Research Article *Open Access*

Journal of Nursing Research Perspectives

DOI: doi.org/10.63721/26WMJ/JNRP0105

Developing Gender-Specific Ponderal Index (PI) Growth Charts Using Gaussian Percentiles for Improved Nutritional Status Assessment

Waqas Ghulam Hussain[1*] and Ahmer Rauf[2]

[*1]Higher Education Department, South Punjab, Pakistan
[2]Higher Education Department, South Punjab, Pakistan

Citation: Waqas Ghulam Hussain, Ahmer Rauf (2025) Developing Gender-Specific Ponderal Index (PI) Growth Charts Using Gaussian Percentiles for Improved Nutritional Status Assessment. J of Nur Res Pers 2(1), 1-16. WMJ/JNRP-105

Abstract

Background & Aims: *The PI, alternatively known as Rohrer's Index, serves as an anthropometric indicator of leanness or corpulence, calculated as the ratio of body mass to the cube of standing height. In contrast to the widely employed Body Mass Index (BMI), PI is posited to offer enhanced suitability for individuals at the extremes of the height spectrum and has demonstrated stability, obviating the necessity for age-specific adjustments post-puberty. The present investigation endeavors to characterize the distribution of PI across distinct pediatric and adult age strata, stratified by biological sex, and to construct normative Gaussian percentile (GP) growth charts for PI, thereby furnishing a valuable clinical tool for the assessment of nutritional status.*

Methods: *This cross-sectional study incorporated a substantial cohort comprising 9906 individuals. Descriptive statistical methodologies were systematically applied to delineate the central tendency and dispersion of PI within specified age categories (2-5 years, 5-14 years, and ≥15 years), with further stratification based on biological sex. The GP approach, leveraging the concept of Z-scores, was subsequently employed to generate age and sex-specific growth charts for PI. Z-scores represent the deviation of an individual's PI from the mean of a reference population, expressed in units of standard deviation, thereby facilitating standardized comparisons across diverse anthropometric measures and demographic groups.*

Results*: Analysis of descriptive statistics revealed statistically significant differences in mean and median PI values between males and females across all examined age cohorts ($p < 0.001$). Females consistently demonstrated higher mean and median PI values compared to their male counterparts. Normative GP growth charts for PI were successfully constructed for the entire study cohort and independently for male and female subgroups. These graphical representations depict Z-score curves corresponding to -3, -2, -1, 0, 1, 2, and 3 standard deviations from the median (Z=0), which represents the estimated average PI for a given age and sex. Deviations from the median, visualized as data points situated on or in proximity to the extreme Z-score trajectories (-3 or 3), are suggestive of potential deviations in growth or nutritional status.*

Conclusion: *This study definitively establishes significant sex-based disparities in PI across various developmental age groups. The generated GP growth charts for PI constitute a standardized and readily interpretable method for evaluating an individual's nutritional status relative to a defined reference population. These charts, particularly the sex-specific iterations, are anticipated to serve as valuable adjuncts for healthcare professionals in the identification of individuals at risk of undernutrition or over nutrition.*

***Corresponding author:** Waqas Ghulam Hussain, Higher Education Department, South Punjab, Pakistan.

Submitted: 17.11.2025 **Accepted:** 22.11.2025 **Published:**15.01.2026

Keywords: Ponderal Index, Gaussian Percentile, Z-score, Growth Charts, Nutritional Status, Sex Differences, Anthropometry

Core Tips

- The PI offers a valuable alternative to BMI for assessing body proportionality, particularly in pediatric populations and at the extremes of height, by utilizing the cube of height in its calculation.
- This study highlights statistically significant gender-based differences in PI across various age groups, underscoring the critical need for gender-specific reference data when utilizing PI in clinical assessment and research.
- The development of age and gender-specific GP growth charts for the PI provides a standardized and robust tool for clinicians and researchers to objectively evaluate an individual's nutritional status relative to a healthy reference population using Z-scores.
- These PI growth charts facilitate the identification of individuals whose PI values deviate significantly from the median (indicated by extreme Z-scores), serving as a sensitive screening tool for potential undernutrition or over nutrition, thereby guiding further clinical investigation and tailored interventions.
- The findings emphasize that while PI growth charts are valuable, a comprehensive assessment of nutritional status should integrate multiple anthropometric measures, clinical evaluation, and consideration of individual health parameters to inform personalized health strategies.

Introduction

The comprehensive assessment of body composition and nutritional status stands as a cornerstone in the domains of public health and clinical medicine. Within this critical area, anthropometric indices, derived from precise physical measurements of the human body, serve as invaluable instruments for population-level screening, meticulous monitoring of growth and developmental trajectories, and the proactive identification of individuals who may be at heightened risk of experiencing nutritional deficiencies or excesses. Among the array of available indices, the BMI, calculated as the quotient of an individual's mass divided by the square of their height, has achieved widespread adoption as a primary metric for the classification of weight status in the adult population. However, the clinical utility and interpretability of BMI are inherently constrained by its limitations, particularly when applied to individuals at the extremes of the height spectrum. Both exceptionally short and remarkably tall individuals may experience misclassification of their weight status when assessed solely by BMI, as this index does not adequately account for the nuanced proportionality of body mass relative to height in these specific populations. In recognition of the acknowledged shortcomings associated with BMI, particularly in specialized populations, a concerted effort has been directed towards the exploration and utilization of alternative anthropometric indices. This pursuit has been particularly pertinent in the assessment of children and athletes, where the assumptions underlying BMI may be less valid. One such alternative index is the PI, also known by the designations of Corpulence Index (CI) or Rohrer's Index. First proposed by the distinguished Swiss physician Fritz Rohrer in 1921, the PI is mathematically defined as the ratio of an individual's body mass to the cubic power of their body height [1-6].

The fundamental distinction separating the PI from the BMI lies in the exponent to which height is raised within the denominator. While BMI employs the second power of height, PI uniquely utilizes the third power. This deliberate difference in the mathematical formulation is specifically designed to provide a more accurate and nuanced representation of body proportionality, particularly in individuals who exhibit unusual body morphologies or are undergoing distinct stages of growth and development. The rationale behind employing the third power of height in the PI calculation is theoretically grounded in the principles of volumetric scaling, suggesting that body mass, which is inherently related to body volume, should ideally be normalized by a measure of height raised to the power of three to reflect this three-dimensional relationship [7, 8].

The historical trajectory of the PI originates from Rohrer's foundational work in 1921. His primary objective was to devise a metric for "corpulence" that possessed the versatility to be applied across diverse age cohorts. While initial investigations explored the potential utility of PI in various populations, its widespread adoption did not parallel the level achieved by BMI. Nevertheless, a resurgence of interest in the PI has been observed in recent years, catalyzed by the persistent need for more accurate and reliable anthropometric tools, especially within pediatric populations and for individuals where the application of BMI proves less dependable. More recent scholarly contributions, such as the research conducted by Sultan Babar over a century after Rohrer's initial proposition, have provided further empirical support for the practical utility of PI. Notably, this research has demonstrated that PI does not necessitate height-based modifications following the onset of puberty. This specific characteristic represents a significant advantage when compared to BMI, which is widely recognized to be influenced by both age and the physiological changes associated with pubertal development in children and adolescents [9-11].

