual energy X-ray absorptiometry (DXA), making it especially attractive to workers in large sample studies. Secondly, the above-cited articles may have been overlooked or ignored; possibly because

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Table 1
Repeated measures of BMI and PFat in the males and females in 2009 (age 12, SD 0.3 years) and 2013 (age 16, SD 0.3 years).

	Females 2009 (N = 131)		Females 2013 (N = 131)		Males 2009 (N = 115)		Males 2013 (N = 115)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Height (cm)	154.4	7.32	165.2	6.3	153.3	7.9	175.7	7.3
Weight (kg)	46.4	9.08	63.2	10.7	45.3	9.2	70.1	12.5
BMI (kg/m^2)	19.4	3.05	23.2	3.8	19.2	3.0	22.7	3.9
PFat	27.1	6.1	31.5	5.9	23.6	7.0	17.6	6.8

they have insufficiently emphasized the problem with BMI in paediatric longitudinal studies or because PFat was assessed in two of these studies by underwater weighing[1] or bioelectrical impedance,[3] rather than more widely accepted (DXA).[4]

On the other hand, the problem has not gone unnoticed. For example, recent reviewers of the relationship between sedentary time and adiposity[5] acknowledged that drawing solid conclusions were confounded by problems associated with the use of BMI in growing children, especially its use in longitudinal studies during adolescence.

In the interest of avoiding further interpretive errors associated with the use of BMI in longitudinal studies involving growing children and adolescents, further evidence and attention to this issue is required. Here we investigate the validity of BMI as a proxy for PFat in a cohort of adolescent males and females by comparing changes in their BMI with changes in their PFat (measured by DXA); and in examining the males and females separately, we investigate any gender related variation in the validity of BMI.

2. Methods

This study was part of the multidisciplinary Lifestyle of our Kids (LOOK) longitudinal study as previously outlined.[6] Characteristics of the participants are shown in Table 1. We obtained repeated measures in grade 6 at age 12 years (SD 0.3) and grade 10 at age 16 years (SD 0.3) from each of 131 females and 115 males. Approximately 90% of the participants had one or both parents of Caucasian descent, 8% of Asian descent, 1% of Indigenous Australian or Polynesian descent, and we had no data on 1% of the families. They were recruited from 29 government-funded primary (elementary) schools mostly in outer suburbs of the territory, relatively homogeneous with respect to average household incomes, which approximated the Australian average.

This study was approved by the ACT Health and Community Care Human Research Ethics Committee and the Ethics Committee at the Australian Institute of Sport.

Height was measured by the same two members of our research team, using a portable stadiometer to the nearest 0.001 m, with heels, buttocks and shoulders touching the wall, and the tragus of the ear and the lower orbital margin approximating a horizontal plane. Weight was measured by electronic scales to the nearest 0.05 kg. Body composition was measured using DXA (Hologic Discovery QDR Series; Hologic, Bedford, MA). Light clothing was worn and total body scans were analysed using QDR Hologic Software Version 12.4:7 to generate lean tissue mass and fat mass from which PFat was calculated. Spine and step phantoms provided by the manufacturer were scanned on a daily basis for quality control assessment and a whole-body phantom was also scanned on a weekly basis. The measures were completed in the latter three months of 2009 and 2013, in primary (elementary) school grade 6 and in secondary school grade 10 respectively.

In order to account for intra-individual dependencies, we fitted a linear mixed model with percentage change as dependent variable, with gender (males vs females) and Measurement (BMI vs PFat) as fixed factors. A random intercept for Subject was included. The model was fitted using R[7] with the package lme4.[8] Assumptions were assessed visually using a QQ-plot and no obvious deviations from normality were detected. Significance testing was performed using Type II F tests with Kenward–Rogers degrees of freedom approximation and $p < 0.05$. Results are reported as estimated mean effects (β), estimated standard errors (SE) and their 95% confidence intervals (95% CI).

3. Results

Table 1 presents the means and standard deviations of height, weight, BMI, PFat for the females and males, each of whom had repeated measures recorded in grade 6 (mean age 12 years, SD 0.3) and during grade 10 (mean age 16 years SD 0.3). Fig. 1 provides a comparative view of the changes in the means of BMI and PFat over the four years in the males and females. Fig. 2 depicts a comparative and contrasting view of the gender specific changes in BMI and PFat by presenting the data as percentage changes in the means.

For BMI, there was no significant difference between boys and girls in the percentage changes in BMI and PFat (β = −0.89, SE = 1.97, 95% CI = [−4.75; 2.97]). Comparing the percentage changes in BMI and PFat for each sex separately, for the girls, there was no significant difference (β = 2.45, SE = 1.39, 95% CI = [−0.27; 5.17]). However, for the boys, there was a significant difference between the changes in PFat and BMI (β = −42.25, SE = 2.23, 95% CI = [−46.22, −38.27]).

