Comparison of Quantile Regression and Gaussian (Z-scores) Percentiles to BSA in Growth Charts With a Pakistani Population

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Abstract

Introduction: In the current study, we construct growth charts of body surface area (BSA) for adults using the quantile regression (QR) approach and growth charts of different Gaussian Percentiles (*Z*-scores) against age. **Methods:** A cross-sectional data consisting of 3,473 individuals aged 5 or more, both males and females were taken from Multan city. Quantile regression (QR) was used to construct BSA growth charts. Growth charts for different *Z*-scores were also constructed. **Results:** For our data set, the mean BSA is 0.48750. The BSA percentiles show a trending higher after the age of 5 until the age of 22, then decrease between age 22 and 35, and then finally increase after age 35. The *Z*-score curve increases slightly after age 5 and then proceeds higher until age 22. After age 22 and before 35 it plateaus and then increases slightly after age 35. **Conclusion:** Since the use of empirical BSA percentiles and *Z*-scores with grouped age provides a discrete approximation for the population percentiles and *Z*-scores, it is more accurate to use continuous BSA percentile and *Z*-score, curves against given ages while using quantile regression and *Z*-score approach. Furthermore, this approach can also be adopted to construct many other growth charts for physiological and medical sciences.

Keywords
obesity, body surface area, quantile regression percentiles, Gaussian percentiles, growth charts

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Introduction

Background

In medical sciences, BSA is a measure to determine the surface of a human body. This tool is used in many measurements in medicine including the calculation of drug amounts and the number of fluids to be controlled. In anesthesiology and critical care medicine, BSA is estimated daily. The calculation of BSA is also useful in several areas related to the metabolism of the body such as fluid requirements, ventilation, extracorporeal circulation, and drug dosages (Furqan & Haque, 2009; Gibson & Nauma, 2003; Khan & Khan, 2008).

There are many sources of literature available that disclose the everyday use of BSA. For example, chronic kidney disease directly depends on the accurate estimation of the glomerular filtration rate (GFR) that is estimated by the modification of diet for renal disease equation and it is normalized to BSA (Ho & Teo, 2010). Cardiac index and drugs (such as Glucocorticoid) are often dosed according to the patient's BSA (Mirblook & Soltani, 2009). It is common to use BSA for the estimation of total blood volume (TBV), red cell volume (RCV), and plasma volume (PV; Salamat, 2007). Hypertension is considered an independent risk factor that can be detected by electrocardiography. It has been established that left ventricular mass varies directly with the BSA (Alaka, 2013). Similarly, stroke volume and cardiac output are standardized into the stroke index and cardiac index after dividing by the patient's BSA (McGee & Nathanson, 2010). The role of BSA is also very important for the dose determination of chemotherapy drugs (Sacco et al., 2010).

The above-mentioned studies expose the importance of measuring BSA. The critical nature of treatments

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depending upon the BSA measures, strictly demands that the BSA predictions should be as accurate as possible (Livingston & Lee, 2001). Some different formulas to calculate BSA have been developed over the years and they give slightly different results. Among these, Shuter & Aslani formula and RD's formula are very common in use (Burton, 2008; Mosteller, 1987; Shuter & Aslani, 2000). The latter said RD's formula is the most commonly used and straightforward formula that gives the BSA as the square root of the product of the weight in kilogram (kg) times the height in centimeters (cm) divided by 3,600.

Many studies disclose the significant differences between the BSA of males and that of females and indicate the need to compute BSA for males and females, separately (Livingston & Lee, 2001). Recently, two BSA formulas have been developed for males and females, separately (Schlich et al., 2010). The present study uses these formulas to compute BSA for males and females, separately. The percentiles and *z*-scores of BSA for a specified age become of particular interest in light of above mentioned clinical practices.

For the construction of such charts, BSA percentiles are needed. The empirical percentiles of BSA with grouped age provide a discrete approximation for the population percentiles so it is more plausible to employ some regression methods to study the effects of different factors on the BSA (Chen, 2005b). Conventional regression methods will not perfectly point out the changes at extreme points of the distribution. For this, we are provided with quantile regression (Koenker & Bassett, 1978). With the help of quantile regression growth charts can be constructed (Chen, 2005a). Growth charts of BSA can be developed separately for males and females (Aslam & Altaf, 2011).

Obesity is used to describe body weight that is much greater than what is considered healthy. It is considered a worldwide challenge to public health. As it has been related to numerous health risks, both physical and psychological, therefore, its prevalence has led the World Health Organization (WHO) to declare it a "global epidemic" (WHO, 2000). A recent report concluded that more than 1.1 billion people in the world are estimated to be overweight and 320 million are calculated to be obese. More than 2.5 million deaths each year are attributed to obesity, a figure expected to double by 2030 (Alberti et al., 2004; Jawad, 2005).

