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Quantile Regression Analysis for Examining Gender Variations in Obesity Prevalence in Pakistan Using Body Surface Area Percentiles in Growth Charts

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Abstract

Constructing growth charts is essential in defining normal growth standards and detecting possible trends in human growth. In the present study, using the data from 9906 adults from Multan and Bahawalpur, Pakistan, we have provided growth charts for BSA using QR percentiles against age. The purpose of the study is to determine the performance of this method for constructing growth charts of BSA in a Pakistani population. The study's outcome also showed that the mean BSA was equal to ± (standard deviation). The QR percentiles showed a declining pattern in the age range of 5 to 25 for the 85th to 95th percentiles, sharp rises in the ages of 25 to 40, and then declining up to the age of 55. This phenomenon implies that BSA rises in the first phase of the life cycle, namely early adulthood, and then stabilizes in middle age before declining in old age. The finding of the present study has important consequences for constructing growth percentile curves for different physiological and pathological states. Therefore, empirical BSA QR percentiles can be used as discrete estimates of population QR percentiles. By using the QR percentiles approach, it is possible to obtain more accurate and smoother continuous BSA QR percentile curves against given ages. This methodology can be used to build growth reference curves for most of the physiological and medical conditions that affect children and adolescents. This will help practitioners to have an understanding of normal growth and to define the variations from the normal growth pattern.

Keywords: Obesity; Body surface area; Gender differences; Quantile regression percentiles; Growth charts

Abbreviations: BSSI: Body Shape and Size Index; BMI: Body Mass Index; BSA: Body Surface Area; QR: Quantile Regression; HT: Height; WT: Weight; WHO: World Health Organization; CDC: Centers for Disease Control

Introduction

Background

The concept of Body Surface Area (BSA) has been a fundamental parameter in various medical fields, including pediatrics, critical care, and oncology. BSA delivers useful information about many physiological traits of metabolism, oxygen utilization, and the distribution of drugs inside the human body. The term BSA was first defined by Du Bois and Du Bois in 1916 as 'the amount of skin that is visible when the subject stands against a piece of white cardboard' [1]. The role of BSA in various medical applications cannot be underestimated. In pediatrics, BSA is employed in the dosing of drugs, especially in children with congenital heart disease [2]. A recent study found that using BSA-based dosing for patients with congenital heart disease was much more effective in determining the right doses of drugs to be administered to pediatric patients [3]. Another recent study revealed that the use of BSA-scaled energy expenditure enhanced identifications of caloric requirement in critically ill individuals [4]. In oncology, BSA is used in the administration of chemotherapy and radiation therapy to decide the right amount to administer to the patient [5]. Showed that using BSA dosing form for giving chemotherapy to children with acute lymphoblastic leukemia had a positive impact on the results of the therapy.

In Pakistan especially where there is evidence of a rising trend in the prevalence of non-communicable diseases, most especially in children, the correct determination of BSA is very important. The Pakistani growth charts are used in clinical practice and can be considered an effective tool for the assessment of children's growth and development [6]. The utilization of different percentile methods for the estimation of BSA can cause discrepancy and error in some instances. The purpose of this study is to examine the QR percentiles of BSA in a Pakistani population. BSA is one of the most common anthropometric measures used in healthcare, especially as a tool for predicting the physiological status of an individual. The usefulness of BSA in multiple clinical uses has been established in this study. In Pakistan, where there is a growing concern about the increasing burden of non-communicable diseases, particularly in children, the accurate measurement of BSA is crucial.

The BSA is one of the most common anthropometric measures that has been widely applied in many branches of medical science, such as medicine and physiology. BSA is employed to assess the surface area of body and the computation of the unit has been of interest in most recent studies. BSA is more accurate in measuring body size than weight, it yields relatively much better results and does not impact the human body [7-8]. There have been several proposals for BSA that may be used to determine the amount of medication or pharmaceuticals that could be used to produce positive impacts on the body. The application of BSA-based dosing has been used to enhance the precision of medication doses in children with congenital heart disease [3]. BSA-based dosing has also been applied in calculating the dosage of Chemotherapy and radiation treatment in cancer patients [3]. In Pakistan, since there is an emerging epidemic of non-communicable diseases particularly affecting children, hence, it is imperative to have an accurate measurement of BSA. The Pakistani growth charts which have been developed and are routinely utilized in clinical practice can be utilized as a reference in evaluating the growth and development of children.

The use of different percentile methods to calculate BSA may lead to inconsistencies and inaccuracies in its estimation. The purpose of the present study is to evaluate the efficacies of the QR percentiles for BSA estimation in the Pakistani population [9]. The substance is classified as a 'global epidemic' by the World Health Organization since it affects both the physical and psychological health consequences [10]. According to recent data, it can be stated that over 1 billion individuals are overweight, 320 million are obese, and approximately 2 million individuals die each year because of obesity. These five million annual mortalities and may at least double by 2030 [11-13].

Obesity rates among people remain a major concern in today's society, with over one billion people being overweight and a hundred and thirty million being obese across the world [10]. Obesity leads to short- and long-term adverse effects on physical and mental health, the rate is expected to rise in the future. A recent study revealed that the frequency of obesity in Iran has been rising in particular through the years that range from 2005 to 2015 with an increased rate of 25%. In the same way, another study observed that the prevalence of obesity in Pakistan had risen by 15% in 2015. BSA is a commonly used anthropometric measure that helps in the determination of the psychological characteristics of an individual. BSA has significant clinical uses in pediatrics as well as oncology fields which make it important to have its measurements accurately determined. The use of QR percentiles for BSA estimation has been proposed as a potential method for improving the accuracy of BSA measurement.

