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Original Article

Determinants of muscle power and force as assessed by Jumping Mechanography in rural Indian children

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Abstract

Objectives: To: 1. Assess muscle function (MF) of rural Indian children (6-11 y, n=232), using Jumping Mechanography (JM) and hand dynamometer, 2. Investigate gender differences, 3. Identify determinants of MF. **Methods:** Data on anthropometry, muscle mass%, diet, physical activity, sunlight exposure, MF (maximum relative power Pmax/mass, maximum relative force Fmax/BW by JM; relative grip strength (RGS) by hand dynamometer) were collected. Pearson's correlation and hierarchical linear regression was performed. **Results:** Pmax/mass, Fmax/BW and RGS of the group were 31.7±5.0W/kg, 3.0±0.3 and 0.4±0.1 (mean±SD), respectively. The Pmax/mass Z-score was -1.1±0.9 and Fmax/BW Z-score was -0.9±1 (mean±SD) which was significantly lower than the machine reference data (p<0.05). Positive association of muscle mass% and protein intake was observed with all MF parameters and moderate+vigorous physical activity with Fmax/BW (p<0.05). Determinants of MF identified through regression for Pmax/mass were age (β=1.83, 95% CI=0.973-2.686), muscle mass% (β=0.244, 95% CI=0.131-0.358) and protein intake (β=3.211, 95% CI=1.597-4.825) and for Fmax/BW was protein intake (β=0.130, 95% CI=0.023-0.237) (p<0.05). Male gender was a positive predictor of having higher Pmax/mass (β=1.707, 95% CI=0.040-3.373) (p<0.05). **Conclusion:** MF was lower than in western counterparts. To optimize MF of rural Indian children, focus should be on improving muscle mass, ensuring adequate dietary protein, and increasing physical activity, especially in girls.

Keywords: Indian Children, JAMAR, Jumping Mechanography, Muscle Function, Rural Children

Introduction

Prior studies suggest that low muscle mass and strength may contribute towards adverse health outcomes in childhood; increased risk of metabolic dysfunction and cardiovascular disease have been described in children with low muscle mass and strength¹⁻⁶. Further, it has been reported that muscles creating higher forces are associated with higher bone mass⁷. Correlations between grip strength and bone health parameters emphasize the theory that muscle contractions play a significant role in bone strength and mass^{8,9}. Thus, optimal development of muscle mass and strength during childhood and adolescence is crucial for overall health and bone growth as well as for reducing the risk of metabolic syndrome, and

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osteoporosis and sarcopenia later in life.

Muscle strength is a composite term which comprises muscle mass, muscle anatomy (size and length of muscle fibres) and muscle outcome i.e. the physical function¹⁰. In children, muscle strength is largely driven by body mass and stature¹¹⁻¹³, and therefore muscle strength is related to age and gender as a result of changes in muscle mass and muscle fibre size¹⁴. However, certain modifiable factors such as physical activity and nutrition also play a key role in determining muscle function¹⁵. Physical activity is a crucial lifestyle factor having several health benefits. Moreover, structured physical activity undertaken during or prior to puberty can have lifelong positive impact via facilitating musculoskeletal health¹⁶. The WHO recommends 60 minutes or more of moderate to vigorous physical activity daily for children and adolescents. However, reports have shown only half of the children and adolescents in India meet these guidelines¹⁷⁻²⁰. Additionally, they have lower muscle mass than their Caucasian counterparts^{21,22}. Hence, it is crucial to study muscle function and its determinants in Indian children. Further, this is even more important in Indian children from rural areas who are more likely to be nutritionally compromised, stunted and underweight than urban children²³.

Evaluation of muscle function, however, is challenging. Grip strength by hand dynamometer is used extensively for muscle function assessment in children. This method measures isometric force at a non-weight bearing part of the body and it does not reflect movement patterns performed during everyday life by children. Hence, grip strength has limited application in assessment of muscle function^{24,25}. Jumping Mechanography is a technique which has been shown to be useful in assessing muscle function in children as it measures dynamic muscle function through different testing manoeuvres that are similar to the movements used during daily physical activities²⁶⁻³⁰.

