J Musculoskelet Neuronal Interact 2024; 24(3):243-258

Journal of Musculoskeletal and Neuronal Interactions JMNI

Original Article

Gender-specific Indian Paediatric and Adult Reference Data for Muscle Function Parameters Assessed Using Jumping Mechanography

Sonal Kasture[1,2], Vaman Khadilkar[1,2], Vivek Patwardhan[1], Anuradha Khadilkar[1,2]

[1]Department of Growth and Paediatric Endocrinology, Hirabai Cowasji Jehangir Medical Research Institute, Jehangir Hospital, Pune, Maharashtra, India;
[2]School of Health Sciences, Savitribai Phule Pune University, Pune, Maharashtra, India

Abstract

Objective: To establish age and gender-specific paediatric and adult reference data for muscle function parameters assessed using Jumping Mechanography in the Indian population. **Methods**: 2056 healthy individuals (1068 males), aged 5 to 60 years, performed 2 tests on a force platform (Leonardo Mechanograph, Novotec). Maximum power (Pmax) was assessed by single two legged jump and maximum force (Fmax) by multiple one legged hopping. LMS method was used to generate age and gender-specific reference curves for 5 – 20y group and mean ± SD and median ± IQR are presented for 21 – 60y group. **Results**: In 5 – 20y group, Pmax and Fmax increased with age while in 21 – 60y group, the parameters declined with age. Females had lower Pmax values than males, consistently through all age groups. In children <15y, there were no intergender differences in Fmax, however, in further age groups, females had lower Fmax ($p<0.001$). Our participants showed lower Pmax and Fmax when compared with machine reference data based on German population ($p<0.001$). **Conclusion**: We present ethnicity-specific reference values for muscle function by Jumping Mechanography. These values are intended to help in clinical assessment of muscle function of Indian population and to identify those at risk of poor muscle function.

Keywords: India, Jumping Mechanography, Muscle Force, Muscle Power, Reference Values

Introduction

The significance of muscle function in both daily activities and exercise performance across one's entire life is widely acknowledged[1]. Moreover, muscle function plays a critical role in determining the risk of numerous lifestyle disorders, osteoporosis and sarcopenia[2]. While the importance of muscle function is thoroughly established, there is a lack of standardized techniques for its quantitative measurement. Muscle mass is often used as a proxy for muscle function; however, research indicates that functional capacity can be modified without concurrent changes in muscle mass in prepubertal children and older populations[3–5]. The most commonly used method for evaluating measurable muscle function involves using dynamometry to measure hand grip force. Also, a few reference datasets for grip strength in children, adolescents and adults are available[6–9]. However, its applicability is limited as it solely measures isometric force at a non-weight-bearing part of the body[10].

Current literature highlights differences in muscle function across diverse ethnic groups. Additionally, there are ethnic differences in the magnitude of negative associations of muscle function with age in adults[11–16]. A study conducted in the United States of America on an ethnically diverse

Sonal Kasture was funded by a Fellowship Grant from University Grants Commission, Government of India. UGC-Ref. No.: 1070/(NET-JULY 2016). The remaining authors have nothing to declare.

Corresponding author: Anuradha Khadilkar, Department of Growth and Paediatric Endocrinology, Hirabai Cowasji Jehangir Medical Research Institute, Jehangir Hospital, Pune, Maharashtra, 411001, India School of Health Sciences, Savitribai Phule University, Pune, Maharashtra, 411007, India
E-mail: anuradhavkhadilkar@gmail.com
dr.anuradha.khadilkar@hcjmri.org.in

Edited by: G. Lyritis
Accepted 17 April 2024

population of older adults has shown that Asians with lower muscle strength were at a higher risk of functional limitations compared to their other ethnic counterparts[17]. Furthermore, studies on grip strength have shown developing countries have substantially lower muscle strength across the life course, than developed countries[18]. These findings emphasize the need for an ethnicity-specific reference database to precisely characterize muscle function.

Innovative approaches, such as portable ground reaction force plates, show promise in assessing dynamic muscle function through different testing procedures. Jumping Mechanography specifically assesses muscle force and power by analysing measurements derived from an individual's ground reaction forces. It also demonstrates reliability and accuracy in evaluating muscle function in both, healthy children[19–21] and those with clinical needs[22–26]. Similarly, it has been shown to be effective in the diagnosis of sarcopenia, prediction of falls, and understanding bone health and mobility in older adults[5,27,28]. Yet, no reference database is available for the clinical assessment of muscle function status of Indian population. Hence, the aim of our study was to establish gender specific paediatric and adult reference data for muscle function parameters assessed using Jumping Mechanography.

Methods

Study Design and Participants

Two separate cross-sectional studies were designed for 2 age groups to generate age and gender-specific reference data for muscle function parameters. The 2 age groups defined were 5 – 20 years and 21 – 60 years. A random sample of 40 healthy boys and 40 healthy girls for each year from 5y to 20y (total n=1200) and 40 men and 40 women for each decade from 21y to 60y (total n=320) was planned to be recruited by stratified sampling method. Consequently, the projected total sample size for the entire study was 1520, encompassing all age groups.

The participants for the 5y – 20y group were recruited from 5 schools and 2 colleges in Pune city, Maharashtra state in Western India. The schools and colleges catered to upper and upper-middle socioeconomic classes[29,30]. Principals of 6 schools and 3 colleges were approached and explained the details of the study. Five schools and 2 colleges gave permission to conduct the study. A letter with information about the study was given to the students to give to the parents. During parents-teachers' meetings, details about the procedures involved in the study were explained to the parents and children and doubts, if any, were cleared. Children who voluntarily agreed to participate were included in the study. An informed written consent was obtained from parents and an assent from children before conducting the measurements. A total of 1703 children and adolescents agreed to participate in the study. Based on the inclusion and exclusion criteria (details given below), a total of 1670 children and adolescents (842 boys, 828 girls) were included in the final analyses.

For the 21y – 60y group, staff and teachers working in the schools and colleges that had agreed to take part in the study were approached for the study. Parents of the children and adolescents enrolled in the paediatric study were also invited to take part. Additionally, we visited 2 banks, 3 private offices, and 2 housing complexes and explained the study procedure. People who voluntarily agreed to take part in the study were included. Informed written consent was obtained from all the adults. A total of 427 adults consented to participate. As per the inclusion and exclusion criteria, 386 adults (226 males, 160 females) were included in the study.

All healthy and physically active individuals belonging to the upper middle class (so that they had adequate access to nutrition and healthcare) based on the monthly income of the family[31], were offered the study. All subjects were assessed by a physician/paediatrician to confirm that they were healthy; medical records were reviewed. Children and adolescents having height or weight below 3rd or above 97th percentile according to Indian reference data[32], adults having Body Mass Index (BMI) below 18 kg/m^2 (underweight) or above 25 kg/m^2 (obese)[33], individuals who had prolonged periods of immobilization in the past 12 months or those who suffered from chronic systemic illnesses were excluded from the study. Those consuming vitamin D or any other drug known to affect bone or muscle health were also excluded. Adults above 40 years were first evaluated for osteoporosis through a DXA (Dual energy X-ray Absorptiometry) scan of the spine. The ones diagnosed to have osteoporosis (T score ≤ -2.5) were excluded and referred to a specialist for further treatment.

Of the 1703 children and adolescents who had agreed to participate, 11 children were excluded as they had weight below the 3rd centile, and 20 were excluded as they had weight above the 97th centile. One child was suffering from epilepsy and one child met with an accident and was injured, after the consenting but before the assessment. Thus, a total of 1670 healthy children and adolescents (842 males, 828 females) were included in the final analyses. For the adult reference database, out of the 427 who had consented, 20 were excluded for having BMI >25 kg/m^2, 5 individuals had BMI <18 kg/m^2 and hence were excluded, 7 individuals were excluded as they were diagnosed to have osteoporosis and 9 people were suffering from chronic Type 2 diabetes mellitus. Hence, 386 healthy adults (226 males, 160 females) free from any medical illnesses were included in the study. The participant flow is illustrated in Figure 1.

Data were collected from July 2018 to June 2021. All the measurements were performed on the same day for each participant. Data were collected under similar conditions at 2 locations: (a) On-site: We visited 3 schools for data collection. (b) At the research institute: Children and adolescents from remaining 2 schools and colleges were called to the research institute for the assessments by appointment. All the adults were called with prior appointments to the research institute for the measurements.

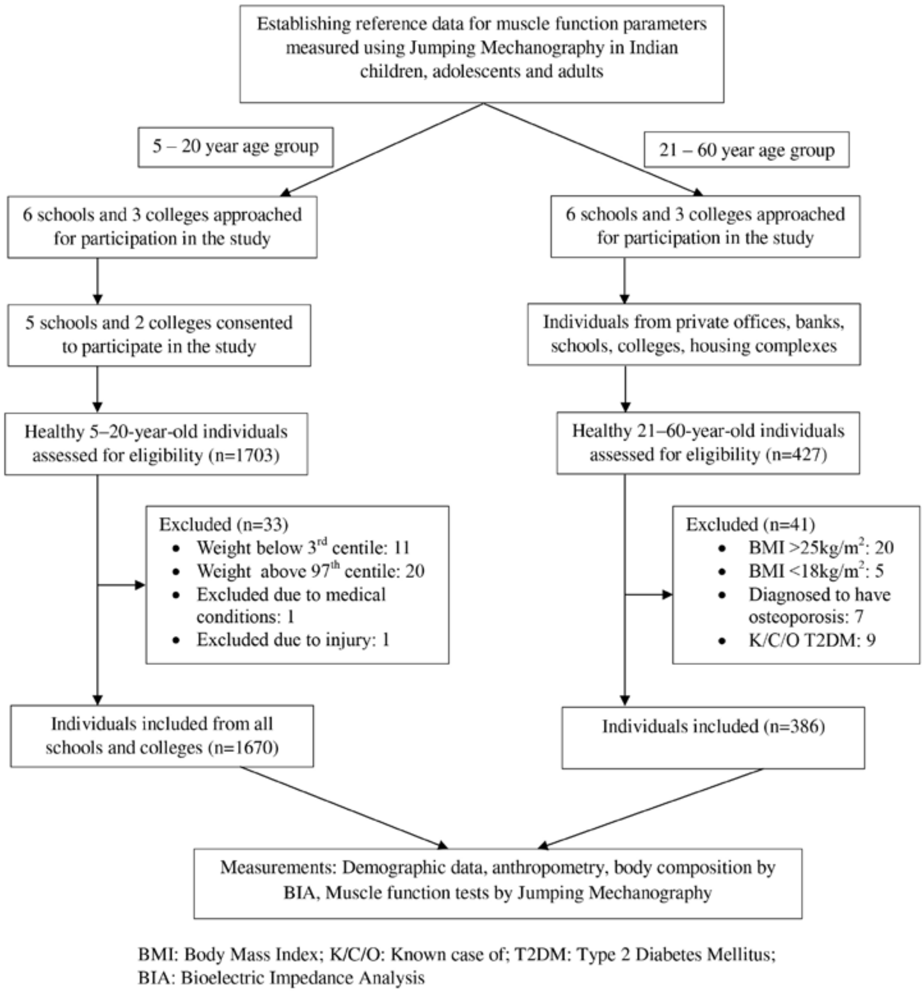

Figure 1. Participant Flow Diagram.