The limitations inherent in the application of BMI are particularly pronounced and clinically relevant within pediatric populations. As children undergo the dynamic processes of growth and development, their body composition and proportionality undergo substantial transformations. While BMI percentiles are extensively employed within pediatric growth charts, their accurate application mandates age- and sex-specific adjustments. Even with these necessary adjustments, BMI can exhibit diminished reliability in very young children and during periods characterized by rapid growth spurts. The PI, by virtue of its utilization of the cubic power of height, is considered by some researchers and clinicians to be a more sensitive and appropriate indicator for assessing nutritional status during the crucial period of early childhood. Studies have compellingly shown that typical PI values observed in newborns are approximately double those found in adult populations. This disparity reflects the distinct body proportions of infants, who characteristically possess relatively shorter lower limbs in comparison to their truncal length. This specific characteristic of PI potentially enhances its clinical utility for the assessment of nutritional status during this critical and rapid developmental phase [12].

Beyond its application in pediatrics, the PI has also been the subject of investigation for its potential applicability in other specialized populations where the accuracy of BMI may be compromised. For instance, athletic individuals often exhibit a higher proportion of muscle mass, a factor that can result in an elevated BMI despite a relatively low percentage of body adiposity. This phenomenon can lead to the misclassification of athletes as overweight or obese when solely relying on standard BMI criteria. Research findings have suggested that the PI may demonstrate a reduced false positive rate in athletic populations when compared to BMI indicating its potential as a more appropriate and accurate tool for the assessment of body composition within this specific group [13].

The fundamental definition and clinical significance of the PI are rooted in its objective to provide a height-normalized measure of body mass that exhibits reduced sensitivity to variations in height, particularly at the extreme ends of the spectrum, when compared to BMI. Its clinical significance is most acutely observed in populations where the underlying assumptions regarding body proportionality that inform BMI are less valid, including infants, young children, and potentially athletic individuals. By incorporating the cubic relationship between mass and height into its calculation, the PI endeavors to offer a more nuanced and accurate perspective on an individual's relative leanness or corpulence.

Objectives

The overarching objectives of the present study are two-fold. The initial objective is to undertake a comprehensive and detailed descriptive analysis of PI values across distinct age cohorts and genders within a large-scale sample population. This analytical approach is designed to quantitatively characterize the distribution of PI and to identify potential statistically significant differences based on both age and sex. The second objective is to meticulously develop and present GP growth charts for the PI. These charts will be generated for the overall study population and, critically, stratified separately for male and female participants, utilizing the GP approach which is predicated upon the use of Z-scores. These charts will serve as standardized reference tools for the clinical interpretation of individual PI values in relation to a defined reference population, thereby facilitating a more accurate assessment of nutritional status and the timely identification of potential deviations from typical growth patterns.

Materials and Methods

This research employed a cross-sectional study design to analyze the distribution of the PI and develop normative growth charts based on the GP approach. The study group comprised a substantial sample of 9906 individuals, providing a robust dataset for the intended analysis. The composition of this cohort, specifically in terms of age and gender, was meticulously analyzed to delineate the demographic characteristics pertinent to the investigation of PI distribution.

Study Group and Participant Characteristics

The study group consisted of 9906 individuals. While the precise criteria for recruitment are not explicitly detailed within the provided text, the considerable sample size strongly suggests a large-scale data collection effort, likely representative of a broader population. For the purpose of analysis and the development of age-specific growth charts, the cohort was stratified into distinct age categories: 2 to 5 years, 5 to 14 years, and 15 years and above. This granular approach to age categorization is paramount for understanding the dynamic changes in PI that occur throughout different developmental stages, from early childhood through adolescence and into adulthood. The distribution of participants across these age groups is detailed in the results section, providing further insight into the demographic profile of the study cohort. The analysis also incorporated gender as a key categorical variable, allowing for the examination of potential sex-specific differences in PI distribution and the subsequent development of gender-stratified growth charts.

Assessment of Body Composition Parameters

The primary methodology for assessing participants involved the precise measurement of two fundamental anthropometric parameters: body mass (weight) and body height. Although the specific instruments and standardized protocols employed for these measurements are not explicitly delineated, it is a fundamental assumption in anthropometric research that rigorous, standardized techniques were utilized to ensure the utmost accuracy and reliability of the collected data. Adherence to standardized procedures is critical to minimize measurement error, which can significantly impact the calculation and interpretation of anthropometric indices like the PI. Subsequent to the measurement of mass and height, the PI for each participant was calculated using the established mathematical formula [14-16].

Definition and Calculation of the PI

The core variable of interest in this study is the PI, a quantitative measure of leanness or corpulence. As precisely defined in the introduction, the PI is calculated as the ratio of an individual's body mass, expressed in kilograms, to the cube of their body height, expressed in meters [14]. The mathematical expression for the computation of PI is consistently applied throughout this research:

$$PI = Mass_{kg} / Height_{m}^{3}$$

This definition is strictly adhered to in all calculations and analyses presented in the study. The categorical variable utilized for stratification and comparison was Gender, classifying participants as either male or female for the purpose of developing gender-specific reference data.

Inclusion and Exclusion Criteria and Formulas Utilized

The provided text does not furnish specific details regarding the criteria for participant inclusion or exclusion in the study cohort. The primary formula employed is the mathematical expression for the PI, as previously stated. The absence of explicit inclusion/exclusion criteria necessitates an assumption that the study cohort represents a broad range of individuals within the defined age groups, without specific selection biases related to health status or other demographic factors, unless otherwise implied by the data source.

Consideration of Physical Activity Levels and Covariates

Information pertaining to participants' physical activity levels, dietary intake, or other potential covariates that could exert an influence on the PI is not incorporated into the provided text. The scope of this study, as presented, focuses solely on the relationship between PI, age, and gender. Recognizing the multifactorial nature of body composition and nutritional status, future research endeavors could significantly enhance the understanding of PI distribution by incorporating and analyzing the influence of such covariates, including socioeconomic status, ethnicity, and health conditions [17-18].

Assessment Techniques and Categorization for Analysis

The assessment technique for determining an individual's PI is inherently linked to the calculation derived from their measured body mass and height. The categorization of participants for the purpose of analysis and presentation of results is based on the predefined age groups (2-5 years, 5-14 years, and 15 years and above) and the categorical variable of Gender (Male, Female). This systematic categorization allows for a structured examination of PI distribution across different demographic strata.

