BMC Women's Health

RESEARCH Open Access

# How does BMI correlate with menarche onset? Evidence from the Italian HBSC cross-sectional study

Domitilla Marconi[1*], Dario Lipari[1], Andrea Pammolli[2], Paola Dalmasso[3], Paola Nardone[4], Alessio Vieno[5], Rita Simi[2,6] and Giacomo Lazzeri[1,2,6]

## Abstract

**Background** Menarche is an important period in a female's life; its time of onset may depend on various factors and could correlate with the development of diseases in adulthood. Our study aims to investigate the relationship between body mass index and age at onset of menarche;

**Methods** We used a unique standardized national dataset on adolescent girls participating in the Italian Health Behaviour in School-aged Children Study. Two independent nationally representative survey datasets: one on 15-year-olds ($n=6505$, year 2017/2018) and one on 11-year-olds ($n=6548$, year 2013/2014) were analysed. The survey instrument was the self-report questionnaire. Median age at menarche and 95% confidence intervals were estimated through Kaplan–Meier analysis. Hierarchical models assessed the relationship between BMI and age at menarche;

**Results** Region-level median age at menarche ranged between 12 years/5 months and 13 years/4 months. Region-level prevalence of overweight among 15-year-old girls ranged between 6% and 24%. Age at menarche was inversely associated with individual BMI (unstandardized regression coefficient beta=-0.81; 95% CI, -0.92 to -0.70). Individual-level and class-level measures of BMI accounted for 215.2% of the region-level variance in age at menarche;

**Conclusions** The results show that girls who were overweight during childhood went through early puberty. Further investigation needs to assess a possible cause-effect relationship.

**Keywords** Early puberty, Puberty, BMI, Overweight, Menarche, Obesity

*Correspondence:
Domitilla Marconi
d.marconi2@student.unisi.it
[1]Post Graduate School of Public Health, University of Siena, Siena 53100, Italy
[2]Research, Education, Prevention and Health Promotion (CREPS), University of Siena, Siena 53100, Italy
[3]Department of Public Health and Paediatrics, University of Torino, Torino 10126, Italy
[4]National Centre for Disease Prevention and Health Promotion, Istituto Superiore di Sanità (National Institute of Health), Rome 00161, Italy
[5] Department of Developmental and Social Psychology, University of Padova, Padova 35131, Italy
[6]Department of Molecular and Developmental Medicine, University of Siena, Siena 53100, Italy

## Background

Adolescence is a crucial phase in the normal development of every person; this period is extremely delicate for young people, as they have not yet learnt how to use those mechanisms and mental processes that are useful for dealing with the challenges and complexities typical of development, so it is necessary to focus more attention on and help adolescents to overcome it by reducing their discomforts, to improve their development. Additional factors, such as pathologies, comorbidities, or ill health status, can further complicate this complex developmental period [1].

Overweight and obesity are common among children and adolescents. According to United Nations Children's Fund (UNICEF) and World Health Organization (WHO) evaluations, overweight (including obesity) was a global problem in the WHO European Region in 2020, with 4,4 million children under 5 years of age (that represent 7,9% of children in this age group), with wide differences between countries [2].

Obesity is a multifactorial condition characterized by increased adiposity and is associated with an enhanced risk of several non-communicable diseases [3]. Health problems in people living with obesity may derive from the adipose tissue represented in these individuals; it is a metabolically active endocrine organ whose morpho-functional units, the adipocytes, are cells that receive and release hormones [4].

In Italy, more than 40% of children 5–9 are overweight or obese [5], about 20% of adolescents 10–19 are overweight or obese [6]; to measure these data were used the threshold values proposed by Cole et al. in 2000 [7]. There are differences between regions and an increasing geographical gradient from North to South [5, 6, 8]. In line with international data, even in Italy, the same correlation between education level and FAS (Family Affluence Scale) and obesity/overweight subsists [9]. According to recent literature, the increase in the prevalence of overweighted girls may be associated with the age of menarche. Girls with overweight had a higher risk of earlier age at menarche than girls without overweight [10, 11].

The term menarche is used to describe the first menstrual cycle in an adolescent's life and this event marks the beginning of puberty and the entry into childbearing age. It comes later in puberty and is an indicator of sexual maturation. Regarding age, in Italy, menarche usually occurs at a median age of 12,9-year-olds [10].

In early adolescence, obesity significantly impacts health by leading to an earlier onset of puberty, characterized by premature thelarche [12] and menarche [13]. Various theories have been proposed to explain this trend towards earlier puberty, including exposure to environmental toxins and shifts in socioeconomic status. However, it is well-established that nutritional status plays a critical role in the timing and progression of puberty. Despite this, the causal direction of this relationship remains unclear—whether weight gain precedes early puberty, early puberty contributes to abnormal weight gain, or both factors are interrelated [14].