4. Discussion

In our sample of adolescent females, change in BMI might be considered a reasonable proxy for change in PFat, but this was not the case in males, where an increase in BMI was associated with a decrease in PFat. The gender differences in the way BMI reflected PFat was reflected by the large variation in effect size of the relationships between these two variables; a small positive non-significant relationship in the females and a very large significant negative relationship in the males. Consequently, inferences from research assuming a direct relationship between change in BMI (or derivatives of BMI, such as z-scores or percentiles) and change in PFat, especially where males are involved, are likely to be flawed. The gender differences in relationships between the changes in BMI and PFat indicate the necessity of analysing longitudinal data concerning BMI in males and females separately.

Our results are in agreement with previous findings[1,3] that in general, the lean mass of a male during the growth phase of adolescence is likely to increase more rapidly than his fat mass. Our data are also consistent with the similarly discordant changes in BMI and change in PFat findings in the quick growth phases of both boys and girls between the ages of 10 and 12 years of age.[4] Consequently, researchers using the change in BMI in adolescent males as a proxy for change in PFat in any investigation of a relationship may find a correlation coefficient of opposite sign to that which may have been derived using PFat.

Researchers have sometimes referred to BMI as “weight status” in longitudinal studies. This may have occurred in part acknowledgement of the problematical nature of BMI, but in so doing often tacitly implies BMI to represent adiposity. At the population or cross-sectional level, use of BMI as a proxy for PFat might be

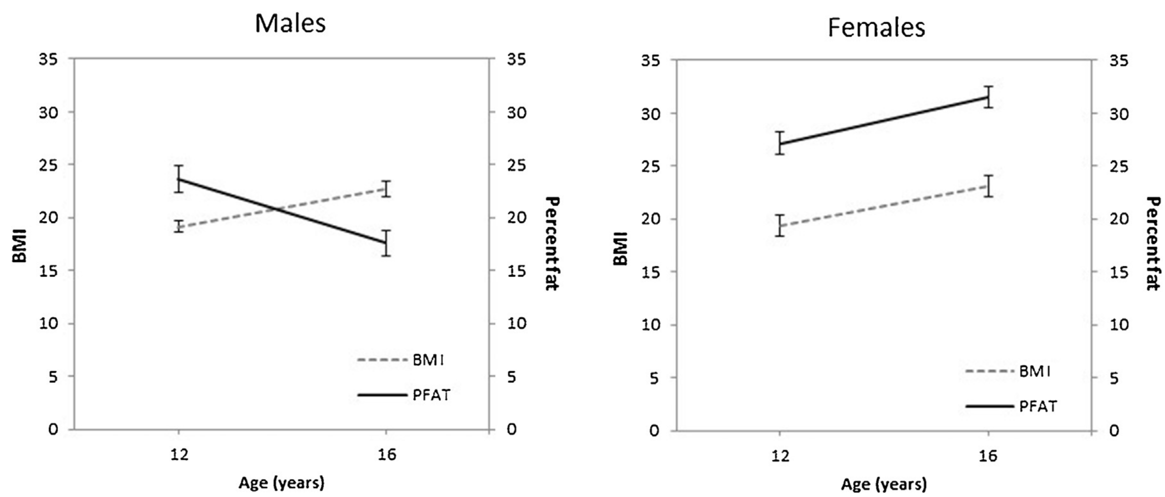

Fig. 1. Repeated measures (means and SE) of BMI and PFat of females and males at 12 and 16 years of age.

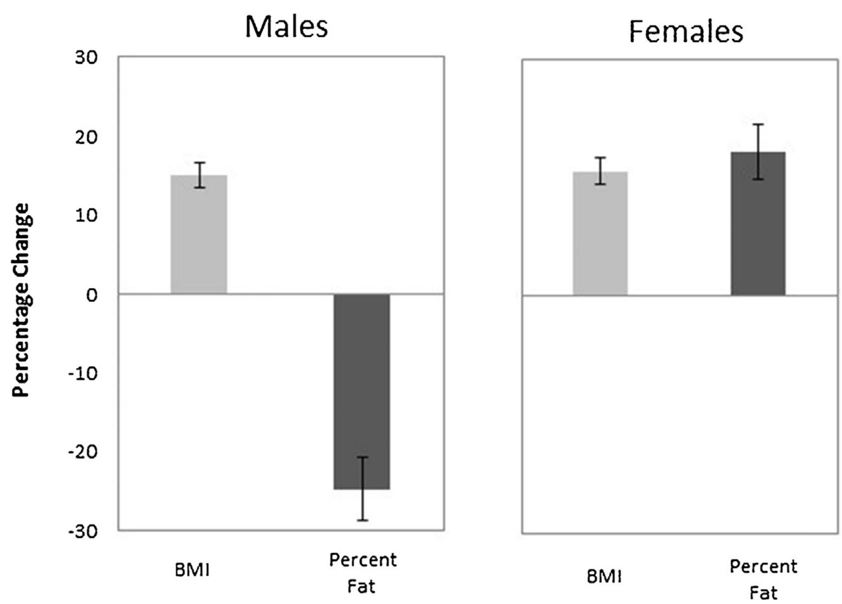

Fig. 2. Percent changes (means and SE) in PFat and BMI of males and females between 12 and 16 years of age.

