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Association between nutrient intake, physical activity, handgrip strength and body composition among Indian adolescents: A cross-sectional study

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Abstract
Background: Hand grip strength is considered a reliable indicator of overall muscle strength and function, and it has been associated with various health outcomes in both adolescents and adults. Inadequate nutrient intake during adolescence can have significant implications for growth, development, and overall health. The present study aims to determine the association between dietary nutrient intake, physical activity, handgrip strength and body composition among adolescent Indian children.
Methods: A cross-sectional study was done on 120 subjects (60 boys and 60 girls) aged 10-15 years chosen purposively from private schools in Delhi. A socio-demographic questionnaire was used to know the general profile of the subjects. Anthropometric measurements of weight, height, and mid-upper arm circumference were measured using a digital weighing machine, stadiometer and seca tape respectively. Muscle strength and muscle mass were measured using a hand grip dynamometer and Tanita body composition analyzer respectively. Dietary data was obtained using a day 24-hour recall along with a food frequency questionnaire (FFQ).
Results: This study found that 67.5% of subjects were normal weight while 32.4% of subjects were overweight or obese. Among these, 47.5% of subjects were vegetarian while 11.6% and 40.83% were eggetarian and non-vegetarian respectively. Among all the subjects, 23.3% of boys and 43.3% of girls had low muscle strength. Anthropometric measurements including increased weight and decreased muscle mass were significantly associated with low muscle strength among boys and girls. Energy (r= 0.375; P=0.01), protein (r= 0.469; P=0.01), iron (r= 0.386; P=0.01) magnesium (r= 0.435; P=0.01) and selenium (r= 0.212; P=0.05) were also significantly associated with muscle strength.
Conclusion: Muscle strength was positively correlated with major macronutrients i.e., energy and protein intake and micronutrients mainly iron, magnesium and selenium which are responsible for influencing and achieving optimal muscle mass and strength among adolescents. Hence, these results may help to understand the factors contributing to achieving optimal muscle strength in adolescents who may benefit from nutritional interventions, thereby preventing or reducing age-associated muscle impairments and their detrimental consequences in the later part of their lives.

Keywords: Muscle strength, adolescents, hand grip dynamometer, diet diversity, nutrition

1. Introduction

Adolescence is the period of transition between childhood and adulthood. During adolescence, the uniform growth of childhood is suddenly altered by an increase in the velocity of growth (Spear 2002) [65]. An increase in the strength of skeletal muscles is a major physiological event during early adolescence. Muscle mass growth occurs during adolescence in both boys and girls, accompanying a linear increase in muscle strength. However, muscle mass growth may be relatively more pronounced among boys due to the greater androgenic effects. Girls reach a plateau of muscle strength increases by about age 15 years while boys demonstrate an acceleration of muscle strength around age 13 years (Roemmich 2014) [60]. The peak increase in muscle strength occurs during the period of early adolescence thus providing a critical window of opportunity to prevent age-related diseases including dynapenia/sarcopenia i.e. the gradual loss of skeletal muscle mass and strength that occurs with advancing age (Morton 2018) [49]. Recent research has paid much attention to poor muscle strength among adolescents and its association with adverse health-related outcomes, including cardiovascular disease, poorer metabolic profile, obesity and musculoskeletal pain as well as premature death from any cause (Ortega 2012) [50].

Furthermore, a cross-sectional study among adolescents reported a prevalence of low muscle strength of 47% among the study population. Unhealthy dietary intake and low physical activity among adolescents are increasingly recognized to be modifiable health-related behavioural determinants of muscle strength among adolescents. Different studies suggest that adequate intake of energy and protein is beneficial for muscle growth, maintenance and repair. Recent studies suggest that caloric restriction induces a chronic decrease in muscle protein synthesis which would limit muscle growth (McIver *et al.*, 2012; Pasiakos and Carbone, 2014) [45, 51]. Several studies have shown that higher energy intake in combination with progressive resistance training induces greater increases in hypertrophy when compared to lower caloric conditions (Garthe *et al.* 2013) [20]. Moreover, muscle growth is an ATP-dependent process, thus adequate energy needs to be available to build muscle (Lambert *et al.* 2004) [38]. Nutritional studies stated that the greatest incidence of nutritional deficiencies exists during adolescence which affects the overall muscle health and is responsible for the early progression of age-related muscle loss later in life. A study suggested that in the absence of sufficient dietary protein intake, muscle is catabolized to provide amino acids to allow for continued endogenous protein synthesis in critical physiological tissues and organs.

