RESEARCH PAPER

# Age- and Gender-Related Differences in Anthropometric Characteristics of Competitive Youth Swimmers Aged 10-14 Years

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**ABSTRACT**

This cross-sectional study assessed anthropometric profiles and body composition in 78 competitive adolescent swimmers (37 females, 41 males; aged 10-14 years) from Nagpur, Maharashtra, India, recruited via purposive random sampling from swimming clubs (≥2 years experience, 4-5 training days/week; no chronic illness/injuries). Measurements included height, weight (stadiometer, scale), circumferences like mid upper arm, waist, hip, thigh, and calf and shoulder width (flexible tape), skinfold thickness (biceps, triceps, subscapular and suprailiac; Slim Guide calipers, left-side means), and body composition via Durnin-Rahaman (1967)[1] density equations (sex-specific), Siri (1956)[2] fat%, and Katch-McArdle (1983)[3] lean mass. One-sample t-tests (α=0.01, two-tailed; MS-Excel) compared age-group means (10+ to 14+) against reference norms, revealing upper-body dominance (e.g., female 14+: biacromial M=43.00±4.41 cm, t=3.180 vs. std 37.7 cm; male 13+: MUAC M=23.50±2.462 cm, t=4.021 vs. std 27.0 cm), reduced truncal girths/skinfolds (e.g., female 12+: waist below norms), and sex-specific patterns (female 13+ fat peak 30.75±2.30%; male 11+ density 1.0612±0.007 g/mL), yielding ecto-mesomorphic adaptations for propulsion/drag reduction.

***Keywords:*** adolescent swimmers, anthropometry, body composition, one-sample t-tests, somatotypes.

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## INTRODUCTION

Adolescence is a critical period of rapid somatic growth, physiological change and motor development that has important implications for both short-term athletic performance and long-term health [4]. Early adolescence (10–14 years) in particular is characterised by marked changes in height, body mass, body composition and motor capacities, and is therefore an important window for monitoring growth and designing age-appropriate training and nutritional strategies for young athletes [4, 5]. Swimming is a global youth sport that places specific demands on the body's anthropometric and physiological characteristics (e.g., lean mass, fat mass distribution, limb proportions, and aerobic/anaerobic fitness); these characteristics interact with technique to determine performance and also influence health outcomes during maturation [6].

Anthropometry and body composition assessments are cornerstone methods for describing growth, nutritional status and physique in adolescent populations [5]. Simple anthropometric indices such as height, weight, circumferences and skinfolds remain practical for field studies and can be compared against international growth references (WHO growth reference 5–19 years) to identify deviations from expected growth trajectories [5, 7]. However, in athletic populations—swimmers included—body weight can mask important differences in body composition (high lean mass vs. low fat mass), so more direct measures like skin-fold–derived body fat estimates can be used to characterise fat mass (FM) and fat-free mass (FFM) accurately which is comparable with sophisticated direct techniques of measuring of body composition [8].

Body composition estimation by anthropometric equations or field tools requires sport- and age-specific validation. In adolescent swimmers, several studies have compared skinfold-based equations and more direct methods, reporting systematic differences across techniques and indicating that selected anthropometric equations (e.g., Durnin and Rahaman) may perform better in this population than generalized formulas [9].

Anthropometric characteristics play a central role in determining growth patterns, nutritional status, and sport-specific physical advantages among children and adolescents. During the critical transition from late childhood to early adolescence (10–14 years), rapid biological maturation influences body size, body composition, and proportional development, with noticeable differences between boys and girls [10, 11]. These age- and sex-related variations can substantially affect performance in sports such as competitive swimming, where body dimensions, limb proportions, and somatotype traits contribute to hydrodynamics, propulsion efficiency, buoyancy, and endurance [12, 13].

Swimming performance in youth athletes is strongly associated with total body size, segmental circumferences, skinfold-derived body fat, and lean mass distribution [14]. Parameters such as height, weight, mid-upper arm circumference (MUAC), chest and hip breadth, thigh and calf circumferences, and shoulder width reflect both genetic predisposition and training-induced adaptation [15]. In addition, skinfold thickness at key sites—including triceps,



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biceps, subscapular, and suprailiac—provides an indirect yet valid estimation of total body fat and adipose tissue patterning, which can influence buoyancy and swimming economy [1, 16].

Body composition, particularly body fat mass and lean body mass, is another critical determinant of swimming performance in youth athletes. Body density equations developed by Durnin and Rahaman [1] and subsequent conversion to body fat percentage using the Siri [2] equation remain widely accepted for adolescent populations. These measurements allow researchers to differentiate age- and sex-related variations in adiposity and muscularity. Further calculations of fat mass and lean body mass using models such as those proposed by Katch and McArdle [3] provide deeper insights into the functional capabilities of young swimmers, including strength, endurance, and metabolic efficiency.

Although several studies have examined anthropometric and physiological correlates of swimming performance, limited research specifically focuses on age- and gender-related differences among competitive swimmers in early adolescence. Understanding these patterns is essential for talent identification, training optimization, growth monitoring, and preventing nutritional or developmental imbalances during intensive training periods [17, 18]. Therefore, the present study aims to assess detailed anthropometric characteristics—including body size, circumferences, skinfold thickness, and body composition—of male and female competitive swimmers aged 10–14 years and to examine how these parameters vary across age and gender.

# METHODOLOGY

**Study Design and Participants:** The present study employed a cross-sectional descriptive design to investigate age- and gender-related differences in anthropometric characteristics among competitive youth swimmers. A total of 78 swimmers (41 males, 37 females), aged 10-14 years, were recruited from swimming clubs in Nagpur city, Maharashtra, India. Purposive random sampling was used to select participants who had a minimum of two years of competitive swimming experience and were engaged in regular training sessions (at least 4-5 days/week) [10].

**Inclusion criteria** were: Age 10–14 years, participation in competitive swimming for ≥2 years & no history of chronic illness or musculoskeletal injury

**Exclusion criteria** included swimmers with recent injuries, chronic diseases, or those unable to complete anthropometric assessments.

**Data Collection:** Data were collected through direct measurement of anthropometric parameters.

**Anthropometric Measurements:** Anthropometric measurements were conducted following standardized procedures recommended by the International Society for the Advancement of Kinanthropometry (ISAK) [19, 20, 21].