Table 1. Anthropometric and body composition characteristics of the 5y – 20y group.

Parameter	Boys (842)	Girls (828)	Total (1670)
Age (y)	12.0 ± 3.7	11.9 ± 3.8	11.9 ± 3.8
Height (cm)	144.6 ± 19.6	140.1 ± 16.2 [a]	142.4 ± 18.1
HAZ#	−0.2 ± 0.9	−0.2 ± 0.9	−0.2 ± 0.9
Weight (kg)	38.4 ± 16.9	35.2 ± 13.4 [a]	36.8 ± 15.4
WAZ#	−0.3 ± 1.0	−0.3 ± 0.9	−0.3 ± 1.0
BMI (kg/m^2)	17.4 ± 3.9	17.2 ± 3.7	17.3 ± 3.8
BAZ#	−0.3 ± 1.0	−0.3 ± 1.0	−0.3 ± 1.0
Fat%	14.0 ± 10.1	20.6 ± 9.4 [a]	17.3 ± 10.3
Fat% Z-score#	−0.5 ± 1.1	−0.3 ± 1.0 [a]	−0.4 ± 1.0
MM%	81.8 ± 9.9	75.2 ± 9.5 [a]	78.5 ± 10.2
MM% Z-score#	0.4 ± 1.0	0.3 ± 0.9 [a]	0.3 ± 1.0
Muscle: Fat	11.4 ± 10.0	5.3 ± 4.6 [a]	8.4 ± 8.4

All values are mean ± SD. [a]Significantly different than boys (p<0.001). #Z-scores are calculated for participants upto 18y of age. HAZ: Height for age Z-score; WAZ: Weight for age Z-score; BMI: Body mass index; BAZ: BMI for age Z-score; Fat%: Fat percentage; Fat% Z-score: Fat percentage Z-score; MM%: Muscle mass percentage; MM% Z-score: Muscle mass percentage Z-score.

Anthropometry and body composition

Standing height was measured for all participants, using a portable stadiometer (Seca 213 Portable Stadiometer, Germany). Body mass and composition (fat percentage, fat mass, fat free mass, bone free lean tissue mass (muscle mass) and total body water) were measured using the bioelectrical impedance analysis (BIA) method (Tanita Body Composition Analyzer (Model BC-420MA)).

Body mass index (BMI) was calculated by dividing the weight in kilograms by height in meters squared. The Z-scores for height for age (HAZ), weight for age (WAZ), BMI for age (BAZ), muscle percentage and fat percentage for age were computed using Indian growth references[32,34] for the paediatric age group.

Muscle function by Jumping Mechanography

The assessment of dynamic muscle function was performed by the Leonardo Mechanograph Ground Reaction Force Plate (Novotec Medical, Pforzheim, Germany). The software provided by the manufacturer (Leonardo Mechanography GRFP version 4.4, Novotec, Pforzheim, Germany) was used for the detection, storage and calculation of the outcomes. Each participant performed 2 types of jumps: single 2 legged jump (s2LJ) and multiple 1 legged hopping (m1LH). Participants were requested to perform each type of jump thrice and the jump with the highest outcome (Pmax for s2LJ and Fmax for m1LH) was selected for subsequent analyses.

Single 2-legged jump (s2LJ)

The jump was performed as a counter-movement jump (the participants briefly squatted before jumping) with freely moving arms. The main outcomes of interest for the s2LJ are the maximum power (Pmax, kW) and maximum power relative to body mass (Pmax/kg, Watt/kg). Maximum velocity (Vmax, m/s) and maximum jump height (Hmax, in m) were used for generating reference centile curves. A new variable, the Nerve – Muscle Index (NMI), was computed to evaluate the jump efficiency[35]. It was defined as the ratio of maximum velocity to relative force (Vmax/(Fmax/BW)) derived from s2LJ.

Multiple 1-legged hopping (m1LH)

The participant was instructed to jump repeatedly (approximately fifteen jumps), as fast as possible on the forefoot of their dominant leg, with freely moving arms. Any repetition with heel contact were excluded from the analysis by the manufacturer's software. The maximum voluntary force (Fmax, kN) and maximum relative force i.e. Fmax normalized to body weight (Fmax/BW) were the main outcome variables for m1LH.

Statistical analysis

Before statistical analyses, all the study parameters were tested for normality. All results have been expressed as mean ± standard deviation. Descriptive statistics were used to describe the characteristics of the participants. Student's t-test was used to test the differences between genders at each age group. Significance level was set at $p<0.05$.

For the 5 – 20 years age group, LMS chart maker 2005 software was used for computing age and gender specific percentile curves for Pmax, Pmax/kg, Fmax, Fmax/BW, Vmax, Hmax and NMI (LMS chartmaker Pro version 2.4, 2008). The LMS (Lambda Mu Sigma) method constructs reference percentiles adjusted for skewness and the variable of interest is summarized by three smooth curves plotted against age, representing the median (M), coefficient of variation (S), and skewness (L) of the measurement distribution[36]. The models were checked using the detrended Q–Q plot, Q tests, and worm plots[37] for goodness of fit.

Thus, gender-specific reference plots showing the 5th, 25th, 50th, 75th and 95th percentiles were computed using the LMS method.

For the 21 – 60 years age group, independent sample t-test was performed to test the differences in muscle function parameters between different age groups and between the two genders. Correlation analyses were performed to test for the association between age, body composition and muscle function parameters.

Results

The results of the 2 age groups, 5 – 20y and 21 – 60y, are presented separately.

5 – 20years age group

Muscle function parameters of children, adolescents and youth from 5 – 20 years with mean age of 11.9 ± 3.8 years are presented. The anthropometric and body composition parameters and s2LJ results are available on the whole group of 1670 (842 males, 828 females) participants while results of m1LH are available on 1563 (793 males, 770 females) participants from the same group who did not differ in any anthropometric or body composition parameters. The number of participants in the 19 and 20 year age groups were low, hence for the convinenince of analyses, these 2 groups were amalgamated and presented as 19+ in further results.

The mean height for age Z-score (HAZ), weight for age Z-score (WAZ) and BMI for age Z-score (BAZ) were calculated based on Indian growth references[32] for the children and adolescents below 18 years of age. The mean HAZ, WAZ and BAZ were close to zero and the SD were close to 1 at most age gender groups in comparison with Indian reference growth data[32]. The mean BMI of the participants above 18 years in this age group was 21.8 ± 2.9 kg/m^2 for males and 21.8 ± 2.7 kg/m^2 for females.

The anthropometric and body composition characteristics of the study population are presented in Table 1.

The close to zero Z-scores of anthropometric and body composition values indicate that the study cohort was on par

Table 2. Muscle function parameters of boys and girls during single 2 legged jump (s2LJ).

Age (years)	Pmax (kW)		Pmax/mass (W/kg)	
	Boys (N=842)	Girls (N=828)	Boys	Girls
5+	0.50 ± 0.3 (40)	0.47 ± 0.2 (43)	28.40 ± 4.8	26.21 ± 4.5 [a]
6+	0.66 ± 0.3 (40)	0.52 ± 0.1 (40) [a]	30.29 ± 4.6	27.70 ± 4.6 [a]
7+	0.76 ± 0.2 (40)	0.60 ± 0.1 (53) [a]	32.15 ± 5.1	28.44 ± 4.2 [a]
8+	0.87 ± 0.5 (42)	0.72 ± 0.2 (70) [a]	32.88 ± 5.9	29.43 ± 5.9 [a]
9+	0.97 ± 0.3 (121)	0.87 ± 0.2 (102) [a]	33.67 ± 5.4	30.62 ± 5.1 [a]
10+	1.12 ± 0.3 (121)	1.08 ± 0.4 (96)	33.96 ± 5.4	31.56 ± 5.3 [a]
11+	1.26 ± 0.3 (62)	1.32 ± 0.3 (66)	36.03 ± 5.3	34.08 ± 5.3 [a]
12+	1.53 ± 0.4 (61)	1.48 ± 0.4 (57)	37.61 ± 7.0	34.53 ± 5.9 [a]
13+	1.82 ± 0.6 (55)	1.54 ± 0.3 (55) [a]	40.27 ± 7.3	34.70 ± 6.3 [a]
14+	2.21 ± 0.5 (50)	1.60 ± 0.4 (42) [a]	44.91 ± 8.1	33.99 ± 7.1 [a]
15+	2.61 ± 0.6 (62)	1.76 ± 0.4 (59) [a]	46.80 ± 7.0	36.62 ± 6.6 [a]
16+	2.57 ± 0.5 (43)	1.75 ± 0.3 (42) [a]	45.16 ± 6.0	35.21 ± 5.1 [a]
17+	2.97 ± 0.7 (42)	1.70 ± 0.3 (42) [a]	46.40 ± 7.9	34.28 ± 5.5 [a]
18+	2.99 ± 0.6 (36)	1.79 ± 0.3 (28) [a]	47.80 ± 7.8	33.33 ± 5.4 [a]
19+	3.04 ± 0.5 (27)	1.78 ± 0.2 (33)	48.02 ± 6.3	32.27 ± 5.8 [a]

[a] Significantly lower than boys ($p<0.001$). The number of individuals is presented in parentheses and is not different between Pmax and Pmax/kg.

Table 3. Muscle function parameters of boys and girls during multiple one legged hopping (m1LH).

