Research Article

Monitoring Skeletal Muscle Growth in Children

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Background: Adequate skeletal muscle mass is essential for the health of both children and adults. Nutritional status of school children is monitored routinely by using the weight, height, and body mass index (BMI) z-score. We aim to 1) establish a low muscle mass index (MMI) in children and 2) develop a practical method to monitor skeletal muscle growth under school settings, in addition to the BMI z-score.

Methods: School-age children were enrolled for anthropometric measurements, body composition analysis, and mobility assessments (grip strength and gait speed). Nominal data of age- and gender-specific body composition (fat, fat free or muscle mass) in children were established in the first phase of the study. Low muscle mass index (MMI) was defined as less than two standard deviations below the mean MMI of each age groups, and the age- and gender-
specific cut off levels were established. A multiple linear regression model was constructed in the second phase to estimate the whole muscle mass level by using age, gender, anthropometric data, and mobility parameters.

Results: Muscle mass index (MMI), increased with age, and higher in male than female. Overweight children had not only high mean MMI, but also wide range of men MMI. Underweight children lost not only adiposity, but also low mean MMI and narrow range of mean MMI. The low MMI levels in male(female) children in the groups of 5-7-, 8-10-, 11-13-, and 14–16-year-olds were 11.5 (10.4), 11.7(10.5), 12.3(11.1), and 13.5(11.7) kg/m2. Low MMI, muscularity, children were found in 1.3% of children with overweight and 13.1% children with underweight. The whole muscle mass in children could be estimated by gender, weight, height, and grip strength, as per the regression model.

Conclusions: Low muscularity children are present in children with under and overweight. In addition to using weight, height, and BMI z-score as an indicator of child nutritional status, grip strength allows not only to provide muscle function, but also to assess muscularity. By using regression model, the muscularity and nutrition status can be used for an individual intervention through nutritional and muscle enhancement program.

Keywords: Skeletal Muscle Mass, Motor Skill, Bioelectric Impedance Analysis, Grip Strength, Physical Activity, Resistance Exercise.

INTRODUCTION

The role of skeletal muscle in health has increasingly gained recognition. Adequate skeletal muscle mass is crucial to the health of both children and adults (1). Skeletal muscles play a role not only in body movement, but also the metabolism of protein, energy, and glucose (2). The amount of skeletal muscle mass changes with age, which increases during growth in childhood, peaks at young adulthood, and declines thereafter (3,4).

Skeletal muscle mass is the main component of motor skill development and physical fitness (5,6). During the growth and development, skeletal muscles lay the physical foundation of body movements, either simple or complex movements. The movements range from mobility, including gait, posture and balance, to limb dexterity. A child learns to master and acquire these movements through active physical activities that become the development of motor skills (6,7).

The amount of skeletal muscle varies from low to high, depending on many factors. As an organ with high plasticity, the skeletal muscle mass can easily be lost or enhanced. (8). Muscle mass is enhanced through an interaction between nutritional, hormonal, and physical activities. Adequate nutrition and active physical activities can enhance skeletal muscle mass. On the other hand, many factors can contribute to low skeletal muscle mass or muscle loss, such as inadequate nutrition, low quantity and/or low-quality protein intake, hormonal disturbances, low level of physical activity, high level of physical inactivity, increased adiposity, and chronic diseases (9).

Promoting and monitoring skeletal muscle growth are important for the child's health. Many age- and gender-specific skeletal mass reference data have been published (10–12). Quantitative measurements of skeletal muscle mass are performed using standard procedures that are only available in research settings (10–12). To monitor children's skeletal mass in the school context where a standard procedure is not available, a more practical assessment tool with the age-, gender-, and ethnic-specific reference data is necessary.

Schools routinely monitor the child's growth and nutritional status by using anthropometric parameters and growth reference data, such as age- and gender-specific weight, height, and BMI z-score. However, the BMI z-score does not reflect body composition (fat mass and fat-free mass, or muscle, ratio) that varies according to age, gender, and ethnicity. We aim to 1) establish the low muscle mass level in children and 2) develop a practical skeletal muscle mass assessment under school settings that could be simultaneously monitored with the current school monitoring program. This muscle mass estimation can be integrated into the routine monitor.