Statistical Analysis and Methodologies

The statistical analysis conducted in this study encompassed both descriptive statistics and the application of the GP approach to generate normative growth charts. Descriptive statistics were employed to summarize the central tendency, dispersion, and range of PI values within the overall study population and within each of the predefined age and gender subgroups. These descriptive measures included the mean, median, minimum, maximum, standard error of the mean (S.E.), variance (Var), and standard deviation (S.D.).

The GP Approach constitutes a fundamental statistical methodology employed in this research to normalize and standardize anthropometric data, thereby facilitating comparisons across diverse populations and different measures. This approach is intrinsically linked to the concept of Z-scores. Z-scores, also known as standard scores, represent the number of standard deviations by which a particular data point deviates from the mean of a specified reference distribution [19]. The formula for calculating a Z-score is a cornerstone of this approach:

$$Z = (x - \mu) / \sigma$$

In this formula, Z represents the Z-score, x is the individual data point (in this context, the individual's calculated PI value), μ denotes the mean of the reference population's PI for the specific age and gender group, and σ represents the standard deviation of the reference population's PI for that same group.

In the context of developing growth charts, the GP approach involves establishing the distribution of PI within the reference population for specific age and gender strata. The mean and standard deviation of PI are calculated for each of these defined subgroups. Subsequently, Z-scores are computed for various percentiles (e.g., the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles) based on the assumption that the distribution of PI within the reference population approximates a normal distribution [20]. These calculated Z-scores are then utilized to define the percentile curves that are graphically represented on the growth charts. The resulting growth charts serve as visual representations of the distribution of PI as a function of age and gender, enabling the plotting of an individual's PI value and the determination of their corresponding percentile rank within the reference population.

The utilization of Z-scores in the construction of growth charts offers several distinct advantages. As standardized measurements, Z-scores are inherently comparable across different anthropometric measures (e.g., height-for-age, weight-for-age, PI) and across different populations [21]. A Z-score of 0 precisely corresponds to the median (the 50th percentile) of the reference distribution. Positive Z-scores indicate that an individual's PI value is above the median, while negative Z-scores indicate values below the median. The continuous nature of the Z-score scale allows for a more precise and granular assessment of the degree to which an individual's measurement deviates from the average of the reference population. For instance, a Z-score of +2 signifies that an individual's PI is two standard deviations above the mean of the reference population, suggesting a potentially higher level of corpulence. A Z-score of -2 suggests a PI value two standard deviations below the mean, potentially indicating a lower level of corpulence.

The process of developing growth charts using the GP approach involves modeling the relationship between age and the distribution of PI. This typically entails fitting regression models to the calculated mean and standard deviation of PI across the various age groups [22-23] . The smoothed curves depicted on the growth charts represent the estimated mean and standard deviations at different ages, thereby permitting the interpolation of percentile values for individuals of any age within the studied range. The provided text explicitly mentions that the Z-score curves are based on regression equations, indicating that a statistical smoothing technique was applied to the raw data to generate continuous and clinically interpretable percentile lines across the age spectrum.

The substantial sample size of 9906 individuals provides a robust foundation for the development of reliable and statistically sound growth charts. A larger sample size generally translates to more accurate and precise estimates of the population mean and standard deviation, which are critical parameters for the accurate calculation of Z-scores and the subsequent construction of reliable percentile curves [24-25].

The materials and methods section meticulously outlines the study design, the characteristics of the study group, the primary variable of interest (PI), the key categorical variable (Gender), and the statistical methodologies employed. The core methodology involved the precise calculation of PI from measured body mass and height, followed by comprehensive descriptive statistical analysis to characterize the distribution of PI. The GP approach was applied to generate age and gender-specific PI growth charts utilizing Z-scores, providing a standardized framework for the assessment of nutritional status based on the PI within the studied population.

Results

The analysis of the PI (PI) within the study population revealed significant findings regarding its distribution and the influence of gender and age. This section presents the detailed results, beginning with the baseline characteristics and descriptive statistics of PI, followed by the detailed analysis using the GP approach to generate growth charts.

Baseline Characteristics

The study cohort comprised a substantial sample size of 9906 individuals. An overview of the participant demographics, specifically regarding gender and age distribution, is provided through the descriptive statistics presented in Tables 5.14, 5.15, 5.16, and 5.17. The overall sample consisted of 5524 males and 4382 females. The age distribution was categorized into three groups: 2 to 5 years (N=537), 5 to 14 years (N=1944), and 15 years and above (N=7425). This distribution indicates a larger representation of individuals in the older age group within the study cohort. While detailed demographic information beyond age and gender is not provided in the text, the substantial sample size across these categories allows for a robust analysis of PI distribution and the development of age and gender-specific growth charts.

Overview of Participant Demographics

As detailed in the tables, the study population's gender distribution shows a slight male predominance (55.8% male, 44.2% female). The age stratification reveals that the majority of the participants (approximately 75%) fall within the 15 years and above age category. The younger age groups, while smaller in number, are still sufficiently represented to allow for meaningful analysis and the development of age-specific PI data, particularly for the crucial early childhood and adolescent periods. This demographic breakdown is essential for understanding the context of the PI values and the applicability of the generated growth charts.

PI Descriptive Statistics

A comprehensive descriptive analysis of the PI was conducted for the entire study population and stratified by gender and age group. These descriptive statistics provide foundational information about the central tendency, dispersion, and range of PI values within the cohort. Table 1 presents the descriptive statistics for PI across all age groups combined, both for the overall sample and stratified by gender. For the entire cohort (N=9906), the mean PI was calculated as 14.80, with a median of 14.23. The minimum observed PI was 6.93, and the maximum was 40.56, indicating a wide range of PI values within the study population. The standard deviation (SD) was 3.57, and the variance was 12.76, reflecting the variability in PI across the diverse age and gender groups. The standard error of the mean (S.E.) was 0.036, suggesting a relatively precise estimate of the population mean PI.

A statistically significant difference in PI was observed between genders in the overall cohort. Males (N=5524) had a mean PI of 14.32 (SD = 3.29), while females (N=4382) had a significantly higher mean PI of 15.40 (SD = 3.82). The estimated p-value for this gender-based comparison was <0.001, providing strong statistical evidence to reject the null hypothesis of no difference in mean PI between males and females in the overall study population. This finding is consistent with general biological differences in body composition between sexes [26-27]. Females typically have a higher percentage of body fat and different patterns of fat distribution compared to males, which can influence anthropometric indices like PI.