Age (years)	Fmax (kN)		Fmax/BW	
	Boys (N=793)	Girls (N=770)	Boys	Girls
5+	0.50 ± 0.2 (20)	0.50 ± 0.2 (27)	2.82 ± 0.3	2.76 ± 0.3
6+	0.59 ± 0.3 (29)	0.53 ± 0.1 (27)	2.77 ± 0.3	2.87 ± 0.3
7+	0.63 ± 0.2 (29)	0.57 ± 0.1 (46) [a]	2.92 ± 0.3	2.81 ± 0.3
8+	0.72 ± 0.3 (40)	0.69 ± 0.2 (65)	2.91 ± 0.3	2.91 ± 0.3
9+	0.79 ± 0.2 (121)	0.78 ± 0.2 (99)	2.85 ± 0.3	2.86 ± 0.3
10+	0.88 ± 0.2 (121)	0.90 ± 0.2 (94)	2.74 ± 0.3	2.80 ± 0.3
11+	0.95 ± 0.2 (62)	1.01 ± 0.2 (63)	2.81 ± 0.3	2.70 ± 0.3
12+	1.10 ± 0.2 (61)	1.14 ± 0.2 (57)	2.77 ± 0.3	2.68 ± 0.3
13+	1.21 ± 0.3 (55)	1.16 ± 0.2 (52)	2.72 ± 0.3	2.69 ± 0.2
14+	1.31 ± 0.3 (48)	1.23 ± 0.2 (42)	2.75 ± 0.3	2.73 ± 0.3
15+	1.54 ± 0.3 (62)	1.27 ± 0.2 (57) [a]	2.84 ± 0.3	2.76 ± 0.3
16+	1.57 ± 0.3 (42)	1.29 ± 0.2 (41) [a]	2.81 ± 0.3	2.69 ± 0.2 [a]
17+	1.71 ± 0.3 (40)	1.27 ± 0.2 (40) [a]	2.83 ± 0.3	2.66 ± 0.3 [a]
18+	1.68 ± 0.2 (36)	1.31 ± 0.2 (27) [a]	2.76 ± 0.4	2.60 ± 0.2 [a]
19+	1.75 ± 0.2 (27)	1.28 ± 0.2 (33) [a]	2.83 ± 0.3	2.49 ± 0.2 [a]

[a] Significantly lower than boys ($p<0.001$). The number of individuals is presented in parentheses and is not different between Fmax and Fmax/BW.

with the Indian reference healthy population.

The age and gender specific mean ± SD values of maximum power (Pmax), maximum relative power- Pmax/body mass (Pmax/kg), maximum voluntary force (Fmax) and maximum relative force- Fmax/body weight (Fmax/BW) of the study population are presented in Tables 2 and 3, respectively. Females were seen to have consistently lower values of Pmax and Pmax/kg at most age groups, as compared to males

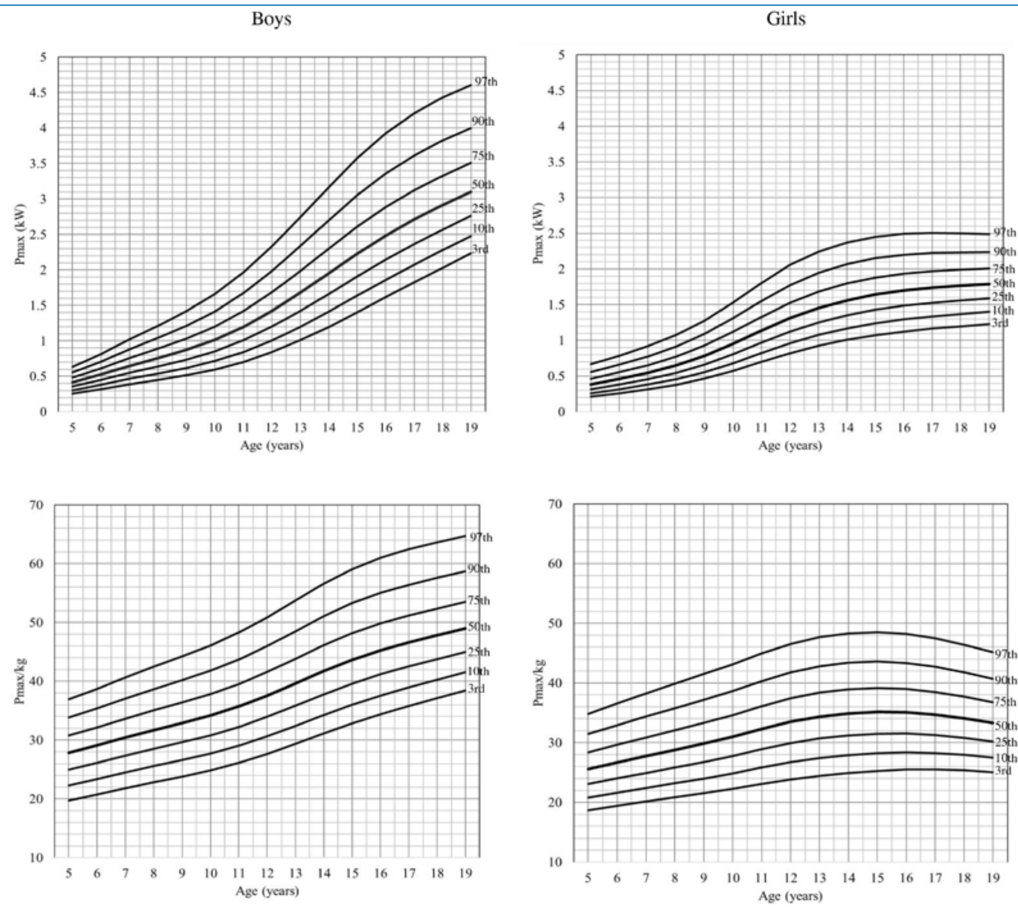

Figure 2. Age dependent smoothened percentile graphs for Pmax and Pmax/kg.

Table 4. Nerve Muscle Index (NMI) of boys and girls.

Age (years)	NMI (m/s)	
	Boys (N=842)	Girls (N=828)
5+	0.68 ± 0.1	0.65 ± 0.1
6+	0.78 ± 0.2	0.72 ± 0.2
7+	0.86 ± 0.2	0.82 ± 0.2
8+	0.87 ± 0.1	0.86 ± 0.2
9+	0.94 ± 0.1	0.91 ± 0.1
10+	0.94 ± 0.2	0.92 ± 0.1
11+	0.98 ± 0.1	0.95 ± 0.2
12+	0.97 ± 0.1	0.95 ± 0.2
13+	1.03 ± 0.2	0.94 ± 0.1 [a]
14+	1.07 ± 0.2	0.94 ± 0.2 [a]
15+	1.03 ± 0.2	0.90 ± 0.2 [a]
16+	1.03 ± 0.1	0.91 ± 0.2 [a]
17+	1.04 ± 0.2	0.90 ± 0.1 [a]
18+	1.01 ± 0.2	0.83 ± 0.1 [a]
19+	0.94 ± 0.2	0.82 ± 0.1

[a] *Significantly lower than boys (p<0.001).*

(p<0.001). No gender differences were found from age 5 to 14 years, in Fmax and Fmax/BW (p>0.001), however, after 15 years of age, females had significantly lower Fmax and Fmax/BW than males (p<0.001). The mean Vmax of the study group was 2.1 ± 0.3 m/s (males: 2.2 ± 0.3 m/s, females: 1.9 ± 0.2 m/s). The mean Hmax was observed to be 0.3 ± 0.1 m (males: 0.32 ± 0.1 m, females: 0.3 ± 0.1 m).

The mean NMI of the study population was 0.9 ± 0.2 m/s (males: 1.0 ± 0.2 m/s, females: 0.9 ± 0.2 m/s). Age and gender specific mean ± SD values of NMI are presented in Table 4. No gender differences were found from age 5 to 12 years in NMI (p>0.001), however, after 13 years of age, females had significantly lower NMI than males (p<0.001).

Further, the correlations between muscle mass percentage and Pmax/kg and Fmax/BW were examined. A significant positive correlation was observed between Fmax/BW and muscle mass percentage in both the genders (males r = 0.4, females r = 0.4, p<0.001 for all). However, no significant correlation was found between Pmax/kg and muscle mass percentage in either boys or girls. Similar correlations were observed between muscle/fat ratio and Fmax/BW in both the genders (males r = 0.3, females r = 0.3, p<0.001 for all).

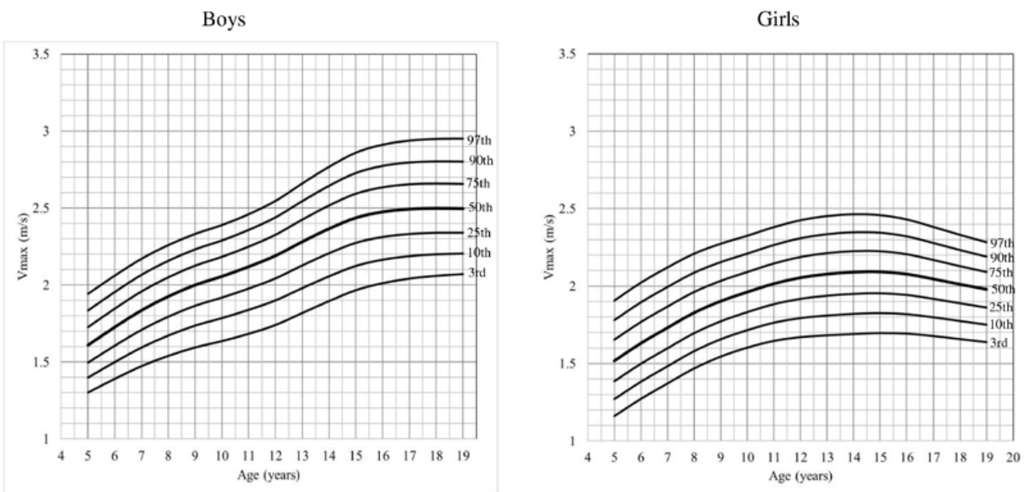

Figure 3. Age dependent smoothened percentile graphs for Vmax.