METHODS

Participants and Setting

From January 2020 to February 2021, healthy schoolchildren, aged 5-16 years, were recruited from five public schools (kindergartens, primary schools, and middle schools) in the Ladkrabang District, Bangkok, Thailand. The children were enrolled in the two-phase studies and grouped into four groups by age: 5-7, 8-10, 11-13, and 14-16 years. The first phase of the study was a descriptive, cross-sectional survey of anthropometric and body composition analysis to establish the age- and gender-specific cut off levels for low skeletal muscle mass. The second phase was to develop a practical assessment tool by using a multiple linear regression model to predict the whole muscle mass. The model was constructed by using the following as predictors: 1) age, gender; 2) anthropometric data (gender, weight, and height); 3) grip strength, a component of physical fitness that reflected muscle strength; and 4) gait speed which reflected physical performance.

Instruments and Procedures

Anthropometric and Body Composition Measurements

Height (cm) was measured using a Tanita WB-380 stadiometer (13). Body composition analysis was performed by using a dual frequency (6.25, 50 kHz) bioelectrical impedance analysis (BIA), Tanita DC 360P (14). After entering age (years), gender (male/female), height (cm), the machine weighed the body weight (kg) and generated the BMI (kg/m2), fat mass (kg) and whole muscle mass (kg). The whole muscle mass was used to calculate the percentage of muscle mass per body weight (% muscle) and muscle mass index (MMI) using the following formulas:

% muscle = whole muscle mass (kg) / body weight (kg) * 100

MMI (kg/m2) = whole muscle mass (kg) / height2 (m)2

MMI represented the amount of total muscle mass adjusted to height. Low muscle mass or low MMI level was defined as a level lower than two standard deviations (SDs) below the mean MMI (mean MMI – 2 SDs). Z-score for BMI-for-age and gender was calculated using the Lambda-Mu-Sigma (LMS) and the WHO calculation guidelines (15). A BMI-for-age z-score of < -2 was defined as wasting/thinness; between -2 and +1 as normal; and > +1 as overweight/obese.

Mobility Assessments

Grip strength was measured in kilograms (kg) of the dominant hand, in the standing position with full elbow extension using a grip dynamometer, Takei T.K.K.5401 GRIP-D(16). Gait speed (m/sec) was calculated from the time in seconds (sec) that the participant took to walk a distance of six meters on a flat pavement or hallway (17). Both grip strength and gait speed were repeated twice.

DATA ANALYSIS

All data were analyzed using the RStudio software (18). In the first phase, the sample size calculation was performed using the pwr package (19). The sample size of 249 schoolchildren for each age group was required to ensure an expected mean of data from a population of 35,500 children within the district, with a confidence level of 0.95, expected standard deviation of 4, and a margin of error of 0.5. The descriptive study of nominal data from body composition analysis was presented as mean ± SD. Z score < 0.05 was significant. Pearson's Chi-squared test was used in the contingency table. The LMS curve and percentile estimation were generated by the gamlss package to construct the muscle mass index percentile curve against age (20). In the second phase, a multiple linear regression model was developed to predict the whole muscle mass using the Stargazer R package (21). Data visualization was generated using the ggplot2 package (22).

