ORIGINAL ARTICLE

Journal of Cachexia, Sarcopenia and Muscle (2018)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI:** 10.1002/jcsm.12361

Skeletal muscle reference for Chinese children and adolescents

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Abstract

Background Skeletal muscle as an essential body composition component plays an important role in maintenance of normal growth and development as well as systemic glucose metabolism in children. No nationwide reference data for skeletal muscle mass for Chinese youths are available in China. We aimed to establish the sex-specific and age-specific percentile reference values of skeletal muscle mass for Chinese children and adolescents.

Methods This study consisted of 10 818 children and adolescents aged 3–17 years in Chinese urban area during 2013–15. Dual-energy X-ray absorptiometry scan was performed to measure whole body muscle mass and appendicular skeletal muscle mass. Lambda-mu-sigma method was used to obtain the sex-specific and age-specific percentile curves of muscle mass indices.

Results Overall, whole body muscle mass and appendicular skeletal muscle mass indices showed an increasing trend with age for both sexes, with boys vs. girls having higher values of all muscle mass indices. Whole body muscle mass index in boys increased slightly before age 9 years and then increased rapidly until 15 years and slowed down thereafter, while the mean values in girls increased slightly before age 8 years, increased rapidly until 14 years and remained stable thereafter. Appendicular skeletal muscle mass index increased rapidly until age 16 years and then increased slightly for boys; by contrast, for girls, the mean values increased consistently before age 14 years but showed a slightly decreasing trend after that.

Conclusions This study established sex-specific and age-specific percentile reference values for skeletal muscle mass for Chinese children and adolescents aged 3–17 years. These reference values can be used to evaluate the muscular development in Chinese children and adolescents.

Keywords Skeletal muscle; Reference; Child; Adolescent

Received: 10 April 2018; Accepted: 24 September 2018
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Introduction

Skeletal muscle is an essential body composition component and plays an important role in maintaining normal movement and posture in both adults and children.[1] Skeletal muscle is considered as a major site of insulin-mediated glucose disposal, accounting for 85% of insulin-mediated glucose utilization.[2] A large body of evidence has shown that in youths, high skeletal muscle mass can increase insulin sensitivity,[3] and low skeletal muscle mass is associated with multiple metabolic risk factors