Centile charts demonstrate the growth of an individual in terms of centile at a specific age in contrast to height-for-age growth charts which show the height of an individual at a given age and about the age centile [14]. CDC and WHO, have provided the growth charts for child growth and development to be employed in the screening of underweight, overweight, and obese children and adults [15]. These charts help in detecting cases of early growth, and assessing the progress of a child. These charts also determine whether a child has any development issues that may be a result of growth, and attending to a particular child with health complications. These growth charts can also be utilized by the clinician to identify initial signs of anomalous growth and development, or poor nutrition and feed intake [16-18].

Being overweight is no longer an exception for many people, as it refers to the state when the body weight is much higher than the recommended one [9]. The substance is regarded as a 'global epidemic' by the World Health Organization since it is linked to physical and psychological health consequences [10]. Using the latest statistics, it is possible to state that more than 1 billion people worldwide are overweight, and 320 million are obese, and approximately 2 million people dying every year due to obesity. Five million annual mortalities are due to obesity, a figure that is likely to double by 2030 [11-13].

Other than practice in pediatrics, the BSA growth charts can be applied in other sub-specialties including public health, research, and investigations. Being the unified tool for the assessment of anthropometric development, these charts may be employed as the basis of the policy to reduce the rate of obesity and other related issues. The methods applied in the construction of BSA growth charts are quantile regression percentiles which are effective in monitoring changes in anthropometric development. These charts can also help clinicians to observe the progress of an individual regarding the age standards or height for age standards and help the practitioners to carry out evidence-based interventions that may enhance the development of humans.

A study [19] establishes growth charts for a novel anthropometric measure, the Body Shape and Size Index (BSSI), tailored for the Pakistani population using quantile regression analysis on a cross-sectional dataset of 7,224 individuals from Multan. The BSSI integrates key anthropometric factors—body

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surface area, body mass index, weight, and height-to better assess obesity-related risks commonly inadequately addressed by traditional metrics. The findings demonstrate significant associations between the BSSI and conventional obesity indicators, revealing a generally linear relationship with age, an increase post-25 year, and a decrease after 50 years. The BSSI exhibits an indirect correlation with obesity, whereby lower values indicate a higher obesity risk and vice versa. This novel index presents valuable implications for obesity assessment and statistical modeling in public health contexts [19]. This cross-sectional study investigates the relationship between obesity and income distribution in Pakistan by examining Body Mass Index (BMI) and the novel Body Shape and Size Index (BSSI) among 2,223 children and adults aged 2 to 19 years in Multan. Data on gender, weight, height, age, and family income were analyzed to understand health outcomes related to socioeconomic factors. The findings reveal that both BMI and BSSI significantly increase with higher family incomes, with mean values of 18.00 and 0.23 for low-income families (income < 10,000) compared to 20.59 and 0.29 for higher-income families (income > 50,000). Additionally, the study indicates that female respondents exhibit higher BMI and BSSI values than their male counterparts. These results underscore the critical influence of income on obesity rates, highlighting the need for targeted public health strategies to address these disparities in Pakistan [20].

A study by Hussain et al. [21] compares quantile regression (QR) and Gaussian (Z-scores) percentiles in constructing growth charts for body surface area (BSA) in a Pakistani adult population, utilizing cross-sectional data from 3,473 individuals aged 5 years and older from Multan. The analysis revealed a mean BSA of 0.48750, with BSA percentiles displaying an upward trend from age 5 to 22, followed by a decline between ages 22 and 35, before increasing again post-35. In contrast, the Z-score growth curve also rose until age 22 before leveling off, with a slight increase thereafter. The findings suggest that employing continuous BSA percentiles and Z-score curves offers a more precise assessment of population growth indicators across ages compared to the traditional grouped methods. This methodological approach may be applicable in creating growth charts for various physiological and medical fields [21].

A study by Shehzad et al. [20] analyzed the effectiveness of Quantile Regression, Gaussian Percentiles, and Raw Percentiles in constructing growth charts for the Body Shape and Size Index (BSSI) among 9,906 participants aged 2 to 60 from Pakistan. The research demonstrated significant relationships between BSSI and demographic factors, including age, gender, and marital status, highlighting non-linear growth patterns. Quantile Regression proved particularly useful for handling outliers and capturing complex relationships. The findings emphasized the need to consider demographic variations in body composition assessments, thereby providing insights for healthcare professionals in developing tailored interventions to promote healthy growth and aging [19].

Objective of Study

The objective of this research work is to provide the gender comparison of estimated quantiles of BSA through quantile regression to examine the BSA gap for the adult population in Pakistan. Such work has been done in previous studies, but this was done for BSSI instead of BSA.

Methodology

Research Design and Sampling Framework

This research utilized a cross-sectional research design to sample 9906 participants from the age range 2-60 years old from different public places in Pakistan. The sampling procedure that was adopted for the study was convenience sampling where participants were recruited from the markets, hospitals, parks, and transport hubs [22]. In the study, data collection among preschool children of age 0-3 years is done through easy sampling while among school-going children aged 4-19 years' data collection was done using convenient and labor-based sampling. Both public and private schools were chosen, and consent was sought from the respective school authorities to carry out the data collection.

