Associations Between Anthropometric Measures and Body Fat Percentage in Iranian Adolescents: a Quantile Regression Analysis

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Posted Date: May 4th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-463636/v1

Title: Associations between Anthropometric Measures and Body Fat Percentage in Iranian Adolescents: A Quantile Regression Analysis

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Abstract

Background: The puerpose of this study was to assess the association between anthropometric measures and skinfold thickness as well as parental obesity and physical activity with body fat percentage (BFP) percentiles using a quantile regression (QR) model within a representative sample of Iranian adolescents.

Methods: In this cross-sectional study, 2873 school children (1472 girls) aged 14-20 years old were selected by multi-stage random sampling approach from different areas of two cities of Fars Province in southern Iran. Demographic characteristics, parental history of obesity, physical activity were collected by using a self-reported questionnaire. Height, weight, waist (WC), hip (HC), arm (AC) circumferences, triceps (TST), abdominal (AST), clavicle muscle (CMST) skinfold thicknesses, and BFP were measured. A QR analysis was used to evaluate the association between the obesity measures with BFP at different quantiles.

Results: The results of QR models showed that circumference measures and skinfold thicknesses were statistically significant positive associations with BFP across all quantiles ($P < 0.05$). Among boys, having a history of obesity in mothers associated with higher BFP at the 15^{th} to 95^{th} percentiles (the parameter estimates ranged from 1.9 to 4.9, $P<0.05$). However, there were statistically significant positive associations between parental obesity with BFP in girls at the 25^{th} to 95^{th} and all percentiles for maternal and paternal obesity, respectively (the prameter estimates ranged 1.6-2.6 and 2.7- 5.6 with $P<0.05$). Moreover, physical activity negatively associated with the lower BFP at 50^{th} to 95^{th} only in grils (prameter estimates ranged -2.5 to -1.7 with $P<0.05$).

Conclusions: This study revealed that anthropometric measures and SF measures associated with higher BFP at all quantiles in Iranian adolescents. The findings of the study also showed that having a history of parental obesity as well as a high physical activity associated with higher and lower BFP, respectively.

Keywords: pediatric obesity, body fat distribution, quantile regression analysis, Iran

Background

Overweight and obesity are defined as abnormal or excessive body fat accumulation that presents a risk to health. Based on the report obtained by a worldwide epidemiological study in 2017, overweight/obesity in children and adolescents has increased tenfold over the past four decades (1). Childhood overweight/obesity is associated with a higher risk of adult obesity, morbidity premature mortality, and one of the most important risk factors of chronic diseases, including cardiovascular diseases, diabetes type II, hypertension, and even cancer (2-6). Therefore, it is necessary to have a proper assessment of body composition for adolescents in clinical settings and public health.

The age- and gender-specific body mass index (BMI) or weight for height percentiles has been extensively used as identification indices for measuring overweight/obesity in youth. However, BMI and weight are not the most sensitive markers for detecting excess body fat (7). There are various reference methods such as Magnetic resonance imaging, Dual-energy X-ray absorptiometry (DXA), or underwater weighting which widely used to estimate body composition accurately. However, these methods have some limitations due to cost issues and measurement complexity. Therefore, researchers have used a variety of anthropometric-based measurements including waist circumference (WC), waist to height ratio (WHtR), waist to hip ratio (WHR), skinfolds thickness (ST), or similar body composition measurements which are simple, low cost and feasible methods (8-12).

Pioneer researchers have evaluated the performance of the aforementioned anthropometric measurements and different statistical methods have been used to assess the association between these indices in children and adolescents (13-16). A systematic review of published studies has shown that body fat percentage (BFP) estimated by the bioelectrical impedance analysis (BIA) method had a perfect correlation with the methods such as densitometric and hydrometric methods (17). The results of the Wohlfahrt-Veje et. al study revealed that the highest correlation and best agreement were found between DXA measurements and triceps and subscapular ST in identifying children with excess fat (16). Freedman et. al study using regression analyses suggested that ST measurements in combination with BMI might be able to improve the estimation of body fatness among adolescents (15).

Most earlier studies examined associations between the measurements using the mean regression analyses, correlation, or agreement analyses which did not capture distinct associations across the entire anthropometric measurements distribution. Additionally, in most body composition studies, the tails of the conditional distributions are more important than the center of them. In order to find a comprehensive model, one can consider a quantile regression (QR) model which has been introduced first by Koenker and Bassett (1978). A QR model is capable of providing more information about the conditional distribution for each quantile and can be used for analyzing linear or non-linear effects of explanatory variables on the outcome at a specific quantile. Examination at multiple points in the distribution of outcome rather than only at the mean, requiring no assumption about the distribution of the regression residuals and giving robust estimators which are not affected by outliers or skewness in the distribution of the outcome variable are the main advantages of QR models (18). Quantile regression has the advantages of allowing examination at multiple points in the distribution of BMI rather than only at the mean. Quantile regression does not require any assumption about the distribution of the regression residuals and, unlike ordinary linear regression, is not influenced by outliers or skewness in the distribution of the dependent variable, providing greater statistical efficiency when outliers are present. In addition, inference on quantiles can accommodate transformation of the dependent variable without the problems encountered in ordinary linear regression.