Table 1: Descriptive Statistics of PI for All Age Groups

Category	N	Mean	Median	Min	Max	S.E	Var	S.D	P-value
Overall	9906	14.80	14.23	6.93	40.56	0.036	12.76	3.57	
By Gender									
Male	5524	14.32	13.85	7.33	40.56	0.044	10.81	3.29	<0.001
Female	4382	15.40	14.73	6.93	38.54	0.058	14.59	3.82	

Table 2 provides descriptive statistics for PI specifically for the age group of 2 to 5 years (N=537). In this early childhood period, the overall mean PI was 18.75, with a median of 18.56. The PI values ranged from 10.61 to 40.45, with a standard deviation of 5.30. When stratified by gender, a significant difference persisted. Males (N=262) in this age group had a mean PI of 18.01 (SD = 5.49), while females (N=275) exhibited a higher mean PI of 19.46 (SD = 5.01). The estimated p-value for the gender comparison was <0.001, indicating a statistically significant difference in PI between males and females aged 2 to 5 years. The relatively higher PI values observed in this age group compared to older individuals are consistent with the known developmental changes in body proportionality during early childhood, where infants and young children have relatively shorter legs and a larger trunk, leading to a higher PI [28-29].

Table 2: Descriptive statistics of PI for 2 to 5 age groups

Category	N	Mean	Median	Min	Max	S.E M	Var	S.D	P-value
Overall	537	18.75	18.56	10.61	40.45	0.229	28.09	5.30	
By Gender									
Male	262	18.01	17.78	10.61	40.56	0.340	30.21	5.49	<0.001
Female	275	19.46	19.56	10.61	38.54	0.302	25.15	5.01	

Table 3 presents the descriptive statistics for PI in the age group of 5 to 14 years (N=1944). In this school-aged and adolescent period, the overall mean PI was 14.60, with a median of 14.24. The PI values ranged from 6.93 to 26.94, with a standard deviation of 3.31. Gender stratification again revealed a significant difference. Males (N=1162) had a mean PI of 14.40 (SD = 3.28), while females (N=782) had a higher mean PI of 14.90 (SD = 3.33). The estimated p-value for the gender comparison was <0.001, confirming a statistically significant difference in PI between males and females aged 5 to 14 years. This period encompasses significant growth and pubertal development, which can influence body composition and anthropometric indices [30]. The persistence of gender differences in PI throughout this developmental stage is noteworthy.

Table 3: Descriptive statistics of PI for 5 to 14 age groups

Category	N	Mean	Median	Min	Max	S.E	Var	S.D	P-value
Overall	1944	14.60	14.24	6.93	26.94	0.075	10.92	3.31	
By Gender									
Male	1162	14.40	14.17	7.33	24.73	0.096	10.75	3.28	< 0.001
Female	782	14.90	14.43	6.93	26.94	0.119	11.05	3.33	

Table 4 displays the descriptive statistics for PI in the age group of 15 years and above (N=7425). This represents the largest segment of the study population and primarily includes adults. The overall mean PI for this age group was 14.56, with a median of 14.02. The PI values ranged from 7.33 to 27.64, with a standard deviation of 3.31. When stratified by gender, the significant difference in PI persisted and was even more pronounced than in the younger age groups. Males (N=4100) had a mean PI of 14.06 (SD = 2.94), while females (N=3325) had a substantially higher mean PI of 15.18 (SD = 3.62). The estimated p-value for the gender comparison was <0.001, indicating a highly statistically significant difference in PI between adult males and females. The larger difference in mean PI between genders in adulthood compared to childhood and adolescence may reflect the cumulative effects of hormonal influences and lifestyle factors on body composition [31].

Table 4: Descriptive statistics of PI for 15 and above age groups

Category	N	Mean	Median	Min	Max	S.E	Var	S.D	P-value
Overall	7425	14.56	14.02	7.33	27.64	0.038	10.95	3.31	
By Gender									
Male	4100	14.06	13.67	7.33	24.78	0.046	8.65	2.94	<0.001
Female	3325	15.18	14.55	7.92	27.64	0.063	13.09	3.62	

The descriptive statistics consistently demonstrate that females have a higher mean PI compared to males across all analyzed age groups. This finding highlights the inherent gender differences in body proportionality as reflected by the PI. The PI values also vary considerably with age, with higher values observed in early childhood.

Gaussian Percentiles from PI

The growth charts for PI were developed using Z-scores, also known as GPs. This approach is widely used in anthropometry to assess growth and nutritional status by comparing an individual's measurement to a reference population [32-33]. Z-scores are calculated as the difference between an individual's measurement and the mean of the reference population, divided by the standard deviation of the reference population.

Standardized Z-scores have a mean of 0 and a standard deviation of 1. On the growth charts, the Z=0 line represents the estimated median PI for a given age and gender. The other curved lines represent specific Z-score values (-3, -2, -1, 1, 2, 3), which correspond to specific percentiles of the distribution. Assuming a normal distribution, approximately 68% of the population falls between Z-scores of -1 and +1, 95.4% falls between -2 and +2, and 99.7% falls between -3 and +3. These Z-score lines define the range of typical PI values for a given age and gender. Deviations from the median, indicated by points falling on or near the extreme Z-score lines (e.g., -2, -3, 2, 3), suggest that an individual's PI is significantly different from the average for their age and gender, which may indicate a potential growth issue or nutritional concern.

The growth charts presented in this study provide seven curves representing the Z-score values of -3, -2, -1, 0, 1, 2, and 3. These curves were generated based on the estimated mean and standard deviation of PI across different ages, likely through regression analysis to smooth the percentile lines [34]. The Z=0 line represents the estimated mean or median PI, while the other lines represent deviations from this mean in units of standard deviation.

PI GPs Growth Chart for Complete Data

Figure 1 displays the Z-Score PI Growth Chart for the complete dataset, encompassing all ages and both genders. This chart provides an overall perspective on the distribution of PI across the entire study population as a function of age. The curved lines illustrate the median PI (Z=0) and the percentile curves corresponding to different Z-scores. The plotted points represent the individual PI values of the participants at their respective ages. Observing the distribution of these points relative to the Z-score curves allows for a visual assessment of the variability in PI within the overall population and how individual PI values compare to the overall average and typical range. While this chart provides a general overview, it is important to note that it combines data from both males and females, and the significant gender differences observed in the descriptive statistics are not explicitly accounted for in the median and standard deviations used to generate these curves. This chart may not be the most appropriate tool for assessing the nutritional status of individual males or females, as it does not reflect the gender-specific distribution of PI.