Convenience sampling was used in the study with adults between the age of 20-60 years who were sampled from public places. A team of two enumerators, one male and one female, was employed to visit homes and collect data using standardized questions [23]. Gender differentiation was a significant contributing aspect of the study. As a result, different questionnaires were created for respondents who identified as male and female. The collected data provides insightful details on the population's socioeconomic, health, and demographic factors.

Target Population and Geographic Scope

The study's target population consisted of people who were at least two years old. Pregnant women weren't included in the study [24]. The sample included both males and females and a major emphasis was made in an attempt to gather information from the Multan and Bahawalpur regions of Pakistan.

Variables of Interest in the Study

The study sought to establish numerous variables with the view of fulfilling the stated objectives of the research. The main dependent variable was BSA which is an anthropometric measure. Exploratory variables involved age with six powers as used by Chen and co-authors in their study [25], and categorical variables involved gender, marital status, monthly income, residential area, and diabetic status [26]. These variables included both the numerical and non-numerical data derived from a wide group of participants.

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Data Collection Process and Procedure

There were two groups of three individuals and each group collected the data with the help of local pediatricians and dietitians. The study was done as a six-month project, with the research being conducted from March to August 2023. Primary data was collected through a self-administered questionnaire and the questionnaire was tailored in two parts. The first section collected basic biographic data like gender and age (rounded at the nearest year) from school enrollment records or parental permission for children below five years old. The second section provided information on the anthropometric measurements that were taken.

Challenges and Engagement with Participants

Despite the best efforts of the research team, several challenges arose when conducting the study and collecting the data as analyzed below. The data was collected objectively by measuring the participant's weight and height through self-completion.

Validation and Consistency of Collected Data

Regarding internal consistency, the reliability of the collected data was determined by Cronbach's Alpha, which had a value of 0.8314 that was found within the normal range of 0.70-0.90 [27]. This means that the collected data is correct and valid for statistical analysis since it conforms with the hypothesized distribution.

Minimization of Bias in Data Analysis

During the data editing and data cleaning process, the observations that did not fit the nature of the research question or were considered outliers were not included to minimize the bias [28]. It was necessary to ensure that the collected data was correct and did not contain any errors to identify the findings of the study as true.

Informed Consent Procedures in Research

Written informed consent was obtained from all respondents.

Sample Size Calculation

In our investigation, we calculate the sample size using the following formula [16].

$$n = \frac{N}{(1+Ne^2)}$$

where

n is the Sample Size

N is the size of the population

e = Precision Level

e= 0.01

$$n = \frac{1872000}{(1+1872000(0.01)^2)}$$

Now,

N= 1872000

n= 9906

Consequently, 9906 children and adults are taken out of two Pakistani cities (Multan and Bahawalpur).

Statistical Analysis and BSA Calculation

The BSA formula is as follows:

$$\mathrm{BSA}(\mathrm{m}^2) = \begin{Bmatrix} 0.000975482 \times WT^{0.46} \times HT^{1.08} \; for\; females \\ 0.000579479 \times WT^{0.38} \times HT^{1.24} \; for\; males \end{Bmatrix}$$

Quantile Regression Model and its Percentiles

This research applied a complex statistical tool called quantile regression (QR) that is appropriate for use where the distribution is not normal. QR also provides an estimate of the density of the response variable if the covariate has been taken into account. It is most appropriate to use when working with non-normal distributions since it can handle extreme values and outliers with ease. QR gives more information about the spread of the response variable as well as its center [29-31]. It has several advantages over the conventional regression techniques that have been used in the past as follows: There is no need to estimate distributional shapes and the existence of outliers will not affect the performance of the method. As discussed earlier in this study, the comparison between the models showed that QR is a better fit in describing the relationship between BSA and covariates [19]. Age may be incorporated into the QR model, and its six powers allowed us to consider age-related variations in BSSI [19]. Let's examine a real-valued random variable with the following distribution function, keeping in mind the ordinary quantile:

$$F(y) = Pr(Y \le y)$$

subsequently, the inverse function of the distribution function mentioned above is the $\tau - t\hbar$ quantile of the real valued random variable Y as given below:

$$Q(\tau) = \inf\ [y : F(y) \ge \tau]$$

where the τ is between 0 and 1. To be more precise, the median is $Q(1/2)$. The estimated $\tau - \mathrm{th}$ sample quantile is $\xi(\tau)$, which is an analogue of $Q(\tau)$, may be formulated as the solution of the optimization problem

$$\min_{\xi \to R} \sum_{i=1}^{n} \sigma_\tau (Y_i - \xi)$$

Where $\sigma_\tau(z) = z[\tau - 1(z < 0)], 0 < \tau < 1$, is usually called the check function.

According to the linear quantile model, the response variable is expressed in terms of covariates through a linear equation [32]. This model was employed in our study to analyze the BSA. Especially, the median regression approach was used where an

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idea is to find the scenario $\xi(\tau) = 0.5$ that results in the smallest sum of the absolute residuals [33]. To develop BSA growth charts we fitted a Quantile Regression (QR) model with the natural logarithm of BSA (log BSA) as the outcome variable. It has been proved in the research that six powers of age are involved as covariates for this method [34]. The values of τ were chosen according to the following scheme: τ = 0.05 to 0.95, to obtain BSA values at the 5th, 10th, 25th, 50th (Median Percentile), 75th, 85th, 90th, and 95th percentiles [35]. The analysis of the theoretical model was performed with the help of the E-VIEWS 7.0 software.