Age / Sex (Cases)	Height (cm)	Weight (kg)	BMI (kg/m2)	Fat Mass (kg)	Whole Muscle Mass (kg)	% Muscle (kg/kg*100)	MMI (kg/m2)	Low MMI Level: mean-2SDs (kg/m2)
5-7 year (n = 811)								
M (n =427)	118.3+7.3	22.7+6.8	16.0+3.3	3.7+4.6	18.2+2.9	82.9+10.4	12.9+0.7	11.5
F (n = 384)	117.9+7.5	22.2+6.8	15.7+3.3	4.0+4.2	17.3+3.0	80.2+8.6	12.3+0.9	10.4
p-value	0.45	0.20	0.16	0.31	<0.05	<0.05	<0.05	
8-10 year (n = 785)								
M (n = 381)	132.0+8.0	32.0+11.2	18.0+4.5	7.4+8.6	23.4+3.72	77.9+13.8	13.3+0.8	11.7
F (n = 404)	133.1+9.0	30.5+9.7	16.9+3.9	6.6+6.0	22.6+4.19	77.0+9.7	12.7+1.1	10.5
p-value	0.07	0.07	<0.05	0.23	<0.05	0.31	<0.05	
11-13 year (n = 998)								
M (n = 497)	151.7+11.6	46.0+15.4	19.5+4.7	10.5+11.4	33.4+6.5	76.3+13.5	14.3+1.1	12.3
F (n = 501)	151.6+7.5	44.4+11.9	19.0+4.1	11.6+8.3	30.6+4.4	71.2+9.2	13.2+1.1	11.1
p-value	0.92	0.05	0.07	0.09	<0.05	<0.05	<0.05	
14-16 year (n = 587)								
M (n = 303)	166.7+7.6	58.7+15.2	21.0+4.8	11.9+11.0	43.4+5.7	78.1+11.1	15.9+1.4	13.5
F (n = 284)	157.5+5.6	51.8+10.6	20.8+4.0	15.8+8.2	33.9+3.4	66.9+8.0	13.6+1.0	11.7
p-value	<0.05	<0.05	0.11	<0.05	<0.05	<0.05	<0.05	

Table 1: Body Composition Analysis and Muscle Mass Index of 3,181 Children (mean + SD)

RESULTS

A total of 3,181 children (1,608 boys, 1,573 girls) were enrolled to the first phase of the study, to establish the age- and gender-specific cut off levels for low skeletal muscle mass. Nominal data of their body composition analysis, percent of muscle mass, MMI, and low MMI levels are presented (Table 1). Body composition analysis revealed that the mean % muscle remained relatively constant in boys from 82.9% in 5-7 years old to 78.1% in 14–16 years old. However, the mean % muscle reduced from 80.2% in 5-7 years old to 66.9% in 14-16 years old girls, reflecting an increased fat component in the female body composition during growth. Boys had more muscle mass than girls, with a mean % muscle of 82.9% vs 80.2% (p <0.05) at 5-7 years and 78.1 % vs 66.9% (p<0.05) at 14-16 years, respectively. The muscle mass index (MMI) and their 3rd, 25th, 50th, and 75th percentile estimation are presented (Figure 1). Low MMI levels (boys, girls) were 11.5, 10. 4 kg/m2 in 5–7 years old; 11.7, 10.5 kg/m2 in 8-10 years old; 12.3, 11.1 kg/m2 in 11-13 years old and 13.5, 11.7 kg/m2 in 14-16 years old, respectively.

The BMI z-score classified the children into three groups. Normal BMI was found in 66.1% (2,103/3,181 cases), overweight/obesity in 26.7% (849/3,181 cases) and wasting/thinness in 7.2% (229/3,181 cases) of the children. The range of MMI levels in each BMI z-score subgroups showed the remarkable finding. The higher BMI z-score was associated with higher mean MMI and wider SD. Children (boys, girls) with wasting/thinness (low BMI z-score) had lower mean MMI with narrow SD at 12.55 + 0.92, 11.37 + 0.59 kg/m2 , but with overweight/obesity had higher mean MMI with wider SD at 14.75 + 1.67, 14.24 + 1.12 kg/m2. The wasting/thinness group had the highest proportion of low MMI, 13.1% (30/299 cases), compared with 1.3% (11/849 cases) of the overweight/obesity groups (Table 2).

	Wasting, Thinness (BMI z-score <= -2)	Normal (BMI z-score between>-2 and <1)	Overweight, Obesity (BMI z-score > 1)
Muscle Mass Index (MMI) (kg/m2)			
Male			
mean + SD	12.55 + 0.92	13.84 + 1.20	14.75 + 1.67
Female			
mean + SD	11.37 + 0.59	12.71 + 0.80	14.24 + 1.12
% Low Muscle Mass Index (Low MMI) Cases*			
Normal MMI (%) **n (male: female)**	86.9% 199 (103:96)	100% 2,103 (987:1,116)	98.7% 838 (488:350)
Low MMI (%) **n (male: female)**	13.1% 30 (21:9)	0% 0	1.3% 11 (9:2)
Total (%) **n (male: female)**	7.2% 229 (124:105) / 3,181	66.1% 2,103 (987:1,116) / 3,181	26.7% 849 (497:352) / 3,181
***Pearson's Chi-squared test # X-squared = 278.57, df = 2, p-value < 0.05**			