Micronutrients including both vitamins and minerals are required for proper growth and development during the adolescent years. Magnesium, iron, zinc and selenium along with different vitamins like vitamin A, vitamin B12, vitamin C, etc. are associated with muscle strength (Hairi 2010) [23]. Magnesium is the second most abundant intracellular cation in the body. Low intake of magnesium is associated with structural damage to muscle cells which is due to increased production of reactive oxygen species, lipid and protein damage and impaired intracellular calcium homeostasis. Also, adolescents are particularly susceptible to iron deficiency anaemia because of their increased blood volume and muscle mass during growth and development. This raises the need for iron to build haemoglobin and protein myoglobin in muscle (Danielewicz 2019) [15]. Other factors that elevate iron needs are increased body weight and the beginning of menstruation for girls. A recent study also suggested that the decline in haemoglobin concentration was directly related to the decline in handgrip strength (Hirani V *et al.* 2016) [28]. Another important nutrient required for the proper functioning of the muscles is zinc. Zinc protects cells against oxidative stress (Marreiro *et al.* 2017) [43]. Oxidative stress, through the accumulation of reactive oxygen species, causes muscle degeneration and a reduction of muscle strength (Prasad 2014) [55]. Thus, food intake patterns of adolescents have been a special concern as it was observed that eating patterns formed in early life are likely to continue into adulthood and then become more ingrained and resistant to change (Chitra & Reddy 2007) [12]. The adolescent years are a window of opportunity to influence lifelong muscle health. Key nutrients for muscle health are energy, protein, Iron, magnesium and zinc. Because of the accelerated muscular, skeletal and endocrine development, nutrient needs are greater during adolescence. Because of the changes that take place in the skeletal muscle in response to energy and macronutrient intake, it is worthwhile to further investigate the relationship between dietary intake and muscle strength. Therefore, this study aims to determine the association between dietary nutrient intake, physical activity, handgrip strength and body composition among adolescent Indian children.

2. Methodology

This was a cross-sectional study done on adolescents aged 10-15 years in Delhi. The duration of the study was 1 year, completed in March 2020. Subjects were selected as per the inclusion and exclusion criteria. Inclusion criteria were adolescents between 10 and 15 years of age (both boys and girls) and willingness to participate in the study. Exclusion criteria were those having any hand injury and acute/chronic pain in the hand, subjects with any fractures, any surgery in the last month and any drug use/ recently on medication. The socio-demographic information of the subjects was obtained using socio-demographic questionnaire.

2.1 Anthropometric measurements

Standing height was measured with a portable stadiometer with the child barefoot. Weight was measured with a portable electronic scale accurate to 100 g (calibration performed using standard weights). BMI was calculated, using World Health Organization (WHO) cutoff values. MUAC was measured using seca tape. To account for changes in anthropometric measures associated with an increase in age and associated pubertal changes, as well as the later growth spurt in boys, the following age groups were defined: Boys (10-12 years), Boys (13-15 years), Girls (10-12 years), and Girls (13-15 years).

2.2 Body composition

For the assessment of body composition, there are several methods including the underwater weighing technique for fat estimation and the total body potassium method for the estimation of lean body mass. Bioimpedance analysis is gaining much importance in estimating body composition. TANITA body composition analyzer analyzes the values using bioelectrical impedance (BIA) which measures the impedance and resistance to the signal as it travels through the water that is found in muscles and fat. The more muscles the person has, the body will hold more water. On the other hand, the greater the amount of water in a person's body, the easier it is for the current to pass through it, although the current is so minimal that the person does not feel thus making it safe, reliable as well as valid tool for the body composition assessment. TANITA body composition analyzer (BC-420) with a sensitivity of 0.1 kg was used to assess the body composition of the subjects (Ploegmakers, 2013) [13].

Tanita utilizes a patented 'foot to foot' pressure contact electrode. A low energy, high-frequency electrical signal (50 kHz, 500 micro amps) is induced and measurement of the baseline resistance to the flow of electrical current in the body is made. The current is passed through the anterior electrode on the scale platform and the voltage drop is then measured on the posterior electrode. The resistance measurement relates directly to the volume of the conductor, which is used to determine total body water, lean body mass and fat mass.

For the measurement of impedance, the subject has to stand on a metal sole plate containing electrodes. Impedance is measured through the legs and lower trunk. The participant's age, weight and body type were fed through the control box. Then, the subject is asked to stand on the metal plate or the platform barefoot. The heels were placed directly on top of the posterior electrodes, while the front part of the foot was in contact with the anterior electrode. The resulting slip includes the fat mass, fat-free mass, muscle mass, body fat percent etc.

The Precautions include that both arms of the subject should be straight down to prevent inaccurate measurement of low body fat percentage and other errors. Measurements should not be taken after a full meal/taking excessive fluid and after a period of intense exercise as it can report false results. The urinary bladder of the subject should be emptied before weighing the subject. The feet of the subject should be properly cleaned as the dirt can become a barrier to the transmission of current. Bloating paper can be used to clean the sole of the feet.