In the current study, we present a QR model to examine the association between some anthropometric measures using simple and easy-to-measure tools such as the ST and anthropometric measurements including triceps skinfold thickness (TST), abdominal skinfold thickness (AST), and clavicle muscle skinfold thickness (CMST) as well as waist circumference (WC), hip circumference (HC), and arm circumference (AC). Therefore, the first aim of the current study was to examine the association between the anthropometric measures and BFP using a QR model in order to have more insight into the effects of these variables especially on upper quantiles of BFP in adolescents.

Many studies showed that childhood obesity is a multi-factorial structure influenced by hereditary factors, such as genetics, family history, racial/ethnic differences, and individual factors including diet pattern, physical activity, and sedentary behavior (19-21). Based on the results obtained by previous studies, children with a high-risk family are more likely to have higher BMI, mainly at the upper percentiles of BMI distribution (22, 23). Moreover, moderate-to-vigorous physical activity could shift the upper tail of the BMI and WC distribution to lower values in youth (24). To the best of our knowledge, limited studies have assessed the effect of parental obesity and physical activity on BFP in children using the QR model. The second objective of this study was to investigate the association of parental obesity and children's physical activity on the BFP distribution of children using QR analysis. Investigating the association between the risk factors of childhood obesity in different percentiles of BFP can prevent loss of valuable information on the entire BFP distribution; particularly its upper part and can help researchers and policymakers to design effective strategies to tackle the excessive weight of adolescents in the early years of life.

Methods

Study Design

In this cross–sectional study, a multi-stage random sampling procedure was used to select 2873 Iranian healthy children (1472 girls) between 14 and 20 years of age from September to December 2014. In the first stage, 16 public schools from four education districts of Shiraz and also 8 public schools were sampled from Jahrom where they are the capital and the second-ranked cities of Fars Province in southern Iran, respectively. In the second stage, two boy’s schools and two girl’s schools were randomly chosen from each district at Shiraz and four boy’s schools and four girl’s schools at Jahrom by using a simple random sampling. In the next step, we randomly chose two or three classrooms from each school, and all the children in the classroom were studied. Oral assent was obtained from children and written informed consent was obtained from their parents before participating in the study. The study was approved by the Ethics Committee of Shiraz University of Medical Sciences.

Clinical Measurements

The dependent/outcome variable was BFP obtained by using the BIA method by hand to hand Omron BF-500 set, Japan. All subjects had to fast for at least 5 h, not engage in strenuous physical activity during the previous 12 h and abstain from consuming caffeine beverages from 24 h before the study.

The other variables were anthropometric measures including height, body weight, circumference measurements (including WC, HC, and AC), BMI, ST (including TST, AST, and CMST). Height and circumference measurements were measured using a tape measure and weight was obtained using a SECA digital scale (Germany), in all the subjects with 0.1 cm and 0.1 kg accuracy, respectively. BMI was calculated by dividing weight (kg) by the square of height (m^2). BMI less than 85^{th} percentile, between 85^{th} and 95^{th} percentile, and above 95^{th} were classified into three groups: normal, overweight, and obese, respectively(25). STs were measured by a graded caliper in three sites of the body (triceps, abdominal, and clavicle muscle), and the average of both right and left sides of the body were recorded to the nearest 0.5 mm.

Parental history of obesity was assessed by using a question, whether their parents (separately) were obese/overweight or not. The time of physical activity (PA) was assessed using the question "How many minutes do you do physical activity during a week?".

Statistical Model

Due to the asymmetric distribution of BFP and some non-ignorable unusual data, a QR model was used to examine the association between the anthropometric measures and BFP at specific quantiles in the current study. QR models enable us to find non-ordinary associations between outcome and explanatory variables. Moreover, in QR models, the ordinary mean regression assumption and being sensitive to the outliers' data can be avoided. The regression coefficients of these models indicate the change in the particular quantile of the distribution of the outcome variable.