The BSA growth charts could then be produced where the calculated percentiles were plotted against the age of the respondents. This approach assisted in displaying the distribution of BSA values by age, and also in the analysis of growth patterns due to the graphical representation. Regarding the curvature of the growth curves, six powers of 'age' were added as covariates in the model [36]. Growth charts are used in the medical field where the growth of the patients is monitored and during this process, the doctors may observe some features of abnormal growth [37]. From the current study, the BSA growth charts developed are applicable for documenting the changes in body size and shape in healthcare settings. From the percentiles of the BSA values at the different ages, the clinician will be in a position to diagnose a problem that is causing a deviation from normal growth patterns at a very early age.

QR assisted in checking the non-normality of the data and provided a wider view of the growth of BSA. As the dependent variable, we specified the natural logarithm of BSA for which the six powers of age were used as covariates enabling us to explore the associations between the two variables adequately. The outcome of the study is consequent growth charts for various age groups and body sizes, which are helpful for physicians and other healthcare practitioners.

Results

Descriptive Analysis of BSA by Demographic Variables

The subsequent descriptive analysis is provided for each variable under investigation. The following table delineates the descriptive statistics of BSA stratified by age groups and facilitating a gender-wise comparison of BSA. The computed p-value for gender-based BSA comparison is statistically significant (p-value = 0.0000), indicating substantial differences in BSA measurements between male and female subjects. The table below depicts the descriptive statistics pertaining to BSA for the pediatric age cohort of 2 to 5 years, segmented by gender. Statistical analysis reveals a highly significant difference in BSA measurements between male and female subjects, with an estimated p-value of 0.0000. This result underscores a notable disparity in BSA across genders within this specific age group, suggesting the necessity for gender-specific reference values in clinical assessments and interventions (Table 1 & 2).

Table 1: Descriptive Statistics of BSA Across All Age Cohorts.

Category	N	Mean	Median	Min	Max	S. E	Var	S. D	P-value
Overall	9906	0.00709	0.00570	0.0011	0.0149	0.00003	0.00001	0.00332	
By Gender									
Male	5524	0.00475	0.005	0.0011	0.0077	0.00002	0.000001	0.00121	<0.001
Female	4382	0.01004	0.0107	0.0019	0.0149	0.00004	0.000007	0.00271	

Table 2: Descriptive Statistics of BSA for Age Groups 2 to 5 Years.

Category	N	Mean	Median	Min	Max	S.E M	Var	S. D	P-value
Overall	537	0.00278	0.0024	0.0011	0.0050	0.00005	0.000001	0.00106	
By Gender									
Male	262	0.00182	0.0018	0.0011	0.0024	0.00002	0.000001	0.00026	<0.001
Female	275	0.00368	0.0037	0.0019	0.0050	0.00004	0.000001	0.00066	

Table 3: Descriptive Statistics of BSA for Age Groups 5 to 14 Years.

Category	N	Mean	Median	Min	Max	S. E	Var	S. D	P-value
Overall	1944	0.00494	0.0044	0.0015	0.0116	0.00005	0.00001	0.00235	
By Gender									
Male	1162	0.00346	0.0035	0.0015	0.0057	0.00003	0.000001	0.00098	< 0.001
Female	782	0.00712	0.0070	0.0028	0.0116	0.00007	0.000004	0.00207	

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The subsequent table delineates the descriptive statistics concerning BSA stratified by age cohorts ranging from 5 to 14 years, alongside a gender-based comparative analysis of BSA measurements. The calculated p-value associated with the gender-specific comparison is (p-value = 0.0000), signifying a statistically significant disparity in BSA between males and females within the specified age groups (Table 3).

The following table presents the descriptive statistics of BSA for individuals aged 14 and older, categorized by gender. The statistical analysis revealed a significant gender-based disparity in BSA, with a p-value of 0.0000, indicating robust evidence against the null hypothesis. This result underscores a meaningful difference in BSA values between males and females, suggesting that gender is an influential factor in the assessment of BSA within this population (Table 4).

Table 4: Descriptive Statistics of BSA for Age Groups 14 Years and More.

Category	N	Mean	Median	Min	Max	S. E	Var	S. D	P-value
Overall	7425	0.00797	0.0062	0.0036	0.0149	0.00004	0.00001	0.00313	
By Gender									
Male	4100	0.00530	0.0053	0.0036	0.0077	0.00001	0.000001	0.00062	<0.001
Female	3325	0.01126	0.0112	0.0079	0.0149	0.00002	0.000002	0.00134	

Inferential Analysis

Quantile Regression Percentiles and Growth Charts of BSA

In this section, an analysis of Quantile Regression (QR) percentiles for the BSA was conducted using both aggregated and segregated datasets. To quantify the influence of various predictors, a median (50th quantile) regression model was implemented (utilizing Eviews 7.0) on the consolidated data set. The results, along with comprehensive discussions, are presented herein. The analysis encompasses the entirety of the dataset. The first column of the results table enumerates the independent variables considered in the model, while the second column details the QR coefficients, which elucidate the effects of each covariate on an individual's BSAI at the median percentile (50th). The third column presents the standard errors associated with the estimated parameters. The fourth column exhibits the t-values corresponding to each estimate, and the fifth column provides the associated p-values for statistical significance. The implications of the model's findings are illustrated within the results. Specifically, the anticipated median BSAI for both males and females at the average age of 30 years derived from specific covariate values in the combined dataset is displayed in the subsequent table (Table 5).