Measurements included:

1. Height – Measured to the nearest 0.1 cm using a stadiometer, with participants standing erect without shoes [20].

2. Weight – Recorded to the nearest 0.1 kg using a calibrated digital weighing scale [20].

3. Mid upper arm circumference (MUAC), Waist, Hip, Thigh, Calf Circumferences, and Shoulder Width – were measured using a flexible tape at standard anatomical landmarks in centimeters [20].

4. Skinfold Thickness - Skinfold thickness was measured at biceps, triceps, subscapular, and suprailiac sites using skinfold calipers (Slim Guide) following standardized procedures [19, 20]. Measurements were taken on the left side of the body, with each site measured thrice and the mean value was used for analysis.

5. Body Composition –

Body density was estimated using the Durnin and Rahaman [1] equations:

Body density (Boys) = 1.1533 - 0.0643 X Log of sum of skin fold thicknesses at all four sites
Body density (Girls) = 1.1369 - 0.0598 X Log of sum of skin fold thicknesses at all four sites.

Body fat percentage was calculated using the Siri [2] equation:
Body fat % = [(4.95 / Body density) - 4.5] X 100

Body fat mass (kg) and lean body mass (kg) were then derived:
Body fat (kg) = Body (%) X Actual body weight (kg) / 100

Lean body mass in kilograms was calculated by the formula given by Katch and McArdle [3].
Lean body Mass (kg) = Body weight (kg) – body fat (kg)

These procedures allow accurate estimation of age- and gender-related variations in both adiposity and muscularity, which are critical for swimming performance [3, 16]. Recorded body indices of swimmers were compared with reference standards for age and gender [7, 22, 23, 24].

**Data Analysis:** Data were coded and analyzed using MS-Excel. Descriptive statistics (mean ± standard deviation, range) were derived for all variables. One-sample t test was performed to compare anthropometric measurements with standard reference values for age and gender (WHO, 2007[7]).
A level of probability at both 0.05 and 0.01 level of significance was assumed to draw conclusions.

## RESULTS

**Table 1: Data on Height and Weight for Female and Male Swimmers**

| Sr. No | Age Groups (Yrs) | Height (cm) | | | | Weight (kg) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | M ± SD | Range | Std | t Values | M ± SD | Range | Std | t Values |
| **FEMALE SWIMMERS (N = 37)** | | | | | | | | | |
| 1 | 10+ (n=9) | **142.50**±5.52 | 133.00-150.00 | 138.3 | 1.555 | **32.66**±5.30 | 25.00-41.00 | 32.5 | 0.290 |
| 2 | 11+ (n=8) | **149.43**±5.44 | 140.00-155.00 | 142 | 3.618** | **37.38**±4.66 | 28.00-45.00 | 33.7 | 2.092 |
| 3 | 12+ (n=8) | **148.81**±6.64 | 139.50-159.00 | 148 | 0.324 | **38.93**±5.56 | 33.00-51.00 | 38.7 | 0.112 |
| 4 | 13+ (n=7) | **148.86**±4.58 | 142.00-155.00 | 155 | 3.270** | **44.93**±8.64 | 29.00-58.00 | 44 | 0.264 |
| 5 | 14+ (n=5) | **156.40**±7.31 | 150.00-170.00 | 159 | 0.583 | **48.80**±8.42 | 39.00-64.00 | 48 | 0.165 |
| **MALE SWIMMERS (N = 41)** | | | | | | | | | |
| 1 | 10+ (n=10) | **140.50**±6.15 | 129.00-153.05 | 137.5 | 1.462 | **32.50**±6.35 | 20.50-43.00 | 31.4 | 0.520 |
| 2 | 11+ (n=7) | **140.93**±8.81 | 129.00-157.00 | 140 | 0.262 | **30.93**±8.13 | 21.00-48.00 | 32.2 | 0.381 |
| 3 | 12+ (n=9) | **156.22**±4.77 | 148.50-163.00 | 147 | 5.522** | **45.17**±9.01 | 35.00-58.00 | 37 | 2.588* |
| 4 | 13+ (n=8) | **158.88**±12.03 | 139.00-176.50 | 153 | 1.291 | **48.50**±12.18 | 28.50-63.00 | 40.9 | 1.657 |
| 5 | 14+ (n=7) | **167.43**±8.60 | 149.00-176.00 | 160 | 2.101 | **58.00**±13.20 | 31.00-71.00 | 47 | 2.033 |

Std-Standard; ** - Significant at both 5 % & 1% levels (p<0.01) i.e. $H_0$ is rejected & $H_1$ is accepted; * - Significant at 5 % level but insignificant at 1 % level (0.01<p<0.05) i.e. $H_0$ is rejected & $H_1$ is accepted at 5% level but $H_0$ is true & $H_1$ is rejected at 1% level; Values without any mark indicate insignificant difference at both 5% & 1% levels (p>0.05) i.e. $H_0$ is true & $H_1$ is rejected.

The anthropometric data (height and weight) presented in Table 1 demonstrates the physical development patterns of competitive swimmers aged 10 to 14 years, with notable gender-specific variations in growth trajectories. Statistical analysis revealed several significant differences between measured values and standardized norms for both height and weight parameters across different age groups.

Among female swimmers, mean height values ranged from 142.50±5.52 cm in the 10+ age group to 156.40±7.31 cm in the 14+ age group. Significant differences from standard norms were observed in the 11+ group ($t$=3.618, $p$<0.01) and 13+ group ($t$=3.270, $p$<0.01), indicating that female swimmers in these age categories exhibited height characteristics that deviated significantly from population standards. The 12+ and 14+ groups showed no significant differences from standards ($p$>0.05), suggesting that growth patterns in these cohorts aligned more closely with normative data.

Male swimmers demonstrated mean height values ranging from 140.50±6.15 cm (10+ group) to 167.43±8.60 cm (14+ group). The 12+ age group showed highly significant differences from standard values ($t$=5.522, $p$<0.01), representing the most pronounced deviation observed in the entire sample. This finding aligns with established literature indicating accelerated growth velocity during early adolescence in male athletes (Baxter-Jones et al., 1995).

Female swimmers' body weight ranged from 32.66±5.30 kg (10+ group) to 48.80±8.42 kg (14+ group), with no significant deviations from standard norms across any age category ($p$>0.05). This suggests that female swimmers maintained weight trajectories consistent with general population norms despite intensive training regimens.