Studies showed that an increase in weight and body mass index (BMI) during childhood correlates with an early onset of puberty [10, 15–17]. So, it is possible to assume that these factors are important in influencing the age of menarche; early onset of menarche has also been correlated with health problems, including breast cancer, cardiovascular disease, and increased mortality rates in general [15].

Our study aims to correlate the age of onset of menarche with the nutritional status of Italian adolescent girls. The present study is one the first to examine the relationship between obesity and age at menarche by utilising standardised data from all Italian regions, without the problems of interpretation that arise from different methodologies and different cohorts.

## Materials and methods

The data presented were obtained from the Italian Health Behaviour in School-aged Children (HBSC) cross-sectional study, following the international HBSC protocol.

All Italian regions were included in the study in order to provide territorially comprehensive coverage. The target population includes all 11–13 and 15-year-old boys and girls inscribed in the first and third grades of lower secondary school and the second grade of upper secondary school. In carrying out the survey, several practitioners were involved and contributed to the work conducted. School principals, classroom teachers, and other school personnel were involved along with local health professionals. Teachers involved in the survey were trained on data collection methods by the Provincial School. Another assignment asked them was to give to the parents, or legal guardian, of each participant the information sheet containing survey details and an opt-out consent form, to be signed and turned in only if the student declines to participate. Each region employed regional coordinators and Local Health Units (LHUs) to conduct and maintain regionally based activities. The national coordination HBSC 2018 Group, consisting of the National Institute of Health and the Universities of Turin, Siena and Padua, coordinated the activities and performed training sessions on 2018 survey methods for the health workers.

### Sampling

Cluster sampling with probability proportional to population size (PPS) was used to obtain a nationally representative sample, with school class as primary sampling unit [18]. More details about this type of sampling method and the main disadvantages are described elsewhere [19]. The Ethics Committee of the Italian National Institute of Health approved the 2018 protocol (PROTPRE876/17, 20 November 201), the protocol also includes the use of an opt-out permission form, in which parents have to explicitly deny consent to their child's participation; failure in returning this signed form was considered as agreement to participation. To preserve the privacy, were adopted all useful procedures to prevent the possible identification of participants, in accordance with European laws [20].

A detailed treatment regarding the purpose, conceptual background, and protocol of the international and Italian study is available elsewhere [21–23].

In the 2017/2018 survey, response rates at school/class level exceeded 85% in most regions [24]. A nationally representative randomized sample of 15-year-old girls ($n = 6505$) was utilized in order to have regionally comparable data on age at menarche and BMI. The girls were sourced from 1131 schools in the 21 regions that joined the Italian HBSC 2017/2018 survey. Sample sizes ranged from 166 (Valle d'Aosta) to 787 (Veneto). Furthermore, aggregated region-level data on BMI among 11-year-old students ($n = 6548$) from 1047 schools from 21 of these regions, which had also participated in the 2013/2014 HBSC Italian survey [19], were used. Sample sizes ranged from 182 (Basilicata) to 1046 (Veneto) [25]. We analyzed the prevalence of overweight 15-year-olds girls for all Italian regions and as an aggregate data using 2017/2018 survey data. The same prevalence was also calculated for overweight 11-year-olds girls through data sourced from the 2013/2014 survey to obtain an independent regional figure of overweight levels. The latter group derived from a sample of predominantly pre-menarche girls (75.1%) obtained from the same population of girls who were 11-year-olds in 2013/2014 that was resampled in 2017/2018 at 15 year-olds.

### Measures

Information regarding the menarche and age of onset of menstrual cycle was obtained through the following questions: "Have you started menstruating?" the answer to which could be "No, I have not started menstruating yet" or "Yes, I started at the age of __ years and _ months." The girls were divided into two categories: pre- or post-menstruation. A considerable number of girls were dropped from our analysis due to lack of age at menarche, specifically 2957 girls (31.5%). Self-reported height and weight were used to calculate the Body mass index (kg/m2). When the participants' BMI data were coded, they were then grouped into the following three categories, using WHO age- and sex-specific cut-offs standard deviation of BMI z score's reference: underweight (SD:<-2), normal weight ($-1 \leq SD < 1$), overweight (SD:>1), obese (SD:>2) [26]. In our analyses, we considered students who were categorized "overweight" or "obese" as overweight.

The geographic area of residence was derived from the Region of residence and classified into North, Central and South Italy according to the Italian National Institute of Statistics (ISTAT) classification [27].

### Socioeconomic status

Socioeconomic status was evaluated through the Family Affluence Scale (FAS3) [28]. The FAS is a validated measure of material affluence that assigns a composite score on six items: number of family-owned computers (none, one, two or more); having own bedroom (yes/no); number of cars in family (none, one, two or more); number of bathrooms (room with a bath/shower or both) (none, one, two or more); having dishwasher at home (yes/no); holidays with family in the last year (none, once, twice or more). The sum-score can be used to create indices of relative ranks within countries. A useful transformation of the FAS summed score is the ridit transformation this procedure is used to categorize an ordinal variable. It gives a rank to the sum of the scores and then, divides the resulting distribution, as in this case, into three parts of equal size (tertiles, 33% each) obtaining the desired High-Medium-Low classification [29].