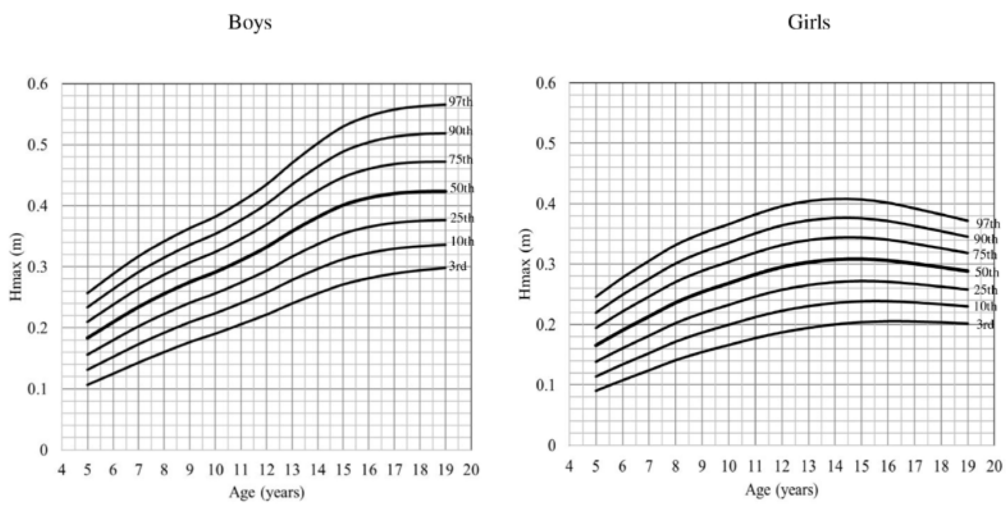

Figure 4. Age dependent smoothened percentile graphs for Hmax.

Additionally, a weak positive correlation was noticed between the Pmax/kg and muscle/fat ratio in males and females (males r = 0.2, females r = 0.1, $p<0.001$ for all).

Reference Percentile Curves

Data were further analysed to produce reference percentile curves for assessing muscle function status in Indian children and adolescents.

Results are presented separately for boys and girls. The age dependent reference curves for Pmax, Pmax/kg, Vmax, Hmax and NMI are obtained from s2LJ, and for Fmax and Fmax/BW are obtained from m1LH.

Age dependent smoothed reference percentile curves for Pmax and Pmax/kg for boys and girls are presented in Figure 2, for Vmax in Figure 3, Hmax in Figure 4, NMI in Figure 5. and for those of Fmax and Fmax/BW are presented in Figure 6.

The reference curves for Pmax showed a clear flattening around 13-14 years in girls which is in contrast to in boys, in whom Pmax continued to increase with age. Similarly, the Pmax/kg reference curves showed a rise with age till 17 years in boys, whereas in girls, the curves presented a downwards

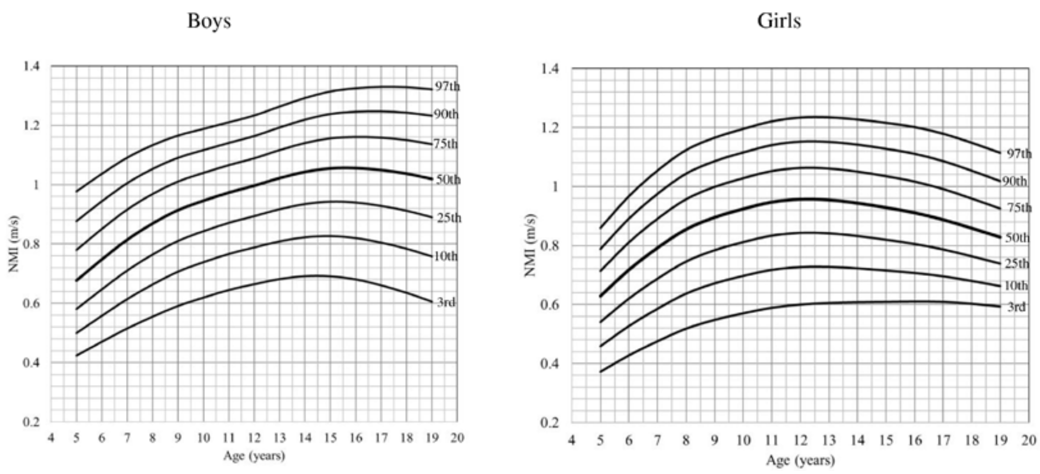

Figure 5. Age dependent smoothened percentile graphs for NMI.

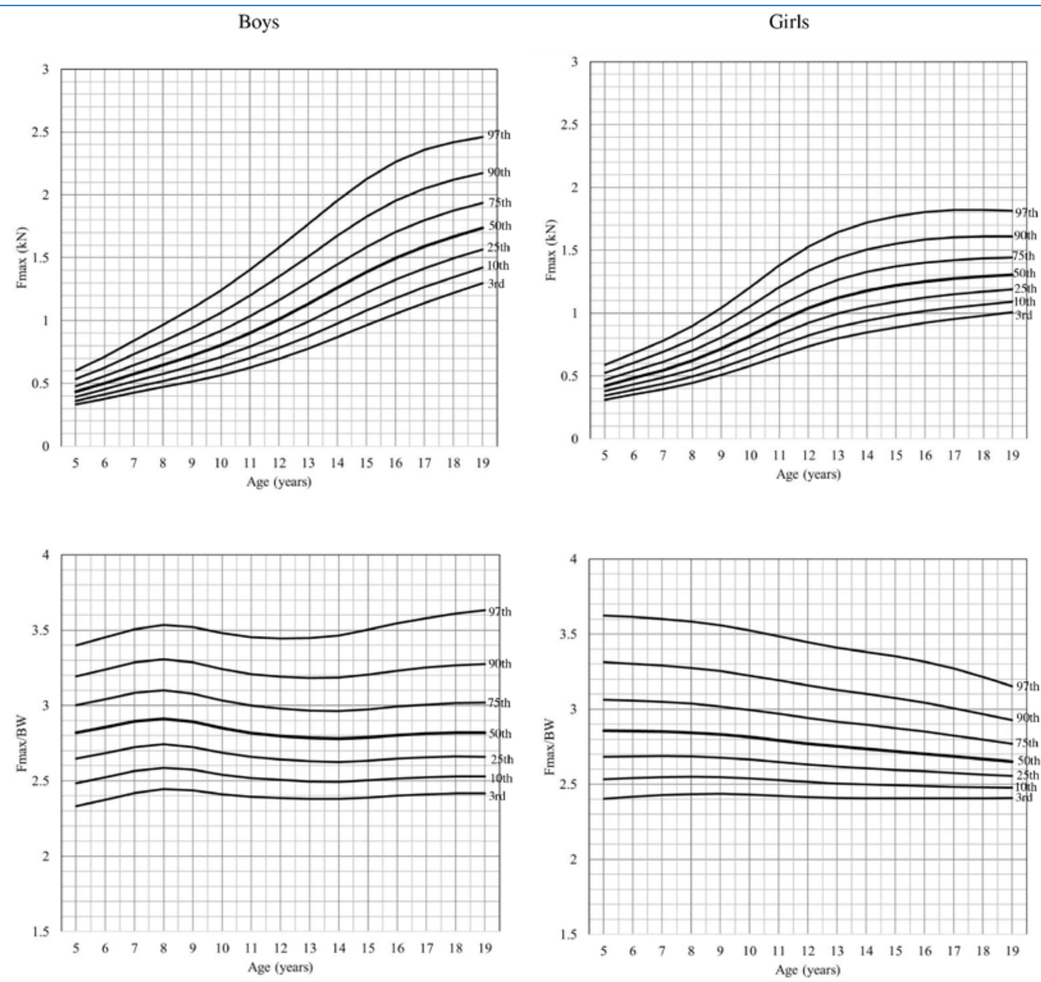

Figure 6. Age dependent smoothened percentile graphs for Fmax and Fmax/BW.

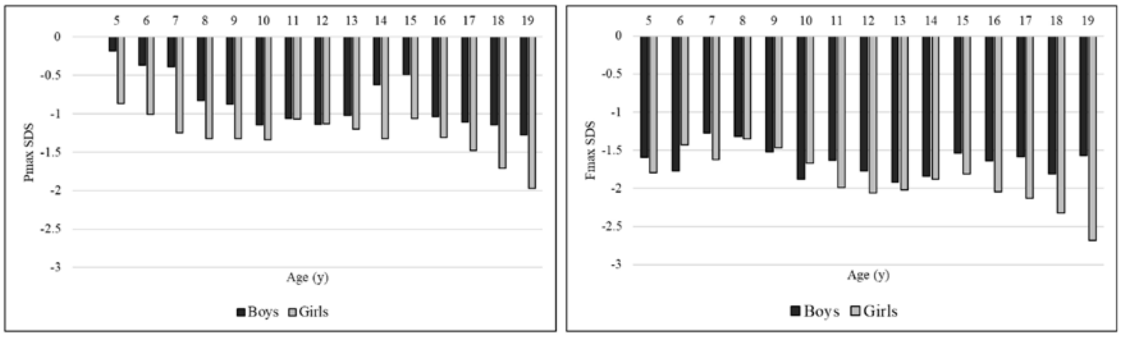

Figure 7. Age wise Pmax SDS and Fmax SDS in boys and girls.

Table 5. Anthropometric and body composition parameters of the adults.