Conversely, male swimmers exhibited weight values from 32.50±6.35 kg (10+ group) to 58.00±13.20 kg (14+ group). Significant differences emerged in the 12+ age group at both the 5% and 1% significance levels ($t$=2.588, $p$<0.01), indicating that male swimmers at this developmental stage possessed body mass characteristics significantly different from population standards.

The shoulder width of female and male swimmers aged 10–14 years was compared with standard reference values using a one-sample t-test. Table 2 shows the means, standard deviations, reference standards, and calculated t-values for each age group.

The mean shoulder widths of female swimmers ranged from 32.94±1.45 cm (10+ years) to 37.60±1.20 cm (14+ years). Significant differences were observed in most age groups when compared to the reference standards. Specifically, 10+ years (t=3.807, p<0.01), 11+ years (t=3.256, p<0.05), 12+ years (t=3.720, p<0.01), and 14+ years (t=2.981, p<0.05) demonstrated significantly greater shoulder widths than the reference standard, while the 13+ years group (t=0.806) did not differ significantly.

**Table 2: Data on Shoulder Width for Female and Male Swimmers**

| Sr. No. | Age Groups (Yrs) | Shoulder Width (cm) | | Std | t Values |
|---|---|---|---|---|---|
| | | M ± SD | Range | | |
| **FEMALE SWIMMERS (N = 37)** | | | | | |
| 1 | 10+ (n=9) | **32.94** ± 1.45 | 30.00 – 35.00 | 31.1 | **3.807**** |
| 2 | 11+ (n=8) | **36.50** ± 3.04 | 33.00 – 41.00 | 33.0 | **3.256*** |
| 3 | 12+ (n=8) | **35.06** ± 0.73 | 34.00 – 36.00 | 34.1 | **3.720**** |
| 4 | 13+ (n=7) | **34.86** ± 2.10 | 31.00 – 38.00 | 35.5 | **0.806** |
| 5 | 14+ (n=5) | **37.60** ± 1.20 | 36.00 – 39.00 | 36.0 | **2.981*** |
| **MALE SWIMMERS (N = 41)** | | | | | |
| 1 | 10+ (n=10) | **35.70** ± 2.49 | 32.00 – 40.00 | 31.2 | **5.715**** |
| 2 | 11+ (n=7) | **33.71** ± 3.77 | 28.00 – 40.00 | 32.6 | **0.779** |
| 3 | 12+ (n=9) | **39.56** ± 3.62 | 35.00 – 45.00 | 34.4 | **4.276**** |
| 4 | 13+ (n=8) | **39.63** ± 3.90 | 32.00 – 45.00 | 35.9 | **2.705*** |
| 5 | 14+ (n=7) | **43.00** ± 4.41 | 35.00 – 49.00 | 37.7 | **3.180**** |

Std-Standard; ** - Significant at both 5 % & 1% levels ($p<0.01$) i.e. $H_0$ is rejected & $H_1$ is accepted; * - Significant at 5 % level but insignificant at 1 % level ($0.01<p<0.05$) i.e. $H_0$ is rejected & $H_1$ is accepted at 5% level but $H_0$ is true & $H_1$ is rejected at 1% level; Values without any mark indicate insignificant difference at both 5% & 1% levels ($p>0.05$) i.e. $H_0$ is true & $H_1$ is rejected

Male swimmers showed higher mean shoulder widths compared to females, ranging from 33.71±3.77 cm (11+ years) to 43.00±4.41 cm (14+ years). Significant differences were observed for 10+ years (t=5.715, p<0.01), 12+ years (t=4.276, p<0.01), 13+ years (t=2.705, p<0.05), and 14+ years (t=3.180, p<0.01), indicating that male swimmers had considerably wider shoulders than the reference standards. The 11+ years male group (t=0.779) showed no significant difference.

Overall, the results indicate a general trend of increasing shoulder width with age in both female and male swimmers, with male swimmers consistently showing greater widths than females.

**Table 3: Data on Mid Upper Arm Circumference (MUAC) for Female and Male Swimmers**

| Sr. No. | Age Groups (Yrs) | Mid Upper Arm Circumference (MUAC) (cm) | | Std | t Values |
|---|---|---|---|---|---|
| | | M ± SD | Range | | |
| **FEMALE SWIMMERS (N = 37)** | | | | | |
| 1 | 10+ (n=9) | **20.39** ± 1.595 | 18.00 – 23.00 | 23.4 | **5.661**** |
| 2 | 11+ (n=8) | **20.33** ± 2.176 | 17.00 – 24.50 | 24.6 | **5.550**** |
| 3 | 12+ (n=8) | **22.00** ± 1.601 | 20.00 – 25.50 | 25.4 | **6.007**** |
| 4 | 13+ (n=7) | **23.29** ± 2.102 | 19.00 – 26.00 | 26.5 | **4.040**** |
| 5 | 14+ (n=5) | **23.80** ± 2.709 | 20.50 – 28.00 | 27.9 | **3.384**** |
| **MALE SWIMMERS (N = 41)** | | | | | |
| 1 | 10+ (n=10) | **19.70** ± 2.667 | 15.00 – 23.00 | 23.3 | **4.269**** |
| 2 | 11+ (n=7) | **19.57** ± 1.917 | 17.50 – 23.50 | 24.9 | **7.356**** |
| 3 | 12+ (n=9) | **22.39** ± 1.868 | 19.00 – 25.00 | 25.7 | **5.316**** |
| 4 | 13+ (n=8) | **23.50** ± 2.462 | 19.00 – 26.00 | 27.0 | **4.021**** |
| 5 | 14+ (n=7) | **25.57** ± 3.245 | 20.00 – 30.00 | 27.8 | **1.818** |

Std-Standard; ** - Significant at both 5 % & 1% levels ($p<0.01$) i.e. $H_0$ is rejected & $H_1$ is accepted; * - Significant at 5 % level but insignificant at 1 % level ($0.01<p<0.05$) i.e. $H_0$ is rejected & $H_1$ is accepted at 5% level but $H_0$ is true & $H_1$ is rejected at 1% level; Values without any mark indicate insignificant difference at both 5% & 1% levels ($p>0.05$) i.e. $H_0$ is true & $H_1$ is rejected

The mean MUAC of female swimmers ranged from 20.33±2.18 cm (11+ years) to 23.80±2.71 cm (14+ years) (Table 3). All age groups showed significantly lower MUAC compared to reference standards (10+ years: t=5.661, p<0.01; 11+ years: t=5.550, p<0.01; 12+ years: t=6.007, p<0.01; 13+ years: t=4.040, p<0.01; 14+ years: t=3.384, p<0.01), suggesting that female swimmers had smaller mid-upper arm circumference relative to normative values for age.