Percentiles and *Z*-scores in different measures have been widely used to help assess young people's nutritional status and growth. Often, percentiles (such as the 5th, 25th, 50th, 90th, and 95th percentiles) and *Z*-scores (e.g., −3 and +3) are used to classify various health conditions, and sex-age-specific measures cut-points (based on *Z*-scores or percentiles) are provided in tables and as smoothed curves on growth charts (Pettersen et al., 2008; Wang & Chen, 2012).

Wu and Tu (2016) explained that the body mass index, defined as weight/height^2, had been widely used in clinical investigations as a measure of human adiposity. For children undergoing pubertal development, whether that function of height and weight represented an optimal way of quantifying body mass for assessing specific health outcomes had not been carefully studied. They proposed an alternative pediatric body mass measure for the prediction of blood pressure based on recorded height and weight data using single-index modeling techniques. Specifically, they presented a general form of partially linear single-index mixed effect models for the determination of that new metric. A methodological contribution of their work is the development of an efficient algorithm for the fitting of a general class of partially linear single-index models in longitudinal data situations. Their proposed model and related model-fitting algorithm were easily implementable in most computational platforms. Their simulations showed superior performance of the new method, as compared to the standard body mass index measure. Using the proposed method, they explored an alternative body mass measure for the prediction of blood pressure in children. Their method is potentially useful for the construction of other indices for specific investigations.

Objective of Study

The basic purpose of this research work is to compare the result of both estimated quantiles of BSA by quantile regression and BSA quantiles of *z*-scores to analyze the BSA gap for adults in Pakistan. A record of previous works comparing BMI concerning the quantile of *Z*-scores but not utilizing BSA.

Methodology

Study Design and Sampling Technique

The study used a cross-sectional design with 3,473 respondents as a sample from Multan, Pakistan. The simple random sample 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 City. Using a random number generator, a sample of 3,473 respondents was chosen from this list. This procedure made it possible to get a representative sample of the adult population of Multan City. It is ensuring that the results could be applied to a broader population.

Setting and Participants

All the adult individuals, both males and females, of age 5 years or more were included in the study but the pregnant women were excluded. Our participants are all adult individuals of age 5 years and more.

Variables and Data Collection

The data consisted of different variables and they were gender, age in years, weight in kg, and height in meters. The data consisted of different variables such as; gender, age in years, weight in kg, and height in meters, were measured using standardized techniques and equipment from Pakistan. Age, Our study includes age, weight, and height as quantitative variables. Data was collected using standard tools for measuring the weight and height of respondents. A special team was hired for the collection of this precious data. The bias of data is also discussed below lines.

Patient and Public Involvement

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

Reliability of Data

The reliability of data is also checked before the statistical analysis using Cronbach's alpha. The value of Cronbach's alpha is .89 which lies in the normal range (i.e., .70–.90).

Bias

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

Study Size

In our study we use the following formula provided by Yamane (1967), to determine the sample size:

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

where; n = Sample Size
N = Population Size
e = Level of precision
Now,
N = 1,872,000 e = 0.017

$$n = \frac{1872000}{(1 + 1872000\{0.017\}^2)}$$

n = 3,473

Hence 3,473 children and adults are taken from the city Multan, Pakistan.

Statistical Methods

The formula of BSA (Schlich et al., 2010) is as follows:

$$BSA\left(m^2\right) = \begin{cases} 0.000975482 \times WT^{0.46} \times HT^{1.08} \ \textit{for femlaes} \\ 0.000579479 \times WT^{0.38} \times HT^{1.24} \ \textit{for males} \end{cases}$$

And expression for z-score is $Z = \frac{x - \mu}{\sigma}$.

One statistical methodology used in our study is the QR approach. This approach covers both descriptive aspects of location and the shape of the response variable. The concept of QR explains the significance of the QR approach when the distribution of the response variable is non-normal (Koenker & Bassett, 1978). In Statistics, for non-normal distribution, the suitable descriptive statistic for location is median rather than mean. So QR gives the estimates of median response variable distribution with the connection of covariates effects. We also know the dispersion of distribution is well analyzed by different data points like quartiles and percentiles etc. The QR approach portrayed the complete picture of response variable distribution, that is, how the covariates affect the location and shape of the response variable. The advantage of QR is that there are no distributional assumptions required and it is a robust technique in handling extreme values and outliers. They also explain that quantile regression gives a more comprehensive picture of the relationship between response variable and covariates.