2.3 Hand grip strength

Grip strength is a measure of muscular strength or the maximum force/tension generated by one's forearm muscles. It can be used as a screening tool for the measurement of upper body strength and overall strength (Ploegmakers, 2013) [13].

The strength of the handgrip relates to the muscle power and physical strength that one generates with their hand. Hand grip strength is an important component to guide individuals during growth, ageing, injury, rehabilitation, training or therapeutic trials. It is measured using a dynamometer that estimates the muscle power produced mainly by the hand and forearm flexor muscles. The maximal voluntary contraction of both dominant and non-dominant arms was measured using a handgrip dynamometer. The subject alternatively gripped the dynamometer with the dominant and non-dominant hand. On each arm, two measurements will be taken at intervals of at least one minute (allowing a one-minute rest) using standard procedures.

2.4 Dietary intake assessment

The diet assessment was done quantitatively by the 24-hour dietary recall method. It is a recollective technique where the subject was asked to recall the food intake for the last 24 hours. It was done on two non-consecutive days (a working day and a holiday) to consider the usual food intake of the subject. For the accuracy of the recall, standardized utensils, including Katori, spoons, ladles and glasses were used. Fasting and feasting days were avoided while taking the dietary recall. The dietary recall method provides quantitatively accurate information on food consumed during the recording period. The specific details including food consistency, type of milk, quality of fat, and size of fruit were also emphasized for the accuracy of the results.

Semi-quantitative FFQ was also used to assess the frequency with which different food products are consumed during a specified period. With the addition of portion size estimates, the method is called a semi-quantitative one which allows the consumption of energy and selected nutrient intakes (Rachmah, 2021) [56]. The food groups included will be cereals, pulses, leafy vegetables, roots and tubers, other vegetables, fruits, nuts, oilseeds, meat and meat products, milk and milk products, sugar, beverages etc. The Food Frequency Questionnaire (FFQ) is used to record the usual intake frequency of listed foods in a pre-established period (Mohammadifard, 2011) [47]. A food frequency questionnaire is a checklist of food and beverages consumed by the subject in a specified time with the frequency response section. With the addition of portion size estimates, the method is called a semi-quantitative food frequency questionnaire. All the food items and beverages were recorded and then separated into different food groups. A food frequency questionnaire is used to assess the frequency of food items consumed by the subject. It analyzes which food items are consumed daily, weekly, fortnight and monthly.

2.5 Physical activity

Physical activity pattern was assessed using the "Global Physical Activity Questionnaire" (GPAQ), developed by WHO for physical activity surveillance in countries. It collects information on physical activity participation in three settings as well as sedentary behaviour, comprising 16 questions (P1-P16). The domains are activities of work, travel to and from places and recreational activities. The WHO global physical activity questionnaire cutoff values were used to analyze the data.

2.6 Statistical analysis

All the data obtained through questionnaire, anthropometric measurement and dietary intake were cleaned, coded and computerized using Microsoft Excel and SPSS software (Statistical Package for the Social Science) version 24.0. Missing data was also checked to prevent errors. The qualitative data was treated to obtain frequencies and percentages. Mean, median, standard deviation and range were obtained using quantitative data. Karl Pearson's correlation test was used to find associations between different variables. Dietary data was entered into Diet Cal software and was compared with the recommendations given by ICMR 2020. Diet Cal software version 10.0 was used to find the percent adequacy and average nutrient intake of the subjects. Regression analysis was done using SPSS version 24.0.

2.7 Ethical clearance

Approval from the Institutional Ethical Committee (IEC) from Lady Irwin College was obtained before conducting the study. Also, a parental written consent and a child's assent form were obtained from all the subjects after explaining to them the purpose and objective of the study. Privacy and confidentiality of the data were maintained. The study information sheet was provided to each subject which contained the details of the study.

3. Results

The present study was undertaken to determine "to determine the association dietary nutrient intake, physical activity, handgrip strength and body composition among adolescent Indian children". The sample size was calculated using a recent prevalence study which reported that
17.5% of subjects had low muscle mass. After calculating, a total of 120 subjects were taken for the study. A socio-demographic questionnaire was developed to know the general profile of the subjects. Physical activity was assessed using the Global Physical Activity Questionnaire (GPAQ). Muscle strength using a hand grip dynamometer, muscle mass using a Tanita body composition analyzer and mid-upper arm circumference using seca tape were measured. A two-day 24-hour recall along with FFQ was used to obtain the dietary information.