There are a few studies on muscle function using hand dynamometer in healthy Indian children and young adults^{31,32}. However, detailed analyses of muscle function using hand dynamometry and Jumping Mechanography and determinants of muscle function, such as nutritional and lifestyle factors, have not been performed in healthy Indian children; there is also scarcity of this data worldwide. There are reports of no gender differences in muscle function parameters in prepubertal children^{24,33,34} however, this has not been studied in the Indian population. We, therefore, undertook this study: (1) To assess muscle function parameters of school children using Jumping Mechanography (maximum relative power Pmax/mass and maximum relative force Fmax/BW) and hand dynamometer (grip strength) in a rural setting in Western India, (2) To investigate if there are gender differences in this population and, (3) To identify determinants of muscle function in these children.

Materials and methods

Study design and participants

This study is a part of a large rural research project in Pune, Western India. This project aims to improve health of the rural population around Pune city through various programs directed at vulnerable age groups including children, adolescents, pregnant women, and the elderly.

The present cross-sectional study was carried out in schoolchildren aged 6–11 years (boys: 7-11 years, girls: 6-10 years) from 2 public schools from 2 villages located about 60 km from Pune. Before choosing this site, rural areas around Pune city were surveyed. A list of schools was obtained from the local governing body. Fourteen schools with children in the selected age group were shortlisted. Nine schools disagreed to participate as they did not wish to invest time in the study implementation, or the school timing was not feasible. Of the five schools which consented to allow the study to be carried out on their premises, two schools were randomly selected. These schools were 8 km apart and the children resided in nearby villages. They had similar lifestyle and food habits. The schools had similar classroom and physical education patterns. The inclusion criteria were pre-pubertal children aged 6-11 years and growth parameters between 3rd and 97th percentile according to Indian reference data³⁵. The girls were younger than boys as girls enter puberty early. Children consuming vitamin D or any other drug known to affect bone or muscle health, having any chronic systemic illnesses or congenital abnormalities were excluded. Parents of all the children (260) who met the age criteria in the selected schools were approached for consent and 240 parents consented to allow their children to participate in the study. Written informed consents were obtained from the parents, while the children gave written informed assents. Paediatricians carried out a medical examination for all the children to rule out chronic disease conditions and congenital abnormalities. After screening and clinical examination of 240 children, 6 were excluded due to medical conditions and 2 children did not give assent. Thus, 232 children (127 boys) were enrolled. The Institutional Ethics Committee gave ethics approval for the study on 18th June, 2018.

Anthropometry and body composition

Standing height was measured 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 through 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^{21,35}.

Biochemical measurements

A random venous blood sample (8 ml) was collected for estimation of haemoglobin and serum 25-hydroxy vitamin D (25(OH)D). Haemoglobin was estimated by spectrophotometry at a wavelength of 555 nm using a Horiba Yumizen H500 hematology analyser. Assessment of serum 25(OH)D was performed by ELISA technique using standard kits (DLD Diagnostika GMBH, intra-assay co-efficient of variation [CV] 5.0%; inter-assay CV 7.8%).

Muscle function

The Leonardo Mechanograph Ground Reaction Force Plate (Novotec Medical, Pforzheim, Germany) was used for assessing dynamic muscle function²⁷. For the detection, storage and calculation of the outcomes, the software provided by the manufacturer (Leonardo Mechanography GRFP version 4.4, Novotec, Pforzheim, Germany) was used.