### Statistical analyses

A continuous variable representing age at menarche was expressed as a median value with 95% CI using the Kaplan-Meier method. A multivariable linear regression model was then used to evaluate the association between BMI and age at menarche among 15-year-olds girls in 2017/2018, adjusted by current age and FAS. The relationship between BMI and age (at menarche) at the individual and region levels was finally assessed through hierarchical models at four levels: individual, school, sampling strata (north, center, south), region. The Model 1 included only age and family affluence; the Model 2 also included individual BMI and the Model 3 included aggregate prevalence of overweight among 11-year-olds in 2013/2014.

The region-level intraclass correlation (ICC), which measures the proportion of the variance in age (at menarche) that is attributable to the region-level, was used. The ICC from Model 2 and Model 3 are expressed as a percentage of the ICC from Model 1, in order to show the change in region-level residual variance. Age at menarche was imputed as current age for those who were premenarcheal. Another regression model was applied to calculate the relationship between the region-wide median age at menarche and the prevalence of overweight among 15-year-olds subjects in 2017/2018 and 11-year-old subjects in 2013/2014. All analyses were carried out using the software SPSS 22.0, Complex Samples module.

## Results

The mean age of 15-year-olds in the 2017/2018 survey was 15.5 years (SD = 0.32), and that of 11-year-olds in the 2013/2014 survey was 11.8 years (SD = 0.31). Among 15-year-olds girls with complete menarche data ($n = 6505$), 1.3% were pre-menarcheal, and the mean FAS score was 8.06 (SD = 2.16).

Differences in the age at menarche were observed among girls and across regions in the sample of 15-year-olds surveyed in 2017/2018. In 95% of individuals, age (at

**Table 1** Summary by region of median age at menarche, and percentage "overweight + obese" at age 15 and at age 11. HBSC study, 2017/2018 and 2013/2014

| Region | 15 year-olds girls (2017/2018) | | | | 11 year-olds girls (2013/2014) |
|---|---|---|---|---|---|
| | Median age at menarche | | | Percentage | Percentage |
| | N | Months (years and months) | 95% CI (months) | Overweight + obese | Overweight + obese |
| Abruzzo | 340 | 151 (12 years 6 months) | (149.41-152.59) | 12.0 | 18.6 |
| Basilicata | 121 | 146 (12 years 5 months) | (142.84-149.16) | 12.4 | 21.8 |
| Bolzano | 295 | 155 (12 years 6 months) | (152.53-157.47) | 6.3 | 10.0 |
| Calabria | 289 | 147 (12 years 5 months) | (145.45-148.55) | 22.0 | 25.8 |
| Campania | 268 | 148 (12 years 5 months) | (146.35-149.65) | 23.9 | 34.1 |
| Emilia R. | 417 | 150 (12 years 5 months) | (148.48-151.52) | 11.8 | 18.5 |
| Friuli V.G. | 363 | 152 (12 years 6 months) | (150.32-153.68) | 12.9 | 15.8 |
| Lazio | 274 | 150 (12 years 5 months) | (148.31–151.70) | 15.6 | 18.6 |
| Liguria | 282 | 152 (12 years 5 months) | (149.65-154.35) | 10.2 | 13.2 |
| Lombardy | 466 | 152 (12 years 5 months) | (150.16-153.85) | 7.2 | 12.2 |
| Marche | 361 | 154 (13 years 5 months) | (151.46-156.54) | 13.7 | 18.1 |
| Molise | 250 | 150 (12 years 5 months) | (148.23-151.77) | 15.7 | 19.8 |
| Piedmont | 320 | 151 (12 years 6 months) | (149.26-152.74) | 9.6 | 15.5 |
| Puglia | 325 | 150 (12 years 5 months) | (148.81-151.19) | 16.8 | 34.6 |
| Sardinia | 89 | 150 (12 years 5 months) | (144.64-155.36) | 17.9 | 11.9 |
| Sicily | 289 | 147 (12 years 5 months) | (145.38-148.62) | 11.6 | 23.0 |
| Tuscany | 325 | 151 (12 years 6 months) | (149.50-152.50) | 10.1 | 15.0 |
| Trento | 477 | 155 (12 years 6 months) | (150.15-153.85) | 7.0 | 10.5 |
| Umbria | 181 | 149 (12 years 5 months) | (147.42-150.58) | 12.4 | 17.3 |
| Valle d'Aosta | 111 | 152 (12 years 5 months) | (148.37-155.63) | 11.7 | 16.4 |
| Veneto | 662 | 153 (12 years 6 months) | (151.26-154.74) | 12.5 | 15.3 |
| All regions | 6505 | 151 (12 years 5 months) | (150.59-151.41) | 12.5 | 17.3 |