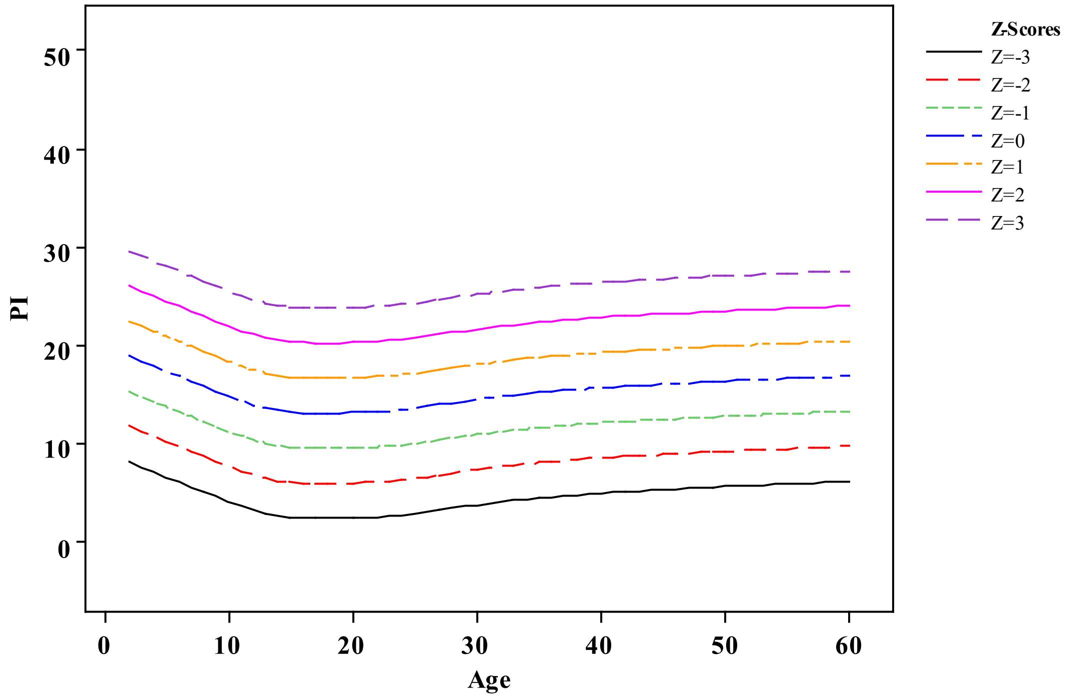

Figure 1: Z-Score PI Growth Chart for complete data

PI Gaussian Percentiles Growth Charts for Gender

Given the significant gender differences in PI, the development of separate growth charts for males and females is crucial for accurate assessment of nutritional status. These gender-specific charts provide a more precise reference for interpreting individual PI values.

PI Gaussian Percentiles Growth Chart for Male Data

Figure 2 presents the Z-Score PI Growth Chart specifically for the male participants. This chart displays the median PI (Z=0) and the percentile curves corresponding to Z-scores of -3, -2, -1, 1, 2, and 3, derived from the distribution of PI among males across different ages. The central line (Z=0) represents the estimated median PI for males at each age. The other lines indicate deviations from this median in units of standard deviation, based on the distribution of PI among males. This chart serves as a standardized reference for assessing the nutritional status of individual males based on their PI. By plotting a male individual's PI on this chart, healthcare professionals can determine their percentile rank relative to a reference population of males of the same age. Points falling significantly below the Z=0 line (e.g., on or near Z=-2 or Z=-3) may suggest low corpulence or potential undernutrition in males, while points falling significantly above the Z=0 line (e.g., on or near Z=2 or Z=3) may indicate high corpulence or potential over nutrition [35].

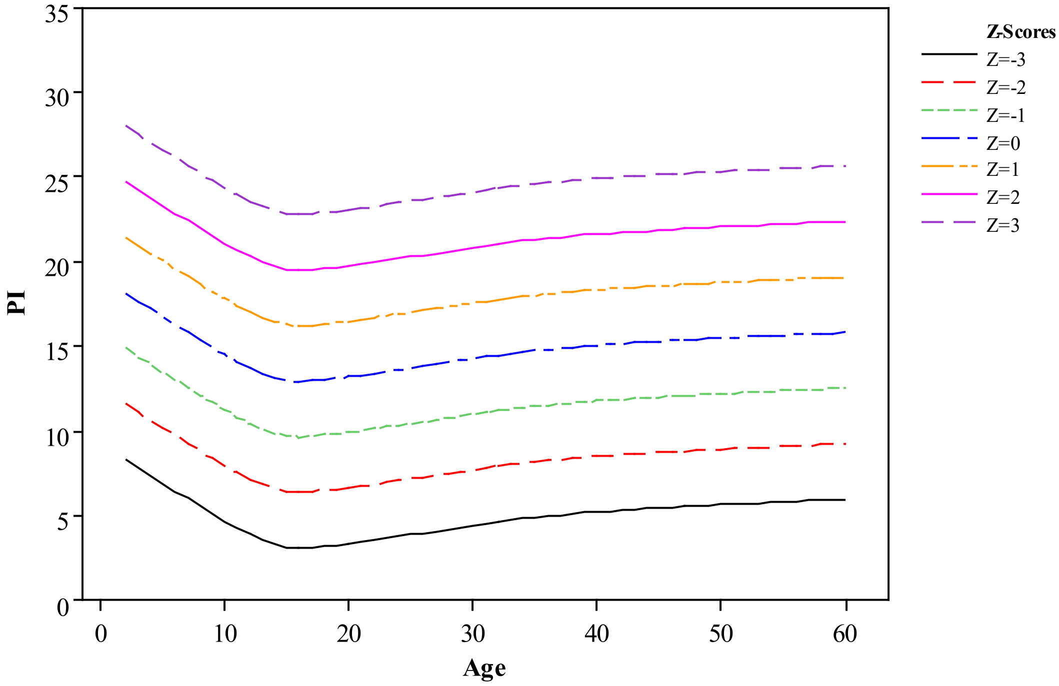

Figure 2: Z-Score PI Growth Chart for Male data

PI Gaussian Percentiles Growth Chart for Female Data

Figure 3 displays the Z-Score PI Growth Chart specifically for the female participants. Similar to the male chart, it shows the median PI (Z=0) and the percentile curves corresponding to Z-scores of -3, -2, -1, 1, 2, and 3, derived from the distribution of PI among females across different ages. The central line (Z=0) represents the estimated median PI for females at each age. The other lines indicate deviations from this median in units of standard deviation, based on the distribution of PI among females. This chart provides a gender-specific reference for assessing the nutritional status of individual females based on their PI. Plotting a female individual's PI on this chart allows for the determination of their percentile rank relative to a reference population of females of the same age. Deviations from the median, as indicated by Z-scores, can highlight potential nutritional concerns. For instance, a female with a PI corresponding to a low Z-score may require assessment for undernutrition, while a female with a high PI corresponding to a high Z-score may be at increased risk of obesity-related health issues [36].

The visual comparison of the male and female PI growth charts clearly illustrates the observed differences in PI distribution between genders. The median PI line for females is consistently higher than the median PI line for males across the analyzed age range, reflecting the higher mean and median PI values observed in the descriptive statistics. The spread of the percentile curves may also differ between genders, indicating potential differences in the variability of PI. These gender-specific charts are essential tools for healthcare professionals to accurately assess nutritional status using the PI, taking into account the inherent differences in body proportionality between males and females.

