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# Age-specific comparison of some morphological parameters of the proximal phalanges of the hand in male children and adolescents from Tajikistan and Western India

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## ABSTRACT

**The aim** of the study was (a) to establish ethnicity-specific differences in such morphological parameters of the proximal phalanges (PP) as the bone length and the width of diaphysis in male children and adolescents from Tajikistan and Western India and (b) to develop regression equations for determining their age based on the size of the PP.

**Materials and methods.** Three hundred and sixty-two X-ray images of the right hand of male subjects were examined. All subjects originated from Tajikistan and Mumbai, India, and aged from 6 to 17 years. The relationship between the subjects' age and the length of the PP (LPP) and the width of the diaphysis of the PP (WPP) was investigated using a simple linear regression and correlation analysis. The LPP and WPP dependence on age was determined using one-way ANOVA and the Kruskal–Wallis test followed by post-hoc analysis by age groups.

**Results.** LPP and WPP of the subjects from Tajikistan and India correlated with age, with the correlation coefficient exceeding 0.5. In both ethnic groups, the correlation coefficients for LPP vs. age was greater than 0.8. The correlation coefficient for WPP vs age ranged from 0.68 to 0.77 in Tajiks and from 0.58 to 0.69 in Indians. Simple linear regression models were developed to predict the age from LPP ($R^2 > 0.6$), except for LPP 5 for Tajiks. The LPP 5 values in Tajiks and the WPP values in both ethnic groups showed weak $R^2$, which ranged from 0.35 to 0.53. Eleven significant differences were identified between the ethnic groups of the same age with respect to LPP and WPP.

**Conclusion.** PP length was a better age predictor than the diaphysis width. The most reliable predictor for both ethnic groups was LPP 2. The PP parameters did not change uniformly over time. The PP demonstrated especially intensive growth between 12 and 15 years. The most significant differences in LPP and WPP between two ethnic groups were found for the ages of 8 and 15–16 years, with LPP and WPP in Tajiks exceeding those in Indians.

**Key words:** hand, phalanges, identification from bones, age estimation, ethnic features.

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# Сравнительная оценка некоторых линейных параметров проксимальных фаланг кисти у детей и подростков мужского пола Таджикистана и Западной Индии в возрастном аспекте

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**РЕЗЮМЕ**

**Цель.** Установить этнические различия в линейных параметрах длины проксимальных фаланг (ПФ) и ширины диафизов ПФ у детей и подростков мужского пола Таджикистана и Западной Индии. Разработать регрессионные уравнения для определения возраста по размерам ПФ.

**Материалы и методы.** Исследовано 366 рентгенограмм правой кисти лиц мужского пола Таджикистана (г. Канибадам) и Западной Индии (г. Мумбаи) 6–17 лет. Зависимость возраста от длины ПФ (ДлПФ) и ширины диафиза ПФ (ШПФ) изучалась с помощью парного линейного регрессионного анализа и корреляционного анализа. Влияние возраста на ДлПФ, ШПФ определялось с помощью однофакторного дисперсионного анализа, критерия Краскела – Уоллиса и последующего post-hoc анализа по возрастам.

**Результаты.** ДлПФ и ШПФ представителей Таджикистана и Индии коррелируют с возрастом, коэффициент корреляции больше 0,5. В обеих этнических группах коэффициенты корреляции между возрастом и ДлПФ превышали 0,8. Коэффициент корреляции возраста и ШПФ у таджиков колеблется в диапазоне 0,68–0,77, у индийцев – 0,58–0,69. Построены парные линейные регрессионные модели для прогноза возраста по ДлПФ с коэффициентом детерминации $R^2$, большим 0,6, за исключением ДлПФ5 для таджиков. ДлПФ5 для таджиков и значения ШПФ для обеих этнических групп показали слабые $R^2$ (0,35–0,53). Найдено 11 значимых различий между равновозрастными этническими группами по ДлПФ и ШПФ.

**Заключение.** ДлПФ является лучшим предиктором возраста, чем ширина диафиза. Самым надежным предиктором для обеих национальностей является ДлПФ2. Увеличение параметров ПФ происходит неравномерно с возрастом. Интенсивный рост ПФ наблюдается преимущественно в интервале 12–15 лет. Больше всего значимых отличий ДлПФ и ШПФ между этническими группами найдено в 8 и 15–16 лет, при этом ДлПФ и ШПФ таджиков превышали индийские.