**Table 2** Linear regression analysis for age at menarche (months) among 15 year-olds. HBSC study, 2017/2018

| Independent variables | Unstandardized regression coefficient (β) | 95% CI |
|---|---|---|
| Body Mass Index (BMI) | -0.75 | -0.86 to -0.64 |
| Current age (months) | 0.29 | 0.20 to 0.37 |
| FAS score | 0.28 | 0.13 to 0.42 |
| Constant | 111.87 | 96.18 to 127.54 |

$p < 0.001$, age at menarche and current age are measured in months

CI = Confidence interval

menarche) ranged between 9 and 15 years and 7 months. No subject was younger than 9 years. The region-level median age (at menarche) ranged from 12 years and 5 months in Marche Basilicata, Campania, Calabria, to 13 years and 5 months in Marche. The region-level prevalence of overweight varied across regions: from 6.3% (Bolzano) to 23.9% (Campania) among 15-year-olds in 2017/2018, and from 10% (Bolzano) to 34.6% (Puglia) among 11-year-olds in the 2013/2014 survey (Table 1).

As shown in Table 2, a significant negative association between individual BMI and age at menarche was observed in 15-year-olds sample. The unitary increase in BMI led to a 1 month earlier onset of menarche (β=-0.75; 95% CI, -0.86 to -0.64). Also considering the single regions (data not showed), without Sardinia, where we have an inverse relation, β = 0.40 (statistically not significant $p = 0.46$ CI (-0.66;1.46), menarche occurred earlier in girls with a higher BMI (β ranged from – 1.09 to -0.03); however, in six regions, Calabria (β=-0.03 $p = 0.91$ CI (-0.45;0.40)), Lazio (β=-0.42 $p = 0.10$ CI (-0.92;0.08)), Piemonte (β=-0.29 $p = 0.24$ CI (-0.78;0.19)), Puglia (β=-0.32 $p = 0.14$ CI (-0.74;0.11)), Sicilia (β=-0.41 $p = 0.12$ CI (-0.93;0.11)) and Valle D'Aosta (β=-0.73 $p = 0.11$ CI (-1.65;0.18)) this relationship was not statistically significant.

A negative association was observed between aggregate prevalence of overweight and median age at menarche among 15-year-olds in 2017/2018 (Table 3) by treating the regions as units. The median age at menarche was approximately 23 days lower (β=-0.06; 95% CI, -0.07 to -0.06), for each percentage of increase in the region-level prevalence of overweight. As the region-level prevalence of overweight ranged between 6% and 24%, the maximum difference observed in the age at menarche was 79 weeks (approximately 20 months). When the analysis was repeated on region-level data on overweight status among 11-year-olds in 2013/2014, the direction of this relationship was similar (β=-0.23; 95% CI, -0.23 to 0.22).

**Table 3** Linear regression analysis for region-level median age at menarche among 15-year-olds in 2017/2018

| Model | | Unstandardized regression coefficient (β) | 95% CI |
|---|---|---|---|
| 1. 15-year-olds girls 2017/2018 | Region-level prevalence of overweight (%) | -0.06 | -0.07 to -0.06 |
| | Constant | 135.34 | 135.22 to 135.46 |
| 2. 11-year-olds girls 2013/2014 | Region-level prevalence of overweight (%) | -0.23 | -0.23 to -0.22 |
| | Constant | 153.13 | 153.03 to 153.23 |

Region-level median age at menarche is measured in months; Region-level of overweight is measured in percent

Model 1: Independent variable: prevalence of overweight among 15-year-olds (2017/2018), $N = 21$ regions, $p < 0.001$

Model 2: Independent variable: prevalence of overweight among 11-year-olds (2013/2014), $N = 21$ regions, $p < 0.001$

CI = Confidence Interval

Data source: HBSC 2017/2018, HBSC 2013/2014

**Table 4** Summary of results from multilevel models of age at menarche (months) among 15-year-olds across 21 regions

| Factors | Model 1 adjusted for structural covariates | Model 2 addition of individual BMI | Model 3 addition of region-level overweight |
|---|---|---|---|
| FIXED EFFECTS (95% CI) | | | |
| Individual level | | | |
| Family affluence Scale (FAS) | 0.25 (0.09 to 0.41)* | 0.17 (0.01 to 0.32)* | 0.17 (0.01 to 0.32)* |
| Current age (months) | 0.13 (0.04 to 0.21)* | 0.14 (0.06 to 0.23)* | 0.14 (0.06 to 0.23)* |
| Body mass index (BMI) | - | -0.81 (-0.92 to -0.70)* | -0.81 (-0.92 to -0.70)* |
| Region level | | | |
| Prevalence of overweight (%) of 11 year-olds in 2013/2014 | - | - | -0.05 (-0.18 to 0.08) |
| RANDOM EFFECTS (SE) | | | |
| Region-level variance | 0.29 (0.55) | 0.59 (0.64) | 0.88 (0.85) |
| Region-level ICC as percentage of model 1 ICC[a] | 100% | 211.4% | 315.2% |
| Strata-level variance (north-center-south) | 3.05 (3.30) | 2.24 (2.56) | 1.45 (2.46) |
| School-level variance | 16.39 (2.06)* | 17.11 (2.10)* | 17.08 (2.10)* |
| Residual (individual level) variance | 5163.33 (99.47)* | 4969.90 (95.89)* | 4969.91 (95.89)* |
| Log likelihood | -26543.51 | -26444.09 | -26445.74 |
| Likelihood-ratio test for change in log likelihood | | $p < 0.001$ | $p < 0.001$ |

