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Comparison of Nonparametric Quantile Regression and Semi-Parametric LMS to Body Mass in Growth Charts with a Pakistani Population

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Abstract

The main objective of the present study is to construct growth charts and set standard values for body mass-for-age for Pakistani adults aged between 2 and 60 years. This study used the NQRM to determine conditional quantile curves and normal values by comparing them with the Cole and Green SPLMS methods. This study consists of a sample of 7,225 participants from Pakistan who were collected in 2022 but followed the World Health Organization guidelines for inclusion. The findings of the current research showed body mass-for-age growth trends in males and females from 2 to 60 years old Pakistani children and adults. It is noteworthy that our results were very similar to those obtained by SPLMS where females had significantly higher body mass than was observed for males in all age groups. Such gender differences in the prevalence of this disease are in line with earlier findings that have indicated similar trends in other populations. This study also underscores the utility of NQRM as an assumption-free and easily implemented method for determining normal values and reference curves. NQRM does not assume a specific distributional form. Hence, it is more appropriate to use NQRM than the traditional parametric methods for understanding the non-linear patterns of the socio-economic predictors and body mass trajectories in Pakistani children and adults. The capacity to fit models of any order and to handle extreme values is useful especially in the present case largely due to the prevailing levels of socio-economic development disparities in Pakistan. The fact that this study has revealed an increased prevalence of obesity and its risks among the Pakistani population has significant implications for obesity prevention and management policies in Pakistan. With the help of growth charts, which reflect the growth of children and adults, doctors can assess the conditions that exist and identify deviations from normal growth. Further, the use of growth reference charts by age and sex could help in the designing of specific strategies to minimize obesity-associated health risks. The findings of this study underscore the relevance of socio-economic contexts to shape body mass change patterns and suggest the utility of NQRM for future population health studies in low- and middle-income countries (LMICs) like Pakistan.

Keywords: Obesity; Non-Parametric Quantile Regression Modelling; Growth Curves; Reference Values; Anthropometric Measures; Semi-Parametric LMS

Abbreviations: NQRM: Nonparametric Quantile Regression Method; SPLMS: Semi-Parametric LMS (Lambda Mu Sigma); QR: Quantile Regression; WHO: World Health Organization; BCPE: Box-Cox-Power-Exponential; BSSI: Body Shape and Size Index; BMI: Body Mass Index; BSA: Body Surface Area; SRS: Simple Random Sampling

Introduction

In the field of medical sciences, standard values, and growth charts are crucial instruments used to evaluate a child's health status and nutritional condition [1]. These curves help healthcare practitioners in diagnosing abnormal growth patterns and coming up with measures to achieve the right growth pattern in children. Further, they serve as the foundation for the teaching aids used in educating parents about the right decisions concerning their children's health [2]. The World Health Organization (WHO) has produced population and country-specific child growth standards which have used a Box-Cox-Power-exponential (BCPE) method to remove irregularities in the data. However, the application of these curves has not been without controversy mainly because of the existence of drawbacks in data accuracy, computational methods, and differentiation processes [3].

The lack of highly accurate and complex statistical techniques has always resulted in the need for the development of other methods of constructing growth curves. NQRM is an accurate, fast, and easily implemented method. The conditional quantile curves and normal values derived from them are more desirable than those obtained from parametric models. Unlike most parametric distributional models, NQRM allows for the estimation of smooth covariate functions without assuming that the distribution of the data is restricted in certain ways. It has been found that this approach is well-suited to constructing growth curves for body mass [4,5]. In this study, the primary goal is to construct growth curves, as well as standard values for adults in Pakistan who are 2 to 60 years old using NQRM. Our approach uses Kernel estimation for local constant Kernel estimation of conditional quantile curves, this enables the estimation of quantiles as a smooth function of covariates without necessarily postulating specific distributional assumptions [6,7]. This makes it ideal for the development of growth curves of body mass and provides a better option for the semi-parametric and parametric methods. A study Hussain et al., [8] 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 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 [8]. 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 [9].