Table 5: The QR Estimates of BSA for Complete Data (τ=0.5).

Variable	Coeff.	SE	t-value	p-value
Constant	0.153358	0.019864	7.72046	0.0000
AGE	0.058746	0.007505	7.82793	0.0000
$(AGE)^2$	0.000834	0.000112	7.409367	0.0000
$(AGE)^3$	-2.14E-06	3.16E-07	-6.78425	0.0000
$(AGE)^{-1}$	-0.063404	0.009084	-6.97967	0.0000
√AGE	-0.147952	0.018972	-7.79829	0.0000
AGE √AGE	-0.010888	0.001422	-7.659001	0.0000

The P-value for all variables is highly significant at the 0.05 level of significance, and the combined data's 50th quantile (Median) BSA is 0.005689. This demonstrates that the BSA is significantly influenced by these six powers of age. The first two powers had a positive impact on BSA, whereas the other four had a negative impact. Appendix A contains the results for the tenth, twenty-fifth, fiftieth, seventy-fifth, eighty-fifth, ninetieth, and ninety-fifth quantiles.

Growth Chart of BSA for Complete Data

The growth charts of BSA are created using the QRM technique with six powers of age in the analysis. The various BSA percentile curves for each individual are obtained. The figure below shows that the BSA rapidly increases between the ages of 2 and 25 for all percentiles, then BSA slightly decreases between the ages of 25 and 38 years, after which it rapidly increases until age 50, after it BSA decreases till the age of 60 years. The BSA also rapidly increases between the ages of 2 and 4years for all quantiles (Figure 1).

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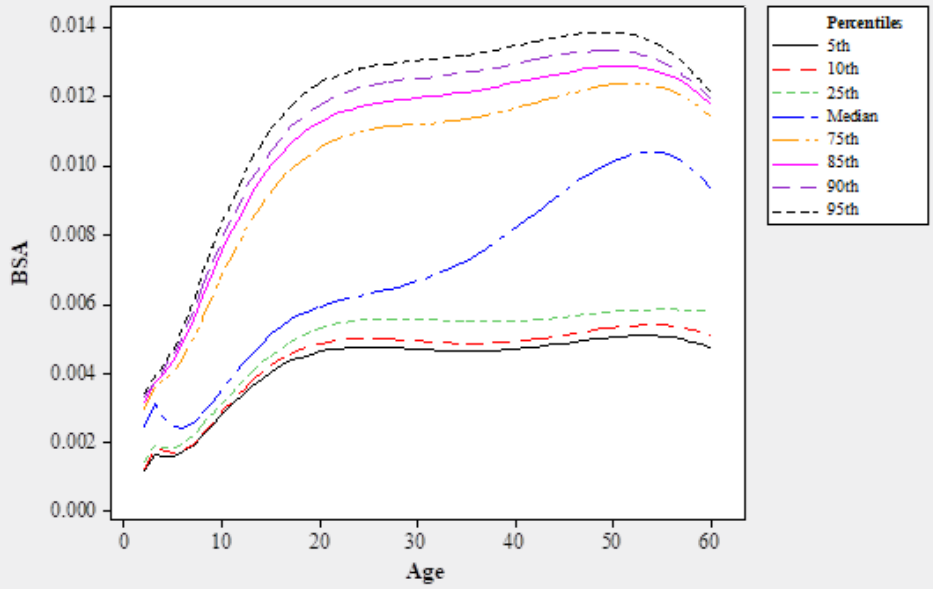

Figure 1: BSA Growth Charts obtained from QR Percentiles for Complete Data.

To create percentile forms, these fixed principles are plotted against age. The BSA curves for eight percentiles (fifth, tenth, twenty-fifth, fiftieth, seventy-fifth, eighty-fifth, ninetieth, and ninety-fifth) are displayed.

QR Analysis of BSA for Gender

In this section we discuss both genders as given below:

Analysis of BSA for Male Data

The analyses have been made for combined and separate data. To determine the effect of variables, the median (50th quantile) regression model is fitted (using Eviews 7.0) on the data. Results are presented, and discussions are made. The given analysis is for male data. The table's first column lists the variables, and the second column lists the QRM coefficients, which illustrate how different covariates affect a person's BSA at the 50th percentile. The estimator's standard errors are listed in column three. The t-value of the estimates is shown in column 4, and the p-values are shown in column 5. The model's demonstration can be seen in the results. The median BSA of both genders at average age (i.e., 30 years) is anticipated based on certain parameters for combined data, and the findings are shown in the table below (Table 6).

Table 6: The QR Estimates of BSA for Male Data (τ=0.5).