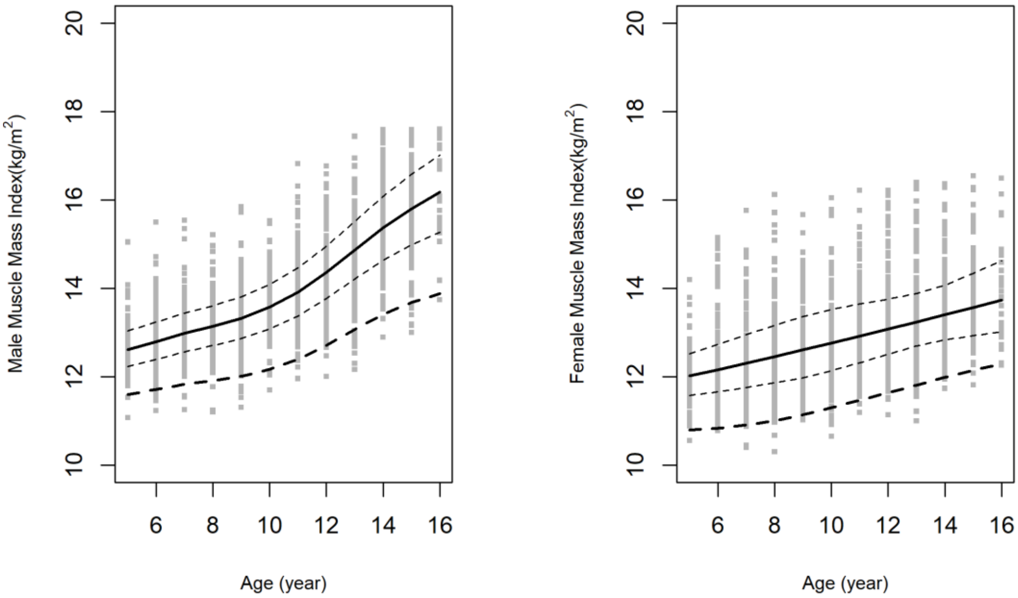
Table 2: BMI z-Score Subgroups and Muscle Mass Index of 3,181 Children

Age (5-16 year)	Height(cm)	Weight(kg)	Grip Strength(kg)	Gait Speed (m/sec)
Gender: Male =1 (295 cases)				
Mean + SD	139.6+16.5	37.51+18.2	18.51+9.7	0.8+0.1
	100-179	12.8-102.6	3-49	0.5-1.25
Gender: Female =0 (303 cases)				
Mean + SD	138.1+15.0	35.6+16.8	15.9+7.3	0.8+0.1
Range (min-max)	98-166	14.1-91.2	3-38	0.5-1.5
Multiple Linear Regression				
Whole Muscle Mass = -22.438+1.072(Gender)+0.105(Weight)+0.296(Height)+0.199(Grip Strength)				
Observations: 598 R2: 0.957 Adjusted R2: 0.957 Residual Std. Error: 1.761 (df = 593) F Statistic: 3,289.176* (df = 4; 593) *p<0.05				

Table 3: The Multiple Linear Regression Model of Whole Muscle Mass of 598 Children

Five hundred ninety-eight children (295 boys, 303 girls) were included in the second phase of the study. Multiple linear regression models were constructed to estimate the whole muscle mass based on age, gender, weight, height, grip strength and gait speed. Gender, weight, height, and grip strength were significant predictors of whole muscle mass. A significant regression equation was found and shown (Table 3).