**Ключевые слова:** кисть, фаланги, идентификация по костям, определение возраста, этнические особенности.

**Конфликт интересов.** Автор декларирует отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

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## INTRODUCTION

The study of the human skeleton with respect to ethnicity and origin-specific features remains an important research area. We need to accumulate data on bone growth patterns in people of different origins because, due to the considerable increase in migration observed over the past decades, more and more people arrive from countries with different climates. The study of bone growth in people coming from other climate zones and areas with a different population structure is of considerable interest to morphologists, as well as pediatricians, traumatologists and forensic experts [1–3]. The need to identify a victim, i.e. to

establish their gender and age, sometimes using only bones or even just bone fragments, arises after industrial and natural disasters with mass casualties, as well as in criminal cases. X-ray is commonly used for identifying badly damaged remains [4]. When analyzing X-ray images, one should remember that the pattern of bone formation and growth may vary in people originating from different countries and even different areas of the same country. Possible reasons responsible for such discrepancies include climatic factors, ethnic characteristics, environmental and geographical factors, which change over time [5]. In developing countries, such as India, age estimation is an important task because illiterate people may not keep proper birth records [6]. In South Asia, up to 65% of children under five years old do not have their birth registered [7]. Regression equations for the single-bone age estimation yield much better results, i.e. closer to real values, if the estimation takes population-specific characteristics into account [8]. Errors are likely to occur if a person is being identified from bones without population-specific morphologic parameters being considered [9]. For instance, a study of the size of the second metacarpal bone in Guamanians and white Americans revealed a difference in the length of this bone between the compared groups [10]. Data collected by the Institute of Demography of the National Research University Higher School of Economics show that during the period from January to July 2018 Tajikistan contributed the most to the Russian Federation's net migration gain [11]. People from Tajikistan come to the Russian Federation together with their children of preschool and school age. This fact provides the rationale for deepening our knowledge on various body structures of Tajik children and their ethnic-specific characteristics. S.S. Mirzoev points towards the ethnic specificity of Tajiks, their specific genotypic and phenotypic features [12]. Osteological studies of people from Tajikistan were carried out as far back as the 1960s [13], so it has been a long time since those results were obtained. The literature search among available sources showed works neither on the growth patterns of the proximal phalanges (PP) of the hand of men from Tajikistan, nor on the approaches for estimating their age from the size of the PP.

The aim of this study was (*a*) to establish ethnicity-specific differences in such morphological parameters of the proximal phalanges as the bone length and the width of the diaphysis in male children and adolescents from Tajikistan and Western India and (*b*) to develop regression equations for determining their age based on the size of the PP.

## MATERIALS AND METHODS

To identify ethnicity-specific characteristics in the morphological parameters of the PP, a comparison was performed among 115 Tajik boys and adolescents aged 6 to 17 years from Konibodom (Tajikistan), which is an area with a continental subtropical climate and a continental mild climate, and 251 boys and adolescents from Mumbai (Western India), which is an area with a tropical monsoon climate. In Tajikistan, the study was conducted in Konibodom, inhabited by 96% of the indigenous Tajik people (Viloyati), which belong to the ethnic group of Tajiks of the cities and oases [14]. In India, the study was conducted in Mumbai, whose inhabitants represent the Indo-Arabian ethnic group. All the X-ray images were obtained in the presence of the author during his trips to India and Tajikistan. Data on the age distribution are presented in Table 1.

Table 1

**Distribution of the examined male children and adolescents between the geographical regions and among the age groups**

| Region | Age, years | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Western India | 14 | 14 | 10 | 10 | 17 | 20 | 27 | 36 | 25 | 37 | 22 | 19 |
| Tajikistan | 5 | 10 | 9 | 8 | 10 | 10 | 11 | 13 | 7 | 15 | 7 | 10 |

X-ray examinations were performed in patients with suspected fractures and in apparently healthy children who complained of pain in the joints of the hand. The study included the images of the right hand obtained from children and adolescents who did not have any skeletal disorders. Parents of the underage subjects signed letters of informed consent for the use of the obtained data in the research work.

X-ray images were obtained at a 60-cm distance from the anode area of the X-ray tube to the film. The length of the PP and the width of the PP diaphysis (at the middle) were measured in the X-ray images of the hand using a sliding caliper with an accuracy of 0.05 mm. The length of each PP was measured from the middle of the semilunar contour of their base to the very distal contour of the head.