A study by Hussain et al., [8] 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 [10]. A study by Shehzad et al., [9,10] 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 [9,10]. The NQRM method has some advantages over traditional methods. Firstly, it does not entail the determination of a given distributional form that may be stringently challenging while handling complicated data. Secondly, it is acceptable for large numbers and other complex situations such as outliers and other non-linear relationships. Thirdly, it offers a reliable technique for generating reference curves without the application of outlier detection [11]. This also provides support for the QR approach for constructing growth curves on body mass. The NQRM can be used in the estimation of reference curves to growth curves other than semi-parametric, and parametric methods. As the proposed method is stable, one can have curves and intervals without an outlier detector as mentioned in [12].

The objective of the present research work is to establish age- and gender-specific growth curves and normal values for Pakistani adults derived via NQRM. The study helps to derive an overall picture of body mass trends in Pakistani adults and explores socio-economic influences on the process. It helps in the formulation of obesity prevention and control guidelines in the context of Pakistan and further understanding of various and multiple linkages between socio-economic factors and body mass change in Pakistani adults. The importance of this study therefore lies in the fact that it offers a chance to fill the existing gap in standard growth values in Pakistan. Therefore, using NQRM and establishing age- and gender-specific curves for Pakistanis gives healthcare providers a useful diagnostic tool to evaluate body mass in adults. However, the findings of the present study guide the development of specific interventions for this population to minimize obesity-associated adverse health effects.

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Material and Methods

Study Design and Sampling Technique

The study used a cross-sectional design with 7225 respondents as a sample from Multan and Bahawalpur two cities of Pakistan. The simple random sampling (SRS) method was used to collect data. With this method of data collection, each member of the population was guaranteed an equal chance of being chosen to participate in the survey as a responder. This was accomplished by compiling an exhaustive list of the population of interest, which comprised all adults living in Multan and Bahawalpur. Using a random number generator, a sample of 7225 respondents was chosen from this list. This procedure made it possible to get a representative sample of the adult population of Multan and Bahawalpur. It is ensuring that the results could be applied to a broader population. The data collection was done in compliance with policies and procedures that are recommended by the World Health Organization (WHO) [13]. The main dependent variables were the body mass-related variables and they were collected in a standardized manner.

Research Setting and Participant Demographics

All the adult individuals, both males, and females, of age 2 years more were included in the study but the pregnant women were excluded. Our participants are all adult individuals of age 2 years and more.

Participant Selection

We used a variety of selection techniques to choose research participants to guarantee a representative and varied sample. We separated the population into subgroups according to age, geography, and socioeconomic level using a convenience sampling technique. Then, to make sure that our sample was representative of the population, we chose individuals from each category. A variety of techniques were used to find the participants, including:

- **Online Advertisements:** We promoted the study to people from a range of socioeconomic backgrounds on well-known websites, including social media and online ads.
- **Local Community Centers:** To reach those who might not have access to internet resources, we collaborated with neighborhood community centers, non-profits, and groups that assist low-income neighborhoods.

Word of mouth: By requesting current participants to recommend friends and relatives who might be interested in taking part in the study, we relied on word-of-mouth advertising. In-person recruitment: To reach a wider spectrum of people, our study team personally recruited participants at public locations like parks, marketplaces, and shopping malls.

Representative Sample

We also took into account the following elements to make sure that our sample was representative of the population:

- **Age Range:** We incorporated individuals from various age brackets to encompass the multiplicity of viewpoints and experiences.
- **Socioeconomic Status:** We select individuals from diverse socioeconomic backgrounds, encompassing low-, middle-, and high-income brackets.
- **Geographic Location:** To represent the variety of experiences and viewpoints found throughout Pakistan, we sought volunteers from both urban and rural areas.

Inclusion Criteria

Participants must be 2 to 60 years of age. Willing to provide informed consent for participation in the study. Able to communicate effectively in the language used for data collection.