3.1 General profile of the subjects

The age profile of the subjects

The age group considered for the study was 10-15 years adolescent boys and girls. This age group were selected as this period is considered to be the window of opportunity wherein proper nutrient intake, dietary behaviour and lifestyle changes including a relatively modest increase in physical activity can significantly improve muscle strength and muscle mass. Out of all the subjects (N=120), 5% were in the age group of 11 years, 23.33% were in the age group of 12 years, 28.33% were in the age group of 13 years, 35.83% in the age group of 14 years and 7.50% in the age group of 15 years.

Family income

In the present study, the data suggest that the income of parents of 34 subjects was less than 1,50,000 per year, 44 had family income between 1,50,000-3 lac per year, 23 had family income 3 lac-5 lac per year, 19 had family income more than 5 lac per year. A study reported that lower-income households purchase less food compared with higher-income households. Food purchasing patterns may mediate income differences in dietary intake quality (French 2019). The Third National Health and Nutrition Examination Survey stated that approximately 0.7 to 1.3 million adolescents (12-15 years of age) lived in food-insufficient families.

Eating habits

Out of the total subjects (N=120), the majority of them i.e. 57 subjects were non-vegetarian followed by 49 subjects who were vegetarian and 14 subjects who were eggetarian. A recent study reported that the intake of good-quality protein is higher among non-vegetarians as compared to vegetarians (Mariotti & Gardner 2019) [42]. Another study reported that vegetarians have more protein deficiencies as compared to non-vegetarians (Shridhar *et al.* 2014) [63]. A study suggested that a vegetarian diet provides relatively large amounts of cereals, legumes, nuts, fruits and vegetables and is usually high in carbohydrates as compared to a non-vegetarian diet (Key 2006) [34]. A study reported that non-vegetarians had a lower intake of fibres, magnesium and selenium and a high intake of saturated fat and trans fat (Rizzo 2013) [59].

3.2 Anthropometric assessment

Anthropometric assessment plays an important role in assessing the nutritional status of subjects. Height, weight, mid-upper arm circumference, muscle mass and muscle strength were assessed and analyzed. The subjects were divided into two age groups. The first age group was 10-12 years and the second group was 13-15 years.

Table 1: Anthropometric assessment of the subjects

Anthropometric assessment	Mean ± SD			
	10-12 years		13-15 years	
	Boys	Girls	Boys	Girls
Height (cm)	148.62±7.74	147.59±.6.81	158±8.6	153.7±5.3
Weight (kg)	42.5±12.3	38.2±7.2	48.5±13.9	47.3±11.3
Body Mass Index (kg/m2)	18.6±4.21	17.5±3.16	19.2±4.2	20.04±4.16
Muscle strength (Dominant hand)	17.4±5.1	15.7±4.9	24.1±6.9	18.78±5.58
Muscle strength (Non-dominant hand)	15.4±4.86	13.4±4.24	22.8±6.29	16.86±5.29
Mid-upper arm circumference (cm)	23.9±2.7	21.83±2.18	24.3±2.9	23.65±3.37
Muscle mass (kg)	30.4±4.4	27.5±2.71	36.06±5.5	30.78±3.73

Height: The mean height of boys 10-12 years and 13-15 years was 148.62±7.74 cm and 158.05±8.6 cm respectively while it was 147.59±6.81 cm and 153.7±5.3 cm respectively among girls. In the present study, boys were taller as compared to girls. Recent studies also suggest that the peak velocity of growth in height is higher in boys (10-13 years) as compared to girls (Goyal 2019) [21]. Another study also reported that growth in height is more in boys as compared to girls (Iuliano 2001). In the present study, a significant association between mean height and muscle strength [r=0.71 (P=0.01)] was obtained among both boys and girls in both age groups. A Study reported that muscle strength is highly dependent on height. Adolescents with growth retardation or short stature have lower muscle strength than adolescents of the same age (Hogrel *et al.* 2012) [29].

Weight: The mean weight of boys 10-12 years and 13-15 years was 42.5kg and 48.5kg respectively while it was 38.2kg and 47.3kg respectively among girls. The mean weight of boys was more than girls in both age groups. In the present study, a significant association between weight and muscle strength [r=0.556 (P=0.01)] was obtained in both age groups. A study reported that weight was a significant predictor of muscle strength for both boys and girls.