Male swimmers exhibited mean MUAC values ranging from 19.57±1.92 cm (11+ years) to 25.57±3.25 cm (14+ years). Significant differences were observed in most age groups: 10+ years (t=4.269, p<0.01), 11+ years (t=7.356, p<0.01), 12+ years (t=5.316, p<0.01), and 13+ years (t=4.021, p<0.01). The 14+ years group (t=1.818) was not significantly different from the reference standard (p>0.05). Overall, male swimmers had slightly higher MUAC than females across corresponding ages, reflecting sex-based differences in muscular development.

Both female and male swimmers showed an incremental increase in MUAC with age, which aligns with normal adolescent growth patterns. Male swimmers demonstrated larger MUAC values than females, especially after 12 years of age, indicating enhanced upper-arm muscularity likely due to both natural growth and training effects.

**Table 4: Data on Trunk Circumferences for Female and Male Swimmers**

| Sr. No | Age Groups (Yrs) | Waist Circumference (cm) | | | | Hip Circumference (cm) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | M ± SD | Range | Std | t Values | M ± SD | Range | Std | t Values |
| **FEMALE SWIMMERS (N = 37)** | | | | | | | | | |
| 1 | 10+ (n=9) | **58.17** ± 8.06 | 39.00 – 69.00 | 69.8 | **4.329**** | **75.44** ± 5.66 | 67.50 – 84.00 | 75.8 | **0.191** |
| 2 | 11+ (n=8) | **62.31** ± 3.46 | 57.00 – 67.00 | 73.2 | **8.327**** | **76.63** ± 4.65 | 69.00 – 84.50 | 81.2 | **2.600*** |
| 3 | 12+ (n=8) | **64.19** ± 4.76 | 58.00 – 73.00 | 74.7 | **6.624**** | **82.19** ± 5.37 | 76.00 – 94.00 | 85.5 | **1.849** |
| 4 | 13+ (n=7) | **68.36** ± 4.74 | 64.00 – 77.00 | 77.6 | **5.514**** | **85.71** ± 5.65 | 75.50 – 93.50 | 91.0 | **2.648*** |
| 5 | 14+ (n=5) | **73.50** ± 8.11 | 64.50 – 84.00 | 80.4 | **2.251** | **89.00** ± 6.73 | 82.00 – 99.50 | 93.9 | **1.926** |
| **MALE SWIMMERS (N = 41)** | | | | | | | | | |
| 1 | 10+ (n=10) | **61.75** ± 7.07 | 48.50 – 75.00 | 69.2 | **3.332*** | **70.25** ± 7.21 | 56.50 – 79.00 | 74.5 | **1.864** |
| 2 | 11+ (n=7) | **58.79** ± 5.72 | 53.00 – 72.00 | 71.9 | **6.064**** | **69.36** ± 6.42 | 60.00 – 82.50 | 78.2 | **3.643*** |
| 3 | 12+ (n=9) | **68.78** ± 8.18 | 58.00 – 81.00 | 74.6 | **2.134** | **81.28** ± 7.77 | 69.00 – 93.50 | 82.6 | **0.510** |
| 4 | 13+ (n=8) | **69.31** ± 7.52 | 56.00-77.00 | 76.8 | **2.817*** | **82.25** ± 9.01 | 66.00 – 91.50 | 85.3 | **0.957** |
| 5 | 14+ (n=7) | **73.43** ± 8.29 | 55.00 – 80.00 | 78.8 | **1.714** | **88.42** ± 10.10 | 70.00 – 103.0 | 90.8 | **0.623** |

Std-Standard; ** - Significant at both 5 % & 1% levels (p<0.01) i.e. H0 is rejected & H1 is accepted; * - Significant at 5 % level but insignificant at 1 % level (0.01<p<0.05) i.e. H0 is rejected & H1 is accepted at 5% level but H0 is true & H1 is rejected at 1% level; Values without any mark indicate insignificant difference at both 5% & 1% levels (p>0.05) i.e. H0 is true & H1 is rejected.

The waist and hip circumferences of female and male swimmers aged 10–14 years were compared with standard reference values using one-sample t-tests (Table 4). Mean waist circumference of female swimmers ranged from 58.17±8.06 cm (10+ years) to 73.50±8.11 cm (14+ years). Significant differences from the reference standards were observed in most age groups: 10+ years (t=4.329, p<0.01), 11+ years (t=8.327, p<0.01), 12+ years (t=6.624, p<0.01), and 13+ years (t=5.514, p<0.01), indicating that female swimmers had smaller waists than reference standards. The 14+ years group (t=2.251) did not reach statistical significance (p>0.05).

Mean hip circumference of female swimmers ranged from 75.44±5.66 cm (10+ years) to 89.00±6.73 cm (14+ years). Significant differences were noted in the 11+ years (t=2.600, p<0.05) and 13+ years groups (t=2.648, p<0.05), while other age groups did not show significant deviation from the reference standard.

Among male swimmers, mean waist circumferences ranged from 58.79±5.72 cm (11+ years) to 73.43±8.29 cm (14+ years). Significant differences were observed for 10+ years (t=3.332, p<0.05), 11+ years (t=6.064, p<0.01), and 13+ years (t=2.817, p<0.05). The 12+ and 14+ years groups did not significantly differ from the reference standard. Mean hip circumferences ranged from 69.36±6.42 cm (11+ years) to 88.42±10.10 cm (14+ years). Only the 11+ years group showed a significant difference (t=3.643, p<0.05), while other age groups did not differ significantly from reference standards.

Both female and male swimmers exhibited increasing waist and hip circumferences with age, consistent with normal growth patterns and sport-specific development. Female swimmers generally had smaller waist circumferences relative to reference standards, while male swimmers showed more variability across ages. Hip circumferences increased progressively but remained closer to normative values, with fewer significant deviations.

One-sample t-tests compared thigh and calf circumferences in female (N=37) and male (N=41) adolescent swimmers to age-specific standards. All female groups showed significantly smaller calf circumferences than standards (e.g., 10+: M=26.72 cm, SD=1.97 <31.4 cm, t=7.130, p<0.01; 14+: t=7.280, p<0.01), while thigh circumferences were non-significantly smaller than the reference standards (p>0.05) among all age groups of female swimmers. Males exhibited significant calf reductions in younger groups (11+: M=25.93 cm, SD=2.72 <32.0 cm, t=5.912, p <0.01; 12+: t=2.732, p <0.05), with thigh differences non-significant except a trend in 12+ (M=42.61 cm <46.0 cm, t=3.222, p <0.05).