Exclusion Criteria

Individuals who are unable or unwilling to participate in the study due to time constraints, health issues, or other personal reasons. Participants with severe cognitive impairments that may hinder their ability to comprehend and respond to the study's questions or tasks. Those who are currently involved in other clinical trials or interventions related to the research topic.

Variables and Data Collection

The data consisted of different variables and they were gender, age in years and body mass (weight) in kg were measured using standardized techniques and equipment from Pakistan. Age and weight are included in our study as quantitative variables. Data was collected using standard tools for measuring the weight of respondents. A special team was hired for the collection of this precious data. The bias of data is also discussed below lines.

Engagement of Patients and Communities

While collecting data from our participants we face many hurdles and then solve them for effective data collection. We collect data through a self-administered way from the patients; their weight was measured accurately.

Data Reliability

The reliability of data is also checked before the statistical analysis using Cronbach's Alpha. The value of Cronbach's Alpha is 0.86 which lies in the normal range i.e. (0.70-0.90).

Bias

While editing and formatting data, we exclude some unusual and irrelevant observations to remove the effect of bias.

Sample Size Determination

This study uses the sample size determination formula given by (Yamane, 1967):

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Where;

N = Population Size

n = Sample Size

e = Level of precision

Now,

N= 1872000 e= 0.01175

n= 7225

As a result, 7225 individuals are taken from Multan and Bahawalpur, South Punjab, Pakistan.

Statistical Methods

For modeling growth curves and estimating normal values, we used nonparametric quantile regression modeling (NQRM) with local constant kernel for the estimation of conditional quantiles. The NQRM approach is based on the method developed by Koenker and Bassett [14], which provides a technique to estimate conditional quantile functions by defining quantiles of the output variable as a function of the observed input variables. As opposed to most other regression models that work to find the least squared residual, QR minimizes the weighted sum of the absolute deviations of the error terms. This approach allows us to estimate covariate functions without a specific distribution [15]. Regarding the implementation of NQRM, we calculated the conditional quantile curves and standard values with the help of the local constant kernel estimation approach. This methodology enables the determination of quantiles as a smooth function of covariate values without having to specify the true density function forms. The curves and values obtained from this study could be useful in understanding the dynamics and designing preventive and intervention measures for obesity in Pakistani adults. We also compared with semi-parametric LMS analysis, which is a common method for the construction of growth charts. This enabled a comparison of the different approaches when identifying the body mass trajectories in Pakistani adults.

NQRM

In parametric type, when covariates Y are deliberated, the linear restricted percentile function, $F(t|Y=y) = y'\alpha(t)$, is assessed after the solution of,

Each percentile can $t \in (0,1)$. The amount$\hat{\alpha}(t)$is said to be t-th percentile of regression [16,17]. The NQRM is superior to SPLMS method due to following reasons:

- There is no assumption of distribution
- In addition to outliers, it is resilient
- This approach can be used with all continuously measured health factors.

Quantile Regression (QR) has been employed to generate growth charts for body mass across the age range of 2 to 60 years, providing comprehensive insights by calculating the 5^{th}, 10^{th}, 25^{th}, median, 75^{th}, and 95^{th} quantiles, which offer a detailed representation of the distribution and various percentile values related to an individual's body mass at different ages. The benefits of this technique are that the distribution of body mass can be tested at several points instead of only in the center. It does not include conclusions about the distribution of residuals from the regression and has little effect on outliers and skewness in the distribution of outcome variables. Polynomial QR models with six powers of age were used to study the sex-specific growth development of body mass. These approximate parameters were developed using a Markov chain marginal He and Hu bootstrap that promotes the QR bootstrap method [18]. QR has been used to create body mass growth charts for both males and females for seven percentiles. For each centile, the fitted body mass values are measured and stored in a data set at each observed age. These values were then compared with age to construct body mass growth charts. In this article, a local kernel approximation of conditional percentile curves used to estimate growth curves and normal values was provided for the NQRM. Further information about this is given in the reference [14]. The regression is calculated with the statistical package E-VIEWS. The method of subjective choice is used for smoothing parameter evaluation and the Gaussian kernel function is needed for the analysis [19].