Variable	Coeff.	SE	t-value	p-value
Constant	0.074980	0.003924	19.10621	0.0000
AGE	0.028459	0.001404	20.26955	0.0000
$(AGE)^2$	0.000371	1.97E-05	18.87566	0.0000
$(AGE)^3$	-8.48E-07	5.17E-08	-16.41856	0.0000
$(AGE)^{-1}$	-0.031097	0.001841	-16.89077	0.0000
√AGE	-0.072165	0.003660	-19.71895	0.0000
AGE √AGE	-0.005100	0.000257	-19.83682	0.0000

The P-value for all variables is highly significant at the 0.05 level of significance, and the combined data's 50th quantile (Median) BSA is 0.00499. This demonstrates that the BSA is significantly influenced by these six powers of age. The first two powers had a positive impact on BSA, whereas the other four had a negative impact. Appendix A contains the results for the tenth, twenty-fifth, fiftieth, seventy-fifth, eighty-fifth, ninetieth, and ninety-fifth quantiles.

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Growth Chart of BSA for Male Data

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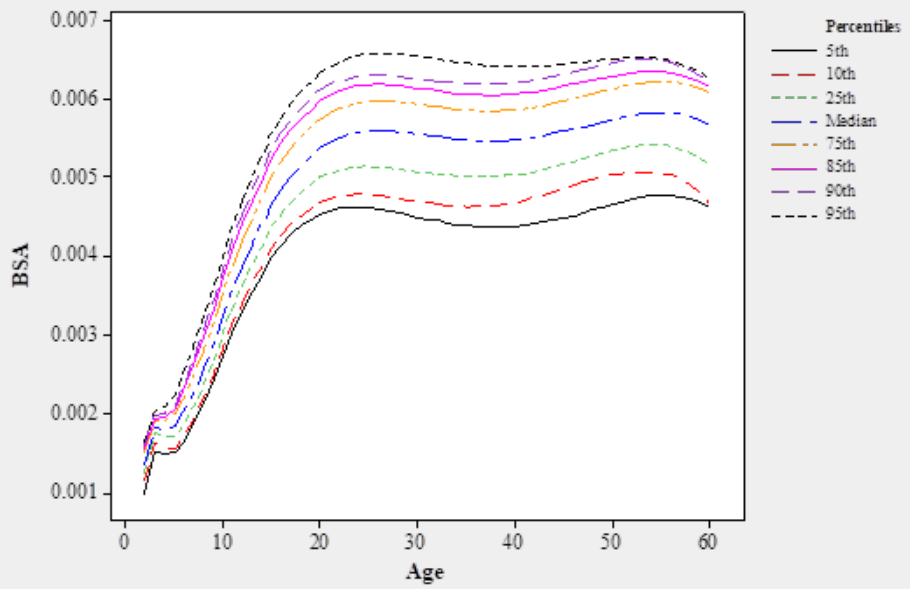

Figure 2: BSA Growth Charts obtained from QR Percentiles for Male Data.

To create percentile forms, these fixed principles are plotted against age. The BSA curves for eight percentiles (fifth, tenth, twenty-fifth, fiftieth, seventy-fifth, eighty-fifth, ninetieth, and ninety-fifth) are displayed.

QR Analysis of BSA for Female Data

The analyses have been made for combined and separate data. To determine the effect of variables, the median (50th quantile) regression model is fitted (using Eviews 7.0) on the data. Results are presented, and discussions are made. The given analysis is for female data. The table's first column lists the variables, and the second column lists the QRM coefficients, which illustrate how different covariates affect a person's BSA at the 50th percentile. The estimator's standard errors are listed in column three. The t-value of the estimates is shown in column 4, and the p-values are shown in column 5. The model's demonstration can be seen in the results. The median BSA of both genders at average age (i.e., 30 years) is anticipated based on certain parameters for combined data, and the findings are shown in the table below (Table 7).

Table 7: The QR Estimates of BSA for Female Data (τ=0.5).

Variable	Coeff.	SE	t-value	p-value
Constant	0.116898	0.008779	13.31571	0.0000
AGE	0.048781	0.003085	15.81340	0.0000
$(AGE)^2$	0.000695	4.24E-05	16.41183	0.0000
$(AGE)^3$	-1.72E-06	1.08E-07	-15.91950	0.0000
$(AGE)^{-1}$	-0.044857	0.004286	-10.46467	0.0000
√AGE	-0.117474	0.008111	-14.48382	0.0000
AGE √AGE	-0.009148	0.00056	-16.34429	0.0000

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The P-value for all variables is highly significant at the 0.05 level of significance, and the combined data's 50th quantile (Median) BSA is 0.010653. This demonstrates that the BSA is significantly influenced by these six powers of age. The first two powers had a positive impact on BSA, whereas the other four had a negative impact. Appendix A contains the results for the tenth, twenty-fifth, fiftieth, seventy-fifth, eighty-fifth, ninetieth, and ninety-fifth quantiles.