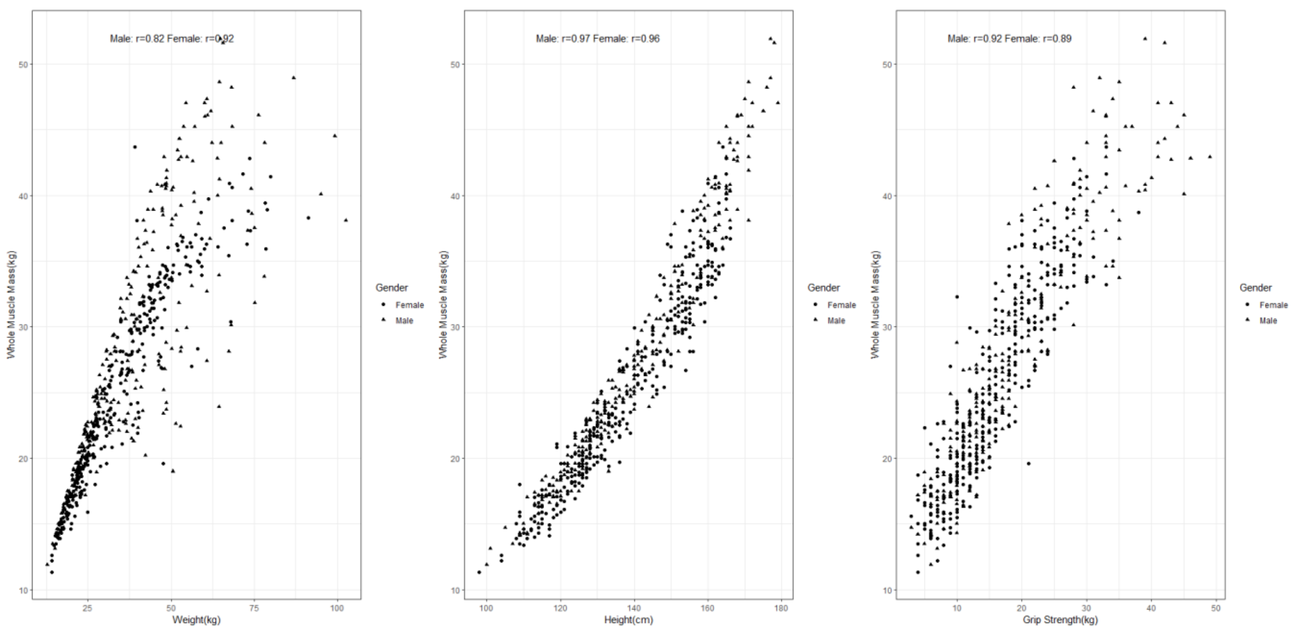
Figure 1: Muscle Mass Index Curves at The 3th,25th,50th,75th centiles



The estimated whole muscle mass of each participant was calculated using the following equation: Estimated whole muscle mass (kg) = -22.438 + 1.072 (gender) + 0.105 (weight) +0.296 (height) +0.199 (grip strength)

Where gender was coded as 1 for male and 0 for female (Table 3). The scatter plot between the whole muscle mass and weight, height, and grip strength are displayed (Figure 2).

Figure 2: Whole Muscle Mass and The Predictors



Dependent variable: Whole Muscle Mass			
	(1)	(2)	(3)
Age	-0.039		
	(0.063)		
Gender	1.098***	1.103***	1.072***
	(0.150)	(0.149)	(0.148)
Weight	0.103***	0.104***	0.105***
	(0.008)	(0.008)	(0.008)
Height	0.303***	0.297***	0.296***
	(0.014)	(0.010)	(0.010)
Grip Strength	0.201***	0.199***	0.199***
	(0.019)	(0.019)	(0.019)
Gait Speed	0.907	0.921	
	(0.565)	(0.564)	
Constant	-23.698***	-23.316***	-22.438***
	(1.367)	(1.219)	(1.096)
Observations	598	598	598
R2	0.957	0.957	0.957
Adjusted R2	0.957	0.957	0.957
Residual Std. Error	1.759 (df = 591)	1.758 (df = 592)	1.761 (df = 593)
F Statistic	2,197.154*** (df = 6; 591)	2,639.251*** (df = 5; 592)	3,289.176*** (df = 4; 593)
Note:	*p<0.1; **p<0.05; ***p<0.01		

Supplementary Table 1: The Multiple Linear Regression Model of Whole Muscle Mass of 598 Children

DISCUSSION

Adopting active lifestyles and staying physically fit during adulthood is necessary to prevent noncommunicable diseases and maintaining mobility in older adults (23,24). However, this health trajectory depends on the development of motor skills or motor competency and physical fitness which occur in early childhood and continue toward adulthood (25). Motor skill development is related to physical activities corresponding to health-related physical fitness and adiposity prevention (26). Adequate levels of motor skill development are essential for maintaining and adopting high-level physical activities in adulthood (27).