Age group	21-30 y		31-40 y		41-50 y		51-60 y	
Gender (N)	Males (75)	Females (40)	Males (40)	Females (40)	Males (61)	Females (40)	Males (50)	Females (40)
Age (y)	24.4 ± 2.6	24.1 ± 2.5	34.2 ± 3.5	35.3 ± 2.9	44.4 ± 2.8	44.0 ± 3.0	56.4 ± 4.8	54.1 ± 4.4
Height (cm)	170.9 ± 7.0	157.7 ± 6.4[a]	169.8 ± 6.0	154.3 ± 6.6[a]	170.1 ± 6.0	155.0 ± 6.8[a]	166.3 ± 5.1	152.7 ± 5.7[a]
Weight (kg)	70.4 ± 13.4	57.1 ± 9.1[a]	72.2 ± 10.4	60.4 ± 12.8[a]	74.0 ± 11.4	63.0 ± 10.5[a]	73.9 ± 9.0	59.9 ± 7.2a
BMI (kg/m^2)	21.8 ± 2.3	21.2 ± 2.2	22.5 ± 2.6	21.2 ± 2.2	22.5 ± 1.9	22.1 ± 2.8	23.4 ± 1.6	23.1 ± 1.4
Fat%	21.5 ± 4.5	31.0 ± 6.7[a]	23.4 ± 4.1	34.4 ± 5.8[a]	23.1 ± 5.2	37.2 ± 4.5[a]	25.9 ± 3.9	36.9 ± 3.1[a]
MM%	74.4 ± 4.2	65.1 ± 6.4[a]	72.7 ± 3.9	61.7 ± 5.5[a]	72.6 ± 4.3	58.2 ± 5.0[a]	69.9 ± 4.7	59.2 ± 2.9[a]
Muscle: Fat	3.7 ± 1.2	2.3 ± 1.2 [a]	3.3 ± 1.0	1.9 ± 0.5 [a]	3.2 ± 0.9	1.6 ± 0.3 [a]	2.8 ± 06	1.6 ± 0.3 [a]

[a]Significantly different than males from corresponding age groups (p<0.001). BMI: Body mass index; Fat%: Fat percentage; MM%: Muscle mass percentage.

trend from 15 years of age (Figure 2). Similar trends were observed in the curves for Vmax (Figure 4), Hmax (Figure 5) and NMI (Figure 6). The reference curves showed a significant increase in both boys and girls in childhood, however, in girls, the curves showed a plateau, starting around 14 years of age.

Similar to Pmax, the reference curves for Fmax started flattening around 14 years in girls, while in boys, a sharp increase was seen till 17 years. The curves for Fmax/kg were flatter than Fmax, both in boys and girls. The relationship between Fmax/kg and age was negative, especially in girls, as the curves showed a downward trend with progressing age. In boys, the relationship was observed to be fairly constant, post adolescence as illustrated in Figure 3.

The manufacturer's software provides the standard deviation scores (SDS) for Pmax and Fmax. These scores are based on the reference data used by the manufacturer which were generated based on muscle function parameters of children and adolescents studying in schools in Germany[38,39]. When the SDS of the children and adolescents from this study were studied, it was observed that Indian children from our study had significantly lower muscle function parameters as compared to the reference data provided by the manufacturer. The Pmax SDS ranged from –0.18 to –1.28 in boys and from –0.87 to –1.97 in girls. The Fmax SDS ranged from –1.32 to –1.92 in boys and in girls it ranged from –1.43 to –2.68. Figure 7 illustrates the comparison of Indian children's muscle function parameters with the reference data provided by the software.

21 – 60years age group

Muscle function parameters of adults from 21 – 60 years with mean age of 38.8 ± 12.2 years are presented. The anthropometric, body composition parameters and s2LJ results are available on the whole group of 386 (226 males, 160 females) participants while results of m1LH are available on 349 (214 males, 135 females) participants.

The anthropometric and body composition characteristics of the adult population in the study are presented age group wise in Table 5.

All the females were significantly shorter and lighter than the males (*p*<0.001) but had similar BMI (*p*>0.05). The males from all age groups were seen to have higher muscle mass

Table 6. Muscle function parameters of males and females.

Age group	21 – 30 y		31 – 40 y		41 – 50 y		51 – 60 y	
Gender	Male	Female	Male	Female	Male	Female	Male	Female
Pmax (kW)	3.2 ± 0.8 3.2 (2.7 – 3.8)	1.9 ± 0.4[a] 1.8 (1.6 – 2.1)	3.1 ± 0.7 3.0 (2.7 – 3.6)	1.8 ± 0.5a 1.6 (1.4 – 2.2)	2.8 ± 0.6 2.7 (2.4 – 3.3)	1.6 ± 0.3[a] 1.6 (1.4 – 1.8)	2.4 ± 0.5 2.5 (2.0 – 2.9)	1.3 ± 0.3[a] 1.3 (1.1 – 1.4)
Pmax/ mass (W/kg)	43.1 ± 7.9 42.4 (37.4 – 49.4)	31.2 ± 5.7[a] 30.9 (27.6 – 34.2)	41.0 ± 7.3 40.2 (36.0 – 44.8)	29.2 ± 5.7[a] 28.4 (25.5 – 32.7)	37.2 ± 7.1 36.9 (32.3 – 42.3)	25.2 ± 4.2[a] 24.9 (21.4 – 28.2)	32.2 ± 6.0 33.3 (27.5 – 36.3)	21.8 ± 3.5a 22.0 (18.3 – 24.6)
Vmax (m/s)	2.5 ± 0.3 2.5 (2.3 – 2.7)	2.0 ± 0.2 [a] 2.0 (1.8 – 2.2)	2.3 ± 0.2 2.3 (2.2 – 2.5)	1.8 ± 0.2 [a] 1.8 (1.7 – 1.9)	2.1 ± 0.3 2.2 (2.0 – 2.3)	1.7 ± 0.2 [a] 1.7 (1.6 – 1.8)	1.9 ± 0.3 2.0 (1.8 – 2.1)	1.5 ± 0.2 [a] 1.5 (1.3 – 1.6)
Hmax (m)	0.4 ± 0.1 0.4 (0.3 – 0.5)	0.3 ± 0.1 [a] 0.3 (0.2 – 0.3)	0.4 ± 0.1 0.4 (0.3 – 0.4)	0.3 ± 0.1 [a] 0.2 (0.2 – 0.3)	0.3 ± 0.1 0.3 (0.3 – 0.4)	0.2 ± 0.04 [a] 0.2 (0.2 – 0.3)	0.3 ± 0.1 0.3 (0.2 – 0.3)	0.2 ± 0.1 a 0.2 (0.1 – 0.2)
NMI (m/s)	1.1 ± 0.2 1.1 (1.0 – 1.2)	1.0 ± 0.2 [a] 1.0 (0.9 – 1.1)	1.0 ± 0.2 1.0 (0.8 – 1.2)	0.8 ± 0.2 [a] 0.8 (0.7 – 1.0)	1.0 ± 0.2 1.0 (0.8 – 1.1)	0.9 ± 0.2 [a] 0.9 (0.8 – 1.0)	0.9 ± 0.2 0.8 (0.7 – 1.0)	0.7 ± 0.2 0.7 (0.6 – 0.9)
Fmax (kN)	1.9 ± 0.3 1.9 (1.6 – 2.0)	1.5 ± 0.2[a] 1.4 (1.3 – 1.6)	1.8 ± 0.3 1.8 (1.6 – 2.0)	1.3 ± 0.2[a] 1.3 (1.1 – 1.5)	1.8 ± 0.3 1.8 (1.6 – 2.0)	1.4 ± 0.2a 1.4 (1.3 – 1.6)	1.7 ± 0.2 1.7 (1.6 – 1.9)	1.2 ± 0.2a 1.2 (1.1 – 1.4)
Fmax/BW	2.7 ± 0.3 2.7 (2.5 – 2.9)	2.5 ± 0.3[a] 2.5 (2.2 – 2.8)	2.5 ± 0.2 2.5 (2.3 – 2.7)	2.3 ± 0.3[a] 2.3 (2.1 – 2.5)	2.5 ± 0.3 2.5 (2.3 – 2.6)	2.3 ± 0.3[a] 2.4 (2.1 – 2.6)	2.4 ± 0.2 2.4 (2.3 – 2.5)	2.1 ± 0.3[a] 2.0 (1.9 – 2.3)

Values are mean ± SD and median (IQR). The Pmax values are expressed in kW and Pmax/mass values are expressed in W/kg. [a]Significantly lower than males from corresponding age group (p<0.001).

percentage and lower fat percentage than the females from corresponding age groups ($p<0.001$).

The age group and gender wise mean ± SD (median – IQR) values of maximum power (Pmax), maximum relative power- Pmax/body mass (Pmax/kg), maximum velocity (Vmax), maximum jump height (Hmax), Nerve Muscle Index (NMI), maximum voluntary force (Fmax) and maximum relative force- Fmax/body weight (Fmax/BW) of the study population are presented in Table 6.

As shown in Table 6, females were observed to have consistently lower values of Pmax, Pmax/kg, Vmax and Hmax at all the age groups, as compared to males ($p<0.001$). On comparing the consecutive age groups, in males as well as females, the Pmax values significantly decreased from the 41 – 50y age group to 51 – 60y age group ($p<0.001$), whereas, the Pmax/kg significantly decreased from 31 – 40y age group to 41 – 50y age group and from 41 – 50y to 51 – 60y age group ($p<0.001$). Vmax and Hmax decreased significantly from 41 – 50y to 51 – 60y age group ($p<0.001$) in males. No significant changes were observed in the NMI values. In females, Vmax and NMI decreased significantly from 21 – 30y age group to 31 – 40y age group and from 41 – 50y to 51 – 60y age group ($p<0.001$). Males had higher Fmax and Fmax/BW at all the age groups, as compared to females ($p<0.001$). In females, the Fmax values significantly decreased from the 41 – 50y age group to 51 – 60y age group ($p<0.001$).

Figure 8 represents the correlation of Pmax and Pmax/mass in males and females across the age groups, respectively. A significant negative correlation was observed between age and Pmax in both the genders (males r = –0.4, females r = –0.5, $p<0.001$ for all). Similar negative correlation was seen between the body mass adjusted Pmax (Pmax/mass) and age (males r = –0.5, females r = –0.6, $p<0.001$ for all).

The correlation of Fmax and Fmax/kg in males and females across the age is shown in Figure 9. A weak but significant negative correlation was observed between age and Fmax in both the genders (males r = –0.2, females r = –0.2, $p<0.001$ for both). Similarly, the body weight adjusted Fmax (Fmax/BW) and age (males r = –0.4, females r = –0.4, $p<0.001$ for both) showed a negative correlation.