The general form of the QR model is written as:

$$Q^{(\tau)}[Y|X_1, X_2, \dots, X_k] = \beta_0{}^{(\tau)} + \beta_1{}^{(\tau)}X_1 + \cdots + \beta_k{}^{(\tau)}X_k$$

where Xs and Y are independent and outcome variables with $\boldsymbol{\beta} = (\beta_0, \beta_1, \dots, \beta_k)^T$ as their regression coefficients at the τ^{th} quantile. These coefficients can be estimated by a classical or Bayesian statistical methods for each τ^{th} quartile ($0 < \tau < 1$). In this study, two QR models were considered: The first model was used to assess the associations between the anthropometric measurements and BFP in adolescents. The effects of the parental obesity (with the presence of PA) on adolescents' BFP were assessed at the particular quantiles of BFP distribution by the second model.

Model I: The association between anthropometric measurements and BFP

Since skinfold thickness and body circumference measurements or a combination of them were extremely highly correlated, it was reasonable to use a combination of these measurements. These measurements were summarized by using the principal component analysis method into two group variables: the averages of three circumference measures (i.e. WH, HC, and AC) were represented as WHA and the average of three skinfold thickness (i.e. TST, AST, and CMST) were denoted as TAC. Therefore the first QR model was considered as follow:

$$Q^{(\tau)}[BFP|WHA, TAC] = \beta_0{}^{(\tau)} + \beta_1{}^{(\tau)}WHA + \beta_2{}^{(\tau)}TAC \quad \text{(I)}$$

As the relationship between these variables and BFP was near quadratic, the square of BFP instead of BFP was used in above model.

Model II: The association between parental obesity and BFP

In the second model, we investigated the association between mother's (MO) and father's (FO) history of obesity, physical activity (PA) and the BFP quantiles as the outcome variable in adolescents. The second model is written as follow:

$$Q^{(\tau)}[BFP|FO, MO, PA] = \beta_0{}^{(\tau)} + \beta_1{}^{(\tau)}FO + \beta_2{}^{(\tau)}MO + \beta_3{}^{(\tau)}PA \quad \text{(II)}$$

where FO and MO are dichotomous variables which indicate whether fathers or a mothers are obese/overweight or not. PA (in min) is the time of activity that an adolescent doing exercises per week. All statistical analyses were performed by using R software (version 4.0.0) (26) with the package "quantreg".

Results

The results of descriptive statistics for adolescent boys and girls are displayed in Table 1. Overall, 2873 students aged 14-20 years old participated in this study. A total of 1401 (48.8%) subjects were boys and about 74.2%, 14.9% and 10.9% of them were normal, overweight, and obese, based on the WHO growth chart for BMI. The mean age (SD) of the participants was 16.05 (1.05) years old which was statistically significant in gender groups. Father's and mother's history of obesity were reported by 16.9%, 16.8% of the boys and 14.6%, 26.1% of the girls. Statistically significant difference was found in the mean of PA in boys and girls (p-value <0.05). The results of the independent samples test showed that means in almost all anthropometric measures were significantly higher in boys than that of girls (p-value<0.05).

Table 1 Descriptive statistics among children

	Boys (n=1401)	Girls (n=1472)	P-value
Gender (n%)	1401 (48.8)	1472 (51.2)	0.20[a]
Age (years)	16.12 (1.08)	15.98 (1.02)	<0.001[b]
Father's history of obesity (yes)	236 (16.9)	214 (14.6)	0.09 [a]
Mother's history of obesity (yes)	236 (16.8)	384 (26.1)	<0.001[a]
PA (min)	247.21 (226.77)	118.12 (142.10)	<0.001[b]
Height (cm)	171.1 (6.98)	160.29 (5.60)	<0.001 [b]
Weight (kg)	64.02 (14.23)	54.52 (10.58)	<0.001 [b]
WC (cm)	80.48 (11.30)	73.61 (9.42)	<0.001 [b]
HC (cm)	94.65 (8.72)	90.95 (7.49)	<0.001 [b]
AC (cm)	26.01 (3.28)	23.95 (3.22)	<0.001 [b]
TST (mm)	15.05 (7.34)	16.65 (6.73)	<0.001 [b]
AST (mm)	19.57 (13.09)	17.40 (6.80)	<0.001 [b]
CMST (mm)	17.24 (9.20)	17.13 (7.01)	<0.001 [b]
BFP (%)	17.14 (8.49)	27.79 (8.91)	<0.001 [b]
BMI (kg/m^2)	21.80 (4.33)	21.19 (3.76)	<0.001 [b]
Normal (n%)	1022 (74.2)	1177 (79.8)	<0.001 [a]
Overweight (n%)	210 (14.9)	191 (13.1)	
Obese (n%)	169 (10.9)	103 (7.1)	