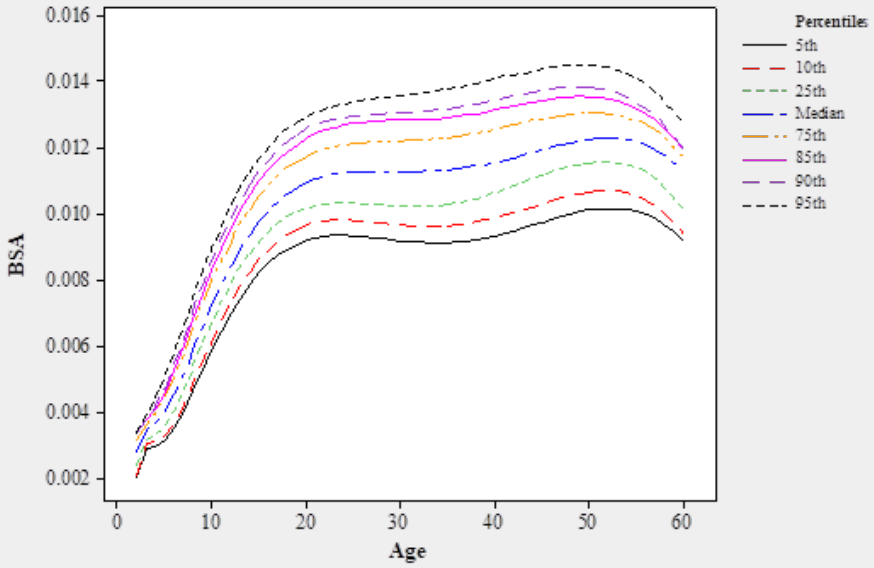

Figure 3: BSA Growth Charts obtained from QR Percentiles for Female Data.

Growth Chart of BSA for Female Data

The growth charts of BSA are created using the QRM technique with six powers of age in the analysis. The various BSA percentile curves for each individual are obtained. The figure below shows that the BSA rapidly increases between the ages of 2 and 26 for all percentiles, then BSA slightly decreases between the ages of 27 and 36 years, after which it rapidly increases until age 52, after it BSA decreases till the age of 60 years. The BSA also rapidly increases between the ages of 2 and 4 years for all quantiles (Figure 3).

To create percentile forms, these fixed principles are plotted against age. The BSA curves for eight percentiles (fifth, tenth, twenty-fifth, fiftieth, seventy-fifth, eighty-fifth, ninetieth, and ninety-fifth) are displayed.

Gender Differences in Body Surface Area and Obesity Prevalence

The quantile regression analysis of Body Surface Area (BSA) data reveals significant differences between male and female participants in the context of obesity prevalence in Pakistan. The median (50th percentile) BSA values indicate a notable gender disparity, with males exhibiting a median BSA of 0.00499 and females displaying a higher median BSA of 0.010653. This difference suggests that, at the median, females have a greater propensity for obesity compared to males, which warrants further investigation into the underlying factors contributing to this disparity. In terms of the relationships between age and BSA, the analysis indicates that both genders experience increases in BSA as they age; however, the coefficients associated with age reveal distinct patterns. For males, certain age powers have a positive impact on BSA, particularly the linear and quadratic terms, demonstrating that as males age, their BSA tends to increase. The higher powers of age exhibit negative coefficients, indicating diminishing returns on BSA increases as age progresses. This combination suggests that while young males experience an initial increase in BSA, older males may face a decline in BSA after reaching a certain age threshold.

Females also show a positive correlation between age and BSA, but with coefficients that indicate a stronger influence of age on the BSA trajectory, especially for the positive terms. The quadratic and linear terms have higher coefficients, reflecting a more pronounced increase in BSA with age among females. The overall trend observed in the female growth chart illustrates a steady increase in BSA from ages 2 to 26, before a slight decline between 27 and 36 years, followed by a resurgence until age 52. This implies that while younger females experience a similar

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initial growth pattern to males, they maintain a prolonged period of BSA increase, which may contribute to the overall elevated average BSA observed in females. The regression results emphasize significant variability in the impact of age on BSA across different percentiles. For both genders, the negative coefficients for age in higher polynomial terms reflect the complexity of the aging process on body composition. However, the magnitude of these effects appears more substantial in females, indicating a potentially greater sensitivity to age-related changes in body composition among women compared to men.

The gender comparison in the BSA quantile regression analysis highlights crucial findings about obesity prevalence in Pakistan. Females exhibit a higher median BSA compared to males, combined with more pronounced positive relationships between age and BSA. These gender-specific trends in body composition underscore the necessity for tailored public health strategies that account for the differences in obesity dynamics between males and females. Targeted interventions addressing the unique health needs and lifestyle factors of each gender could be beneficial in effectively tackling obesity and improving overall health outcomes in the population.

Discussion

The results presented in this study elucidate significant gender differences in Body Surface Area (BSA), suggesting a notable disparity in obesity prevalence among males and females in Pakistan. The findings indicate that the median BSA for females (0.010653) is considerably higher than that of males (0.00499), a difference that achieves statistical significance (p-value < 0.001). These results are consistent with prior research indicating that women generally exhibit higher rates of body fat and BSA than men, likely due to differences in physiological and hormonal factors [19, 38-39]. The higher median BSA for females indicates a potential predisposition to obesity, necessitating targeted interventions tailored to gender-specific health needs [11, 40-43].

The descriptive analysis stratified by age cohorts reveals critical insights into BSA growth trajectories across different developmental stages. In the pediatric age cohort of 2 to 5 years, females also exhibit a higher BSA (mean: 0.00368) compared to males (mean: 0.00182), highlighting early onset differences that could have lasting implications for obesity risk [44-45]. The pronounced gender differences at an early age underscore the relevance of establishing gender-specific reference values for BSA in clinical assessments and interventions [46-48]. The growth rates of BSA suggest that both genders experience increases in BSA with age, although the patterns diverge significantly. Male participants show a temporary increase in BSA until around age 22, followed by a decline until age 35, which could be indicative of hormonal changes, lifestyle shifts, or increased physical activity levels during young adulthood [1,50-52].