Recalling the ordinary quantile, consider a real-valued random variable characterized by the following distribution function

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

then the quantile of the real-valued random variable Y is defined as the inverse function of the above distribution function, that is,

$$Q(\tau) = inf\{y : F(y) \ge \tau\}$$

where the τ lies between 0 and 1, that is, $0 < \tau < 1$. In particular, the median is $Q(1/2)$. The estimated $\tau - th$ sample quantile is $\xi(\tau)$, which is an analog 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. The linear quantile model assumes that the response variable is a linear function of covariates (Koenker & Bassett, 1978). The case that minimizes the sum of absolute residuals, is usually known as median regression (Chen, 2005a; Koenker, 2005).

Another statistical methodology used in our study is the z-score. To calculate the z-scores of a person's BSA, the first step is to find out the corresponding regression coefficients for BSA, which are β_0, β_1, β_2, β_3, β_4,β_5, and β_6, and MSE, and obtain the mean as:

$$Mean(BSA) = \beta_0 + Age\beta_1 + (Age)^2\beta_2 + (Age)^3\beta_3 + (Age)^{1/2}\beta_4 + (Age)^{-1}\beta_5 + (Age)^{1/2}(Age)\beta_6$$

Next take the natural log of the observed BSA and standardized it using the following formula (Pettersen et al., 2008).

$$Z = \frac{ln(BSA) - Mean(BSA)}{\sqrt{MSE}}$$

For the construction of BSA growth charts using QR, we take the natural logarithm of BSA (log BSA) as a dependent variable. It has been established to involve six powers as covariates for the QR (Chen, 2005a). We take τ=.05, .10, .25, .50, .75, .85, .90 and .95 for computation of 5th, 10th, 25th, 50th (median), 75th, 85th, 90th, and 95th BSA percentiles respectively using QR. The BSA growth charts are constructed for BSA percentiles, plotting BSA percentiles against the age of the respondents. We use E.VIEWS 7.0 to run the QR for the BSA percentiles. Similarly, we construct the growth charts for the given *z*-scores, that is, Here we use six powers of the age to combat curvature of growth curves (Chen, 2005a).

Results

Participants

In our data set of 3,473 individuals, 1,965 were men (56.58%) and 1,508 were women (43.42%).

Descriptive Analysis

The mean age of respondents is 23.21±14.45 (SD) years. These figures are 22.03±13.77 and 24.74±15.20 for men and women, respectively. The mean BSA of the respondents is 0.4875±0.1392 (SD)m^2, the mean weight is 55.47±19.28 (SD)kg and the mean height is 60.98±7.82 (SD)inch. A 95% confidence interval (CI) for BSA is computed as (0.4829, 0.4922) while the similar CIs are (0.5041, 0.5179) for males and (0.4293, 0.4403) for females.

Inferential Analysis

To explore the growth pattern of BSA, the 85th percentile is used as a preliminary analysis. Table 1 displays the estimated parameters of the percentile for BSA data, respective t-statistics, and p-values. The respective p-values state all the estimated coefficients to be statistically significant except one. Since the age covariates are found to be statistically significant in predicting the BSA, the same covariates are used to compute different percentiles for growth charts of BSA against age (Chen, 2005a).

Table 1. QR Parameter Estimates With $85th$ Percentile of BSA.

Parameter	Coefficient	*t*-Statistic	Prob.
Intercept	−17.17	−4.18	.00
AGE	−3.05	−2.89	.00
$(AGE)^2$	−0.02	−2.01	.04
$(AGE)^3$	0.00004	1.55	.12
$(AGE)^{-1}$	16.48	5.37	.00
√AGE	11.36	3.54	.00
AGE √AGE	0.40	2.38	.02

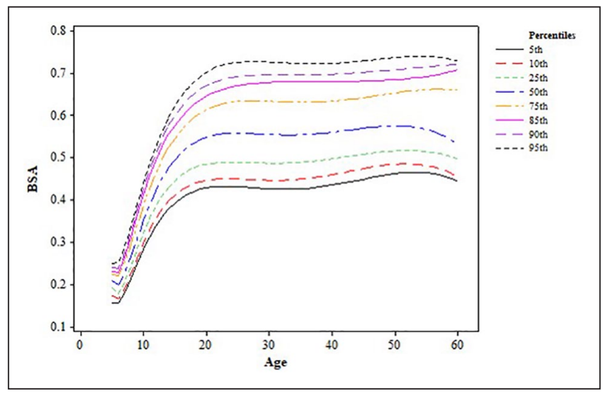

Figure 1. Growth chart of BSA QR percentiles.