Values: mean (SD) for continuous variables and n (%) for categorized variables

[a] P-values are derived from Chi squared tests, [b] P-values are derived from t-test (p-value < 0.05 was statistically significant)

Abbreviation: PA physical activity, WC waist circumference, HC hip circumference, TST triceps skinfold thickness, AST abdominal skinfold thickness, CMST clavicle muscle skinfold thickness, BFP body fat percentage, BMI body mass index

Table 2 shows the parameter estimates on BFP across boys and girls for the quantile regression models at 5th, 15th, 25th, 50th, 75th, 85th, and 95th percentiles. As shown in Table 2, for the first model (model I), statistically significant associations were observed between WHA and TAC with higher BFP in all percentiles for boys and girls meaning that they have a higher impact on determining the BFP in adolescents boys and girls. Model II shows the effect of parental obesity and PA for boys and girls across the percentiles. The results of this model showed that for boys, obesity in fathers was associated with higher BFP at the 15th percentile (b= 1.5, 95% CI: 0.10 to 2.82) and 50th percentile (b= 2.8, 95% CI: 1.45 to 5.20). However, history of obesity among mothers was significantly associated with higher BFP at all percentiles except at the 5th percentile (b= 0.7, 95% CI: -0.13 to 2.21). For girls, regression coefficients in FO were associated with the higher BFP at all percentiles showing that adolescents' girls with obese fathers had more BFP than others. Moreover, the parameter estimates in MO were positive and significant on BFP at all percentiles except at lower percentiles (5^{th} and 15^{th} percentiles). In general, children who lived in a family with obese mothers had more BFP than others did, especially at the higher percentiles of BFP.

The results of Table 2 revealed that the number of minutes of PA per week had a negative relationship on BFP, with significant associations with lower BFP at percentiles 50^{th} (b= -2.40 , 95% CI: -3.66 to -1.14), 75^{th} (b= -1.94 , 95% CI: -3.36 to -0.52), 85^{th} (b= -1.70 , 95% CI: -3.05 to -0.35) and 95^{th} (b= -2.50 , 95% CI: -4.40 to -0.6) in girls. Although there was a negative association between the most of coefficients for the number of minutes of PA in boys, no significant association was found between the parameter estimates for the number of minutes of PA at all BFP percentiles.

Please insert Table 2 here

Figure 1 outlines the trends obtained from the effect of WHA and TAC on BFP at all percentiles. In each panel, the horizontal and vertical axes represent the percentiles of the BFP and the regression coefficients, respectively. Two lines with the vertical segments as 95% confidence interval are included in each panel to indicate the parameter estimates on all percentiles of BFP for boys and girls. In general, there was an increasing trend in regression parameter estimates at almost all quantiles of BFP. WHA and TAC had significant and strong associations with higher BFP across all quantiles. The effects of TAC were monotonically increasing and sharper in the tails of the BFP distribution for boys (Figure 1a). However, greater variability (wider CIs) was observed in regression coefficients for girls compared to boys, especially at 5th and 95th percentiles.

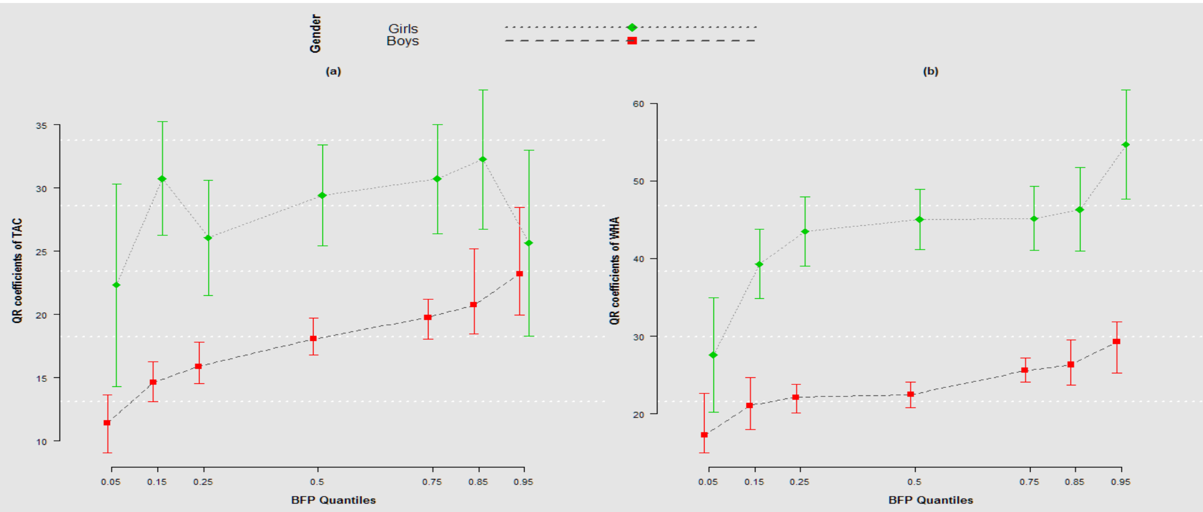

Fig. 1 Parameter estimates and 95% confidence intervals of TAC and WHA on BFP percentiles