The study data were processed statistically. Regression analysis was performed to determine the relationship between the age of the study subjects and the morphological parameters of their PP. The quality of the regression model was evaluated using the determination coefficient $R^2$ and the overall significance assessed by the *F*-test. The residual normality was assessed using the Kolmogorov-Smirnov normality test. The residuals were tested for having expectation zero using the one-sample t-test. For normally distributed data, the relationship between the age of the examined children and the length of the PP and the width of the PP diaphysis was assessed using Pearson's correlation coefficient (*r*). The Spearman rank-order correlation coefficient (*rs*) was used for non-normally distributed data. The significance of the correlation coefficients was assessed using Student's t-test. The Shapiro–Wilk normality test was used for small samples of the PP length and diaphysis width values within each age group.

The age-specific comparison of the PP length and diaphysis width was carried out using either a parametric analysis (one-way analysis of variance, or one-way ANOVA) or a non-parametric analysis (Kruskal – Wallis test, or *H*-test), depending on the data distribution in a given age group. Further post-hoc pairwise comparisons between the age groups were carried out using the Student's *t*-test after one-way ANOVA or the Mann – Whitney *U*-test if the Kruskal – Wallis *H*-test had been previously used. In both cases, multiple comparisons were processed using the Benjamini – Hochberg procedure (false discovery rate, or FDR). The morphological parameters of the PP in children and adolescents of the same age from Tajikistan versus Western India were also compared using *t*-test for normal distribution and *U*-test for non-normal distribution.

Descriptive statistics were given as *M (SD)* for normally distributed PP length and diaphysis width values and as $Me(Q_1–Q_3)$ for non-normally distributed values, where *M* is the mean, *SD* is the standard deviation, *Me* is the median, $Q_1$ and $Q_3$ are the first and third quartiles, respectively. The threshold for statistical significance was set at 0.05 for all hypothesis testing criteria.

## RESULTS AND DISCUSSION

An age-specific comparison of the length of the PP and the width of the PP diaphysis was performed in male subjects from Tajikistan and Mumbai. In this paper, LPPX refers to the length of a proximal phalanx and WPPX refers to the width of the diaphysis of a proximal phalanx, with X being the finger number. Study data are presented in Figures 1 and 2 for India and Tajikistan, respectively. The interquartile ranges show that the PP length values in the subjects from both ethnic groups had a smaller dispersion compared to the PP diaphysis width values.

The PP length values in the subjects from both ethnic groups have a smaller dispersion compared to the PP diaphysis width values (Fig. 1, 2).

The PP length and diaphysis width did not grow uniformly over time (all significant results were obtained using the Benjamini – Hochberg procedure [FDR correction]). The growth periods were as follows:

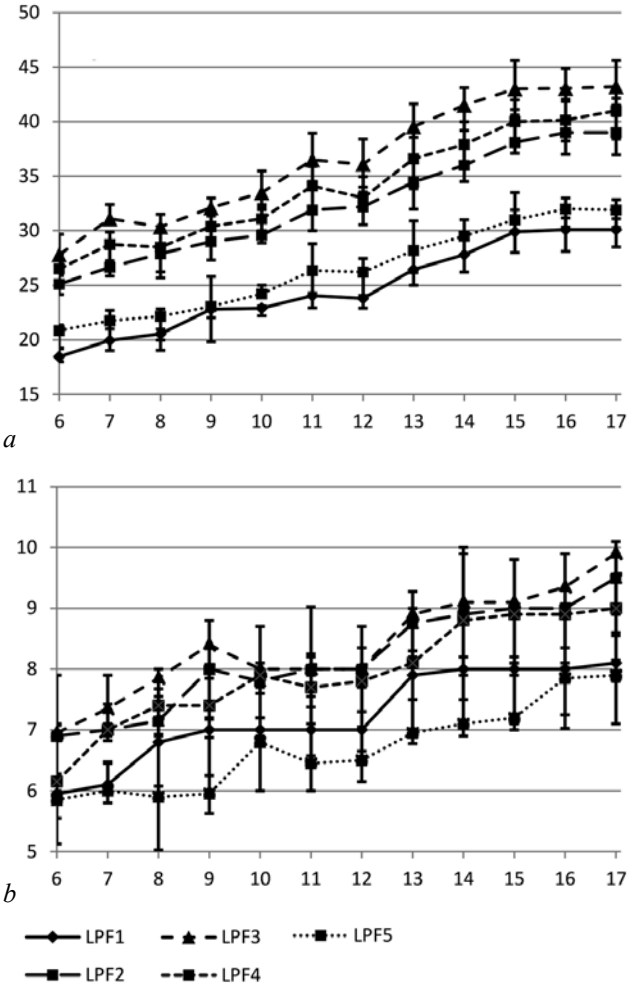


Fig. 1. Changes in morphological parameters of the proximal phalanges of the hand in boys and adolescents from Western India: *a* – length of a proximal phalanx (LPP); *b* – width of the diaphysis of a proximal phalanx (WPP), mm. The horizontal axis shows age (years); the vertical axis shows morphological parameters of the bones (mm). The curve represents median values; the whiskers show the first and third quartiles. PP1 to 5 denote proximal phalanges of the 1st to 5th finger.