The amount of skeletal muscle mass or muscle quantity is a physical attribute of motor skill development (6) and a component of physical fitness related to health (5). Promoting and long-term monitoring of skeletal muscle growth are important to an individual's health. With proper nutrition and physical activity, skeletal muscle mass reaches its peak in young adulthood (3). In addition, maintaining normal levels of skeletal muscle mass during adulthood is a key to healthy aging (28). On the other hand, inadequate nutrition, low physical activity, increased adiposity or chronic disease can result in a low muscle mass, which is associated with several adverse health outcomes in children (29–33).

'Sarcopenia' is a condition with low muscle mass that can result in loss of muscle function. An adult with sarcopenia is defined as an adult who loses an amount of skeletal muscle mass and muscle function by age-related process, in comparison with healthy middle-aged adults. Low skeletal muscle mass with increased adiposity is often found in sarcopenic obesity (34). However, pediatric sarcopenia is more difficult to define (9).

To find a case of sarcopenia, direct measurement or quantitative assessment of skeletal muscle is a crucial step.

Quantitative assessment of skeletal muscle mass can be performed using several methods, such as dual energy X-ray absorptiometry (DXA), bioelectrical impedance analysis (BIA), ultrasound, CT, and MRI (35). DXA is considered the gold standard and commonly used with readily available reference data for children (10,36). BIA is another preferred choice because of its safety, accessibility, and portability. BIA can measure either the whole muscle mass or appendicular skeletal muscle mass (ASM) alone and has been used in children and adolescence (37,38). A recent systematic review showed that the evaluation of skeletal muscle mass in children using BIA correlated well with DXA (38). Furthermore, The ASM to fat ratio has been proposed to identify pediatric sarcopenic obesity, a low muscle mass in overweight children (39).

Dual-frequency BIA was used as an investigation tool to establish the nominal data of the whole muscle mass. Our nominal data of the whole muscle mass from the 3,181 schoolchildren showed that the skeletal muscle mass increased over time along with the growth of the children. Boys had more skeletal muscle mass than girls. The amount of skeletal muscle mass increased significantly during puberty, especially in boys. The mean MMI (males, females) was 12.9, 12.3 kg/m2 in 5-7 years old compared to 15.9, 13.6 kg/m2 in 14-16 years old children, respectively. These findings were consistent with other studies in children and adolescents (10,36,39,40). There was also evidence of increasing body adiposity associated with child growth. Girls had more adiposity than boys, reflected by a decrease in % muscle of the body (males, females) which dropped from 82.9%, 80.2% in the 5–7 years old to 78.1 %, 66.9% in the 14–16 years old children, respectively.

The age-, gender-specific cut off levels for low MMI were established and used to identify children with low MMI in different nutritional status. The amount of skeletal mass was correlated with the BMI z-score. Children with a low BMI z-score had lower skeletal mass, low MMI. Children with both low BMI z-score and low MMI, not only lost the adiposity, but also skeletal muscle mass. Children with overnutrition (high BMI z-score) were associated with high adiposity. However, the amount of skeletal muscle mass in these children could be high, normal, or even low. Low MMI was identified in about 1.3% of the children with overweight/obesity. Children with a normal BMI z-score showed no evidence of low MMI which indicated a normal amount of skeletal muscle mass (Table 2).