Age at menarche is measured in self-report age in months, or current age for pre-menarcheal girls

Model 1: Adjusted only for current age and FAS

Model 2: Adjusted for individual BMI measure in addition to current age and FAS

Model 3: Adjusted for region-level prevalence of overweight (%) among 11-year-olds in 2013/2014, in addition to individual-level BMI, current age and FAS

CI = Confidence Interval

[a]Region-level Intraclass Correlation Coefficient (ICC) measures the proportion of observed variation in age at menarche attributable to region level

*$p < 0.05$ significant result for Fixed or Random Effect

To evaluate the association between BMI and age at menarche multilevel regression models were used. No significant differences in age at menarche emerged among the regions; only the coefficient of current age and FAS differed significantly (Table 4: Model 1). In the second model, in addition to the significant difference in the coefficient of current age, region-level variance in age at menarche, increased the ICC by 111.4%, for each unit increase in BMI, age at menarche was approximately and significantly1 month lower ($p < 0.001$, CI (-0.92; -0.70)) (Table 4: Model 2). In the third model, the fixed-effect estimates did not change, but accounted for a further 215.2% of region-level ICC in age at menarche (Table 4: Model 3). In this final model, for each unit increase in BMI at the individual level, menarche occurred approximately 1 month earlier (β=-0.81; 95%CI, -0.92 to -0.70). In all three models, the school-level coefficient proved significant (Table 4); thus, age at menarche varied with BMI, but in a different way among schools. This variation was not significantly different among regions, nor at the strata level (North, Center and South).

## Discussion

As already pointed out by other authors furthermore were observed significant variations in age at menarche across European and North American countries, Italy and Portugal showed the lower values for age at menarche [30], our data show that the mean age at menarche differs by at least 1 year also between the Italian regions. In literature different studies show the correlation between overweight/obesity and early puberty in girls [16, 31–33].

Recently, the decreasing rate of the age of menarche in industrialized countries differs among countries, and this

may be linked to the variation in the prevalence of obesity [34]. An European study supported the hypothesis that there is a positive relationship among lowering age at menarche and being overweight [35]. Our work contributes to increasing knowledge regarding this hypothesis as well. In accordance with the results of the previous Italian 2013/14 HBSC in Italy [36], also the 2017/18 survey found a five-fold difference in the prevalence of overweight among 15-year-old girls in all Italian regions. The highest rates of overweight were observed in central and southern Italy, while the lowest rates were seen in northern regions. In particular, the lowest median ages at menarche were observed in southern regions (e.g., Calabria and Campania), where the predominance of overweight is higher.

Longitudinal studies suggest that BMI is one of the risk factors influencing the development of early puberty [17, 35, 37]; this is in accordance with the inverse association between BMI and age at menarche found at individual and class level in our study.

Two different strands of thought can be identified in the literature regarding the correlation between obesity and the time of menarche onset: there is a direct link between leptin, gonadotropin and puberty timing [38], and early puberty is the leading factor in the development of later obesity [34].

Our view is related to the first of the two proposed hypotheses, but it is possible that there is a crosstalk between the theme whereby a redundancy in effects is created.

Furthermore, given the possible influence of some genes on the menarche-overweight association demonstrated by some authors [39], the influence of genetic and environmental factors needs to be studied in more detail.

Adolescence, in both genders, is described as a complex developmental period as multi-factor acts together to induce and promote ponderal excess status (dietary habits, sedentary, genetic, and environment) [40]. In girls, this effect is strongly present due to the increase in estrogen, leading to enhanced insulin resistance [41].

The study has some limitations, such as the study's cross-sectional nature and the self-reported information. BMI which is the epidemiological benchmark indicator is mostly used to measure overweight and obesity [19, 24, 26]. It is important to note that BMI, as a "population study" index, is not able to evaluate the real body composition, as well as it does not allow us to know the distribution of body fat across the subject. Therefore, people with considerable the same BMI may have considerably different fat mass [42]. Higher BMI is not necessarily associated with increased fat mass (e.g., a bodybuilder might present a high BMI but low-fat mass and still be categorized as overweight or obese). However, even though the girls made a bias against their BMI due to excessive emotional sensitivity toward their weight, there is no recorded bias in the correlation between this data and the age of menarche onset, because going to correlate the remembered age and the effective age of menarche are highly related, particularly when the recall is closer to the age of menarche [43, 44].

Our work, thanks to data collected using a standardized methodology, helps to present up-to-date data about the association between adolescent obesity and menarche onset across Italian regions.