Figure 2 displays the parameter estimates of model II on quantiles of BFP. Figure 2a-2c shows the regression coefficients (and 95%CI) for MO, FO, and PA, respectively. As shown in Figure 2a, FO was increasingly associated with higher BFP in girls, especially at the upper percentiles of the BFP (75th, 85th, and 95th percentiles). On the other hand, FO in boys did not significantly associate with BFP in almost all the quantiles, indicating that history of obesity in fathers did not play an important role in increasing BFP of adolescent boys. The results of Figure 2b showed that except at the 5th percentile, all coefficients were positive at all quantiles which shows an increasing trend and the positive impact of MO on BFP percentiles. Although greater variations were found in CI for boys, there was no significant difference between regression coefficients in girls and boys. For PA, a decreasing trend was obtained from the quantile coefficients of BFP in girls, displaying statistically significant associations between PA and lower BFP across the quantiles more than 50th. However, the associations between PA and BFP fluctuated at both lower and upper BFP quantiles for boys.

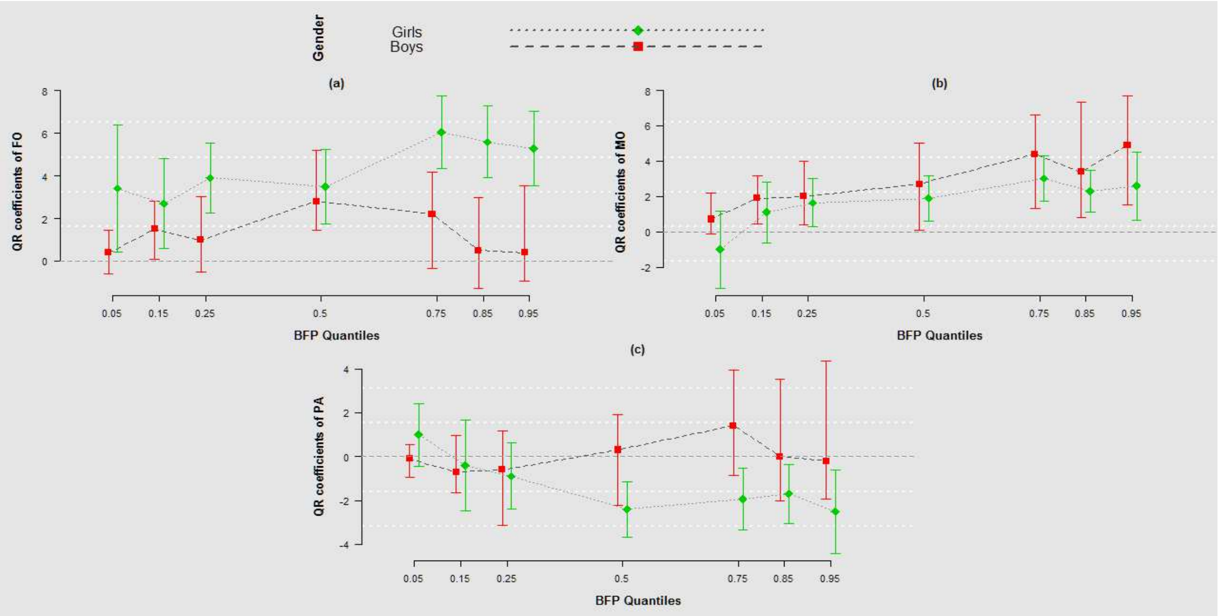

Fig. 2 Parameter estimates and 95% confidence intervals of FO, MO, and PA on BFP percentiles

Discussion

The current study was aimed to investigate the association between anthropometric measures, family history of obesity as well as physical activity, and BFP by using QR models within a sample of Iranian school children. As compared with other mean regression models, one of the prominent features of QR models is that the regression coefficients across the quantiles can provide more consistent and precise estimates of the independent variables in the upper tails of the BFP variable.

As far as we know, this study was the first to use the BFP and QR model to study the association between the combination of circumference measures and skinfold thickness at different quantiles of BFP. Findings from our study indicated that circumference measures and skinfold thickness had significant positive associations with BFP in Iranian adolescents similar to other studies conducted in Brazil, the US which found high correlations between anthropometric measures such as BMI, WC, and BFP (27, 28). Previous studies showed that SFs alone or in combination with BMI measure body fatness better than BMI alone (15, 28, 29).