Two types of jumps were performed by all the participants: single 2 legged jump (s2LJ) which detected the maximum relative power and multiple 1 legged hopping (m1LH) which detected the maximum relative force^{28,36}. Each type of jump was repeated until 3 acceptable jumps (as per the protocol described below) were obtained, and the jump with the greatest peak power/force was used for analyses. Moreover, the weight adjusted variables enabled to discern the effect of lifestyle factors on muscle function dissociated from their effect on growth. The tests were performed at the school with the child dressed in light clothing without shoes. The inter-day test-retest measurements of the main outcome parameters of these tests have shown low variability ranging from 3.4% to 6.4% in healthy children²⁷.

Single 2-legged jump (s2LJ)

The jump was performed as a counter-movement jump (the children briefly squatted before jumping) with freely moving arms. The main outcome of interest for the s2LJ is the maximum power relative to body mass (Pmax/mass, Watt/kg). This test also gives the Esslinger Fitness Index (EFI) which is Pmax/mass normalized to age and gender and the standard deviation score of EFI (EFI-SDS).

Multiple 1-legged hopping (m1LH)

The child was instructed to jump repeatedly (approximately fifteen jumps), as fast as was possible on the forefoot of their dominant leg. Any repetition with heel contact were excluded from the analysis by the manufacturer's software. Maximum relative force i.e. Fmax normalized to body weight (Fmax/BW) was considered the main outcome variable for m1LH. Fmax/BW standard deviation score (Fmax-SDS) was also used for analysis to explore the muscle function of Indian children in this study as compared to the reference data provided by the manufacturer.

Grip strength

Grip strength of the non-dominant hand was measured using a Jamar® Plus+ Digital Hand Dynamometer (Patterson Medical, Warrenville, IL, USA) as per standard procedure protocol³⁷. A new variable 'relative grip strength' was calculated to adjust for the effect of body weight (Grip strength/body weight GS/kg (no unit)).

Demographic, dietary and physical activity data

Demographic data, details of parents' education and sunlight exposure of the children were recorded using a validated questionnaire³⁸ administered to the children in the presence of their primary caregiver. The sunlight exposure questionnaire assessed aspects like timing and duration of sunlight exposure, mode of transport, use of sunscreen and type of clothes worn. Dietary data were recorded using the 24 hour dietary recall method over three non-consecutive days including one holiday or a Sunday. Nutrient intakes were then computed using the cooked food database software, C-Diet (version 3.2)³⁹.

Physical activity was recorded through the QPACE questionnaire validated for Indian children^{40,41}. Activities were classified as inactivity, light, moderate and vigorous activity based on the energy spent in performing that activity. Activities like watching television, playing games on the mobile phone, sitting in the classroom, studying, sleeping were classified as inactivity while household work, games where the child was seated were categorized as light activity. Walking, cycling, swimming, dancing were considered as moderate activity and games like skipping with a rope, kho-kho (a traditional Indian tag game that involves running and chasing), kabaddi (a traditional Indian contact team sport, played between 2 teams), football, cricket, other running games were categorized as vigorous activity^{42,43}. Weekly minutes of each activity were computed for each child.

Statistical analysis

Statistical analysis was carried out using the IBM SPSS Statistics for Windows (version 26.0.0, IBM Corp, Armonk, NY, USA). Before statistical analyses, all the study parameters were tested for normality. All results have been expressed as mean \pm standard deviation. Student's t-test was used for normal variables to test the differences between genders and non-parametric tests were carried out for non-normal variables. Pearson correlations were computed to estimate the association of various anthropometric, body composition, physical activity and dietary factors with Pmax/mass, Fmax/BW and RGS. Significance level was set at $p < 0.05$.

To examine the role of gender between dependent and independent variables, we intended to carry out both, mediation and moderation analyses. However, we could not perform mediation analysis as our data did not comply with conditions for same⁴³. Subsequently, we used



Figure 1. Comparison of (A) Esslinger Fitness Index standard deviation score (B) Maximum relative force standard deviation score in girls and boys.

moderation analyses to explore if gender was a moderator of the association between muscle function and various independent variables. An interaction term of gender and other independent variables was generated (gender*other independent variables). This interaction term was entered in the regression model as an independent variable along with gender and independent variables, sequentially. It was observed that gender was not a moderator but a significant predictor of muscle function when tested individually with the dependent variable (details in results section). Hence, to assess predictors of muscle function parameters, gender was entered in the first block along with age of the child in a hierarchical regression model. Height and muscle percentage (anthropometry and body composition parameters) were entered in the 2nd block. The lifestyle factors namely physical activity and dietary protein intake (g/kg body weight) were entered in the 3rd block.