Results

Participants

The sample size is comprised of 7,225 people; 2034 of which were male (55.83%) while 3191 were female (44.17%).

Descriptive Analysis

In the first descriptive analysis of the sex groups at each age, we observed that the data is non-parametric as all the groups were found non-significant from a normal distribution of body mass ($p<0.05$). Moreover, the data set itself contains outliers, which means that there is a need to use a method that is both robust and flexible.

Growth Charts

When the body mass was plotted against age for both boys and girls, no clear trend was established, implying that growth likely differed between Pakistani men and women. Therefore, to overcome these differences, we used the non-parametric quantile regression modeling (NQRM) [20], while developing gender-specific growth charts. Percentile curves of body mass for females and males are shown in Figures 1 and 2 accordingly. These curves illustrate how the progression is different between the genders of the identified group. Compared to the previous methods, the NQRM approach enables a conditioning estimate of

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quantile functions, which gives a better insight into human growth by quantifying the degree of variation in the growth process at different quantile levels. To enable the comparative assessment between the NQRM approach and the semi-parametric LMS analysis (SPLMS), we constructed growth charts by applying both methods (Figure 3). Hence, the median (50% percentile) curves computed using these two methods are almost similar as seen in Figure 2, which confirms the validity of NQRM. In this comparison, this study focuses on the various strategies that can be used when constructing growth charts with an emphasis on precision and accuracy [21]. The comparison of the 50% growth curve in body mass shows a large difference in the rates of growth between male and female individuals. As shown in Figure 4, male growth curves are higher than females across all ages except at approximately 48 years when females' body mass drops sharply. This might be due to better nourishment among both genders which may result in better health and fitness.

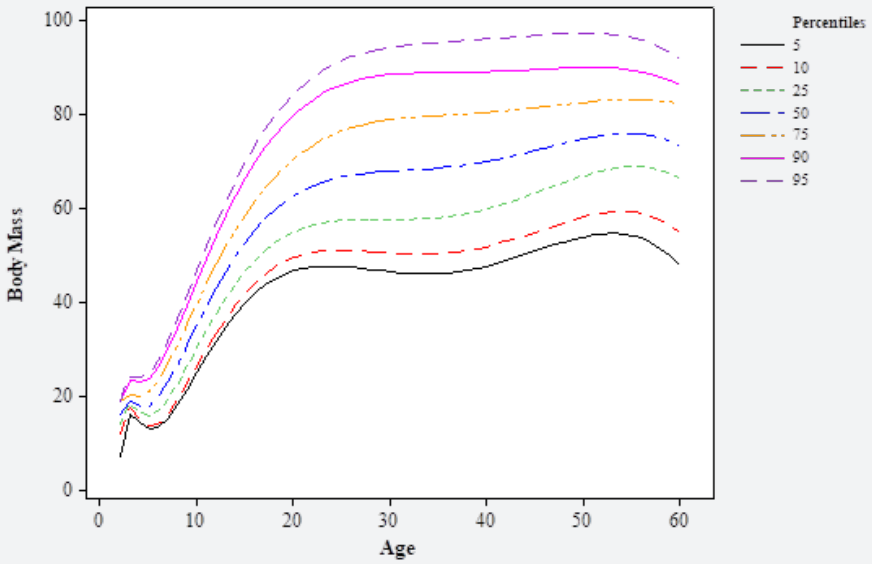

Figure 1: Growth charts obtained using NQRM for Pakistani males.