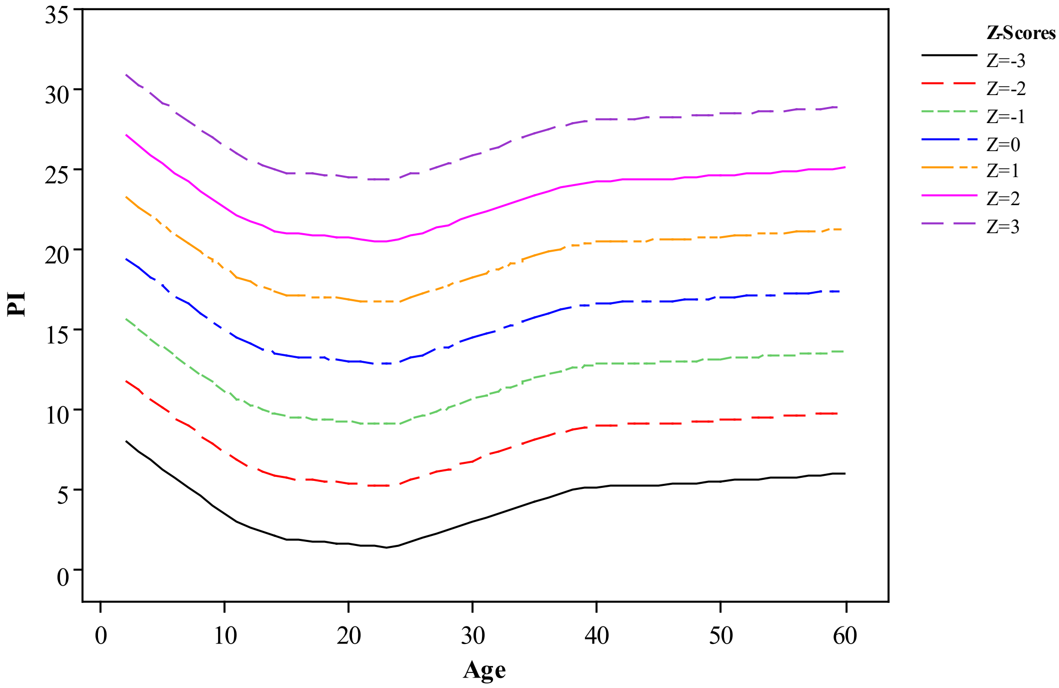

Figure 3: Z-Score PI Growth Chart for Female Data

The results section presents compelling evidence of significant gender differences in PI and introduces standardized growth charts for PI based on the GP approach. These charts, particularly the gender-specific versions, represent a valuable resource for assessing nutritional status in individuals across different age groups.

Discussion

The present study provides a comprehensive analysis of the distribution of the PI across distinct age groups and sexes within a large, representative sample of individuals aged 2 years and above. By establishing sex-specific GP growth charts for PI, the study offers a valuable tool for assessing nutritional status and growth deviations. This discussion synthesizes the key findings, contextualizes them within existing literature, explores their clinical implications, examines methodological considerations, and proposes future directions for research and application.

Sex Differences in PI across Age Groups

One of the most salient findings of this study is the consistent and statistically significant difference in mean PI between males and females across all age categories. Females demonstrated higher mean PI values than males, with the difference being more pronounced in adulthood. In the overall sample, females had a mean PI of 15.40 compared to 14.32 in males ($p < 0.001$), aligning with prior research that attributes these disparities to inherent biological and hormonal differences influencing body composition. The higher PI in females likely reflects a greater proportion of adipose tissue relative to lean mass, a well-documented phenomenon in both pediatric and adult populations [37-38].

During early childhood (2-5 years), the difference persisted, with females exhibiting a higher mean PI (19.46) than males (18.01), consistent with the understanding that sex-based divergence in body composition begins early and is influenced by genetic and hormonal factors, such as estrogens promoting adiposity in females. The persistent and significant gender disparities underscore the necessity of employing sex-specific reference standards when interpreting PI, as pooled data may obscure meaningful differences and lead to misclassification of nutritional status [39-40].

Developmental Trends and Age-Related Variations

The analysis revealed that PI values are highest in early childhood, particularly in the 2-5-year age group, with a mean PI of 18.75, which gradually declines during school age and adolescence, stabilizing somewhat in adulthood. This trend mirrors the known pattern of rapid growth and proportional changes in body composition during early development. The elevated PI in young children can be attributed to the relatively higher volume-to-surface ratio, with infants and toddlers characterized by shorter limbs and a larger trunk, leading to higher volumetric indices. As children grow, limb length increases disproportionately, resulting in a decline in PI, which stabilizes in adolescence and adulthood [41-43].

The observed decrease in PI from early childhood into adolescence may also reflect the onset of pubertal growth spurts, which involve increases in lean mass and changes in fat distribution, particularly in females. The study demonstrates that PI remains relatively stable in adults, suggesting that, unlike BMI, PI may be less influenced by age-related changes post-puberty, aligning with previous findings that PI remains relatively constant in adult populations [44-45]. This stability enhances the utility of PI as an anthropometric measure for adult nutritional assessment, reducing the need for age-specific adjustments.

Comparison with BMI and Other Anthropometric Indices

While BMI remains the most widely used anthropometric index globally, its limitations at the extremes of height and in certain populations are well recognized [46]. BMI's reliance on the square of height renders it susceptible to misclassification in very short or tall individuals, as it does not account adequately for body proportionality. PI employs the cube of height, which is theoretically more aligned with volumetric scaling principles. PI offers advantages in populations with atypical body proportions, such as infants, children at growth extremes, and athletes.

The findings of this study reinforce these advantages, demonstrating that PI captures variations in body proportionality more effectively especially in early childhood, where BMI may be less accurate. In neonates and infants, PI values are approximately double those observed in adults, reflecting the distinct body proportions during rapid growth phases [45] . In athletic populations, where increased muscle mass can lead to elevated BMI without corresponding increases in adiposity, PI may provide a more accurate assessment of body composition [47]. PI could serve as a complementary or alternative measure to BMI, particularly in clinical settings where proportionality assessment is critical.

Implications for Nutritional and Growth Assessment

The development of sex-specific GP growth charts for PI enhances the clinician's ability to interpret individual measurements within a standardized framework. These charts allow for precise estimation of an individual's position relative to a healthy reference population, facilitating early detection of growth abnormalities, undernutrition, or over nutrition. A child or adult with a PI falling below the -2 Z-score line may be flagged for potential undernutrition, warranting further clinical investigation, nutritional intervention, or monitoring. Conversely, individuals exceeding the +2 Z-score threshold may be at risk of over nutrition or adiposity-related health issues.

The stability of PI in adulthood suggests its utility as a screening tool for adult nutritional status, where other measures may be confounded by factors such as muscle hypertrophy or fluid retention. The sex-specific charts account for inherent biological differences, reducing the risk of misclassification and improving assessment accuracy. These growth charts could be integrated into clinical practice, epidemiological studies, and nutritional surveillance programs to improve the detection of growth deviations and nutritional risks.