BMI: BMI has been classified using WHO growth reference standards (BMI for age) 2007. For each of the age groups, different percentile scores have been given defining whether the subject is underweight, normal, overweight or obese. Among girls, 43 subjects (71.6%) were normal, 9 (15.1%) were overweight and 8 (13.3%) were obese. Similarly, among boys, 39 subjects (65%) were normal, 15 subjects (25%) were overweight and 6 subjects (10%) were obese. In the present study, a significant association between BMI and muscle strength [r=0.34 (P=0.01)] was obtained. Several studies suggested that long-term obesity among adolescents is associated with poor muscle strength later in life. Another study reported that the BMI of adolescents had a positive correlation with muscle strength (Hasan, Kamal, & Hussein 2016) [24]. A study suggested that underweight and overweight adolescents had lower grip strength than the normal weight adolescents (Lad 2013) [36].

Hand grip strength: In the present study, it was observed that boys have greater muscle strength in both dominant and non-dominant hands as compared to girls. Several studies also suggest that adolescent boys have higher values than adolescent girls on measures of muscle strength. This is because, among girls, growth is characterized by increased estrogen levels and increased mass and strength of bone relative to that of muscle, whereas in boys, increases in testosterone fuel large increases in muscle, resulting in greater muscle mass and muscle strength (Ervin 2013; Lang 2011) [16]. Girls reach a plateau of muscle strength increases by about age 15 years while boys demonstrate an acceleration of muscle strength around age 13 years (Roemmich 2014) [60]. Thus, early adolescence is a critical window of opportunity to prevent muscle loss and attain peak muscle mass and strength. A study reported that 47% of adolescents have low muscle strength (Timpka *et al.* 2013) [67]. High muscular strength among adolescents was associated with a 20-35% lower risk of early death from any cause and also from cardiovascular diseases (Ortega 2012) [50].

According to a recent study, muscle strength is divided into three categories: weak, normal and strong based on different cut-off values (Gaikwad 2016) [19]. A study suggests that the percentage of weak muscle strength is higher among girls as compared to boys. In the present study, muscle strength among boys was more as compared to girls. Among boys, 23.33% of subjects have weak muscle strength whereas it was 43.3% among girls.

Mid-Upper Arm Circumference (MUAC): The mean MUAC among boys was more than girls in both age groups. Recent studies suggested that boys have greater MUAC than girls due to more accumulation of lean muscle among boys as compared to girls. A study suggested that MUAC is significantly associated with muscle strength in both boys and girls (Chilima and Ismail 2001) [11]. In the present study, a significant association between MUAC and muscle strength [r= 0.45 (P=0.01)] was obtained. A study reported that muscle strength increases linearly as MUAC increases (Lemma & Shetty 2009) [40].

MUAC is divided into three categories: normal, moderate acute malnutrition and severe acute malnutrition. According to a study, the percentage of adolescents who were malnourished was 4.2% (Jeyakumar 2013) [32]. In the present study, the data indicate that 1.6% of subjects were moderately malnourished while the rest 98.3% of subjects were normal. The reduction in the percentage of malnourished children can be due to adequate intake of food and increased physical activity among the subjects. A study reported that muscle strength demonstrated a linear increase from under-nourished to normal subjects among adolescents (Lemma & Shetty 2009) [40].

3.3 Physical activity

Among the subjects, 23.3% of subjects had low physical activity, 73.3% subjects were moderately active and 3.3% subjects had high physical activity. Most of the subjects reported involvement in various school activities and were actively participating in the sports events of the school, mostly including cricket, marathon, football and badminton. A study indicates that physical activity induces muscle hypertrophy with an associated increase in muscle strength (Behringer *et al.* 2010) [6]. A study reported that low physical activity is a modifiable health-related behavioural determinant of muscle strength among adolescents. A low level of physical activity causes a decrease in muscle mass and strength and results in increased fatigability due to changes in muscle metabolism (Rimmer *et al.* 2012) [58]. Several studies suggested that physical activity is significantly associated with muscle strength. Low level of physical activity is linked to cardio-respiratory problems, musculoskeletal pain and increased risk of muscle loss and bone injuries (Henriksson *et al.* 2020) [25].

3.4 Dietary analysis

A two-day 24-hour recall along with FFQ was used to obtain the dietary information. The mean intake of nutrients was analyzed using Diet Cal software and the percent adequacy of all the nutrients was determined and compared with the RDA value given by ICMR (2020) for a balanced diet as shown in Table 2 and Table 3. Food group frequency and percent, food group adequacy were also determined to know the dietary pattern of boys and girls among both the age groups. The mean intake and percent adequacy of all the nutrients are shown below.