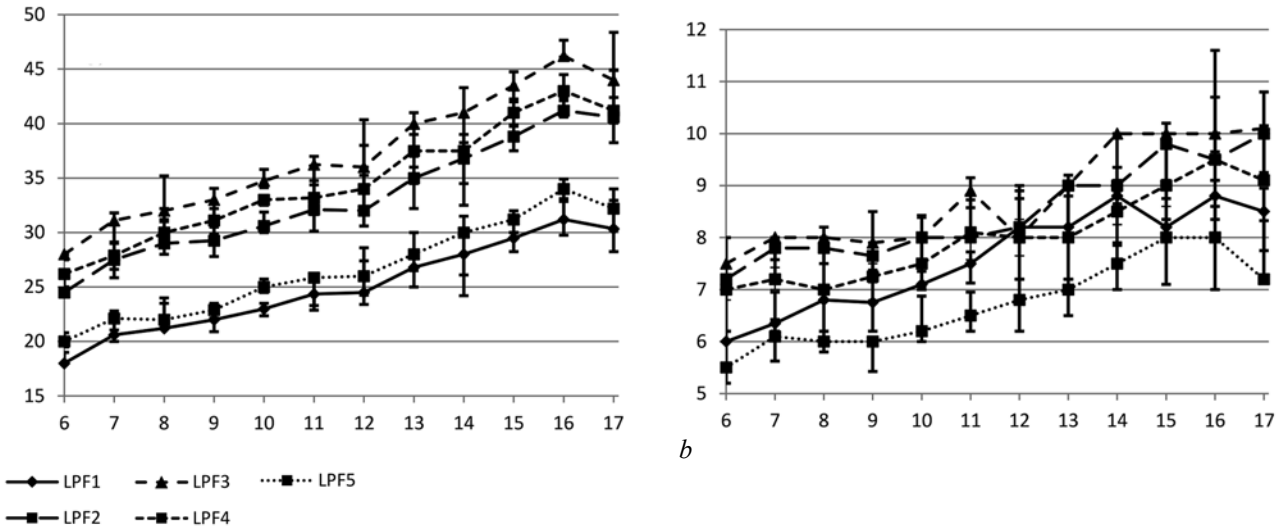


Fig. 2. Changes in morphological parameters of the proximal phalanges of the hand in boys and adolescents from Tajikistan: *a* – length of a proximal phalanx (LPP); *b* – width of the diaphysis of a proximal phalanx (WPP), mm. The horizontal axis shows age (years); the vertical axis shows morphological parameters of the bones (mm). The curve represents median values; the whiskers show the first and third quartiles. PP1 to 5 denote proximal phalanges of the 1st to 5th finger.

– Indian subjects from Mumbai, PP length. LPP1, LPP2, LPP3, LPP4: 6–7, 12–13 and 14–15 years; LPP4 also 8–9 years; LPP5: 10–11, 12–13, 14–15 years;

– Indian subjects from Mumbai, PP diaphysis width. WPP1 to 5: 12–13 years;

– Tajik subjects, PP length. LPP1: 14–15 years; LPP2: 6–7, 7–8, 15–16 years; LPP3, LPP5: 9–10, 15–16 years; LPP4: 9–10, 14–15, 15–16 years;

– Tajik subjects, PP diaphysis width: no significant differences between the adjacent age groups.

The Kruskal – Wallis *H*-test and ANOVA showed a significant increase in the studied morphological parameters of the PP with age. However, the post-hoc analysis revealed that the statistically significant difference in the morphological parameters assessed between age pairs was greater for the PP length compared to the diaphysis width both in Indians (by 20.6% on the average) and Tajiks (by 32.9%) (Table 2).

The correlation analysis of individual osteometric parameters of the PP of the hand was performed using the Spearman rank-order correlation.