The results of our study revealed that linear combinations of anthropometric measures, as well as ST measures, can be used to estimate BFP in both genders. Although parameter estimates of TAC and WHA were increased at BFP quantiles, the estimated regression coefficients of TAC were a better identification than WHA. Using 2647 healthy Danish children, Wohlfahrt-Veje et al. found the highest correlation and best agreement between ST and BFP compared with other measures of fatness in identifying children with excess fat (30).

Along with other published studies, we found that living in a family with a history of parental obesity associated with an increased risk of childhood obesity (22, 23, 31-33). A recent systematic review identified 32 studies showing moderate or strong parent-child obesity associations in which both parent obesity were more likely to be strong (63%) than those with either father (24.5%) or mother (30.2%)(34). Based on the results obtained by Cheraghi et. al, compared to children with low-risk families, children with a high-risk family are more likely to have higher BMI, mainly at the upper percentiles of BMI distribution for both genders (22). Using a sample of children aged 2-15 years old, Whitaker et. al study showed having overweight, obese, and severely obese parents increased the odds of childhood obesity by over 2, 12, and 22 times compared with having two normal-weight parents, regardless of age, sex, socioeconomic status, and ethnicity (23). Our study showed that the history of obesity in mothers had an important effect on childhood obesity than father obesity with no evidence for any sex difference. The role of mother in childhood obesity is supported by most of the studies which found mother-child associations were significantly stronger than father-child associations (23, 33, 35-37). Moreover, there is evidence of an association between maternal overweight at the10th, 50th, and 90th of fat mass index and interaction between the obesity-risk-allele score and the maternal overweight at 95th percentile of fat mass index (38). Vogler et al. study proposed that 40-80% of genetic factors contribute to BMI differences among subjects (39). However, it should be noted that although parental obesity is considered as a genetic factor for childhood obesity, environmental factors such as lifestyle, dietary patterns, screen time pattern or sedentary behaviors, as well as physical activity can be considered as the main factors which are a none separable aspect in this field.

Our results indicated there was a negative association between PA and BFP across the quantiles in adolescents displaying that longer PA significantly associated with lower BFP in adolescents. These findings are in line with the results obtained from previous studies in that PA consistently associated with obesity measures in adolescents (40-42). Many studies have used BMI as an outcome for measuring adolescent obesity and reported that children who had more PA had lower BMI values. Using a sample of adolescents, PA and muscle strengthening exercising had negative significant associations with obesity indices at the 95th percentile (24, 40). Mitchell et al. reported stronger associations of PA at the higher percentiles of BMI and WC (24). However, BMI may not be a useful body composition index for measuring body fat of adolescents and may not discriminate between fat and muscular children (7). Using fat mass and lean mass measures as body composition indices provide more accurate results about BFP (43). A systematic review of the literature among adolescents revealed that there were more consistent results between PA levels and fat mass or fat mass percent especially in boys than those reported other anthropometric indices (44). In our study, Boys had greater mean circumference measures than girls (mean of WC, HC, AC, AST, and CMST were statistically significant). However, TST and BFP were greater in girls than that of boys (means of BFP, TST were grater, with P-values less than 0.05). Although there were negative associations between the PA at the lower and upper percentiles of BFP, no statistically significant association was found between PA at all quantile regression coefficients of BFP in boys. The parameter estimates of PA in boys had more fluctuation than in girls. It can be attributed to unknown determinants of fat gain including diet pattern, socio-demographic factors, genetic factors, and perturbations of sex hormone regulation (45). Generally, girls tend to have much less physical activity than boys. Physical activity among girls is an attempt to manage weight, emotional coping, and being healthier (46). Therefore, it is necessary to control the factors that may have an effect on the results of sex differences.

This study had three main limitations that should be considered. First, given that the nature of the cross sectional study, it is not possible to generalize findings to other populations and have causal inferences. Second, the history of parental obesity and time of physical activity were collected using a self-reported questionnaire which may introduce recall bias or misunderstanding of the questionnaire items. Finally, we did not consider other predictor variables such as eating habits or biological measures which may affect to childhood obesity changes.