Although the study has those limitations, it has gained new knowledge about the timing of menarche on a representative sample of Italian girls. In addition, the girls involved in the survey were closer to the menarche thus reducing the recall bias and increasing the value of these data at the time of the menarche, thus limiting the memory bias and increasing the value of these data. Premenarchal age girls were included in hierarchical models equalizing the age at menarche with the present one. This comparatively precautionary procedure involved only a few cases (1.3% of 15-year-olds girls were pre-menarche) was used to prevent strengthening the correlation between increased BMI and lower age at menarche. This also allowed us to optimize e the number of girls involved in the study.

## Conclusions

Our study confirms the association between early menarche and overweight/obesity based on data from a national surveillance program employing standardized methodologies. Given the robustness of this approach and the need for further investigation, we suggest expanding the analysis to include a comparison of nutritional data and age of menarche among girls from all European countries participating in this surveillance program. This broader comparison could provide valuable insights into the consistency and variability of this association across different populations.

#### Acknowledgements

We thank all students who completed the questionnaires. Special thanks go to the school head teachers, class teachers and other school staff who actively participated in the implementation of the HBSC survey. We thank all the Regional and Local Health Unit coordinators and the health workers for their fundamental contribution to the HBSC. We further thank all the members of the 2018 HBSC-Italia Group. The publication was possible thanks to the specific contribution of the University of Siena for the support of Open Access and funds from the Department of Molecular and Developmental Medicine.

#### Author contributions

G.L., D.L., D.M. conceptualized and designed the study; A.P. analysed the data. G.L., D.L., D.M.; wrote the first draft. P.N., R.S., P.D. and A.V; critically reviewed the manuscript and approved the final version. All authors have read and agreed to the published version of the manuscript.

#### Funding

The Italian HBSC survey was promoted and funded by the Ministry of Health/National Centre for Disease Prevention and Control (CCM) and the

Italian National Institute of Health (CCM Gestione trasferimento progressivo sorveglianze (26 May 2016–31 December 2017)).

### Data availability

The data presented in this study are available in accordance with the Italian HBSC data access policy. Requests should be directed to paola.nardone@iss.it, member of the National Centre for Disease Prevention and Health Promotion, Italian National Institute of Health.

## Declarations

### Ethics approval and consent to participate

The study was conducted according to the guidelines of the Declaration of Helsinki. In 2018, the Italian HBSC study protocol and questionnaire were formally approved by the Ethics Committee of the Italian National Institute of Health (Ref. PROT-PRE876/17, 20 November 2017).

### Consent for publication

Not applicable.

### Informed consent

Informed consent was obtained from all the subjects involved in the study. The data collection was anonymous, and no directly identifiable information on individual pupils were collected. Consent was also obtained by the pupils, who were reminded verbally and in writing that participation was voluntary.

### Conflict of interest

All authors declare that they have no conflict of interest.

### Competing interests

The authors declare no competing interests.

Received: 8 March 2024 / Accepted: 20 January 2025
Published online: 29 January 2025