Results

Anthropometric, biochemical characteristics, muscle function parameters and lifestyle factors of 232 rural schoolchildren (boys: 127, girls: 105) stratified by gender, have been summarized in Table 1. Girls were significantly younger than boys, as the inclusion criterion for age was different for both the genders (since girls enter puberty early). No significant differences were observed in the height, weight and BMI Z-scores of girls and boys. In terms of body composition, muscle percentage Z-scores were comparable in girls and boys, although girls had significantly higher fat percentage Z-score as compared to boys ($p < 0.05$).

The mean haemoglobin concentration of the children was 13.2 ± 0.9 g/dl with no significant difference between the genders. Mean serum 25(OH)D concentration was

68.6 ± 23.6 nmol/l in boys and 73.1 ± 25.9 nmol/l in girls, with no significant difference and with 20% of children being deficient (25(OH)D < 50 nmol/l)⁴⁴.

Pmax/mass and RGS were found to be significantly lower in girls than in boys ($p < 0.05$) with Fmax/BW showing no significant differences. Figure 1 illustrates the Esslinger Fitness Index standard deviation score (EFI-SDS) and Fmax/BW standard deviation score (Fmax/BW-SDS) of the children in this study. The Esslinger Fitness Index (EFI) was significantly different (85.3 ± 12.4) ($p < 0.05$) than the reference data provided by the software. The EFI-SDS of all children together was -1.1 ± 0.9 which is significantly lower ($p < 0.05$) indicating that Indian children in this study had lower Pmax/mass than the reference group. Furthermore, when EFI-SDS in both the genders was compared, it was observed that boys had significantly higher EFI-SDS (-0.9 ± 1.0) than girls (-1.2 ± 0.8) ($p < 0.05$). Also, study children had lower Fmax/BW as depicted by the lower Fmax/BW-SDS (-0.9 ± 1) ($p < 0.05$), however no significant gender differences were found among the children (Boys: -0.9 ± 1.0 , girls: -0.8 ± 0.9) ($p > 0.05$). (Figure 1).

The duration of sunlight exposure was similar in both genders, and around a third of the children reported sunlight exposure of less than 30 minutes every day, about two-thirds between 30 to 60 minutes, and only 3% of more than 60 minutes. Boys spent significantly more time in moderate + vigorous physical activity (median (IQR): 305 (202–490) minutes/week) than girls (290 (120–450) minutes/week) ($p < 0.05$) on a weekly basis. Girls were engaged in light activity for longer periods (430 (240–705) minutes/week) than boys (200 (150–292) minutes/week) ($p < 0.05$). The amount of time spent in inactivity per week was similar in boys and girls. Majority of the children had less than 420 minutes of weekly moderate and vigorous activity (70%).

Table 1. Gender wise differences in anthropometric, biochemical, muscle function and lifestyle parameters of the children