Nutrient intake

The mean nutrient intake and percent adequacy of the diets of the subjects were determined and compared with the RDA value given by ICMR (2020) for a balanced diet. The data is given below:

Energy

The RDA of energy for boys and girls of 10-12 years was 2220 kcal and 2060 kcal respectively whereas RDA for boys and girls 13-15 years was 2860 kcal and 2400 kcal respectively. The percent adequacy among girls was more than boys in both groups. This can be due to changes in eating patterns among boys and girls. A study reported that the overall consumption of fast food was more in girls as compared to boys which leads to more intake of energy among girls (Morse 2009) [48]. A study suggested that intake patterns among adolescents are congruent with known sexual dimorphisms for body composition and pubertal development. Consistent with their higher energy requirements in early adolescence, girls consume significantly larger amounts of food than boys (Jodhun 2016) [33].

Protein

The mean intake of protein in 10-12-year-old boys and girls and 13-15-year-old boys and girls were 26.2 g/day and 26.6 g/day respectively and 36.4 g/day and 34.7 g/day respectively. The percent adequacy among the 10-12 year age group was higher as compared to the 13-15 years age group. The protein in the diet was adequate among boys and girls in both age groups. The majority of the subjects (57%) were non-vegetarians consuming more meat and meat products having a high biological value of protein, also adequate consumption of milk and milk products, pulses and soybean was seen among vegetarians.

Fat

The percent adequacy of fat was higher among girls as compared to boys in both age groups. The percentage adequacy among 10-12 year and 13-15 year boys was 111.7% and 117.59% respectively. Among girls, it was 113.7% and 136.82%. The consumption of fat is more than the RDA in both age groups. This can be due to the consumption of more fast food among subjects as they were very fond of eating pizza, patties, samosa and bread pakora.

Minerals

Iron

Adolescence is a time of increased iron needs because of the expansion of blood volume and increases in muscle mass (Powers 2018) [54]. The percent adequacy of iron is higher among 10-12 year girls as compared to 13-15 year girls. This can be due to the lack of green leafy vegetables in the diet of the subjects.

Magnesium

Adequate consumption of magnesium was observed among 10-12 year subjects. The consumption is almost twice the RDA recommended by ICMR among 10-12 year boys and 1.5 times the RDA among girls. This is due to more intake of pulses and nuts by the subjects among both the age groups which are rich in magnesium.

Table 2: Mean intake of nutrients among 10-12 year subjects

Nutrients	Boys			Girls		
	RDA (ICMR 2020)	Mean ± SD	Percent adequacy (%)	RDA (ICMR 2020)	Mean ± SD	Percent adequacy (%)
Energy (kcal)	2220	1178±313.09	53.6%	2060	1725±317.7	83.7%
Protein (g)	26.2	47.5±11.18	181.2%	26.6	50.4±10.5	189.4%
Fat (g)	35	44.61±14.71	127.42%	45	51.27±21.36	113.7%
Iron (mg)	12	13.62±3.95	113.5%	16	17.38±4.53	108.1%
Zinc (mg)	7	6.41±2.29	91.5%	7.1	6.91±2.57	97.3%
Magnesium (mg)	223	236.42±154.72	1062%	214	224.09±86.8	04.6%

Table 3: Mean intake of nutrients among 13-15 year subjects

	Boys			Girls		
Nutrients	RDA (ICMR 2020)	Mean ± SD	Percent adequacy (%)	RDA (ICMR 2020)	Mean ± SD	Percent adequacy (%)
Energy (kcal)	2860	927±439.23	70.07%	2400	1903±423.8	81.69%
Protein (g)	36.4	56.7±20.37	104.54%	34.7	54.2±14.2	104.52%
Fat (g)	50	52.92±18.38	117.5%	35	54.7±21.5	136.82%
Iron (mg)	15	16.62±4.71	51.95%	17	17.59±4.69	65.16%
Zinc (mg)	11.9	7.97±2.71	72.47%	10.7	7.94±2.71	72.19%
Magnesium (mg)	294	276.9±129.1	167.87%	270	269.8±87.9	128.48%

Food group

The mean intake of cereal was higher among the 13-15-year age group. The percent adequacy was around 50% among boys and girls in both the age groups. Among cereals, stuffed paratha was commonly consumed by the subjects. Intake of pulses, roots and tubers, fruits and milk and milk products was adequate among boys and girls in both the age groups. A low intake of green leafy vegetables was observed. Different studies also suggested that the intake of green leafy vegetables is low in adolescence (Kimmons 2009) [35]. The commonly consumed fruits were apple, banana, orange and guava. Fried savory snacks included in the diet were bread pakora and samosa contributing to a high intake of trans fatty acids. Homemade mathri was another commonly consumed snack among subjects.

3.5 Association between nutrient intake and muscle strength

The association between nutrient intake, and muscle strength was obtained using Karl Pearson's correlation test. The value is obtained at a 1% and 5% level of significance. The data is given in Table 4.