Female participants demonstrate a steadier increase in BSA, with growth observed up to age 26, followed by a slight decline during early adulthood, before witnessing another increase until age 52. This pattern can be attributed to biological factors, including the influence of hormonal changes related to puberty and menopause, which can substantially affect body composition over time [53-56]. The quantile regression analysis further emphasizes notable differences in how age affects BSA across genders. While both genders exhibit positive correlations between age and BSA, the impact is more pronounced in females. This finding aligns with the work of [57]. which highlights that females typically accumulate body fat at a faster rate than males, particularly during puberty and after childbearing years. The negative coefficients for higher polynomial terms, particularly in males, suggest that while young males experience significant BSA increases, they may encounter a plateau or decline as they age. The positive impact of age on BSA among females throughout their reproductive years indicates a sustained trajectory of growth that contributes to the gender disparity observed in obesity prevalence [45,58-60].

The analysis indicates that the male cohort's BSA experiences a more abrupt decline in older age brackets, implying a need for targeted public health strategies aimed at mitigating risks associated with obesity in aging males. For females, the prolonged increase in BSA necessitates interventions that combat obesity and its associated health risks, particularly during income-earning and reproductive years when lifestyle choices may have profound implications on health outcomes. Tailored public health strategies should thus address the unique lifestyle factors, cultural beliefs, and dietary habits influencing BSA across genders and age cohorts. The findings underscore a critical need for gender-sensitive public health policies addressing obesity prevalence in Pakistan. The significant differences in BSA between genders throughout various age cohorts warrant the development of tailored interventions that consider the distinct health needs, lifestyle factors, and biological influences experienced by males and females. The implications of this study reinforce the importance of further research aimed at understanding the complex interplay between gender, age, and body composition in developing effective strategies for obesity prevention and management.

Conclusion

In conclusion, this study provides compelling evidence of significant gender differences in BSA and their implications for obesity prevalence among the adult population in Pakistan. The findings demonstrate that females exhibit higher median BSA values compared to their male counterparts, underpinning a greater vulnerability to obesity-related health risks. Through the application of quantile regression analysis, the study successfully highlights the intricate relationship between age and BSA, revealing distinct patterns that differ by gender. Males experience a temporary increase in BSA during their early years, with a subsequent decline in older age, whereas females show a

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more sustained growth trajectory that extends into middle age. These insights emphasize the necessity for targeted public health strategies that are sensitive to gender-specific health dynamics. Interventions aimed at addressing the rising prevalence of obesity need to account for the unique physiological and lifestyle factors that contribute to differences in body composition between men and women. The study illustrates the advantages of employing quantile regression methods for analyzing BSA and constructing growth charts, providing a sophisticated understanding of growth patterns that traditional methods may overlook.

The implications of this research extend beyond academic interest, offering practical applications for clinicians, public health officials, and policymakers. By providing detailed BSA growth charts based on empirical data, this study can serve as a critical resource for monitoring and assessing growth and obesity trends within the Pakistani population. Ultimately, the research advocates for the integration of more nuanced metrics, such as BSA, into public health initiatives to combat the escalating obesity epidemic effectively and improve overall health outcomes in Pakistan. Continued research into the interplay between gender, age, and body composition will be pivotal in refining strategies aimed at promoting healthy growth and mitigating obesity-related health issues across diverse populations.

Recommendations for Future Research

The following recommendations should be considered for future research:

- To complete cross-sectional surveys to compare changes in BSA over the years.
- Examining the association between BSA and other health-related factors including metabolic syndrome, cardiovascular disease, and cancer.
- Creating an individual's BSA models based on such demographic profiles.
- Investigating the success of interventionist efforts in increasing healthy body composition employing BSA as the best outcome measure.

Strength and Limitations

This study possesses several strengths that enhance its credibility and potential impact. One of the primary strengths is the large sample size of 9,906 participants, which allows for robust statistical analysis and increases the generalizability of the findings to the broader Pakistani population. Furthermore, the application of quantile regression analysis provides a nuanced understanding of Body Surface Area (BSA) across various percentiles, effectively capturing the variability in BSA rather than relying solely on mean values. This methodological choice, coupled with a focus on gender-specific insights, highlights significant differences between males and females regarding obesity prevalence, informing targeted public health interventions. Additionally, the development of BSA growth charts is a valuable output, offering healthcare professionals a practical tool for monitoring and assessing growth in clinical settings.

Despite its strengths, the study also has notable limitations that warrant consideration. The cross-sectional design limits the ability to infer causality, providing only a snapshot of BSA and obesity at a specific point in time. Moreover, the reliance on convenience sampling may introduce selection bias, as participants were primarily recruited from public spaces, potentially excluding underrepresented groups in the population. Additionally, variations in body composition may not be fully accounted for due to the dependence on established formulas for calculating BSA, which may not accurately reflect the unique characteristics of the population studied. These limitations highlight the need for continued research that addresses the complexities of body composition and obesity dynamics in diverse populations, as well as longitudinal studies to explore changes in BSA over time.

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Conflict of Interest

The authors have no conflict of interest.

Authorship

All the authors are contributed significantly to the design, data collection, analysis, and interpretation of the results. All authors have read and approved the final manuscript.

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