Further, the correlations between muscle mass percentage and Pmax/kg and Fmax/BW were examined. A significant positive correlation was observed between Pmax/

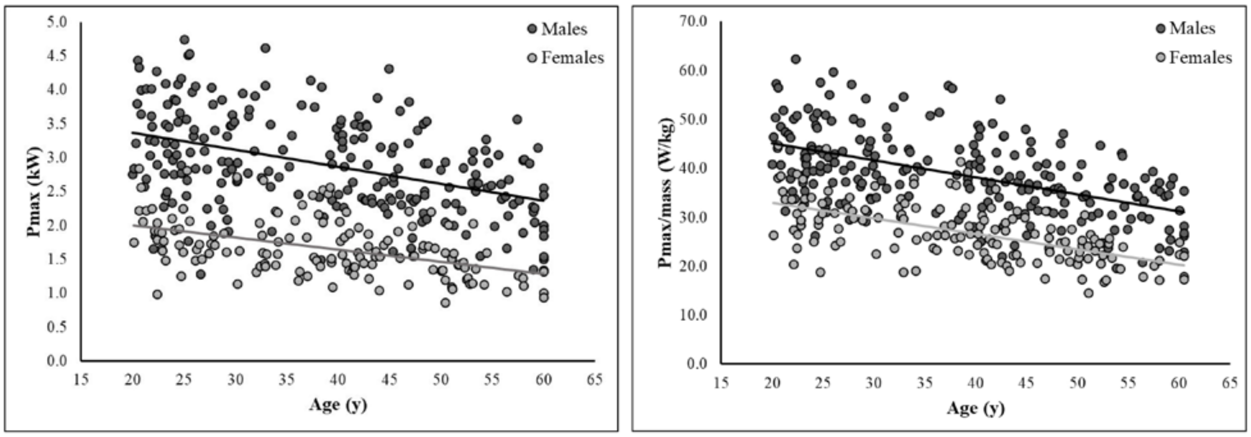

Figure 8. Correlation of Pmax and Pmax/mass with age in males and females.

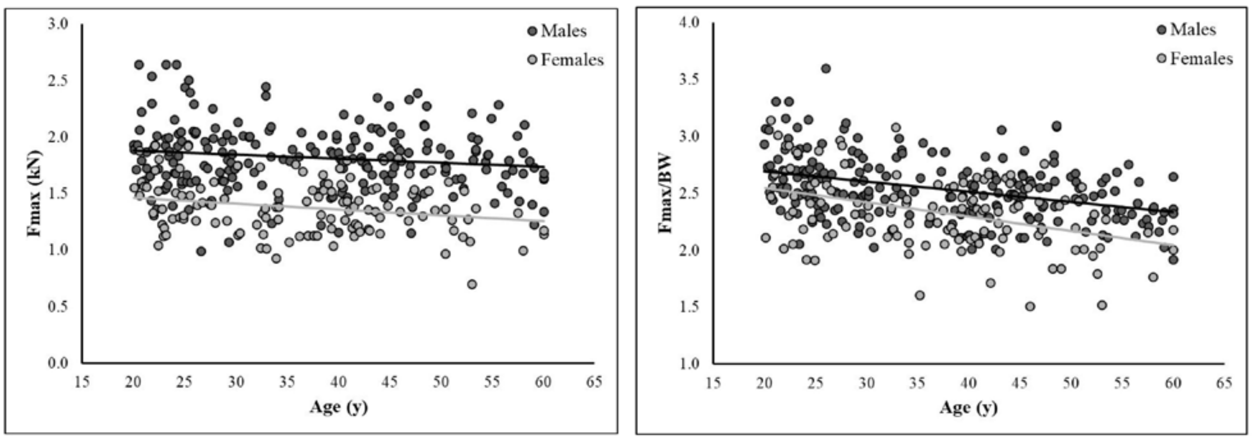

Figure 9. Correlation of Fmax and Fmax/BW with age in males and females.

mass and muscle mass percentage in both the genders (males r = 0.4, females r = 0.6, p<0.001 for all). Similarly, Fmax/BW was positively correlated with muscle mass percentage in both the genders (males r = 0.4, females r = 0.5, p<0.001 for all). Similar correlations were observed between muscle/fat ratio and Pmax/mass in both the genders (males r = 0.3, females r = 0.5, p<0.001 for all). Also, a positive correlation was observed between the Fmax/BW and muscle/fat ratio in males and females (males r = 0.4, females r = 0.5, p<0.001 for all).

When the age associated decline in muscle mass percentage and Pmax/mass were compared, the decline in Pmax/mass was observed to be in excess as compared to that of muscle mass percentage, both in males and females as demonstrated in Figure 10a. Similar pattern was observed when the decline in Fmax/BW was compared with the decline in muscle mass percentage linked with increase in age. This relationship is shown in Figure 10b. However, the difference in percent reduction of Fmax/BW and muscle mass percentage was not as sharp as that observed with Pmax/mass.

The SDS for Pmax and Fmax are provided by the manufacturer's software. These scores are based on the data of muscle function parameters of healthy adults from Germany[40]. The SDS of the Indian adults from this study were seen to be significantly lower than their Western counterparts. The Pmax ranged from –1.61 to –1.97 in males and from –1.89 to –2.30 in females. The Fmax SDS ranged from –3.06 to –2.74 in males and in females it ranged from –2.64 to –4.06. Figure 11 shows the comparison of Indian adults' muscle function parameters with the reference data provided by the manufacturer.

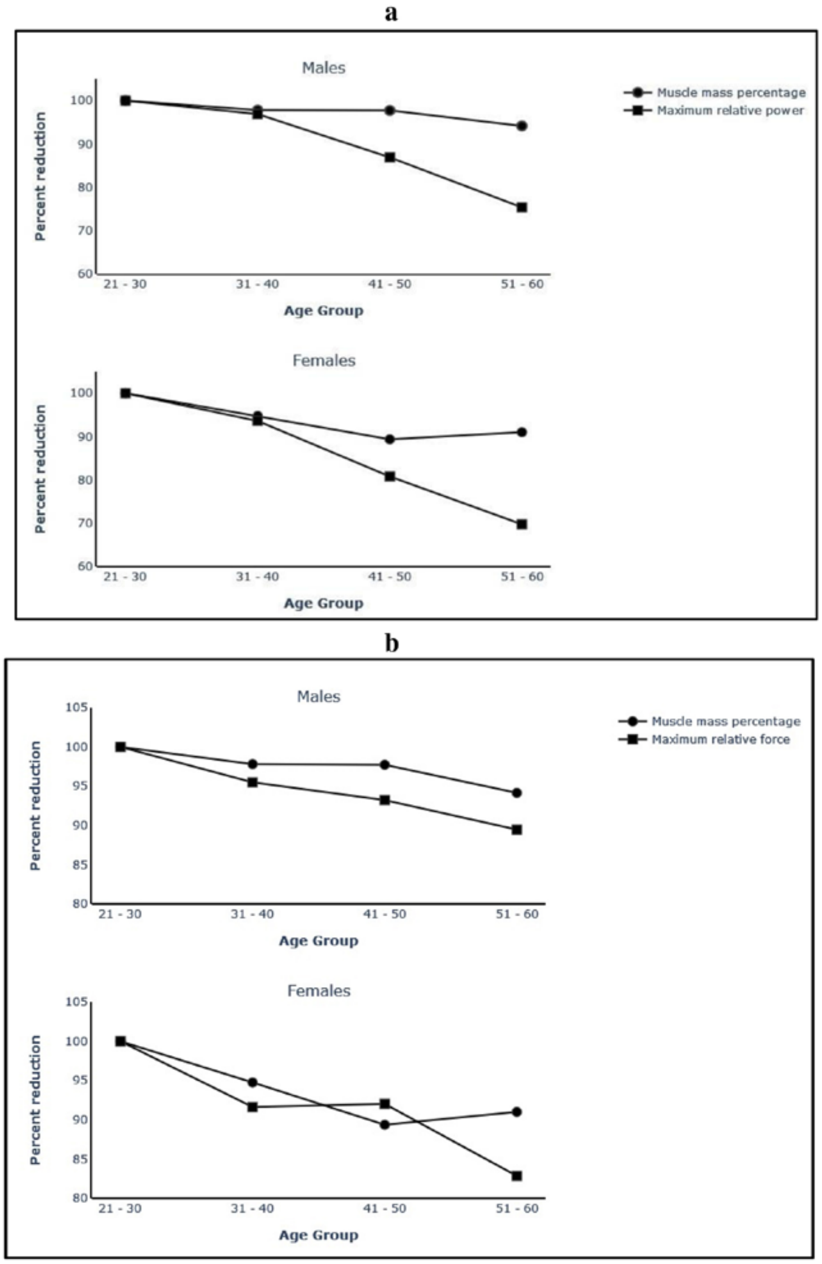

Figure 10. a: Comparison between the age wise percent reduction in Pmax/mass and muscle mass percentage in males and females. b: Comparison between the age wise percent reduction in Fmax/BW and muscle mass percentage in males and females.

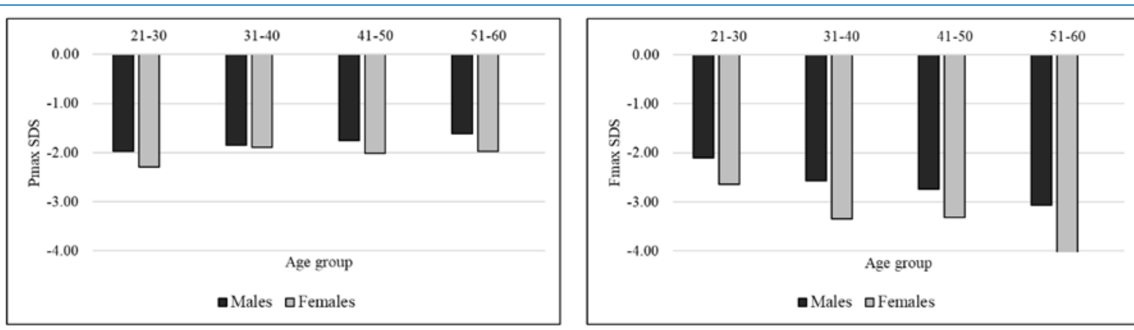

Figure 11. Age wise Pmax SDS and Fmax SDS in males and females.

Discussion

In this cross-sectional study, we present age and gender specific reference values for muscle function parameters as measured by Jumping Mechanography, for the first time in Indian children, adolescents, and adults. To our knowledge, this is the second largest study (1670 children and adolescents and 386 adults) on reference data for Jumping Mechanography outcomes. The paediatric sample size is greater than the earlier published studies on Jumping Mechanography[38,39,41], whereas the adult sample size is comparable to other similar studies[42–44]. Additionally, we have also provided smoothed reference curves for maximum power, maximum power relative to body mass, maximum velocity, maximum jump height, NMI, maximum voluntary force, and maximum force relative to body weight. These reference data and percentile curves will facilitate the accurate assessment of muscle function in the Indian population.