Table 4: Association between nutrient intake and muscle strength

Nutrient	Muscle strength	
	Value	Significance
Energy	r= 0.375	P=0.01
Protein	r= 0.469	P=0.01
Iron	r= 0.386	P=0.01
Magnesium	r= 0.435	P=0.01
Selenium	r= 0.212	P=0.05

Energy: Energy intake was significantly associated with muscle strength [r= 0.375 (P=0.01)] among both boys and girls in both age groups. A linear relationship between energy intake and muscle strength was obtained. A study also suggested that caloric restriction induces a chronic decrease in muscle protein synthesis which would limit muscle growth (Pasiakos and Carbone 2014) [51]. A similar significant association was obtained between energy intake [r=0.4289, P=0.01)] and muscle mass among both boys and girls. This corroborates with a recent study that suggests that energy intake plays a vital role in the relationship between body composition and physical activity having a direct effect on both muscle mass and strength (Peterson 2015) [52].

Another study suggests that greater energy intake causes greater increases in both muscle mass and muscle strength among adolescents. High energy intake leading to obesity is a major determinant of low muscle strength (Silva 2017) [64]. A study suggested that greater energy intake elicited greater increases in both muscle mass and muscle strength (Rozenek *et al.* 2002) [62]. The mechanism by which energy surplus induces greater hypertrophic changes is seemingly related to an augmented muscle protein synthetic response during periods of positive energy balance (Millward *et al.* 1994) [46]. Evidence shows that a positive energy balance alone drives increases in lean mass provided sufficient dietary protein is consumed (Churchward-Venne *et al.*, 2013) [13]. Moreover, muscle growth is an ATP-dependent process, thus adequate energy needs to be available to build muscle (Lambert *et al.* 2004) [38].

Protein: Protein intake plays an important role in maintaining muscle health as it contributes to greater muscle strength and muscle mass. In the present study, protein intake was significantly associated with muscle strength [r= 0.469 (P=0.01)]. A similar significant association was also obtained between protein intake and muscle mass [r= 0.428 (P=0.01)]. A study suggested that, in the absence of sufficient dietary protein intake, muscle is catabolized to provide amino acids to allow for continued endogenous protein synthesis in critical physiological tissues and organs. During the phase of rapid growth, dietary protein requirements are elevated to provide the necessary amino acid building blocks for muscle protein manufacturing and adaptation, as well as changes in supporting tissue.

Iron: A significant association was also obtained between iron intake [r= 0.386 (P=0.01)] with muscle strength of both dominant and non-dominant hands. During adolescence, increased blood volume and muscle mass raise the need for iron to build haemoglobin and protein myoglobin in muscle (Danielewicz 2019) [15]. Recent studies suggest that the decline in haemoglobin concentration is directly related to the decline in handgrip strength because the body uses iron to build haemoglobin and protein myoglobin in muscle which contributes to muscle strength (Danielewicz 2019; Hirani V *et al.* 2016) [15, 28]. During high-intensity physical activity, iron helps the body convert carbohydrates into energy (Ilangovan 2015) [30]. Another study also reported that low intake of iron is associated with poor physical performance (Beard 2001) [5].

Magnesium: In the present study, magnesium intake [r= 0.435 (P=0.01)] was significantly associated with muscle strength. A study suggested that magnesium plays an important role in muscle contraction and relaxation and also helps in the synthesis of muscle protein thus, adequate magnesium intake is shown to increase muscle strength among adolescents (Welch 2016) [69]. A study suggested that low intake of magnesium is associated with structural damage to muscle cells which is due to increased production of reactive oxygen species. A well-adjusted magnesium and calcium balance is indispensable for healthy muscle function. It controls the transmission of impulses from nerves to muscles, and ensures that the continued inflow of calcium is prevented and that the nerve excitability is lowered leading to the desired relaxation (Zhang *et al.* 2017) [73]. A study reported that magnesium is also a cofactor for numerous enzymatic reactions including energy metabolism and protein synthesis (Welch 2016) [69].

Selenium: A similar significant association was obtained between selenium intake [r= 0.212 (P=0.05)] and muscle strength. A study also suggested that selenoproteins, selenium affects muscle synthesis and function (Rederstorff 2006) [57]. Selenium is important in normal muscle function because of its role in selenoenzymes such as glutathione peroxidase that protect muscle against oxidative damage (Chariot 2003) [10].

3.6 Association between physical activity and muscle strength

A significant association between physical activity and muscle strength in both boys and girls was obtained [r=0.209 (P=0.05)]. A study also indicated that physical activity induces muscle hypertrophy with an associated increase in muscle strength (Behringer *et al.* 2010) [6]. A recent study also suggested that physical activity is significantly associated with muscle strength among adolescents. Recent research also suggested that muscle-strengthening physical activity in adolescents is significantly associated with muscle health (Martinez 2011) [44]. A study reported that high levels of physical activity have been found to optimize skeletal development early in life, thus preventing age-related muscle loss and bone loss among adolescents (Herrmann 2015) [26].