The second phase of this study was designed to develop a practical assessment of skeletal muscle mass by using a multiple regression model. Schools routinely monitor children's growth or nutritional status by using anthropometric parameters such as weight and height that are adjusted for age and gender. Two other parameters of the mobility assessments (grip strength and gait speed) were added to the routine monitoring to estimate the whole muscle mass of the schoolchildren. The results showed that gender, weight, height, and grip strength were strong predictors of the whole muscle mass. The whole muscle mass could be estimated by the following equation (Table 3):

whole muscle mass = -22.438 + 1.072 (gender) + 0.105 (weight) + 0.296 (height) + 0.199 (grip strength)

Grip strength reflects muscle strength, which is a component of physical fitness, while gait speed reflects physical performance. Both parameters have been used along with muscle quantity or muscle mass to identify adults with a low amount of skeletal muscle mass, known as sarcopenia (41,42). Grip strength is a simple measure of muscle strength and correlates well with total muscle strength (43,44). Gait speed in children has characteristics depending on intraindividual variability (45). Each child has a preferred gait speed to lower the metabolic cost. However, children with obesity have a higher metabolic cost during walking (46). This could explain our findings from the multiple regression equation that only grip strength was an important parameter to estimate the whole muscle mass. The data from the 598 children showed that the grip strength increased with age, while the preferred gait speed remained relatively constant. These findings were similar to a previous study (47). Adjusted grip strength with BMI has been used to identify children at risk of sarcopenic obesity (48).

This study has limitations. First, the emergence of the Covid-19 pandemic during the end of the first phase of the study prolonged the cross-sectional survey in school-age children, especially the data collection process. Second, the multiple regression equation to predict the whole muscle mass was performed by using anthropometric, muscle function, and physical performance. Other parameters recently proposed, such as calf circumference, which have recently been advised as another adult sarcopenia case finding parameter, were not included in the equation. Third, further study is required to validate the multiple regression equation and the management paradigm.

CONCLUSIONS

Muscle mass index (MMI), increased with age, and higher in male than female. Overweight children had not only high mean MMI, but also wide range of mean MMI. Underweight children not only lost adiposity, but also had low mean MMI and narrow range of mean MMI. Low muscularity children are presence in children with under and overweight. We established the low MMI levels in children ranging from childhood to adolescent and developed a regression model to predict the whole muscle mass in children by using gender, weight, height, and grip strength. Skeletal muscle mass status can be simultaneously monitored along with nutritional status, BMI z-score, at school where a BIA is not available. This allows an individual intervention according to the child's muscularity and adiposity status.

Implications for School Health

We propose the following management paradigm for the double-burden malnutrition issue that many schools are facing, so is from our studies (Table 2). Child adiposity and muscularity can be monitored by either an estimated muscle mass by using our multiple regression model using age, gender, weight, height, and grip strength or by conventional BIA measurement. Children with high BMI z-score and normal muscle mass should receive a normal calorie diet in conjunction with nutritional intervention in meal structure, food balance, and avoiding or making better choice on snacks. The focus is to enhance the level of physical activities, through structural and nonstructural activities, and limit the screen time. Aerobic exercise is recommended (49). Children with high BMI z-scores and low muscle mass, sarcopenic obesity, should receive nutritional intervention and increase resistance exercise. Multimodal exercise programs, including aerobic and resistance exercise are recommended (50,51). Children with low BMI z-scores and normal or low muscle mass should receive adequate calories and maintain a high protein diet along with engaging in normal level of physical activities. Due to thinness, resistance exercise is not recommended to avoid physical injury. Support from the family and school is important for the sustainable implementation of behavioral modification programs that promote self-awareness in weight, physical activities, diet intake, and unhealthy lifestyles. Additionally, setting weekly activity goals, offering verbal praise and other appropriate rewards along with positive social support can help the children adopt the modification program.

Human Subjects Approval Statement

This study was reviewed and approved by the Institution Ethics Committee (EC_KMITL_62_010) and was the Part I of the age-related muscular mass changes study in the Ladkrabang District, Bangkok. Written informed consent was obtained from all subjects, signed by parents and children.

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Data Availability Statements

The datasets generated during and/or analyzed during the current study are available in the [N raksadawan, natte (2021), "Child5to16", Mendeley Data, V1, doi: 10.17632/8mfp39zz4b.1] repository.

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