Conclusions

In conclusion, the QR model is an efficient statistical approach that enables us to examine the association between anthropometric indices as well as environmental factors across the entire distribution of BFP. This study demonstrated that a linear combination of anthropometric measures and ST measures associated with higher BFP at all quantiles in Iranian adolescents. The findings of the study also showed that having a history of parental obesity as well as a high physical activity associated with higher and lower BFP respectively. Furthermore, more significant parameter estimates were observed at higher BFP quantiles. The results of the present study help health policymakers to pay more attention to the factors related to childhood obesity especially at higher levels of quantiles of obesity indices. There is a need to develop more effective strategies for increasing adolescent's and their parent's awareness about the consequences of growing overweight and obesity among children. Implementing health care programs in schools as well as educating their parents can prevent this health concern and help students have a healthier lifestyle.

List of abbreviations

BFP: body fat percentage; QR: quantile regression; WC: waist circumference; HC: hip circumference; AC: hip circumference; TST: triceps skinfold thickness; AST: abdominal skinfold thickness; CMST: clavicle muscle skinfold thickness; BMI: body mass index; DXA: Dual-energy X-ray absorptiometry; WHtR: waist to height ratio; WHR: waist to hip ratio; ST: skinfold thickness; BIA: bioelectrical impedance analysis; PA: physical activity; WHA: waist hip arm; TAC: triceps abdominal clavicle muscle; FO: father's obesity; MO: mother's obesity

Ethics approval and consent to participate

Oral consent was obtained from the children and their parents gave written informed consent before participation in the study. This study was approved by the ethics committee of Shiraz University of Medical Sciences.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

Funding

The research grant provided by Research Deputy of Shiraz University of Medical Sciences. Funding body of the study did not play any role in the design of the study, collection, analysis, and interpretation of data and in writing the manuscript.

Authors' contributions

AA contributed in analyzed the data, and interpreted the results, wrote the manuscript drafting. **ST** contributed in designed the study, analysis of data, interpretation the results. **MA** contributed in interpretation the results wrote the manuscript drafting. All authors have read and approved the manuscript**.**