A similar significant association was obtained between physical activity and mid-upper arm circumference in boys but not significant in the case of girls. A study suggested a significant association between poor physical activity and malnutrition among adolescents. A significant association was also obtained between muscle strength and BMI [r=0.348 (P=0.01)]. Recent studies also suggest that muscle strength increases significantly with increasing BMI in both boys and girls among adolescents.

4. Discussion

Adolescence is a period of transition between childhood and adulthood. It is a period of nutritional vulnerability due to increased dietary requirements for growth and development. An increase in the strength of skeletal muscles is a major physiological event during adolescence. Skeletal muscle not only contributes to physical strength and performance but also contributes to efficient macronutrient utilization and storage. In childhood, boys and girls of the same age have similar muscle strength whereas in adolescence, gain in muscle strength is greater in boys. The gender difference in muscle strength can be because women tend to have a lower proportion of their lean tissue distributed in the upper body (Lafortuna 2005) [37].

There are different factors like age, variation in height and weight, dietary behaviour and level of physical activity which are associated with changes in muscle strength during growth. Unhealthy dietary intake and low physical activity among adolescents are increasingly recognized to be modifiable health-related behavioural determinants of muscle strength among adolescents. Different studies suggest that adequate intake of energy and protein is necessary for optimizing muscle mass, maintenance and repair. Recent research also indicates that different micronutrients like iron, magnesium and selenium were also associated with muscle protein synthesis and thus have a positive impact on muscle strength (Abrams 2010; Alawi 2018; Chariot 2003) [10, 3, 1].

Food intake patterns of children have been a special concern as it was observed that eating patterns formed in early life are likely to continue into adulthood and then become more ingrained and resistant to change (Chitra & Reddy 2007) [12]. Environmental influences play an important role in the development of food behaviour in children. Several factors affect adolescent's food habits including family, peers, irregular meal patterns and snacking. These factors influence nutrient intake and thus directly impact muscle strength development among adolescents.

Increased physical activity is recommended during adolescence as it leads to increased muscle strength and muscle mass and prevents any age-related loss of muscle that can lead to sarcopenia later in life (Morton *et al.* 2018) [49]. Muscle weakness and muscle strength imbalance caused by physical inactivity are important risk factors for injuries during any sports activity and can lead to musculoskeletal pain and other problems. Given the changes that take place in the skeletal muscle in response to nutrient intake and physical activity, it is worthwhile to further investigate the relationship between nutrient intake, physical activity and muscle strength.

5. Conclusion

Adolescence is a transitional period of physical and psychological human development between childhood and adulthood. It is considered a critical period for the attainment of peak bone mass and peak muscle mass that occurs during early adolescence. Accelerated muscular and skeletal development leads to increased nutrient needs. In the present study, the intake of protein and fat was adequate in both age groups. Also, the intake of different food groups including cereals, pulses, milk and milk products was adequate except for green leafy vegetable intake which was least among all food groups. Green leafy vegetables are a good source of iron, magnesium and selenium. Low intake of GLVs leads to deficiency of these important nutrients and leads to weakened muscle strength among adolescents (Yadav 2017) [72]. Muscle mass and muscle strength development is a major event occurring during adolescence. It was observed that muscle strength was significantly associated with energy and protein intake. Iron, magnesium and selenium were also significantly associated with muscle strength. Energy and protein intake were also positively associated with muscle mass and mid-upper arm circumference. Physical activity was significantly associated with muscle strength and muscle mass. A significant association between BMI and muscle strength was also observed. Given the changes that take place in the skeletal muscle in response to nutrient intake and physical activity, it is worthwhile to further investigate the relationship between dietary intake, physical activity and muscle strength.

Thus, it can be concluded that nutrient intake and adequate physical activity have a significantly positive association with muscle strength among boys and girls in both age groups.

6. Limitations

This was a cross-sectional study. The study was conducted on a small sample size so, the results cannot be generalized to the total population. Also, the results were based on self-reported dietary intake data by the subjects. So, memory bias in the case of 24-hour dietary recall could be a limitation.

7. Recommendations

Subjects and their parents should be made aware of the importance of adolescence period and its importance in attaining peak bone mass and muscle mass. Also, awareness about the importance, timing and type of physical activity is important. A balanced diet is key to good health so, avoiding high-fat, high-sugar food will help in preventing obesity. Extended periods of sedentary behaviour should be avoided and outdoor games like badminton, cricket etc. should be promoted to achieve the recommended level of physical activity.

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