The Nerve Muscle Index is a newly defined parameter to evaluate jump efficiency and, hence, the muscle function. This index has been introduced in a recently published large longitudinal study[35]. It is a ratio of maximum velocity to relative force. It is beneficial to establish an interrelationship between the two factors and analyze whether the observed performance was primarily influenced by the velocity factor (serving as a proxy for neuro-motor coordination) or by the force factor (serving as a proxy for muscular strength). Higher the NMI, higher is the movement efficiency. This is the second study to use this parameter and provide the reference curves. The NMI values in our study started declining in girls post 13 years of age, and in boys post 14 years of age. The observed phenomenon may be attributed to diminished movement efficiency resulting from insufficient muscle coordination and reduced flexibility which may stem from reduced physical activity. Indian children and adolescents were observed to have lower Nerve Muscle Index than the German children and adolescents[35]. In the adult cohort, the NMI did not exhibit drastic changes. It reduced significantly only in females along with age.

We found significant gender differences in Pmax and Pmax/kg at all age groups, while the gender differences in Fmax and Fmax/BW were evident post adolescence, females had lower values. This difference can be explained through the action of androgens on muscle. Testosterone exerts a strong anabolic effect on muscles[45]. As the levels of testosterone are higher in boys, they gain greater muscle mass and function. A recent Chinese study has shown that a high concentration of serum testosterone contributes to gains in muscle mass and hand grip strength in male adolescents[46]. Age and anthropometric parameters strongly influence the development of muscle function during growth[38,41]. The shapes of the curves for Pmax and Fmax in the percentile graph in our study exhibited comparable patterns. A linear rise with age was seen in prepubertal children for both the parameters. Girls reached a plateau in adolescence, while boys maintained a steady increase throughout childhood. Our findings align with the fact that muscle function is a function of height and girls stop growing earlier than boys[47–49]. These results match previously published data on Jumping Mechanography outcomes[41,50].

Similar trend was observed in the centiles of Pmax after adjusting for body mass; a linear increase with age where girls plateaued earlier as compared to boys. However, after correction for weight, Fmax remained relatively constant in boys across ages, consistent with prior observations of Fmax/BW[39,41], however, in girls, Fmax/BW showed a declining trend with age. A probable explanation for this decline may be due to a decrease in physical activity in girls with increasing age[51] and higher body fat percentage as compared to boys[34]. The girls in this study had a significantly higher body fat percentage than boys from 11 years of age.

In the adult age group from our study, a significant sexual dimorphism was observed in muscle function, with females showing lower levels than their male counterparts, in all decades. A possible explanation for this can be a similar one as in the children. Females have higher body fat percentage than males and a lower muscle/fat ratio[52]. Similar results were seen in our study where females had significantly lower muscle/fat ratio than males and lower muscle function. Additionally, the higher levels of testosterone in males may be responsible for the higher muscle function. Studies have shown positive association between serum testosterone levels and muscle strength in both men and women[53,54]. A study from South Korea has reported that men and women with low testosterone levels have weak muscle strength after adjusting for muscle mass[54]. Furthermore, the muscle function parameters in this study exhibited a negative association with age, in both males and females. These findings are similar to other studies conducted on muscle function in adults[42–44]. The existing hypothesis suggests that age-related decline in muscle mass is the cause of the decline in muscle function. However, the extent of the decline in both muscle mass and muscle function differs with age. A recent longitudinal study has shown that there is an early and pronounced age-related decline in muscle power, assessed by Jumping Mechanography, as compared to muscle mass[55]. As muscle power is the product of force and velocity, as per this study, the significant decrease in muscle power appears to be attributed to an early decline in the largest and fastest contracting type II muscle fibers. This decline is linked to a general demyelination of the central and peripheral nervous system resulting in a slowdown of axonal conduction velocity with age and the prevalence of type I muscle fibers. This phenomenon is observed in both men and women, with the only sex-specific difference being the smaller and decreasing size of type II muscle fibers in women compared to men as age increases. Additional intrinsic changes in actin-myosin structures, motor units, as well as hormones and metabolism contribute to reduced muscle power, potentially explaining the earlier decline in women compared to men in our study[56]. Thus, the importance of assessment of muscle function in adults is emphasized and makes it a more relevant parameter in diagnosis of sarcopenia.

The healthy Indian children and adults were seen to have very low Z-scores when compared to the German reference data[38–40]. The participants in this study were shown to have lower muscle function though all the participants were physically active and had adequate nutrition. These changes may be attributed to mainly different body sizes and body composition. These discrepancies in muscle function justfy the need for ethnic specific reference data.

This is the first study to establish Indian reference data for muscle function parameters assessed by Jumping Mechanography. The advantages of the assessment tool are that it is quick, reliable, reproducible, accurate, and gives quantitative results. The strength of this study lies in the adequate sample size. The measurements were performed by only 2 observers, one of whom (SK) was present at all measurements. This assured the uniformity in measurements during the whole study.

Jumping Mechanography has proved beneficial in assessing muscle function of children with diseases and disorders affecting muscular health[22,23,25]. This Indian reference data will help in precise assessment of muscle function of Indian children requiring specific treatments to preserve muscle function and avoid further deterioration. Furthermore, measurement of muscle function is a key component in the diagnosis of sarcopenia[57]. Studies have shown the criticality of using ethnicity specific cut offs of muscle parameters for diagnosing sarcopenia in Indian population[58,59] as Indians have lower muscle mass and strength than their Western counterparts. The adult reference data generated in our study will help in accurate diagnosis of sarcopenia in Indian population and aid in devising strategies to prevent falls and fractures.

The study is limited by its cross-sectional design. A longitudinal study design may help to better explore the relationship between age and muscle function. At the same time, however, the results from this study can serve as a starting point for future studies. Secondly, we were not able to collect data on pubertal staging in children and adolescents as most of the data collection took place in schools, and most of the participants who visited the institute for assessments denied assent. Data on muscle function in relation to pubertal development would have further added to our understanding of muscle function. Also, we could not use the LMS method for adult data as the numbers were modest. Additionally, this study includes participants from only one city. To increase the applicability of the results, a bigger study with more centres can be conducted.

In conclusion, this study presents gender-specific paediatric and adult reference data on the main parameters assessed by Jumping Mechanography from a large cohort. Our results are intended to assist clinicians in the assessment of muscle function by Jumping Mechanography in the Indian population.

Ethics approval

Ethical approval for the study was granted by the Ethics Committee Jehangir Clinical Development Centre Pvt. Ltd. on 18th June 2018 (ECR/352/Inst/MH/2013/RR-16).

Acknowledgements

We wish to express our sincere thanks to all the participants in this study. We also wish to thank the school and college principals, teachers, and school staff. We are extremely grateful to Mrs. Sandhya Gaikwad and Ms. Prachi Gaikwad for their immense help in acquiring participants for this study. We also wish to express our appreciation to Ms. Sujata Chauthmal and Ms. Radhika Gaikwad for helping out in data collection. Special thanks to Mr. Ketan Apte for his invaluable technical support.

References

1. Wolfe RR. The underappreciated role of muscle in health and disease. Am J Clin Nutr 2006;84(3):475–82.
2. Orsso CE, Tibaes JRB, Oliveira CLP, Rubin DA, Field CJ, Heymsfield SB, et al. Low muscle mass and strength in pediatrics patients: Why should we care? Clin Nutr 2019;38(5):2002–15.
3. Granacher U, Goesele A, Roggo K, Wischer T, Fischer S, Zuerny C, et al. Effects and Mechanisms of Strength Training in Children. Int J Sport Med 2011;32:357–64.
4. Moore AZ, Caturegli G, Metter EJ, Makrogiannis S, Resnick SM, Harris TB, et al. Difference in muscle quality over the adult life span and biological correlates in the baltimore longitudinal study of aging. J Am Geriatr Soc 2014;62(2):230–6.
5. Zengin A, Pye SR, Cook MJ, Adams JE, Rawer R, Wu FCW, et al. Associations of muscle force, power, cross-sectional muscle area and bone geometry in older UK men. J Cachexia Sarcopenia Muscle 2017;8(4):598–606.
6. Duran I, Wloka KR, Martakis K, Spiess K, Alexy U, Schoenau E. Multivariable reference centiles for maximum grip strength in childhood to young adults. Eur J Clin Nutr 2023;(June):1–7.
7. Shetty M, Balasundaran S, Mullerpatan R. Grip and pinch strength: Reference values for children and adolescents from India. J Pediatr Rehabil Med 2019;12(3):255–62.
8. Bohannon RW, Wang YC, Bubela D, Gershon RC. Handgrip strength: A population-based study of norms and age trajectories for 3-to 17-year-olds. Pediatr Phys Ther 2017;29(2):118–23.
9. Nara K, Kumar P, Kumar R, Singh S. Normative reference values of grip strength, the prevalence of low grip strength, and factors affecting grip strength values in Indian adolescents. J Phys Educ Sport 2023; 23(6):1367–75.
10. Rauch F, Neu CM, Wassmer G, Beck B, Rieger-Wettengl G, Rietschel E, et al. Muscle analysis by measurement of maximal isometric grip force: New reference data and clinical applications in pediatrics. Pediatr Res 2002;51(4 I):505–10.
11. Schiller BC, Casas YG, Tracy BL, DeSouza CA, Seals DR. Age-related declines in knee extensor strength and physical performance in healthy Hispanic and Caucasian women. Journals Gerontol - Ser A Biol Sci Med Sci 2000;55(12):563–9.
12. Doldo NA, Delmonico MJ, Bailey JA, Hand BD, Kostek