**Table 5: Data on Leg Circumferences for Female and Male Swimmers**

| Sr. No | Age Groups (Yrs) | Thigh Circumference (cm) | | | | Calf Circumference (cm) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | M ± SD | Range | Std | t Values | M ± SD | Range | Std | t Values |
| **FEMALE SWIMMERS (N = 37)** | | | | | | | | | |
| 1 | 10+ (n=9) | **42.83** ± 4.48 | 35.50 – 49.00 | 43.1 | **0.181** | **26.72** ± 1.97 | 23.50 – 29.50 | 31.4 | **7.130**** |
| 2 | 11+ (n=8) | **43.13** ± 3.63 | 37.00 – 48.50 | 45.7 | **1.870** | **27.88** ± 2.58 | 23.00 – 30.00 | 33.1 | **5.351**** |
| 3 | 12+ (n=8) | **45.31** ± 3.82 | 40.00 – 53.00 | 46.5 | **0.941** | **28.50** ± 2.56 | 25.00 – 33.00 | 34.0 | **6.452**** |
| 4 | 13+ (n=7) | **49.64** ± 4.35 | 42.00 – 57.00 | 48.4 | **0.812** | **30.29** ± 2.64 | 25.00 – 33.00 | 35.4 | **5.471**** |
| 5 | 14+ (n=5) | **48.70** ± 3.87 | 45.00 – 56.00 | 49.0 | **0.210** | **27.80** ± 2.80 | 22.50 – 30.00 | 35.5 | **7.280**** |
| **MALE SWIMMERS (N = 41)** | | | | | | | | | |
| 1 | 10+ (n=10) | **41.35** ± 6.07 | 30.00 – 49.00 | 42.2 | **0.370** | **27.80** ± 4.98 | 22.50 – 41.00 | 30.4 | **0.387** |
| 2 | 11+ (n=7) | **43.43** ± 13.50 | 31.00 – 75.00 | 44.1 | **0.132** | **25.93** ± 2.72 | 22.00 – 30.50 | 32.0 | **5.912**** |
| 3 | 12+ (n=9) | **42.61** ± 3.160 | 38.00 – 49.00 | 46.0 | **3.222** | **30.33** ± 3.05 | 26.00 – 36.00 | 33.1 | **2.732*** |
| 4 | 13+ (n=8) | **45.56** ± 4.92 | 37.00 – 52.00 | 47.9 | **1.355** | **31.56** ± 3.73 | 25.00 – 37.50 | 34.9 | **2.533** |
| 5 | 14+ (n=7) | **50.07** ± 9.57 | 31.50 – 63.00 | 49.3 | **0.210** | **32.64** ± 3.59 | 27.50 – 38.00 | 36.1 | **2.552** |

Std-Standard; ** - Significant at both 5 % & 1% levels ($p<0.01$) i.e. $H_0$ is rejected & $H_1$ is accepted; * - Significant at 5 % level but insignificant at 1 % level ($0.01<p<0.05$) i.e. $H_0$ is rejected & $H_1$ is accepted at 5% level but $H_0$ is true & $H_1$ is rejected at 1% level; Values without any mark indicate insignificant difference at both 5% & 1% levels ($p>0.05$) i.e. $H_0$ is true & $H_1$ is rejected.

Both female and male swimmers showed a general increase in thigh and calf circumference with age. Female swimmers displayed significant enlargement of calves across all ages, suggesting sport-specific adaptations in lower limb musculature, while thigh circumference remained comparable to reference standards. Male swimmers showed modest increases, with significant differences mainly in the 12+ years group for thighs and 11–12+ years for calves.

**Table 6: Data on Upper Arm Skinfold Thicknesses for Female and Male Swimmers**

| Sr. No | Age Groups (Yrs) | Biceps (mm) | | | | Triceps (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | M ± SD | Range | Std | t Values | M ± SD | Range | Std | t Values |
| **FEMALE SWIMMERS (N = 37)** | | | | | | | | | |
| 1 | 10+ (n=9) | **10.44** ± 4.60 | 4.00 – 19.00 | 7.76 | **1.750** | **13.44** ± 5.273 | 5.00 – 25.00 | 15.4 | **1.110** |
| 2 | 11+ (n=8) | **7.50** ± 4.00 | 3.00 – 15.00 | 8.01 | **0.340** | **10.88** ± 3.059 | 6.00 – 17.00 | 15.9 | **4.340**** |
| 3 | 12+ (n=8) | **8.19** ± 3.46 | 4.00 – 13.50 | 8.19 | **0.000** | **12.88** ± 2.421 | 10.00 – 17.00 | 16.2 | **4.120**** |
| 4 | 13+ (n=7) | **13.71** ± 3.53 | 8.00 – 19.00 | 8.39 | **4.260**** | **17.29** ± 2.603 | 13.00 – 21.00 | 17.8 | **0.550** |
| 5 | 14+ (n=5) | **8.80** ± 3.71 | 5.00 – 15.00 | 8.58 | **0.160** | **15.40** ± 4.587 | 9.00 – 23.00 | 19.3 | **2.250** |
| **MALE SWIMMERS (N = 41)** | | | | | | | | | |
| 1 | 10+ (n=10) | **6.90** ± 4.48 | 2.00 – 17.00 | 6.48 | **0.250** | **11.50** ± 6.917 | 5.00 – 28.00 | 14.7 | **1.220** |
| 2 | 11+ (n=7) | **5.86** ± 1.36 | 3.00 – 7.00 | 6.30 | **0.860** | **7.86** ± 2.030 | 5.00 – 10.00 | 14.8 | **9.030**** |
| 3 | 12+ (n=9) | **6.22** ± 1.75 | 4.00 – 9.00 | 6.04 | **0.310** | **10.00** ± 4.000 | 5.00 – 20.00 | 15.7 | **4.280**** |
| 4 | 13+ (n=8) | **7.75** ± 2.73 | 4.00 – 13.00 | 5.76 | **2.060** | **11.88** ± 2.421 | 8.00 – 15.00 | 13.7 | **2.130** |
| 5 | 14+ (n=7) | **6.57** ± 3.54 | 4.00 – 15.00 | 5.55 | **0.760** | **11.57** ± 4.531 | 6.00 – 20.00 | 12.9 | **0.780** |

Std-Standard; ** - Significant at both 5 % & 1% levels ($p<0.01$) i.e. $H_0$ is rejected & $H_1$ is accepted; * - Significant at 5 % level but insignificant at 1 % level ($0.01<p<0.05$) i.e. $H_0$ is rejected & $H_1$ is accepted at 5% level but $H_0$ is true & $H_1$ is rejected at 1% level; Values without any mark indicate insignificant difference at both 5% & 1% levels ($p>0.05$) i.e. $H_0$ is true & $H_1$ is rejected.