generally acceptable, but at the longitudinal within-subject level it is not. Moreover, any statistical application of BMI, as in percentiles or z-scores, does not resolve the underlying problem associated by BMI in longitudinal paediatric studies.

In addition to the above-mentioned review[5] in which the authors expressed their concerns surrounding the use of BMI, to assist understanding of how publications may be adversely affected, we provide some specific examples of publications where authors may have concluded or explained things differently had they recognised the potential complications involved with using BMI in longitudinal studies.

One group reported that screen time predicted increases in skinfolds in males and females, but predicted increases in BMI in females but not males[9]; this is likely to be explained by increases in BMI being representative of increased adiposity in the females, but not in the males. Furthermore, had authors of another study[10] understood that change in BMI is likely to represent different patterns of change in PFat in males and females entering adolescence, their interpretation of their finding that home-based physical activity was associated with relatively greater decreases in BMI z-score in the females may well have been different. In another study of 9–15 year-olds, spending more time in sedentary behaviour was associated with increased BMI at higher BMI percentiles but not at lower BMI percentiles.[11] This finding is likely to be explained, at least in part, by BMI bearing little relationship with adiposity at lower percentiles.[3]

The BMI-PFat relationship may also have implications for a meta-analysis which concluded that in children ages 1–6 years, consumption of fruit juice was associated with an increase in BMI *z*-score, while there was no association in children ages 7–18 years. We offer the possible explanation that in contrast with younger children up to the age of 10 years,[4] change in BMI between the ages of 10 and 18 years is less likely to reflect change in adiposity, especially when there are males involved. We also consider a report of a strong longitudinal association between fitness (20 m shuttle run) with a function of BMI during adolescence,[12] where the authors concluded that lower fitness levels were related to overweight/obesity. Our current data suggests that an alternative inference for the males (their increasing BMI likely to correspond with decreasing fatness), is that they were less likely to score highly in the shuttle run endurance test, where aerobic power relative to body weight is advantageous, simply because they were bigger, not fatter. Another group found that decreases in sports participation and hours spent in physical education were associated longitudinally with increases in BMI z-scores from age 10 to 13 years of age.[13] However, drawing on previous publications in younger participants,[1,3,4] as well as current reported data, any inference that decreased participation in sport and physical education was associated with increased adiposity, especially in boys, is tenuous.

A large scale study of BMI during the first four years of adolescence[14] concluded that the rarity of BMI transitions from obese to normal weight classification indicated that any notion of what is known as "puppy fat" disappearing on maturation must be abandoned. However, given that the increased BMI of the males was likely to have been accompanied by increased lean mass rather than fat mass, the notion of a loss of "puppy fat" might well hold.

While potential problems of interpretation may arise in longitudinal studies when BMI is employed as a proxy for adiposity, researchers are likely to be alerted to these problems when more direct measures of adiposity assessments accompany the BMI measures. Such an example is found in a study where BMI increased in both boys and girls between grades 5 and 7 while PFat (estimated by bio-impedance) decreased among boys.[15] This led the authors to describe BMI in terms of the rather nebulous descriptor "weight status" rather than and specific reference to adiposity.

A strength of this report is in the clarity of its outcomes, including the gender differences signified by the contrasting effect sizes describing differences in the percentage changes in BMI and PFat. A limitation of the current study lies within the nature of our cohort, which was predominantly white. Our findings might not apply to adolescents of other race or ethnicity,[2] although it is noted that our findings are consistent with those from a Japanese adolescent cohort.[3]

5. Conclusion

Following similar previous findings in both boys and girls during the quick growth periods of late childhood, use of change in BMI as proxy for change in relative adiposity in adolescent males, but not females, is problematical. During this rapid growth phase in adolescent males, increased BMI is likely to correspond with reductions in PFat; a finding warranting re-evaluation of published longitudinal studies and reviews where this discordance has not been recognised.

Practical implications

- As previously shown to be the case for younger boys and girls, BMI is best avoided as a proxy for PFat in longitudinal studies of adolescent males.
- Change in BMI, in contrast to previous findings in younger girls, is a reasonable proxy for change in PFat in early adolescent females.
- Conclusions from published longitudinal studies and reviews in adolescent cohorts where change in BMI is used to represent change in adiposity in adolescent boys may require reconsideration.

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