Parameters	Boys (127)	Girls (105)	Total (232)
Age	9.4 ± 0.8	8.4 ± 0.9 ^a	8.9 ± 1.0
HAZ	-0.9 ± 0.8	-0.8 ± 0.8	-0.9 ± 0.8
WAZ	-1.2 ± 0.8	-1.2 ± 0.8	-1.2 ± 0.8
BAZ	-1.0 ± 0.9	-1.1 ± 0.9	-1.1 ± 0.9
Fat percentage	7.9 ± 7.5	10.8 ± 5.0 ^a	9.2 ± 6.6
Fat percentage Z score	-1.2 ± 1.0	-1.0 ± 0.8 ^a	-1.1 ± 0.9
Muscle percentage	88.0 ± 7.2	85.1 ± 4.9 ^a	86.7 ± 6.4
Muscle percentage Z score	1.1 ± 0.8	0.9 ± 0.7	1.0 ± 0.8
Haemoglobin (g/dl)	13.2 ± 0.9	13.2 ± 0.9	13.2 ± 0.9
Serum 25(OH) D (nmol/l)	68.6 ± 23.6	73.1 ± 25.9	70.6 ± 24.7
Maximum Relative Power (W/kg)	33.3 ± 5.0	29.7 ± 4.3 ^a	31.7 ± 5.0
Maximum Relative Force (g)	3.0 ± 0.3	3.0 ± 0.3	3.0 ± 0.3
Grip strength (kg)	10.3 ± 2.6	8.2 ± 2.4 ^a	9.4 ± 2.7
Relative Grip strength	0.5 ± 0.1	0.4 ± 0.1 ^a	0.4 ± 0.1
Sunlight exposure (minutes/day)	39.0 ± 12.0	36.0 ± 11.0	38.0 ± 11.0
Energy intake (kcal/day) (Percentage of RDA)	1771.0 ± 340.0 (96.8)	1515.0 ± 358.0 ^a (90.2)	1655.0 ± 370.0 (93.7)
Protein intake (g/day) (Percentage of RDA)	50.0 ± 12.0 (156.0)	37.0 ± 11.0 ^a (124.2)	44.0 ± 13.0 (141.1)
Fat intake (g/day)	52.1 ± 13.4	43.7 ± 12.3 ^a	48.2 ± 13.5
Protein intake (g/kg body weight)	2.1 ± 0.4	1.7 ± 0.5 ^a	2.0 ± 0.5

All values are mean ± SD. ^aSignificantly different than boys (p<0.05), HAZ: Height for age Z-score, WAZ: Weight for age Z-score, BAZ: BMI for age Z-score, 25(OH)D: 25 hydroxy Vitamin D.

Table 2. Correlation coefficients of body composition parameters, physical activity and dietary factors with body weight adjusted muscle function parameters stratified by gender.

Parameters	Boys			Girls			All		
	Maximum relative power	Maximum relative force	Relative grip strength	Maximum relative power	Maximum relative force	Relative grip strength	Maximum relative power	Maximum relative force	Relative grip strength
Age (y)	0.33 ^a	0.02	0.10	0.31 ^a	0.27 ^a	0.11	0.44 ^a	0.09	0.21 ^a
Height (cm)	0.19 ^a	-0.15	-0.01	0.29 ^a	0.05	0.11	0.33 ^a	-0.08	0.13
Fat %	-0.25 ^a	-0.35 ^a	-0.26 ^a	-0.25 ^a	-0.10	-0.25 ^a	-0.31 ^a	-0.25 ^a	-0.29 ^a
Muscle %	0.25 ^a	0.35 ^a	0.25 ^a	0.23 ^a	0.09	0.24 ^a	0.30 ^a	0.25 ^a	0.29 ^a
Inactivity (min/wk)	0.06	-0.04	0.06	-0.20	0.09	-0.24 ^a	-0.03	0.02	-0.04
Light activity (min/wk)	-0.07	-0.12	-0.22 ^a	0.13	0.16	0.16	-0.14	0.05	-0.14
Moderate+ Vigorous activity (min/wk)	0.01	0.12	-0.08	-0.03	0.24 ^a	0.04	0.03	0.18 ^a	0.01
Daily protein intake (g/kg bw)	0.37 ^a	0.38 ^a	0.26 ^a	0.30 ^a	0.14	0.25 ^a	0.44 ^a	0.23 ^a	0.35 ^a

^a p<0.05, Fat %: Fat percentage, Muscle %: Muscle percentage, min/wk: Minutes/week, g/kg bw: gram per kg body weight.