The biceps and triceps skinfold thicknesses of female and male swimmers aged 10–14 years were compared to standard reference values using one-sample t-tests (Table 6).

Mean biceps skinfold ranged from 7.50±4.00 mm (11+ years) to 13.71±3.53 mm (13+ years) among female swimmers. Significant differences were observed in the 13+ years group (t=4.260, p<0.01), while other age groups



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did not differ significantly from reference standards. Mean triceps skinfold ranged from 10.88±3.06 mm (11+ years) to 17.29±2.60 mm (13+ years) for female swimmers. Significant differences were observed in the 11+ years (t=4.340, p<0.01) and 12+ years (t =4.120, p<0.01) groups, while other age groups showed no significant deviation from reference values.

For male swimmers, mean biceps skinfold ranged from 5.86±1.36 mm (11+ years) to 7.75±2.73 mm (13+ years). No significant differences were observed for most age groups except a marginal difference in the 13+ years group (t=2.060, p>0.05). Mean triceps skinfold ranged from 7.86±2.03 mm (11+ years) to 11.57±4.53 mm (14+ years). Significant differences were found in the 11+ years (t=9.030, p<0.01) and 12+ years (t=4.280, p<0.01) groups, indicating higher triceps fat deposition relative to reference standards.

Both female and male swimmers showed variable patterns in upper limb subcutaneous fat, with triceps skinfold generally showing more significant differences than biceps. Female swimmers exhibited higher triceps skinfold thickness than males, reflecting sex-specific differences in fat distribution during adolescence.

**Table 7: Data on Trunk Skinfold Thicknesses for Female and Male Swimmers**

| Sr. No | Age Groups (Yrs) | Subscapular (mm) | | | | Suprailiac (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | M ± SD | Range | Std | t Values | M ± SD | Range | Std | t Values |
| **FEMALE SWIMMERS (N = 37)** | | | | | | | | | |
| 1 | 10+ (n=9) | **10.11** ± 3.64 | 4.00 – 16.00 | 12.0 | **1.556** | **13.00** ± 5.54 | 3.00 – 20.00 | 9.54 | **1.873** |
| 2 | 11+ (n=8) | **9.38** ± 4.55 | 5.00 – 20.00 | 12.9 | **2.046** | **11.13** ± 3.89 | 6.00 – 18.00 | 10.43 | **0.476** |
| 3 | 12+ (n=8) | **10.13** ± 2.20 | 8.00 – 14.00 | 13.1 | **4.050**** | **11.63** ± 2.55 | 8.00 – 17.00 | 11.32 | **0.365** |
| 4 | 13+ (n=7) | **15.57** ± 5.29 | 10.00 – 26.00 | 14.2 | **0.732** | **16.86** ± 4.29 | 12.00 – 24.00 | 12.22 | **3.058** |
| 5 | 14+ (n=5) | **12.40** ± 6.80 | 5.00 – 25.00 | 15.1 | **1.051** | **13.20** ± 6.97 | 5.00 – 26.00 | 13.12 | **0.030** |
| **MALE SWIMMERS (N = 41)** | | | | | | | | | |
| 1 | 10+ (n=10) | **10.50** ± 8.02 | 3.00 – 30.00 | 11.0 | **0.165** | **10.10** ± 6.44 | 3.00 – 26.00 | 6.50 | **1.481** |
| 2 | 11+ (n=7) | **6.57** ± 1.29 | 5.00 – 9.00 | 10.9 | **8.889**** | **7.57** ± 3.20 | 4.00 – 12.00 | 6.83 | **0.613** |
| 3 | 12+ (n=9) | **14.67** ± 19.72 | 5.00 – 70.00 | 12.0 | **0.406** | **10.78** ± 4.94 | 5.00 – 22.00 | 7.16 | **2.197** |
| 4 | 13+ (n=8) | **10.50** ± 2.06 | 6.00 – 13.00 | 11.4 | **1.234** | **14.63** ± 4.61 | 6.00 – 22.00 | 7.66 | **4.272**** |
| 5 | 14+ (n=7) | **12.57** ± 5.80 | 5.00 – 25.00 | 11.0 | **0.716** | **14.71** ± 5.23 | 7.00 – 24.00 | 8.37 | **3.209** |

Std-Standard; ** - Significant at both 5 % & 1% levels (p<0.01) i.e. $H_0$ is rejected & $H_1$ is accepted; * - Significant at 5 % level but insignificant at 1 % level (0.01<p<0.05) i.e. $H_0$ is rejected & $H_1$ is accepted at 5% level but $H_0$ is true & $H_1$ is rejected at 1% level; Values without any mark indicate insignificant difference at both 5% & 1% levels (p>0.05) i.e. $H_0$ is true & $H_1$ is rejected.

One-sample t-tests compared subscapular and suprailiac skinfold thicknesses in female (N=37) and male (N=41) adolescent swimmers against age-specific standards. Among females, significant deviation occurred only in the 12+ group for subscapular skinfolds (M=10.13 mm, SD=2.20 <13.1 mm standard, t=4.050, p<0.01); other groups showed non-significant differences (e.g., 13+ suprailiac: M=16.86 mm, SD=4.29>12.22 mm, t=3.058, p>0.01).

Males exhibited significant reductions in two groups: 11+ subscapular (M=6.57 mm, SD=1.29 <10.9 mm, t=8.889, p<0.01) and 13+ suprailiac (M=14.63 mm, SD=4.61 >7.66 mm, t=4.272, p<0.01), with high variability noted in some ranges (e.g., male 12+ subscapular up to 70 mm). Subscapular and suprailiac skinfold thicknesses demonstrated age- and sex-specific variations. Female swimmers exhibited higher suprailiac thickness in mid-adolescence, while male swimmers showed greater variability in subscapular and suprailiac sites, reflecting differential fat deposition patterns.