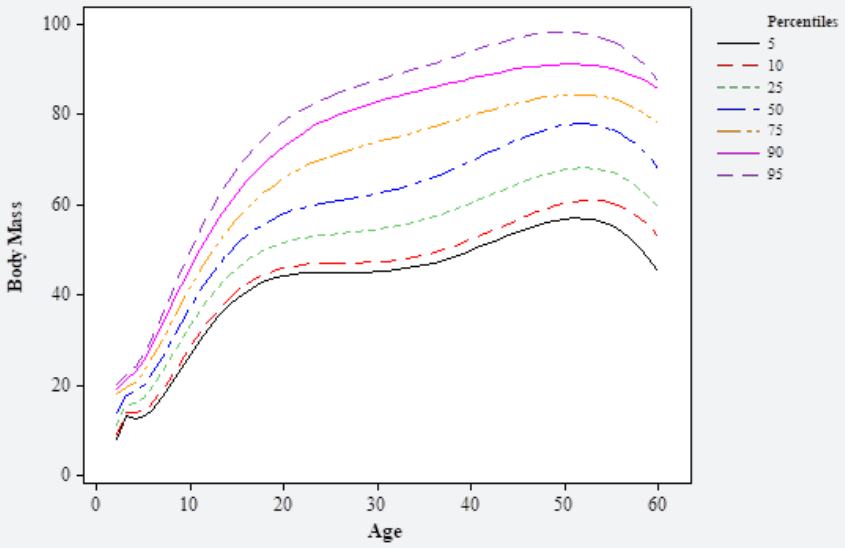

Figure 2: Growth charts obtained using NQRM for Pakistani females.

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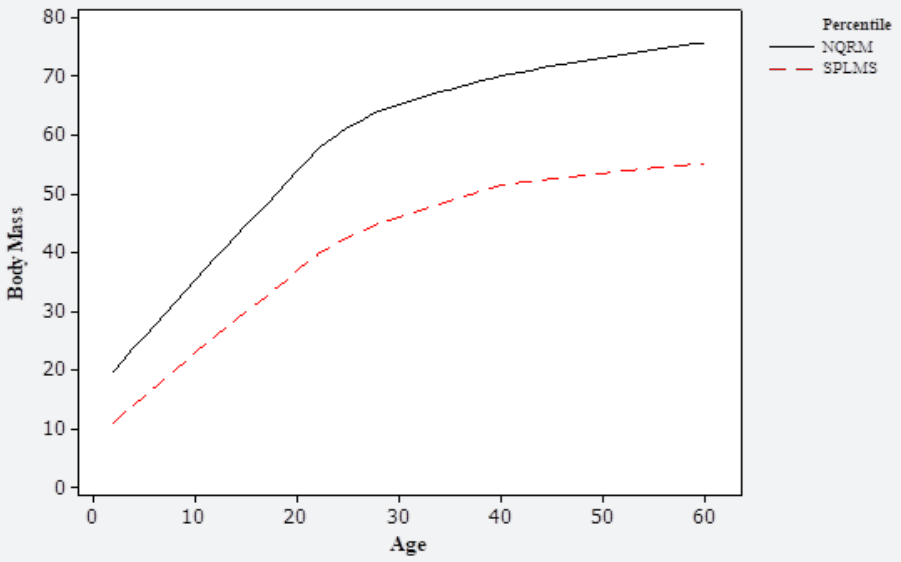
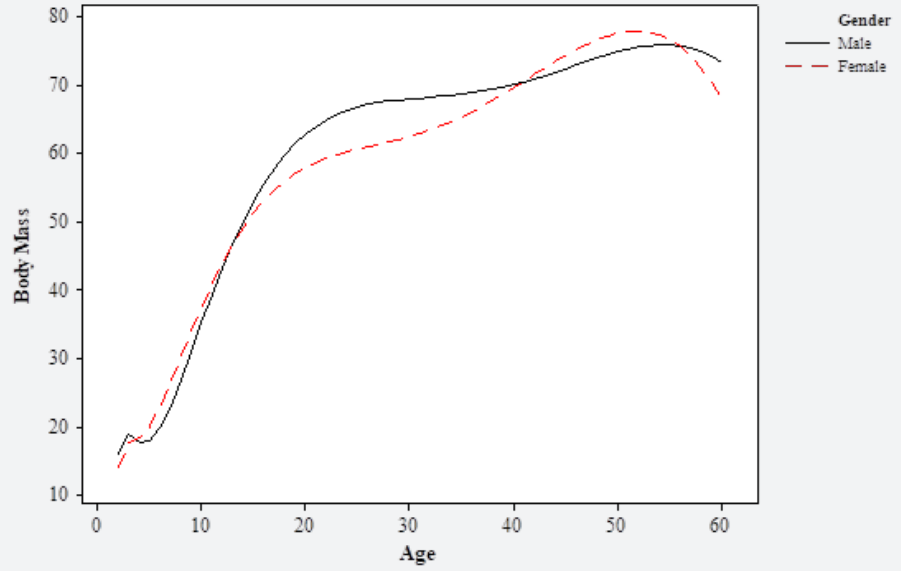