The diets of the children were adequate in terms of daily energy intake, protein and fat intake and fulfilled the RDA for Indian children of this age group which is 1350 – 2190 kcal/day for energy and 20.1–39.9 g/day of protein⁴⁵. As

per ICMR's definition of a balanced diet, proteins should provide 10-15% of the total energy intake; for girls in this study proteins provided 9.7% of the total calorie intake. Additionally, the diets were found to be deficient in calcium

Table 3. Determinants of muscle function parameters.

	Maximum Relative Power		Maximum Relative Force		Relative Grip Strength	
Model R ²	37.200		17.700		20.100	
Predictors	β (95% CI)	<i>p</i>	β (95% CI)	<i>p</i>	β (95% CI)	<i>p</i>
Block 1 R ²	21.500		1.900		7.000	
Gender (Boys)	1.707 (0.040 – 3.373)	0.045	-0.071 (-0.178 – 0.037)	0.196	0.035 (0.001 – 0.070)	0.046
Age (years)	1.830 (0.973 – 2.686)	<0.05	0.046 (-0.009 – 0.101)	0.103	0.012 (-0.006 – 0.029)	0.198
Block 2 R ²	8.800		9.000		6.700	
Height (cm)	0.124 (-0.005 – 0.253)	0.060	-0.006 (-0.014 – 0.003)	0.195	0.001 (-0.002 – 0.004)	0.507
Muscle Percentage	0.244 (0.131 – 0.358)	<0.05	0.012 (0.005 – 0.019)	0.002	0.004 (0.002 – 0.007)	0.001
Block 3 R ²	6.900		6.800		6.400	
Inactivity (minutes/week)	-0.001 (-0.004 – 0.001)	0.195	-7.755 ⁻⁵ (-0.002 – 0.002)	0.293	-2.900 ⁻⁵ (-0.001 – 0.001)	0.228
Light activity (minutes/week)	-0.002 (-0.005 – 0.001)	0.150	-0.001 (-0.002 – 0.001)	0.238	-4.362 ⁻⁵ (-0.001 – 0.001)	0.149
Moderate+vigorous activity (minutes/week)	0.001 (-0.002 – 0.003)	0.656	0.001 (0.003 – 0.004)	0.020	4.906 ⁻⁶ (-0.001 – 0.001)	0.851
Protein intake (g/kg BW)	3.211 (1.597 – 4.825)	<0.05	0.130 (0.023 – 0.237)	0.017	0.058 (0.024 – 0.093)	0.001

CI: Confidence interval, g/kg BW: gram per kg body weight.

and iron, as the children consumed 433±212 mg/ day of calcium as opposed to the RDA of 600–800 mg/day thus, meeting 68% of the RDA. The consumption of dietary iron was calculated to be 9.6±2.8 mg/day which accounted for only 57% of the RDA which is set at 13–21 mg/day.

To further assess the relationship of anthropometry, body composition, physical activity and dietary parameters with muscle function, correlations were computed. To adjust for the effect of body weight on the muscle function parameters, correlations were tested using relative variables (Table 2). In boys, Pmax/mass, Fmax/BW and RGS showed a positive correlation with muscle percentage (Pmax/mass $r=0.25$, Fmax/BW $r=0.35$, RGS $r=0.25$, $p<0.05$ for all) and a negative correlation with fat percentage (Pmax/mass $r=-0.25$, Fmax/BW $r=-0.35$, RGS $r=-0.26$, $p<0.05$ for all). RGS had a negative correlation with the amount of time the boys engaged in light activity on a weekly basis ($r=-0.22$, $p<0.05$). Daily protein intake had a positive correlation with all 3 muscle function parameters in boys (Pmax/mass $r=0.37$, Fmax/BW $r=0.38$, RGS $r=0.26$, $p<0.05$ for all). In girls, Pmax/mass was positively correlated with age, height, muscle percentage and daily protein intake (g/kg body weight) (age $r=0.31$, height $r=0.29$, muscle percentage $r=0.23$, daily protein intake $r=0.30$, $p<0.05$ for all) and negatively with fat percentage ($r=-0.25$, $p<0.05$). Fmax/BW showed a significant positive correlation with age and the amount of time the girls spent in moderate and vigorous activity weekly (age $r=0.27$,