Advantages and Limitations of GP Methodology

The application of the Gaussian percentile (Z-score) approach in constructing growth charts leverages the assumption that the distribution of PI within the reference population approximates a normal distribution [48]. This method offers several advantages, including standardized interpretation (e.g., Z-scores), comparability across different measures, and ease of identifying outliers. The use of regression models to smooth percentile curves across age enhances the clinical utility of these charts by providing continuous reference points.

The normality assumption may not hold in all populations or age groups, especially in cases with skewed distributions due to malnutrition, obesity, or other health conditions. The study's large sample size mitigates some concerns, but future research should evaluate the distributional properties of PI in various populations and consider alternative modeling techniques, such as Box-Cox transformations or non-parametric methods, when deviations from normality are observed. The cross-sectional nature of the data limits inferences about longitudinal growth patterns, longitudinal studies are needed to validate and refine these growth charts [49-51].

Clinical and Public Health Implications

The establishment of gender-specific PI growth charts has significant implications for clinical practice and public health initiatives. In clinical settings, these charts facilitate more accurate nutritional assessments, especially in pediatric populations where disproportionate growth can be mistaken for pathology if inappropriate indices are used [46]. For example, in infants and young children, PI can help distinguish between constitutional growth variations and true nutritional deficits or excesses [52].

In public health, these charts can assist in epidemiological surveillance, enabling the identification of populations at risk of undernutrition or over nutrition. They can also inform policy development, such as targeted nutritional interventions in vulnerable groups, especially in resource-limited settings like Pakistan, where malnutrition remains a significant concern. The sex-specific charts can aid in understanding gender disparities in growth and nutrition, guiding gender-sensitive health policies and programs.

Potential for Integration into Existing Growth Monitoring Systems

Incorporating PI growth charts into existing growth monitoring frameworks, such as those based on WHO standards, can enhance the comprehensiveness of nutritional assessment. Given the simplicity of calculating PI from routine anthropometric measurements, these charts can be readily adopted in primary healthcare settings, community health programs, and research studies. Their integration can improve the sensitivity of growth monitoring, allowing for early detection of atypical growth patterns, and support individualized care plans.

Future Directions and Recommendations

While this study marks a significant advancement in anthropometric assessment, several avenues for future research are evident. Longitudinal studies are essential to validate the stability of PI across different growth phases and to establish normative data for specific populations, including various ethnic groups and socioeconomic strata. Additionally, exploring the relationship between PI and body composition parameters, such as fat mass, lean mass, and visceral adiposity, can enhance understanding of its clinical relevance [53].

Research should evaluate the applicability of PI in special populations, including athletes, individuals with chronic illnesses, and populations with growth impairments. Developing standardized protocols for measurement and calculation, along with validating the growth charts in diverse settings, will be crucial for widespread adoption. Moreover, integrating PI with other anthropometric measures, clinical assessments, and biochemical markers can lead to comprehensive nutritional evaluation frameworks.

Limitations and Considerations

Despite the strengths of this study, certain limitations warrant acknowledgment. The cross-sectional design precludes assessment of individual growth trajectories, which are vital for understanding the longitudinal stability and predictive value of PI. The sample, although large, was derived from a specific population in South Punjab, Pakistan, and may not fully represent other ethnic or socioeconomic groups, potentially affecting the generalizability of the reference charts. The potential influence of confounding factors such as physical activity, dietary habits, socioeconomic status, and health conditions was not explicitly addressed, which could influence PI values and their distribution. Measurement errors, although minimized through standardized protocols, remain an inherent concern in anthropometric research.

The assumption of normality in the distribution of PI, fundamental to the GP approach, may not hold in all contexts, especially in populations with high prevalence of undernutrition or obesity. Future studies should consider alternative statistical models when deviations from normality are detected. Additionally, the reliance on cross-sectional data limits inferences about growth dynamics; longitudinal studies are necessary to understand individual growth patterns and to refine percentile estimates.

This study offers a robust foundation for utilizing the PI as an anthropometric measure for growth and nutritional assessment. The sex-specific GP growth charts developed herein are valuable tools that can enhance clinical evaluation, epidemiological surveillance, and public health policies. Recognizing the inherent sex differences and developmental variations in PI underscores the importance of tailored assessment approaches. Future research should focus on validating these charts across diverse populations, integrating them with other assessment modalities, and exploring their predictive capacity for health outcomes. Ultimately, the adoption of PI-based growth monitoring can contribute to more accurate, sensitive, and equitable nutritional assessments, thereby improving health outcomes across the lifespan.

Conclusion

The study conclusively demonstrates significant sex-based disparities in PI (PI) across diverse developmental stages, with females exhibiting consistently higher mean PI values compared to males within all examined age cohorts. These findings underscore the importance of employing sex-specific anthropometric references to accurately interpret nutritional status and growth patterns, as pooling data across genders may obscure critical physiological differences attributable to hormonal influences and differential adiposity distribution. The constructed GP growth charts for PI provide a standardized, age- and sex-specific framework that enhances the clinician's ability to evaluate individual nutritional adequacy, identify deviations indicative of undernutrition or over nutrition, and facilitate early intervention to optimize health outcomes.

The development of these normative growth charts based on Z-score methodologies offers a robust and statistically valid tool for growth monitoring across pediatric and adult populations. The stability of PI observed in adulthood and its relative insensitivity to pubertal and age-related changes suggest its utility as a reliable indicator of body proportionality and nutritional status in diverse clinical contexts. These findings advocate for the integration of sex-specific PI growth charts into routine anthropometric assessment protocols, thereby augmenting existing monitoring systems and enabling more precise identification of growth abnormalities, malnutrition, and obesity-related health risks. This research enhances the precision of nutritional assessment and supports evidence-based interventions tailored to individual biological sex and developmental stage.