Figures 3: Comparison of SPLMS method and NQRM for median percentile of body mass using Pakistani individuals.



Figures 4: Gender comparison of NQRM for median percentile of body mass.

Table 1 lists the regression quantiles for each quantile obtained as the age was observed in the study. Table 1 is highly useful to determine the appropriating trend of behavioral characteristics of the individuals of Pakistan so that human growth for different ages and quantiles can be better understood. Table 1 shows the body mass median percentile values for male and female people at different ages. The age of the data is progressively increased from 2 to 60, forming quantiles. This table helps to better understand human growth patterns over a range of ages and quantiles by offering insightful information about the trend of behavioral traits of individuals in Pakistan. Interestingly, the median body mass values for both sexes rise gradually with age, suggesting that there

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is a positive relationship between body mass and age. This pattern holds for all quantiles, indicating that people tend to gain more body mass as they age. For instance, the median body mass of boys is 16 at age 2 and rises to 68 at age 30. Similarly, for females, the range of median body mass is 14 at age 2 to 62.53 at age 30. Notable gender disparities in patterns of body mass increase are also shown by the data. For the majority of ages, men typically have a larger median body mass than women. For example, the median Body Mass at age 20 is 57.96 for females and 62.86 for males. Male and female variances in muscle mass and body composition might be the cause of this discrepancy.

Table 1: Median percentile values of Body Mass with age for both genders.

Age	Male	Female	Age	Male	Female
2	16	14	32	68.24	63.52
3	18.84	17.58	33	68.37	64.1
4	17.73	18.29	34	68.52	64.73
5	18	20	35	68.69	65.43
6	19.91	22.78	36	68.9	66.19
7	23	26.24	37	69.15	66.99
8	26.79	30	38	69.43	67.85
9	30.91	33.8	39	69.76	68.75
10	35.12	37.46	40	70.13	69.68
11	39.22	40.88	41	70.53	70.63
12	43.11	44	42	70.98	71.59
13	46.72	46.78	43	71.45	72.54
14	50	49.23	44	71.94	73.48
15	52.95	51.36	45	72.46	74.38
16	55.55	53.17	46	72.98	75.22
17	57.83	54.71	47	73.5	75.98
18	59.79	56	48	74	76.65
19	61.46	57.07	49	74.48	77.2
20	62.86	57.96	50	74.92	77.61
21	64.03	58.69	51	75.3	77.86
22	64.98	59.29	52	75.61	77.91
23	65.75	59.8	53	75.84	77.74
24	66.36	60.24	54	75.96	77.33
25	66.84	60.63	55	75.95	76.64
26	67.2	60.99	56	75.8	75.64
27	67.48	61.35	57	75.5	74.32
28	67.7	61.71	58	75	72.62
29	67.86	62.1	59	74.3	70.53
30	68	62.53	60	73.36	68
31	68.12	63			

The table illustrates how, for both males and females, the rate of increase in body mass decreases gradually when age exceeds thirty. Numerous variables, including aging-related decreases in bone density and muscle mass, as well as dietary and lifestyle modifications, might be to blame for this drop. According to the statistics, girls experience this reduction sooner in life than males, which may mean that as they age, women's bodies change more quickly than men. Table 1 offers a complete overview of the behavioral feature trend of Pakistani persons across all age groups and quantiles. Age-related increases in body mass are a prominent trend, with gender variations in growth patterns to be noted. Additionally, the research indicates that at the age of 30, there appears to be a steady decline in body mass gain, with women's bodies changing more quickly than men's as they age. Healthcare practitioners and legislators may utilize this data to better understand population health patterns and create focused programs that encourage illness prevention and healthy lifestyles.