Table 2

**Changes in LPP and WPP with respect to age and post-hoc analysis results**

| Parameter | Mumbai (India) | | | Tajikistan | | |
|---|---|---|---|---|---|---|
| | Multiple and pairwise comparison | *p*-value | Number of pairwise differences between age groups | Multiple and pairwise comparison | *p*-value | Number of pairwise differences between age groups |
| LPP1 | H-test, U-test | < 0.001 | 54 | one-way ANOVA, Tukey's test | < 0.001 | 37 |
| LPP2 | H-test, U-test | < 0.001 | 56 | H-test, U-test | < 0.001 | 50 |
| LPP3 | H-test, U-test | < 0.001 | 55 | H-test, U-test | < 0.001 | 50 |
| LPP4 | H-test, U-test | < 0.001 | 57 | H-test, U-test | < 0.001 | 53 |
| LPP5 | H-test, U-test | < 0.001 | 55 | H-test, U-test | < 0.001 | 44 |
| WPP1 | H-test, U-test | < 0.001 | 42 | H-test, U-test | < 0.001 | 34 |
| WPP2 | H-test, U-test | < 0.001 | 43 | H-test, U-test | < 0.001 | 37 |
| WPP3 | H-test, U-test | < 0.001 | 45 | one-way ANOVA, Tukey's test | < 0.001 | 24 |
| WPP4 | H-test, U-test | < 0.001 | 42 | H-test, U-test | < 0.001 | 35 |
| WPP5 | H-test, U-test | < 0.001 | 48 | H-test, U-test | < 0.001 | 27 |

Note. LPP1–5: length of the first to fifth proximal phalanges of the hand; WPP1–5: width of the diaphysis of the proximal phalanges of the hand; *H*-test: Kruskal – Wallis test; *U*-test: Mann – Whitney test; one-way ANOVA: one-way analysis of variance.

Linear regression equations were developed to be used as a method for determining the age of male subjects in Tajikistan and Western India.

If all the bones of the hand are available, multiple linear regression is the best method for age estimation. If only separate bones are available for testing, a single bone can be used to create the regression equation [8].

The regression models were developed during the correlation and regression analysis that can be used to estimate the age of 6 to 17-year-old boys and adolescents from Mumbai and the indigenous Tajik people (Viloyati) (Table 3).

The length of the PP in boys and adolescents from Tajikistan and Western India showed a closer correlation with age than the width of the PP diaphysis (Table 3). All rank correlation coefficients for age versus bone length exceed 0.8. In contrast, the correlation coefficients for the PP diaphysis width ranged from 0.58 to 0.75 in both study groups. It was found that nine out of ten correlation coefficients for Tajik boys and adolescents exceeded those of Indians by an average of 8%.

Table 3

**Regression models for the age estimation of 6 to 17-year-old children and adolescents in Mumbai (India) and Tajikistan developed using data on the length of the PP and the width of the PP diaphysis of the hand**

| Parameter | Regression model | *F*-test, *p*-value | Adjusted $R^2$ | Correlation coefficient *rs* | Applicability of the model* |
|---|---|---|---|---|---|
| Mumbai (India) | | | | | |
| LPP1 | Age = – 3.049 + 0.596 × LPP1 | < 0.001 | 0.682 | 0.820 | yes |
| LPP2 | Age = – 5.538 + 0.529 × LPP2 | < 0.001 | 0.718 | 0.827 | yes |
| LPP3 | Age = – 5.327 + 0.466 × LPP3 | < 0001 | 0.712 | 0.822 | yes |
| LPP4 | Age = – 5.518 + 0.507 × LPP4 | < 0.001 | 0.705 | 0.822 | yes |
| LPP5 | Age = – 3.681 + 0.583 × LPP5 | < 0.001 | 0.659 | 0.814 | yes |
| Tajikistan | | | | | |
| LPP1 | Age = – 4.576 + 0.645 × LPP1 | < 0.001 | 0.706 | 0.848 | yes |
| LPP2 | Age = – 5.401 + 0.516 × LPP2 | < 0.001 | 0.745 | 0.874 | yes |
| LPP3 | Age = – 3.457 + 0.404 × LPP3 | < 0.001 | 0.664 | 0.879 | yes |
| LPP4 | Age = – 4.213 + 0.454 × LPP4 | < 0.001 | 0.6915 | 0.879 | yes |

Note. LPP1–5: length of PP 1 to 5; age is given in years.
*The practical applicability of the model.
All the correlation coefficients shown in Table 3 are statistically significant. All the residuals follow a normal distribution and have zero expectation.

M.A.Grigoryeva, E.S.Anushkina [15] point out that the choice of the optimal regression model may be complicated even if the object is not damaged. Mathematical models yield the most accurate results when the proportional composition of the studied population resembles as much as possible the composition of the population used to develop the equations [5].