Eight percentiles (5th–95th) curves of the BSA are shown in Figure 1 it is clear that the BSA is quickly downward between ages 2 to 5 for all percentiles and then quickly growing between ages 5 to 50 years and after that this behavior moves downward for 5th to 75th percentiles but for 85th to 95th percentiles, BSA quickly growing between the ages 5 to 35 and after that this behavior moves downward until age 55 and quickly moves upward until age 60.

Seven *z*-score curves (−3 to +3) of the BSA are shown in Figure 2. The curved lines printed on Figure 2 are the *z*-scores. The line labeled 0 represents the median (z=0), which is, generally speaking, the average. The other curved lines are *z*-score lines (i.e., z=−3, −2, −1, 1, 2, 3), which indicate distance from the average. The median and *Z*-score lines are derived from the measurement of BSA (Wang & Chen, 2012).

Discussion

Key Results

The present study yields that the mean BSA is 0.4875. Since in Pakistan, it is not common practice to compute

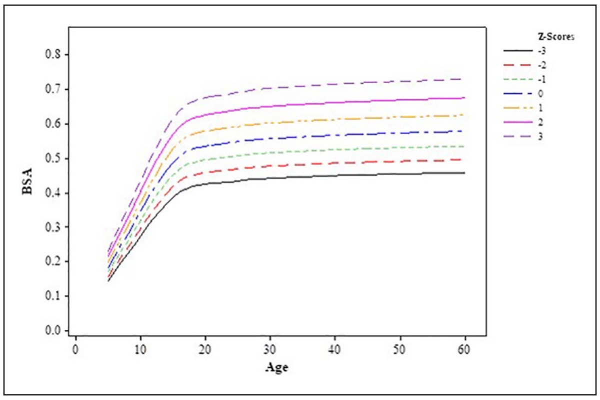

Figure 2. Growth chart of BSA gaussian (*Z*-score) percentiles.

BSA or *Z*-scores with separate equations so our findings are not directly comparable with available studies in Pakistan. However, these figures for BSA are comparatively high as compared to those given in some international studies. These figures are considerably lower than those of our computed ones. The BSA depends on more than just height and weight. Other influential factors include age, gender, marital status, and other socioeconomic status factors of the individual. However, the distribution of BSA is approximately normal and results are consistent with some already available empirical results (Aslam & Altaf, 2011). By comparing the BSA of married and unmarried, we find that married have a significantly higher BSA. Generally, we take values of *z*-score between −3 and +3 based on the level of significance. In our present study, we also take values of *z*-score between −3 and +3.

The results of the 85th percentile illustrate that if we take, for example, a person of age 30 then the percentile of BSA will be 0.6788. In other words, 85% of the population age 30 will have BSA lower than 0.6788 and 15% of them will have about 0.6788. When the growth chart of the BSA *z*-score is observed then we use a curve that is approximately equal to the curve of percentile for QR.

For the comparison of both growth charts, we use the 85^{th} percentile curve from Figure 1 and $z=+1$ curve from Figure 2 (Wang & Chen, 2012). From both figures, it is observed that initially both curves (85th percentile & $z=+1$) show the same pattern and increase rapidly. But after age 20, the curve of percentile increases but in low amount and then tends to smooth pattern until age 50, and then it shows an increasing trend. From the curve of *z*-score ($z=+1$), we observe that there is a rapidly increasing pattern from age 5 to 15 and then moves upward until age 30. In a comparison of these two techniques, we use 85th percentile and $z=+1$ curves because these correspond to each other.

Strength and Limitations

The major advantage of this study is that it compares two different statistical approaches (Quantile Regression & *Z*-Scores) from the perspective of obesity. We also identify some limitations in our study. One potential problem is the lack of control for certain demographics, for instance, smoking and non-smoking status, pregnancy, socio-economic status, ancestry, etc. These issues may be valid topics for future work.

Conclusions

Following some available studies (Koenker, 2005), we use the quantile regression and z-score to construct the growth chart of an individual's BSA. The BSA growth charts provide a guideline for medical practitioners to decide about different dosages and other treatments, where needed. With a similar approach of QR and *z*-score, we can construct growth charts for other age-related variables of medical measurements for the population of Pakistan. Such growth charts may be used as reference growth charts if a suitable size of relevant data is collected for all ages.

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Author Contributions

Waqas Ghulam Hussain Atif Akbar & Farrukh Shehzad provide substantial contributions to the conception and design, or acquisition of data, or analysis and interpretation of data; Waqas Ghulam Hussain make drafting of the article and revised it critically for important intellectual content; and Farrukh Shehzad & Atif give final approval of the version to be published. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest for the research, authorship, and/or publication of this article.

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Ethical Approval

This study was approved by the Department of Statistics, The Islamia University of Bahawalpur, Bahawalpur, Pakistan.

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