MC, Rabon-Stith KM, et al. Muscle-power quality: Does sex or race affect movement velocity in older adults? J Aging Phys Act 2006;14(4):411–22.
13. Xu F, Cohen SA, Greaney ML, Earp JE, Delmonico MJ. Longitudinal Sex-Specific Physical Function Trends by Age, Race/Ethnicity, and Weight Status. J Am Geriatr Soc 2020;68(10):2270–8.
14. Vásquez E, Germain CM, Tang F, Lohman MC, Fortuna KL, Batsis JA. The Role of Ethnic and Racial Disparities in Mobility and Physical Function in Older Adults. J Appl Gerontol 2020;39(5):502–8.
15. Araujo AB, Chiu GR, Kupelian V, Hall SA, Williams RE, Clark RV, et al. Lean mass, muscle strength, and physical function in a diverse population of men: A population-based cross-sectional study. BMC Public Health 2010;10(508):1–8.
16. Kaur J, Miller R, Freitas E, Bemben D, Bemben M. Racial/ethnic differences in bone mineral density, muscle function and fat mass in young women 2019;18(2):103–13.
17. McGrath RP, Ottenbacher KJ, Vincent BM, Kraemer WJ, Peterson MD. Muscle weakness and functional limitations in an ethnically diverse sample of older adults. Ethn Heal 2020;25(3):342–53.
18. Dodds RM, Syddall HE, Cooper R, Kuh D, Cooper C, Avan Aihie Sayer. Global variation in grip strength: A systematic review and meta-analysis of normative data. Age Ageing 2016;45(2):209–16.
19. Fricke O, Weidler J, Tutlewski B, Schoenau E. Mechanography - A new device for the assessment of muscle function in pediatrics. Pediatr Res 2006; 59(1):46–9.
20. Schoenau E, Fricke O. Interaction between muscle and bone. Horm Res 2007;66(SUPPL. 1):73–8.
21. Matheson LA, Duffy S, Maroof A, Gibbons R, Duffy C, Roth J. Intra-and inter-rater reliability of jumping mechanography muscle function assessments. J Musculoskelet Neuronal Interact 2013;13(4):480–6.
22. Maratova K, Soucek O, Matyskova J, Hlavka Z, Petruzelkova L, Obermannova B, et al. Muscle functions and bone strength are impaired in adolescents with type 1 diabetes. Bone 2018;106:22–7.
23. Duran I, Martakis K, Stark C, Alberg E, Bossier C, Semler O, et al. Experience with jumping mechanography in children with cerebral palsy. J Musculoskelet Neuronal Interact 2017;17(3):237–45.
24. Macdonald HM, Nettlefold L, Maan EJ, Côté H, Alimenti A. Muscle power in children, youth and young adults who acquired HIV perinatally. J Musculoskelet Neuronal Interact 2017;17(2):27–37.
25. Vill K, Ille L, Blaschek A, Rawer R, Landgraf MN, Gerstl L, et al. Jumping Mechanography as a Complementary Testing Tool for Motor Function in Children with Hereditary Motor and Sensory Neuropathy. Neuropediatrics 2017; 48(6):420–5.
26. Edouard T, Deal C, Van Vliet G, Gaulin N, Moreau A, Rauch F, et al. Muscle-bone characteristics in children with Prader-Willi syndrome. J Clin Endocrinol Metab 2012;97(2):275–81.
27. Parsons CM, Edwards MH, Cooper C, Dennison EM, Ward KA. Are jumping mechanography assessed muscle force and power, and traditional physical capability measures associated with falls in older adults? Results from the hertfordshire cohort study. J Musculoskelet Neuronal Interact 2020;20(2):168–75.
28. Buehring B, Krueger D, Fidler E, Gangnon R, Heiderscheit B, Binkley N. Reproducibility of jumping mechanography and traditional measures of physical and muscle function in older adults. Osteoporos Int 2015;26(2):819–25.
29. Singh T, Sharma S, Nagesh S. Socio-economic status scales updated for 2017. Int J Res Med Sci 2017; 5(7):3264.
30. Mundhe N. Identifying and mapping of slums in pune city using geospatial techniques. Int Arch Photogramm Remote Sens Spat Inf Sci - ISPRS Arch 2019;42(5/W3):57–63.
31. Pandey VK, Aggarwal P, Kakkar R. Modified bg prasad's socio-economic classification-2018: The need of an update in the present scenario. Indian J Community Heal 2018;30(1):82–4.
32. Khadilkar V, Yadav S, KK A, Tamboli S, Banerjee M, Cherian A, et al. Revised IAP Growth Charts for Height, Weight and Body Mass Index for 5- to 18-year-old Indian Children. Indian Pediatr 2015;52:47–55.
33. Misra A, Chowbey P, Makkar BM, Vikram NK, Wasir JS, Chadha D, et al. Consensus statement for diagnosis of obesity, abdominal obesity and the metabolic syndrome for Asian Indians and recommendations for physical activity, medical and surgical management. J Assoc Physicians India 2009;57(2):163–70.
34. Chiplonkar S, Kajale N, Ekbote V, Mandlik R, Parthasarathy L, Borade A, et al. Reference centile curves for body fat percentage, fat-free mass, muscle mass and bone mass measured by bioelectrical impedance in Asian Indian children and adolescents. Indian Pediatr 2017;54(12):1005–11.
35. Martakis K, Alexy U, Stark C, Hahn A, Rawer R, Duran I, et al. Jumping Mechanography: Reference Centiles in Childhood and Introduction of the Nerve–Muscle Index to Quantify Motor Efficiency. J Clin Med 2023;12(18):5984.
36. Cole TJ, Green PJ. Smoothing reference centile curves: The lms method and penalized likelihood. Stat Med 1992;11(10):1305–19.
37. Van Buuren S, Fredriks M. Worm plot: A simple diagnostic device for modelling growth reference curves. Stat Med 2001;20(8):1259–77.
38. Busche P, Rawer R, Rakhimi N, Lang I, Martin DD. Mechanography in childhood: References for force and power in counter movement jumps and chair rising tests. J Musculoskelet Neuronal Interact 2013;13(2):213–26.
39. Lang I, Busche P, Rakhimi N, Rawer R, Martin DD. Mechanography in childhood : references for grip force , multiple one-leg hopping force and whole body stiffness. J Musculoskelet Neuronal Interact 2013;13(2):227–35.

40. Rittweger J, Schiessl H, Felsenberg D, Runge M. Reproducibility of the Jumping Mechanography As a Test of Mechanical Power Output in Physically Competent Adult and Elderly Subjects. J Am Geriatr Soc 2004;52(1):128–31.
41. Sumnik Z, Matyskova J, Hlavka Z, Durdilova L, Soucek O, Zemkova D. Reference data for jumping mechanography in healthy children and adolescents aged 6-18 years. J Musculoskelet Neuronal Interact 2013;13(3):297–311.
42. Runge M, Rittweger J, Russo CR, Schiessl H, Felsenberg D. Is muscle power output a key factor in the age-related decline in physical performance? A comparison of muscle cross section, chair-rising test and jumping power. Clin Physiol Funct Imaging 2004;24(6):335–40.
43. Tsubaki A, Kubo M, Kobayashi R, Jigami H, Takahashi HE. Normative values for maximum power during motor function assessment of jumping among physically active Japanese. J Musculoskelet Neuronal Interact 2009;9(4):263–7.
44. Anliker E, Rawer R, Boutellier U, Toigo M. Maximum ground reaction force in relation to tibial bone mass in children and adults. Med Sci Sports Exerc 2011;43(11):2102–9.
45. Kadi F. Cellular and molecular mechanisms responsible for the action of testosterone on human skeletal muscle. A basis for illegal performance enhancement. Br J Pharmacol 2008;154(3):522–8.
46. Xu Y, Wen Z, Deng K, Li R, Yu Q, Xiao SM. Relationships of sex hormones with muscle mass and muscle strength in male adolescents at different stages of puberty. PLoS One 2021;16(12 December):1–13.
47. Surana V, Dabas A, Khadgawat R, Marwaha RK, Sreenivas V, Ganie MA, et al. Pubertal onset in apparently healthy Indian boys and impact of obesity. Indian J Endocrinol Metab 2017;21(3):434–8.
48. Khadgawat R, Marwaha RK, Mehan N, Surana V, Dabas A, Sreenivas V, et al. Age of onset of puberty in apparently healthy school girls from northern India. Indian Pediatr 2016;53(5):383–7.
49. Khadilkar V, Khadilkar A, Arya A, Ekbote V, Kajale N, Parthasarathy L, et al. Height Velocity Percentiles in Indian Children Aged 5–17 Years. Indian Pediatr 2019;56(1):23–8.
50. Gabel L, Macdonald HM, Nettlefold L, Race D, McKay HA. Reference data for jumping mechanography in Canadian children, adolescents and young adults. J Musculoskelet Neuronal Interact 2016;16(4):283–95.
51. Swaminathan S, Selvam S, Thomas T, Kurpad A V., Vaz M. Longitudinal trends in physical activity patterns in selected urban south Indian school children. Indian J Med Res 2011;134(8):174–80.
52. Marwaha RK, Tandon N, Garg MK, Narang A, Mehan N, Bhadra K. Normative data of body fat mass and its distribution as assessed by DXA in indian adult population. J Clin Densitom 2014;17(1):136–42.
53. Chiu HT, Shih MT, Chen WL. Examining the association between grip strength and testosterone. Aging Male 2021;23(5):915–22.
54. Kong SH, Kim JH, Lee JH, Hong AR, Shin CS, Cho NH. Dehydroepiandrosterone Sulfate and Free Testosterone but not Estradiol are Related to Muscle Strength and Bone Microarchitecture in Older Adults. Calcif Tissue Int 2019;105(3):285–93.
55. Wiegmann S, Felsenberg D, Armbrecht G, Dietzel R. Longitudinal changes in muscle power compared to muscle strength and mass. J Musculoskelet Neuronal Interact 2021;21(1):13–25.
56. Larsson L, Degens H, Li M, Salviati L, Lee Y Il, Thompson W, et al. Sarcopenia: Aging-related loss of muscle mass and function. Physiol Rev 2019;99(1):427–511.
57. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Sarcopenia: Revised European consensus on definition and diagnosis. Age Ageing 2019;48(1):16–31.
58. Zengin A, Kulkarni B, Khadilkar A V., Kajale N, Ekbote V, Tandon N, et al. Prevalence of Sarcopenia and Relationships Between Muscle and Bone in Indian Men and Women. Calcif Tissue Int 2021;109(4):423–33.
59. Pal R, Aggarwal A, Singh T, Sharma S, Khandelwal N, Garg A, et al. Diagnostic cut-offs, prevalence, and biochemical predictors of sarcopenia in healthy Indian adults: The Sarcopenia-Chandigarh Urban Bone Epidemiological Study (Sarco-CUBES). Eur Geriatr Med 2020;11(5):725–36.