Although multivariate tests showed a significant increase in the PP length and diaphysis width with age, and the correlation analysis confirmed these relationships for all the morphological parameters studied, well-fitting regression models ($R^2 > 0.6$) could be developed only for the length of PP1 to 4.

The models developed for the age estimation from the length of the PP in boys and adolescents from Western India were of approximately the same quality: the determination coefficients ranged from 0.66 (PP5) to 0.72 (PP2). The best regression model for the age estimation in Indian boys (Mumbai) was developed using LPP2 as the independent variable ($p < 0.001$).

LPP2 was also the best predictor of age in boys and adolescents from Tajikistan. The determination coefficient of the LPP2 model was 0.75 ($p < 0.001$) and it significantly exceeded the coefficients for other models.

When comparing the regression models developed for the two ethnic groups studied, it was found that the length of the PP between 6 and 17 years grew faster in Tajik boys and adolescents, whose multipliers of the independent variables exceeded those in the Indian subjects of the same age in four of the five models (PP2-4) (Table 3). The growth in width of PP1 to PP3 diaphysis in children and adolescents of Tajikistan also exceeded that in the Indian subjects of the same age. However, the diaphysis width of PP4 and PP5 grew faster in the Indian subjects from Mumbai.

A comparative analysis of the PP sizes in boys from Western India and Tajikistan revealed several differences (Table 4).

Table 4

**Age-specific differences in the morphological parameters of PP between two ethnic groups**

| No. | Parameter | Age, years | P-value | Mumbai (India) | Tajikistan |
|---|---|---|---|---|---|
| 1 | LPP1 | 8 | 0.005 | 20.6 (19.0 21.0) | 22.2 (1.9) |
| 2 | LPP2 | 8 | 0.021 | 27.2 (1.7) | 29.4 (2.0) |
| 3 | LPP3 | 8 | 0.029 | 30.1 (2.0) | 32.6 (2.4) |
| 4 | LPP4 | 8 | 0.022 | 28.0 (2.1) | 30.5 (2.2) |
| 5 | WPP1 | 12 | 0.020 | 7.1 (0.9) | 8.1 (1.2) |
| 6 | WPP2 | 15 | 0.040 | 9.0 (8.1 9.8) | 9.5 (8.8 10.0) |
| 7 | WPP4 | 15 | 0.027 | 8.9 (8.1 9.0) | 9.2 (0.9) |
| 8 | LPP2 | 16 | 0.021 | 38.6 (2.3) | 40.9 (1.9) |
| 9 | LPP3 | 16 | 0.002 | 43.3 (2.3) | 46.6 (1.8) |
| 10 | LPP4 | 16 | 0.005 | 40.2 (2.2) | 43.2 (2.0) |
| 11 | WPP4 | 16 | 0.023 | 8.7 (0.9) | 9.9 (1.1) |

LPP1–4: length of the proximal phalanges of the first to fourth fingers; WPP1–4: diaphysis width of the proximal phalanges of the first to fourth fingers.

Eight-year-old Tajik boys had longer PP of fingers 1, 2, 3, 4 compared to the Indian boys of the same age. In the age range between 9 and 14 years, no significant differences in the studied morphological parameters of the PP were found, except for WPP1, which was significantly greater in the subjects from Tajikistan. The analysis of X-ray images showed that the width of the PP diaphysis in the first and second fingers was significantly greater in 15-year-old boys from Tajikistan compared to the Indian boys of the same age. Also, the length of PP2, PP3, and PP4, as well as the diaphysis width of PP4, were greater in 16-year-old subjects from Tajikistan versus 16-year-old Indian boys.

## CONCLUSION

The most accurate estimation of the age of children and adolescents between 6 and 17 years is achieved when a researcher uses data from the same ethnic group. The bone length is the better predictor of the age of Tajik and Indian (Mumbai) children and adolescents than the diaphysis width if the age is estimated based on the size of the proximal phalanges of the hand. The length of the proximal phalanx of the second finger is the most reliable predictor of age for both ethnic groups. An osteometric study conducted in boys and adolescents aged between 6 and 17 years revealed that the proximal phalanges of the hand did not grow uniformly over time. The PP demonstrated intensive growth between 12 and 15 years. Most of the significant between-group differences in the length and diaphysis width were found for the ages of 8 and 15–16 years, with the greater length and width values observed in Tajiks compared to the Indian (Mumbai) subjects of the same age.

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