moderate + vigorous activity $r=0.24$, $p<0.05$ for both). RGS had a positive correlation with muscle percentage and daily protein intake (g/kg body weight) ($p<0.05$) and negative correlation with fat percentage and the amount of time spent in inactivity ($p<0.05$).

As significant differences were observed in Pmax/mass and RGS among girls and boys, we explored the data to assess the relationship of gender and other independent and dependent variables. On performing moderation analysis, the co-efficients of the interaction terms were insignificant (for gender*age: $\beta=-0.458$; 95% CI=-1.861–0.944, $p=0.520$, gender*height: $\beta=0.049$; 95% CI=-0.134–0.231, $p=0.599$, gender*muscle percentage: $\beta=0.036$; 95% CI=-0.178–0.251, $p=0.739$). However, gender individually had a significant co-efficient when tested with Pmax/mass ($\beta=1.707$; 95% CI=0.040–3.373, $p<0.05$). Hence, gender was entered into the regression model as an independent predictor.

Further, data were analysed using hierarchical linear regression models to identify the determinants of muscle function parameters (Table 3). Separate models were run for each muscle function parameter. To ascertain the predictors of effective muscle function, the body mass/weight adjusted parameters of muscle function (Pmax/mass, Fmax/BW, RGS) and muscle mass and protein intake were used in the regression model. A hierarchical regression analysis was performed, and variables were added in 3 blocks (Block 1:

Gender and age, Block 2: Height, muscle percentage, Block 3: Inactivity, light activity, moderate + vigorous activity, daily protein intake (g/kg). These variables explained the highest variance in Pmax/mass ($r^2=37.2$), followed by RGS ($r^2=20.1$) and then in Fmax/BW ($r^2=17.7$).

It was observed that being a boy was a positive predictor of having higher Pmax/mass ($\beta=1.707$, 95% CI=0.040–3.373) and RGS ($\beta=0.035$, 95% CI=0.001–0.070) ($p<0.05$, for both). Age was found to be a positive predictor of only Pmax/mass ($\beta=1.830$, 95% CI=0.973–2.686) ($p<0.05$). In block 2, height and muscle percentage were entered as independent variables. Height was not found to be a significant predictor of all the 3 muscle function parameters. Further, muscle mass percentage was found to be a statistically significant predictor of muscle function although the co-efficient for Fmax/BW and RGS was low ($p<0.05$).

Lifestyle factors were entered in the 3rd block. Time spent in moderate and vigorous physical activity weekly was found to be a statistically significant predictor of Fmax/BW however the co-efficient was not clinically significant ($\beta=0.001$, 95% CI=0.003–0.004). Daily protein intake (g/kg body weight) was a significant determinant of Pmax/mass ($\beta=3.211$, 95% CI=1.597–4.825), Fmax/BW ($\beta=0.13$, 95% CI=0.023–0.237) and RGS ($\beta=0.058$, 95% CI=0.024–0.093) ($p<0.05$, for all).

Discussion

Our study in healthy rural schoolgoing 6-11 year old prepubertal children suggests that muscle percentage and protein intake along with age and gender were important determinants of muscle function. Significant gender differences were observed in maximum relative power and relative grip strength. More than half of the children had sunlight exposure of more than 30 minutes per day and almost 80% of the children were vitamin D sufficient (25(OH) D >50 nmol/L). However, only 30% of children engaged in more than 420 minutes of moderate to vigorous intensity physical activity weekly (as per the recommendations of WHO¹⁷). The children consumed diets adequate in energy, however, the amount of protein was low for the energy consumed. Moreover, the intakes of calcium and iron were lower than the RDA.