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Discussion

Key Findings

The objective of the current study is to identify the effects of socio-economic status on body mass trajectories among Pakistani adults using methods of non-parametric quantile regression modeling and semi-parametric LMS analysis. The outcomes of this study emphasize the need to apply various strategies when developing growth charts and, therefore, maintain consistency and reliability. The results presented in this study reveal that NQRM can be useful when constructing the growth charts of Pakistani adults and analyzing the data sets containing non-normal distribution with outliers. The approach makes it possible to estimate the conditional quantile functions. This offers a better picture of growth in humans than the conventional fixed quantile regression analysis. The outcomes also highlight the necessity of analyzing differences in growth by sex characteristics. The application of these growth patterns shows that male and female individuals grow differently, which requires the use of sex-specific factors and separate growth charts. Compiling the results of the comparative analysis between NQRM and SPLMS, it is observed that both techniques are similar thereby proving the effectiveness of NQRM. This finding indicates that NQRM can be used as an approach when SPLMS cannot handle the complications of the data set.

It is therefore important that readers and practicing healthcare professionals pay attention to the study's findings, particularly when dealing with patients with weight-related disorders. Through the application of NQRM in the form of growth charts, the readers or healthcare providers are in a position to make better evaluations of the health status of the patient and plan better on treatment measures. Hence, this study is useful to construct the new growth chart of Pakistani adults using the NQRM. This approach enables one to get additional insight into human growth and development considering the variability of growth for each quantile and the differentiation of growth curves for both male and female individuals [22-24]. Future studies could further expand on how other factors related to growth patterns in Pakistani adults can be affected, including socioeconomic status, living in urban or rural areas, and levels of physical activity. Taking into account these factors alongside NQRM would create a more holistic picture of growth patterns among this population. Besides, being an important element of research, NQRM can be helpful in the clinic for patients with weight-related disorders and develop a tailored treatment plan. This way, with NQRM, healthcare providers will be able to come up with correct estimations of normal values and reference curves that will prove beneficial in delivering better diagnoses and treatment plans for patients.

Limitations of Study

This study used non-parametric quantile regression modeling (NQRM) to quantitatively assess the effects of socio-economic factors on the body mass progression in Pakistani adults. However, the application of NQRM can lead to complex models with multiple quantiles, especially when they are used with a complex system, which may be difficult to explain or present to an audience that does not have a technical background, underlining the need for effective communication strategies. Moreover, NQRM demands a significant sample size to obtain the quantiles' effect estimates, and inadequate data can cause imprecise or erroneous results, thus future studies need to have a large sample size and/or apply more sophisticated methods.

Conclusion

In the end, it is concluded that this current study illustrates the applicability of the NQRM in establishing growth charts of Pakistani adults hence providing a broader view of human growth by showing growth variation in terms of different quantiles and account for the sexual dimorphism in growth pattern. The findings of this study have indicated that NQRM is a credible and additional method for growth curve estimation as the value of estimation derived is comparable to that of SPLMS analysis. This is particularly well illustrated when comparing the estimates of both age groups and underscores the reliability of NQRM in capturing the complicated growth dynamics in humans. The results of this study also highlight how crucial it is to take into account local and regional differences in Pakistani people's growth patterns. The growth patterns found in this study show notable variations from those seen in populations from other countries, highlighting the necessity of reference growth curves appropriate to a given location. Healthcare providers who treat patients with weight-related diseases will be greatly impacted by this since it will enable them to provide more precise assessments of their patient's health and modify treatment regimens accordingly. The study's findings also emphasize how crucial it is to build growth charts with a variety of techniques to guarantee accuracy and precision. This will eventually help to shape evidence-based policies in areas like nutrition and healthcare.

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Informed Consent / Patient Consent

The data has been collected with the consent of respondents.

Data availability statement

Data will be available upon request.

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