Body composition parameters of female and male swimmers aged 10–14 years are presented in Table 8. Body density, body fat percentage, body fat mass, and lean body mass were assessed using skinfold-based equations [1, 2, 3].

Female Swimmers: Mean body density ranged from 1.0296±0.005 g/mL (13+ years) to 1.0433±0.018 mL (14+ years). The lowest density was observed in the 13+ years group, suggesting higher fat accumulation. Mean body fat ranged from 24.46±4.01% (11+ years) to 30.75±2.30% (13+ years). The highest body fat percentage occurred at

13+ years, indicating a puberty-related increase in adiposity. Body fat mass ranged from 8.15±3.10 kg (10+ years) to 13.94±3.48 kg (13+ years). Mean lean body mass ranged from 24.52±3.96 kg (10+ years) to 36.64±7.65 kg (14+ years), showing a steady increase with age.

**Table 8: Data on Body Density, Body Fat (BF) and Lean Body Mass (LBM) for Female and Male Swimmers**

| Sr. No. | Age Groups (Yrs) | Body Density (g/mL) | | Body Fat (%) | | Body Fat (kg) | | Lean Body Mass (kg) | |
|---|---|---|---|---|---|---|---|---|---|
| | | M ± SD | Range | M ± SD | Range | M ± SD | Range | M ± SD | Range |
| **FEMALE SWIMMERS (N = 37)** | | | | | | | | | |
| 1 | 10+ (n=9) | 1.0432 ± 0.016 | 1.0231 – 1.0744 | 24.57 ± 7.27 | 10.72 – 33.82 | 8.15 ± 3.10 | 3.71 – 12.27 | 24.52 ± 3.96 | 17.86 – 31.25 |
| 2 | 11+ (n=8) | 1.0433 ± 0.009 | 1.0285 – 1.0592 | 24.46 ± 4.01 | 17.33 – 31.28 | 9.18 ± 2.07 | 6.07 – 12.20 | 28.20 ± 3.52 | 20.96 – 34.26 |
| 3 | 12+ (n=8) | 1.040 ± 0.006 | 1.0324 – 1.0482 | 25.97 ± 2.50 | 22.24 – 29.47 | 10.20 ± 2.22 | 7.34 – 14.70 | 28.74 ± 3.54 | 25.35 – 36.30 |
| 4 | 13+ (n=7) | 1.0296 ± 0.005 | 1.0216 – 1.0348 | 30.75 ± 2.30 | 28.35 – 35.53 | 13.94 ± 3.48 | 8.55 – 20.03 | 30.99 ± 5.38 | 20.46 – 37.97 |
| 5 | 14+ (n=5) | 1.0424 ± 0.018 | 1.0204 – 1.0744 | 25.00 ± 8.07 | 10.72 – 35.10 | 12.16 ± 4.26 | 5.04 – 17.55 | 36.64 ± 7.65 | 28.43 – 48.96 |
| **MALE SWIMMERS (N = 41)** | | | | | | | | | |
| 1 | 10+ (n=10) | 1.0563 ± 0.017 | 1.0245 – 1.0816 | 18.73 ± 7.60 | 7.65 – 33.16 | 7.85 ± 4.24 | 1.57 – 15.69 | 24.90 ± 5.69 | 10.81 – 32.54 |
| 2 | 11+ (n=7) | 1.0612 ± 0.007 | 1.0541 – 1.0742 | 16.45 ± 2.98 | 10.81 – 19.60 | 5.25 ± 2.14 | 2.70 – 9.41 | 24.97 ± 6.03 | 17.66 – 38.60 |
| 3 | 12+ (n=9) | 1.0534 ± 0.012 | 1.0195 – 1.0711 | 19.98 ± 6.29 | 12.14 – 35.53 | 9.45 ± 4.66 | 4.25 – 19.90 | 35.72 ± 5.40 | 29.78 – 45.83 |
| 4 | 13+ (n=8) | 1.0478 ± 0.006 | 1.0390 – 1.0603 | 22.43 ± 2.74 | 16.85 – 26.42 | 11.01 ± 3.24 | 4.80 – 14.70 | 37.49 ± 9.19 | 23.70 – 48.85 |
| 5 | 14+ (n=7) | 1.0489 ± 0.011 | 1.0296 – 1.0658 | 21.96 ± 4.94 | 14.44 – 30.77 | 13.28 ± 5.21 | 4.48 – 21.54 | 44.72 ±8.57 | 26.82 – 54.09 |

Std-Standard; ** - Significant at both 5 % & 1% levels ($p<0.01$) i.e. $H_0$ is rejected & $H_1$ is accepted; * - Significant at 5 % level but insignificant at 1 % level ($0.01<p<0.05$) i.e. $H_0$ is rejected & $H_1$ is accepted at 5% level but $H_0$ is true & $H_1$ is rejected at 1% level; Values without any mark indicate insignificant difference at both 5% & 1% levels ($p>0.05$) i.e. $H_0$ is true & $H_1$ is rejected.

Male Swimmers: Body density ranged from 1.0478±0.006 mL (13+ years) to 1.0612±0.007 mL (11+ years). Lower density at 13+ years corresponds to higher fat percentage. Body fat ranged from 16.45±2.98% (11+ years) to 22.43±2.74% (13+ years). Males had generally lower body fat percentages than females across all ages. Fat mass ranged from 5.25±2.14 kg (11+ years) to 13.28±5.21 kg (14+ years). Lean body mass increased progressively with age, from 24.90±5.69 kg (10+ years) to 44.72±8.57 kg (14+ years), reflecting growth and muscle development.

Females showed higher overall body fat percentages than males, particularly at 12–13 years, reflecting sex-specific fat accumulation during puberty. Lean body mass increased with age in both sexes, but males showed a more pronounced gain, consistent with higher muscle accretion.

# DISCUSSION

Comprehensive analysis across different anthropometric domains reveals adolescent swimmers possess a specialized physique distinct from population norms, characterized by upper-body dominance and drag-minimizing leanness. Mid-upper arm circumference (MUAC) elevations (female 12+: t=6.007, p<0.01; male 13+: t=4.021, p<0.01) alongside expanded shoulder widths (female 10+: t=3.807, p<0.01; male 14+: t=3.180, p<0.01) indicate hypertrophic and skeletal adaptations optimizing stroke leverage and propulsion efficiency (Barbosa et al., 2021[25]). Conversely, consistent truncal reductions—waist circumferences universally smaller (female 10+: t=4.329, p<0.01; male 11+: t=6.064, p<0.01)—and calf circumferences (female all groups t=5.351 to 7.280, p<0.01) reflect aerobic training's fat-mobilizing effects, yielding ecto-mesomorphic somatotypes ideal for aquatic hydrodynamics [26].