The maximum relative power and maximum relative force generated by muscles in these rural Indian children was lower than the machine reference data as shown in Figure 1. Furthermore, studies conducted in children in Germany and Czech Republic have reported similar muscle function (Pmax/mass, Fmax/BW, grip strength) in girls and boys of prepubertal age^{24,33,34}. To the best of our knowledge, no Indian data are available on muscle power and muscle force assessed by Jumping Mechanography. Our prior research on body composition in Indian children has shown gender differences in muscle mass and fat mass as early as 5 years²¹. As muscle mass may be one of the predictors of muscle function, we tested for gender differences in the

muscle function parameters in this study. Our study reports significantly different muscle function parameters (Pmax/mass and RGS), with girls having lesser muscle function than boys. These results are in line with the earlier published studies which show that Fmax/BW is independent of age, gender, and fitness levels, while Pmax/mass depends on age and physical activity^{24,33,34}. However, gender differences in Pmax/mass were observed post-puberty in previous studies. The difference seen in our study may be attributed to lower protein intakes and lower level of moderate and vigorous physical activity in girls as compared to boys.

To compare the effective muscle function, the body weight/mass adjusted values of power and force were considered. Indian children were found to have lower values for maximum relative power compared to the Czech children, while slightly higher values for the maximum relative force for boys of similar age group were observed²⁴.

Studies that have described the grip strength of non-dominant hand measured by JAMAR hand dynamometer in children of similar age group have reported grip strength to be higher than the rural Indian children in our study. A study conducted in the United States of America in 3 to 17 year olds has reported the mean grip strength of girls in the age group 6-10 years to be 12.1 kg and of boys in the age group 7-11 years to be 15.5 kg⁴⁶. Another study from Chile in 6-18 years⁴⁷ found the mean values of grip strength equal to 10 kg in girls of 6-10 years and 12.2 kg in boys of 7-11 years whereas the mean grip strength of the rural Indian children was 8.2 kg in girls and 10.3 kg in boys. Dodds et al have noted that differences in grip strength exist with respect to different countries and ethnicities. They also demonstrate in a review that the average grip strength measurements are significantly lower in developing countries as compared to developed countries⁴⁸. Additionally, the lower values of muscle function may be attributed to the lower muscle mass in Indian children^{21,22}, as well as lower levels of physical activity¹⁸⁻²⁰.

We aimed to explore the data to understand factors other than weight that may determine muscle function. The other factors positively correlated with muscle function were muscle percentage, protein intake and physical activity while fat percentage had a negative correlation with muscle function. Studies determining factors in addition to body size, like the modifiable factors namely diet and physical activity, are scarce.

Our findings suggest that daily protein intake and muscle percentage are important predictors of muscle function. Our results also imply that being a boy increases the chance of having higher muscle function.

This is the first Indian study to assess muscle function and to evaluate determinants of muscle function using the Jumping Mechanography. Although the assessments were done cross-sectionally, in view of scarcity of data in this age group, our results underline the importance of optimal nutrition to attain adequate muscle mass and hence, better muscle function. The limitations of this study are that we assessed physical activity using a questionnaire; although a

validated questionnaire was used, there may have been some recall bias. The study would have been stronger with the use of a more reliable method to quantify physical activity. Since we studied prepubertal children, we were not able to describe muscle function during pubertal years. More studies covering wider age groups including pubertal years are required.

In conclusion, we have evaluated muscle function parameters, i.e., the maximum relative power, maximum relative force and hand grip strength in pre-pubertal rural Indian schoolchildren. These children had lower muscle function than their Western counterparts. Muscle percentage and daily protein intake along with gender were found to be the crucial determinants of muscle function; boys had better muscle function than girls. Further studies, including intervention studies, are required for studying and optimising muscle function in rural Indian children.

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