### References

1. Casey BJ, Duhoux S, Cohen MM. Adolescence: What Do Transmission, Transition, and Translation Have to Do with it? Neuron. 2010.
2. Levels and trends in child malnutrition. New York. 2023 May. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/file:///C:/Users/lipari/Downloads/JME-2023-United-Nations-Levels-and-Trends-in-Child-Malnutrition.pdf
3. New WHO. report: Europe can reverse its obesity epidemic. 2022 May. Available from: https://www.who.int/europe/news/item/03-05-2022-new-who-report--europe-can-reverse-its-obesity--epidemic
4. Funcke J-B, Scherer PE. Beyond adiponectin and leptin: adipose tissue-derived mediators of inter-organ communication. J Lipid Res. 2019;60(10):1648–97. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0022227520323014
5. Lauria L, Spinelli A, Buoncristiano M, Nardone P. Decline of childhood overweight and obesity in Italy from 2008 to 2016: results from 5 rounds of the population-based surveillance system. BMC Public Health. 2019;19(1):618. Available from: https://bmcpublichealth.biomedcentral.com/articles/https://doi.org/10.1186/s12889-019-6946-3
6. ISS. Sistema di Sorveglianza HBSC HealthBehaviour in School-aged Children Risultati Della Rilevazione 2018 - Stato Nutrizionale Attivitga' Fisica. 2018. Available from: chrome-extension: //efaidnbmnnnibpcajpcglclefindmkaj/https://www.epicentro.iss.it/hbsc/pdf/sovrappesoeobesità.pdf
7. Cole TJ. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ. 2000;320(7244):1240. Available from: https://www.bmj.com/lookup/doi/https://doi.org/10.1136/bmj.320.7244.1240
8. Sorveglianza PASSI. 2021. Available from: https://www.epicentro.iss.it/passi/dati/sovrappeso
9. Spinelli A, Buoncristiano M, Nardone P, Starc G, Hejgaard T, Júlíusson PB et al. Thinness, overweight, and obesity in 6- to 9-year-old children from 36 countries: The World Health Organization European Childhood Obesity Surveillance Initiative—COSI 2015–2017. Obes Rev. 2021;22(S6). Available from: https://onlinelibrary.wiley.com/doi/10.1111/obr.13214
10. Lazzeri G, Tosti C, Pammolli A, Troiano G, Vieno A, Canale N et al. Overweight and lower age at menarche: evidence from the Italian HBSC cross-sectional survey. BMC Womens Health. 2018;18(1):168. Available from: https://bmcwomenshealth.biomedcentral.com/articles/10.1186/s12905-018-0659-0
11. Matsuo LH, Adami F, Pereira LJ, Silva DAS, Vasconcelos FDAG, Longo GZ et al. Age at menarche and its association with overweight including obesity and socio-economic conditions of Brazilian schoolgirls: A time-trend analysis. Nutr Bull. 2022;47(1):70–81. Available from: https://onlinelibrary.wiley.com/doi/10.1111/nbu.12544
12. Herman-Giddens ME, Slora EJ, Wasserman RC, Bourdony CJ, Bhapkar MV, Koch GG et al. Secondary Sexual Characteristics and Menses in Young Girls Seen in Office Practice: A Study from the Pediatric Research in Office Settings Network. Pediatrics. 1997;99(4):505–12. Available from: https://publications.aap.org/pediatrics/article/99/4/505/75275/Secondary-Sexual-Characteristics-and-Menses-in
13. Kaplowitz P. Pubertal development in girls: secular trends. Curr Opin Obstet Gynecol. 2006;18(5):487–91. Available from: https://journals.lww.com/00001703-200610000-00003
14. Kaplowitz PB. Link Between Body Fat and the Timing of Puberty. Pediatrics. 2008;121(Supplement_3):S208–17. Available from: https://publications.aap.org/pediatrics/article/121/Supplement_3/S208/29259/Link-Between-Body-Fat-and-the-Timing-of-Puberty
15. Ibitoye M, Choi C, Tai H, Lee G, Sommer M. Early menarche: a systematic review of its effect on sexual and reproductive health in low- and middle-income countries. PLoS ONE. 2017;12(6):e0178884.
16. Currie C, Ahluwalia N, Godeau E, Nic Gabhainn S, Due P, Currie DB. Is obesity at individual and national level associated with lower age at menarche? Evidence from 34 countries in the Health Behaviour in School-aged children study. J Adolesc Heal off Publ Soc Adolesc Med. 2012;50(6):621–6.
17. Holmgren A, Niklasson A, Nierop AFM, Gelander L, Aronson AS, Sjöberg A et al. Pubertal height gain is inversely related to peak BMI in childhood. Pediatr Res. 2017;81(3):448–54. Available from: https://www.nature.com/articles/pr2016253
18. Bennett S, Woods T, Liyanage WM, Smith DL. A simplified general method for cluster-sample surveys of health in developing countries. World Health Stat Q. 1991;44(3):98–106.
19. Lazzeri G, Giacchi MV, Dalmasso P. The methodology of the Italian HBSC 2010 study (Health Behaviour in School-aged Children). Ann di Ig Med Prev e di Comunità. 2013;(3):225–33. Available from: https://doi.org/10.7416/AI.2013.1925
20. Mondschein CF, Monda C. The EU's General Data Protection Regulation (GDPR) in a Research Context. In: Kubben P, Dumontier M, Dekker A, editors. Fundamentals of Clinical Data Science. Cham: Springer International Publishing; 2019. pp. 55–71. Available from: http://link.springer.com/https://doi.org/10.1007/978-3-319-99713-1_5
21. Candace C, Joanna I, Michal M, Michela L, Zuzana V, Felicity W, Health Behaviour in School-Aged Children (HBSC study protocol: background, methodology and mandatory items for the 2013/14 survey. 2014. Available from: https://drive.google.com/file/d/1FZ8c2Xa_FcZ5Yx5gPXkPtlbV545NKhnx/view
22. Roberts C, Freeman J, Samdal O, Schnohr CW, De Looze ME, Nic Gabhainn S et al. The Health Behaviour in School-aged Children (HBSC) study: methodological developments and current tensions. Int J Public Health. 2009;54(S2):140–50. Available from: http://link.springer.com/https://doi.org/10.1007/s00038-009-5405-9
23. Lazzeri G, Vieno A, Charrier L, Spinelli A, Ciardullo S, Pierannunzio D, et al. The methodology of the Italian Health Behaviour in School-aged children (HBSC) 2018 study and its development for the next round. J Prev Med Hyg. 2021;62(4):E926–33.
24. ISS. Sistema di Sorveglianza HBSC Health Behaviour in School-aged Children Risultati Della Rilevazione 2018 - Tassi Rispondenza 2018. Available from: chrome-extension: //efaidnbmnnnibpcajpcglclefindmkaj/https://www.epicentro.iss.it/hbsc/pdf/presentazione.pdf
25. Nardone Paola P, Daniela C, Silvia S, Angela D, Serena C, Franco et al. La Sorveglianza HBSC 2018 - Health Behaviour in School-aged Children: risultati dello studio italiano tra i ragazzi di 11, 13 e 15 anni. 2020. Available from: chrome-extension: //efaidnbmnnnibpcajpcglclefindmkaj/https://www.epicentro.iss.it/hbsc/pdf/HBSC-2018.pdf
26. De Onis M. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ. 2007;85(09):660–7. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2636412/pdf/07-043497.pdf/