Acknowledgements

Not applicable

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Figures

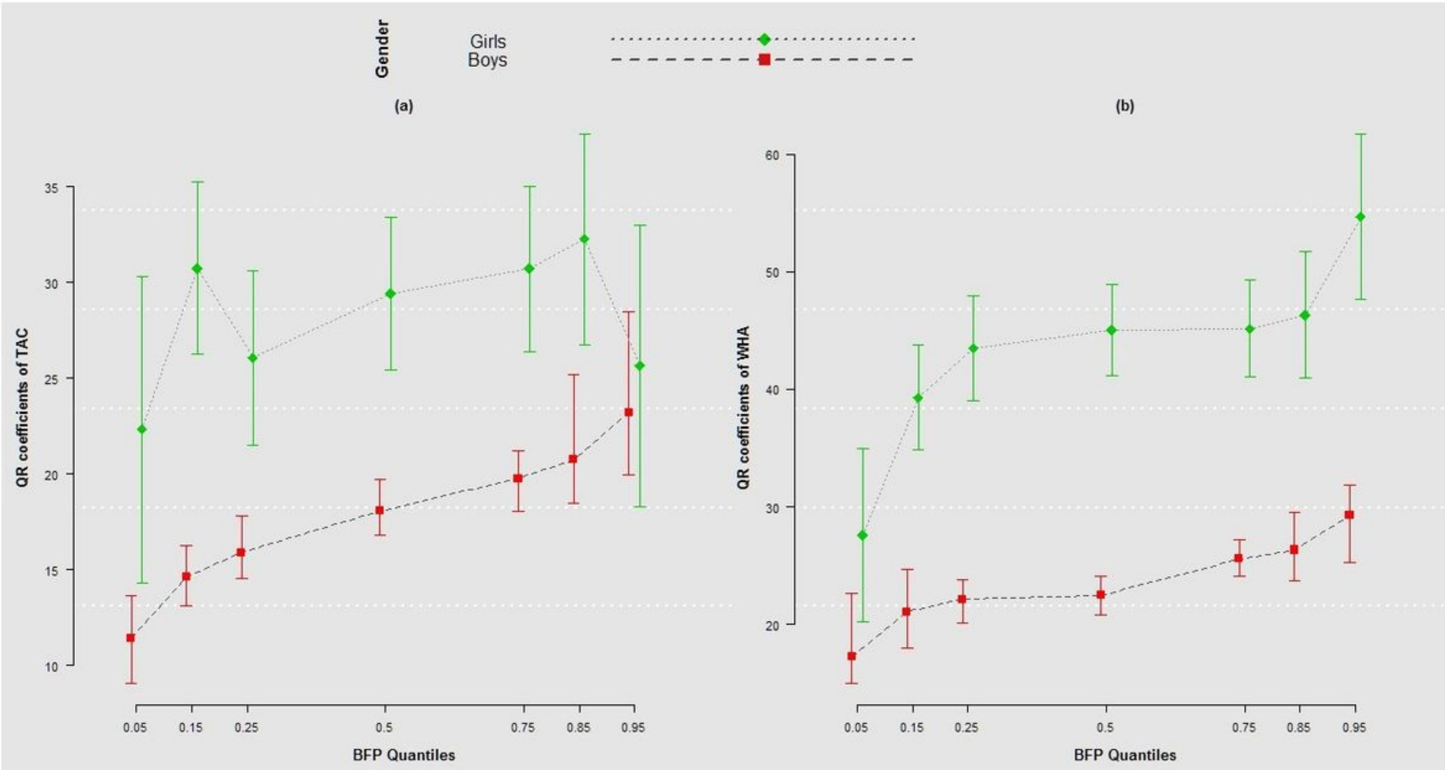

Figure 1

Parameter estimates and 95% confidence intervals of TAC and WHA on BFP percentiles

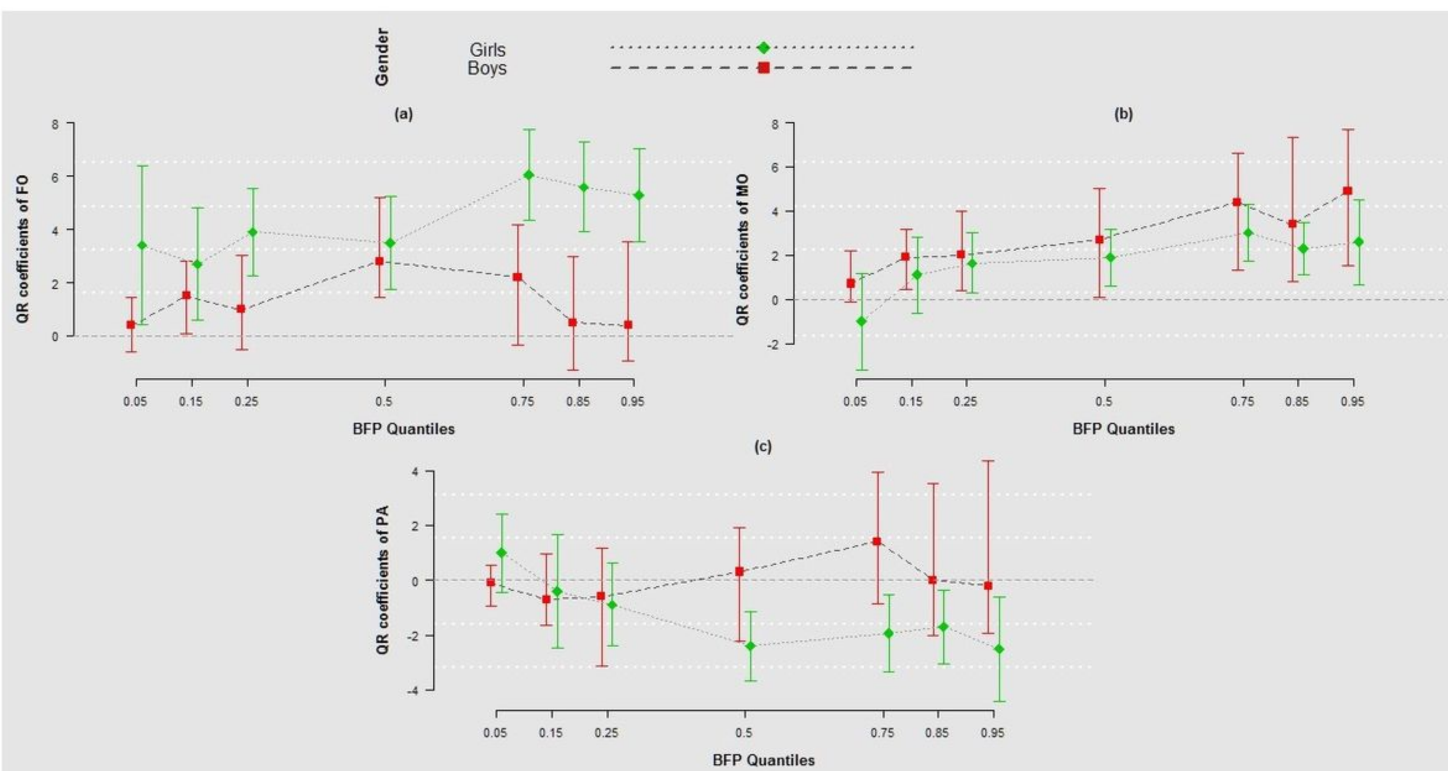

Figure 2

Parameter estimates and 95% confidence intervals of FO, MO, and PA on BFP percentiles