**Sex- and Maturation-Specific Patterns**

The robust increases in MUAC and shoulder breadth particularly reflect enhanced development of the upper limb musculature, essential for propulsive efficiency in swimming [13]. The discrepancy between male and female increases becomes more pronounced beyond age 12, indicating the onset of puberty-mediated divergence. Sex-dimorphic trajectories emerged: females exhibited progressive body fat accrual peaking at 13+ years (30.75±2.30%) with preserved gluteal-femoral depots, while males maintained lower adiposity (16.45-22.43%) and superior lean body mass (14+: 44.72±8.57 kg), reflecting androgen-mediated partitioning [10]. Skinfold patterns varied regionally—triceps reductions in younger cohorts (male 11+: t=9.030, p<0.01) versus biceps preservation in female 13+ (t=4.260, p<0.01)—suggesting stroke-specific subcutaneous remodeling. Height advantages during peak velocity phases (female 11+: $t=3.618$, $p<0.01$; male 12+: $t=5.52$, $p<0.01$) without excess weight accrual indicate nutritional optimization supporting linear growth absent in sedentary controls [27].

**Increasing Sexual Dimorphism after Age 12:**
The data clearly demonstrate that sex differences intensify with advancing age. Males surpass females in height, shoulder width, MUAC, thigh circumference, and lean body mass from age 12 onward. These patterns parallel the testosterone-induced muscular hypertrophy, skeletal broadening, and reductions in relative fat mass typical of male pubertal development [11, 28]. By contrast, females show increases in triceps, subscapular, and suprailiac skinfolds—sites most responsive to estrogen-driven fat deposition. Lean body mass values accentuate this divergence: males reach 44.7 kg at age 14, compared with 36.6 kg in females, while female fat percentage remains markedly higher (25–31% versus 16–22% in males). These findings are in accordance with literature documenting widening sex-related differences in body composition across early adolescence [10, 16].

**Evidence of Training-Related Morphological Adaptations:**
The consistent presence of significant t-values for MUAC, waist circumference, and calf girth in multiple age groups indicates clear deviations from non-athlete reference standards. This suggests that repeated exposure to swim training elicits specific musculoskeletal adaptations even before full biological maturation is achieved. Like, females exhibited significant calf girth differences at all age groups, reflecting enhanced development of plantar flexors due to repeated kicking. Males demonstrated significant calf girth differences from 11+ to 14+, highlighting progressive lower-limb muscular development. These findings align with reports that adolescent swimmers exhibit elevated limb girths and reduced adiposity compared to non-athletes [29].

**Skinfold Pattern Reflects Adiposity Trajectories Associated with Puberty:**
Female swimmers demonstrated substantially higher triceps, suprailiac, and subscapular values than males, reflecting typical female fat distribution. Significant differences in female triceps and male suprailiac values at specific ages highlight critical windows where adiposity shifts occur. These patterns reinforce the differential hormonal pathways influencing fat accumulation in boys and girls [11, 16].

**Body Composition Trends Indicate Sex-Specific Performance Advantages:**
Body density and lean body mass favored males across all age groups. Higher lean mass and lower fat mass in boys correspond with enhanced propulsive force generation, buoyancy control, and anaerobic capacity [30]. Conversely, moderately elevated fat stores in females may enhance buoyancy but can moderate power output. These dynamics reflect recognized sex-specific performance tendencies in adolescent swimmers.

**Performance Correlates and Hydrodynamic Implications**
These morphological signatures confer measurable competitive edges: biacromial expansions enhance pull-phase torque, reduced waist/lower leg girths minimize drag coefficients, and elevated MUAC optimizes oar-like arm function [22]. The sole non-significant male 14+ MUAC ($t=1.818$) and female 13+ shoulders ($t=0.806$) suggest maturation convergence toward adult norms, though persistent significances across 80% of comparisons affirm swimmer-specificity [33].

**Alignment with Existing Literature:**
The findings of the present study are congruent with earlier reports showing:
Swimmers possess greater muscularity and lower adiposity relative to untrained peers [33]; Sex-related anthropometric divergence accelerates during early adolescence due to differential endocrine profiles [10, 34] and Limb girths and body composition indices are predictive of swimming performance potential [13, 35, 36]. Thus, the study reinforces the role of biological maturation and regular training in shaping anthropometric profiles.

## CONCLUSIONS

Adolescent swimmers demonstrate a specialized anthropometric profile characterized by enhanced upper-body dimensions (elevated MUAC, broader shoulders), reduced truncal and calf girths, and optimized lean mass relative to population norms, conferring hydrodynamic advantages for propulsion and drag reduction. Sex-specific patterns—progressive fat accrual in females versus male muscularity—interact with maturation to produce ecto-mesomorphic somatotypes ideal for competitive swimming, with 80% of comparisons achieving statistical significance. These morphological adaptations likely arise from combined genetic selection and training stimuli, supporting taller statures during growth spurts without excess adiposity, thus preserving power-to-weight ratios essential for performance. Such profiles hold prognostic value for talent identification, particularly biacromial width and regional skinfold reductions correlating with stroke efficiency. Cross-sectional limitations necessitate longitudinal validation with controls, precise maturity assessments, and effect sizes to delineate causality and generalizability. Kinanthropometric screening could enhance swimmer development programs, emphasizing individualized nutrition and stroke mechanics tailored to these distinctive physiques.

The study confirms that significant age- and gender-related differences exist in the anthropometric characteristics of competitive youth swimmers. Growth patterns were evident across all variables, with substantial increases in height, weight, MUAC, trunk and leg circumferences, and lean body mass from ages 10 to 14 years. Gender disparities became pronounced after age 12, with male swimmers demonstrating higher lean body mass, greater shoulder width, and lower body fat percentages, while females exhibited higher skinfold thickness and fat mass consistent with normal pubertal physiology.

These findings indicate that adolescent swimmers undergo predictable growth and training adaptations, but biological maturity strongly influences anthropometric outcomes. Such differences must be considered in coaching, training progression, and talent identification.

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