27. ISTAT. Territorio. 2016 Dec. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.istat.it/it/files/2017/12/C01.pdf
28. Currie C, Molcho M, Boyce W, Holstein B, Torsheim T, Richter M. Researching health inequalities in adolescents: The development of the Health Behaviour in School-Aged Children (HBSC) Family Affluence Scale. Soc Sci Med. 2008;66(6):1429–36. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0277953607006077
29. Bross IDJ. How to Use Ridit Analysis. Biometrics. 1958;14(1):18. Available from: https://www.jstor.org/stable/2527727?origin=crossref
30. Steppan M, Whitehead R, McEachran J, Currie C. Family composition and age at menarche: Findings from the international Health Behaviour in School-aged Children study. Reprod Health. 2019;16(1):176. Available from: https://reproductive-health-journal.biomedcentral.com/articles/https://doi.org/10.1186/s12978-019-0822-6
31. Li W, Liu Q, Deng X, Chen Y, Liu S, Story M. Association between Obesity and Puberty Timing: a systematic review and Meta-analysis. Int J Environ Res Public Health. 2017;14(10):1266.
32. Huang A, Reinehr T, Roth CL. Connections between obesity and puberty. Curr Opin Endocr Metab Res. 2020;14:160–8.
33. Zhou X, Hu Y, Yang Z, Gong Z, Zhang S, Liu X, et al. Overweight/Obesity in Childhood and the risk of early puberty: a systematic review and Meta-analysis. Front Pediatr. 2022;10:795596.
34. Walvoord EC. The timing of puberty: is it changing? Does it matter? J Adolesc Heal off Publ Soc Adolesc Med. 2010;47(5):433–9.
35. Gårdstedt-Berghog J, Niklasson A, Sjöberg A, Aronson AS, Pivodic A, Nierop AFM et al. Timing of menarche and pubertal growth patterns using the QEPS growth model. Front Pediatr. 2024;12. Available from: https://www.frontiersin.org/articles/10.3389/fped.2024.1438042/full
36. Cavallo Franco L, Patrizia D, Paola V, Alessio L, Giacomo GD. 4° Rapporto sui dati HBSC Italia 2014. 2016. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.epicentro.iss.it/hbsc/pdf/ReportnazionaledatiHBSCItalia2014.pdf
37. Silventoinen K, Jelenkovic A, Palviainen T, Dunkel L, Kaprio J. The Association Between Puberty Timing and Body Mass Index in a Longitudinal Setting: The Contribution of Genetic Factors. Behav Genet. 2022;52(3):186–94. Available from: https://link.springer.com/https://doi.org/10.1007/s10519-022-10100-3
38. Kaplowitz PB. Link between body fat and the timing of puberty. Pediatrics. 2008;121 Suppl:S208–217.
39. Anderson SE, Dallal GE, Must A. Relative weight and race influence average age at menarche: results from two nationally representative surveys of US girls studied 25 years apart. Pediatrics. 2003;111(4 Pt 1):844–50.
40. Hur JH, Park S, Jung MK, Kang SJ, Kwon A, Chae HW, et al. Insulin resistance and bone age advancement in girls with central precocious puberty. Ann Pediatr Endocrinol Metab. 2017;22(3):176–82.
41. De Paoli M, Zakharia A, Werstuck GH. The role of estrogen in insulin resistance: a review of clinical and preclinical data. Am J Pathol. 2021;191(9):1490–8.
42. Cui Z, Stevens J, Truesdale KP, Zeng D, French S, Gordon-Larsen P. Prediction of Body Mass Index Using Concurrently Self-Reported or Previously Measured Height and Weight. Krukowski RA, editorPLoS One. 2016;11(11):e0167288. Available from: https://doi.org/10.1371/journal.pone.0167288
43. Jansen W, Van De Looij-Jansen PM, Ferreira I, De Wilde EJ, Brug J. Differences in Measured and Self-Reported Height and Weight in Dutch Adolescents. Ann Nutr Metab. 2006;50(4):339–46. Available from: https://www.karger.com/Article/FullText/94297
44. Koprowski C, Coates RJ, Bernstein L. Ability of Young Women to Recall Past Body Size and Age at Menarche. Obes Res. 2001;9(8):478–85. Available from: http://doi.wiley.com/https://doi.org/10.1038/oby.2001.62


## Publisher's note