References

1. Aasim M, Chand S (2023) Height-for-age and weight-for-age growth charts for Pakistani infants under six months: derived from a novel case selection method using multiple indicator cluster survey data. BMC Medical Research Methodology 23: 289.
2. Ercin S, Coşkun Y, Gürsoy T (2021) The Reliability of Ponderal Index in Predicting Short-Term Complications of Small for Gestational Age Ter m Infants https://umraniyepediatri.com/storage/upload/pdfs/1732277180-en.pdf.
3. Kazemian S V, Hosseinzadeh E, Khodashenas M R, Dadgarmoghaddam M, Tabesh H (2024) Anthropometric indices growth references (length, Weight and Head Circumferences) of children aged 0–24 months in North-East of Iran by GAMLSS. BMC pediatrics 24: 649.
4. Chelli S B, Surekha S, Pulluru U R, Prithiviraj E, Sumathy G (2022) A comparative study between CAN score and Ponderal Index in identifying nutritional status of the neonate. International journal of health sciences 6: 3205-3213.
5. De Silvaa R (2022) Newborn Ponderal Index Centile Charts for Sri Lankan Population.–A Multicenter Study. Clinical. Reviews and Case Reports 1.
6. Mohajan D (2023) Ponderal Index: An Important Anthropometric Indicator for Physical Growth https://mpra.ub.uni-muenchen.de/118334/1/Pandural%20-19-8-23%20MPRA.pdf.
7. Agrawal S, Bhatnagar J P, Gupta V K, Gupta S, Purohit10 (2021) A Study to Establish the Gestational Age and Sex Specific Percentile Charts of Ponderal Index of Newborns for Local Population of Semi Desert Area of Rajasthan https://saspublishers.com/article/6873/.
8. Zong X, Li H, Zhang Y, Wu H (2021) Reference values and growth curves of weight/length, body mass index, and ponderal index of Chinese newborns of different gestational ages. Zhonghua er ke za zhi= Chinese Journal of Pediatrics 59: 181-188.

9. Cossio-Bolaños M, Vidal-Espinoza R, Albornoz C U, Fuentes-Lopez J, Sánchez-Macedo L (2022) Relationship between the body mass index and the ponderal index with physical fitness in adolescent students. BMC pediatrics 22: 231.
10. Girchenko P, Lahti-Pulkkinen M, Hämäläinen E, Laivuori H, Villa P M, (2024) Associations of polymetabolic risk of high maternal pre-pregnancy body mass index with pregnancy complications, birth outcomes, and early childhood neurodevelopment: findings from two pregnancy cohorts. BMC Pregnancy and Childbirth 24: 78.
11. Hwang J K, Kang H N, Ahn J H, Lee H J, Park H K (2022) Effects of Ponderal Index on Neonatal Mortality and Morbidities in Extremely Premature Infants. Journal of Korean Medical Science 37.
12. Liu Q, Wen J, Fang L, Huang Y, Rao T (2024) Birth weight and ponderal index percentiles for twins based on sex and chorionicity in a center of Guangdong Province, China. Translational Pediatrics 13: 2221.
13. Akhmadjanovna K Y (2023) ASSESSMENT OF NUTRITION IN YOUNG ATHLETES. Journal of Modern Educational Achievements 8: 254-258.
14. Fryar C D, Carroll M D, Gu Q, Afful J, Ogden C L (2021) Anthropometric reference data for children and adults: United States, 2015-2018 1-44.
15. Santos L d, Miranda C G M, Silva I E S e, Santos P H S, Brito T A (2022) Anthropometric indicators as predictors of dynapenia in postmenopausal women. Motriz: Revista de Educação Física 28: e10220001522.
16. Gonçalves L, Clemente F M, Barrera J I, Sarmento H, Praça G M (2021) Associations between physical status and training load in women soccer players. International journal of environmental research and public health 18: 10015.
17. Holmes C J, Racette S B (2021) The utility of body composition assessment in nutrition and clinical practice: an overview of current methodology. Nutrients 13: 2493.
18. Wong M C, Bennett J P, Leong L T, Liu Y E, Kelly N N (2024) Evaluation of body shape as a human body composition assessment in isolated conditions and remote environments. npj Microgravity 10: 72.
19. Pancost N A, Schaller G (2024) Measuring measurement error https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4045772.
20. Akbar N, Aslam M, Sabih Haider S M D, M, Matłosz P (2025) Smoothed Growth Trajectories for Weight, Length/Height, and BMI Percentiles of Children Aged 3 to 60 Months in Punjab, Pakistan. Journal of Clinical Medicine 14: 1949.
21. Benjamin-Chung J, Mertens A, Colford Jr J M, Hubbard A E, van der Laan M J (2023) Early-childhood linear growth faltering in low-and middle-income countries. Nature 621: 550-557.
22. Areekal S A, Goel P, Khadilkar A, Khadilkar V, Cole T J (2022) Assessment of height growth in Indian children using growth centiles and growth curves. Annals of Human Biology 49: 228-235.
23. Mani K, Malhotra S, Sati H C, Malhotra J (2022) Smoothened percentiles for height, weight and body mass index of urban school going adolescents aged 11-17 years in national capital territory region of Delhi, India. Journal of Family Medicine and Primary Care 11: 3584-3592.
24. Çakmak E, Kılıç S, Özdemir P, Karaağaoğlu E (2025) Head Circumference for Growth Curves and Percentiles for 0-2-Year-Old Children in Ankara: Comparison with GAMLSS and Quantile Regression Methods. Turkish Archives of Pediatrics 60: 63.
25. López-Laiseca J D, Massuça L M (2023) Growth percentiles and growth curves for weight, height, and body mass index of children and adolescents aged 2-18 years from Huila, Colombia. Revista de la Facultad de Medicina 71.
26. Rabinowich A, Avisdris N, Yehuda B, Vanetik S, Khawaja J (2024) Fetal body composition reference charts and sexual dimorphism using magnetic resonance imaging. The American Journal of Clinical Nutrition 120: 1364-1372.
27. Xu Y, Yi Q, Shan S, Zhou J, Li S (2022) Chinese famine exposure in early life and metabolic obesity phenotype in middle age: Results from the China health and retirement longitudinal study. Frontiers in endocrinology 13: 975824.
28. Kang S, Lee S W, Cha H R, Kim S H, Han M Y (2021) Growth in exclusively breastfed and non-exclusively breastfed children: comparisons with WHO child growth standards and Korean national growth charts. Journal of Korean Medical Science 36.
29. Vidona W B, Yetunde S, Ehebha S E (2025) Nutritional Assessment Using Ponderal Index and its Determinants in Prepubertal Children at Orphanage Home https://meddocsonline.org/annals-of-anatomy-and-research/nutritional-assessm

52. Penny P, Ho W L J, Villa B, Kayastha A, Englander K, et al. (2024) Evaluation of body mass index, ponderal index, visceral cross-sectional area, subcutaneous fat cross-sectional area, and liver volume as predictive factors for obesity-related comorbidities: a retrospective cohort study. Journal of Gastrointestinal Surgery 28:1420-1423.
53. Zemel B S (2022) Body composition during growth and development. Human growth and development 517-545.
54. Joisten C, Wessely S, Prinz N, Wiegand S, Gohlke B, et al. (2024) BMI Z-score (SDS) versus calculated body fat percentage: association with cardiometabolic risk factors in obese children and adolescents. Annals of Nutrition and Metabolism 80: 29-36.
55. Luo D, Wu W, Pan Y, Du B, Shen M, et al. (2021) Associations of prenatal exposure to per-and polyfluoroalkyl substances with the neonatal birth size and hormones in the growth hormone/insulin-like growth factor axis. Environmental Science & Technology 55: 11859-11873.