Table 1 Characteristics of study population by sex

Age (years)	*N*	Height (cm)	Weight (kg)	BMI (kg/m²)	FM (kg)	FFM (kg)	Muscle Mass (kg)	ASM (kg)	ULSM (kg)	LLSM (kg)	FMI (kg/m²)	FFMI (kg/m²)
Boys												
3	129	103.0 ± 4.2	16.4 ± 1.9	15.4 ± 1.2	5.4 ± 1.2	11.5 ± 1.2	10.9 ± 1.2	3.6 ± 0.6	1.0 ± 0.2	2.5 ± 0.5	5.0 ± 1.0	10.8 ± 0.7
4	268	109.3 ± 5.1	18.6 ± 2.7	15.5 ± 1.5	5.9 ± 1.5	13.3 ± 1.7	12.6 ± 1.7	4.4 ± 0.8	1.2 ± 0.2	3.2 ± 0.6	4.9 ± 1.1	11.1 ± 0.8
5	321	115.7 ± 5.0	21.2 ± 3.9	15.7 ± 1.9	6.6 ± 2.3	15.3 ± 2.0	14.6 ± 2.0	5.4 ± 1.0	1.4 ± 0.2	4.0 ± 0.8	4.8 ± 1.4	11.4 ± 0.9
6	409	123.0 ± 5.6	25.1 ± 5.0	16.5 ± 2.4	7.6 ± 3.0	17.6 ± 2.5	16.8 ± 2.4	6.6 ± 1.2	1.6 ± 0.3	5.0 ± 1.0	4.9 ± 1.7	11.6 ± 1.0
7	404	128.7 ± 6.4	28.8 ± 6.5	17.3 ± 2.8	8.5 ± 3.7	19.8 ± 3.0	18.9 ± 2.9	7.8 ± 1.4	1.8 ± 0.3	6.0 ± 1.2	5.1 ± 1.9	11.9 ± 1.1
8	397	133.0 ± 6.7	61.0 ± 7.1	17.4 ± 2.7	9.2 ± 4.2	21.8 ± 3.3	20.8 ± 3.2	8.8 ± 1.6	2.0 ± 0.3	6.8 ± 1.3	5.1 ± 2.0	12.3 ± 1.1
9	332	138.7 ± 7.5	36.2 ± 9.5	18.6 ± 3.7	11.7 ± 5.8	24.5 ± 4.4	23.5 ± 4.3	10.2 ± 2.0	2.2 ± 0.4	7.9 ± 1.6	6.0 ± 2.6	12.7 ± 1.5
10	339	144.3 ± 7.8	41.0 ± 11.3	19.5 ± 3.9	13.4 ± 6.6	27.1 ± 5.1	26.0 ± 5.0	11.4 ± 2.4	2.4 ± 0.5	9.0 ± 1.9	6.3 ± 2.8	12.9 ± 1.5
11	329	149.9 ± 8.2	45.0 ± 12.0	19.8 ± 4.0	14.0 ± 6.9	30.9 ± 6.2	29.6 ± 6.0	13.3 ± 3.0	2.9 ± 0.7	10.5 ± 2.4	6.2 ± 2.8	13.6 ± 1.8
12	358	157.1 ± 9.8	50.9 ± 13.2	20.4 ± 3.9	15.0 ± 7.2	35.6 ± 7.8	34.1 ± 7.5	15.6 ± 3.7	3.4 ± 0.8	12.3 ± 2.9	6.0 ± 2.6	14.2 ± 2.0
13	309	163.6 ± 8.8	55.0 ± 13.1	20.4 ± 3.7	14.3 ± 6.8	41.0 ± 7.8	39.4 ± 7.6	18.2 ± 3.7	4.0 ± 0.9	14.2 ± 2.8	5.3 ± 2.3	15.2 ± 1.9
14	306	168.5 ± 7.9	61.6 ± 14.9	21.6 ± 4.4	15.4 ± 8.0	46.0 ± 7.8	44.2 ± 7.5	20.4 ± 3.7	4.6 ± 0.8	15.9 ± 2.9	5.4 ± 2.7	16.2 ± 2.1
15	453	171.1 ± 6.9	62.5 ± 13.2	21.3 ± 3.9	15.1 ± 7.5	48.0 ± 7.3	46.0 ± 7.0	21.2 ± 3.5	4.8 ± 0.8	16.4 ± 2.8	5.1 ± 2.4	16.3 ± 2.0
16	538	172.3 ± 6.5	65.1 ± 13.0	21.9 ± 3.9	16.3 ± 8.1	49.2 ± 7.3	46.9 ± 7.0	21.5 ± 3.5	4.9 ± 0.8	16.6 ± 2.8	5.4 ± 2.6	16.5 ± 2.1
17	617	173.2 ± 6.5	67.2 ± 13.8	22.4 ± 4.1	16.2 ± 8.1	50.7 ± 7.6	48.4 ± 7.3	22.1 ± 3.6	5.1 ± 0.8	17.0 ± 2.9	5.4 ± 2.6	16.8 ± 2.1
Girls												
3	135	101.8 ± 3.9	15.7 ± 1.6	15.1 ± 1.0	5.7 ± 1.0	10.5 ± 1.1	10.0 ± 1.0	3.2 ± 0.5	0.9 ± 0.1	2.3 ± 0.4	5.5 ± 0.8	10.2 ± 0.7
4	269	107.4 ± 4.7	17.6 ± 2.5	15.2 ± 1.3	6.1 ± 1.5	12.0 ± 1.5	11.3 ± 1.5	3.9 ± 0.7	1.0 ± 0.2	2.9 ± 0.6	5.3 ± 1.1	10.4 ± 0.7
5	251	115.0 ± 5.1	20.3 ± 3.2	15.3 ± 1.6	6.8 ± 1.8	14.0 ± 1.7	13.3 ± 1.7	4.9 ± 0.8	1.2 ± 0.2	3.7 ± 0.6	5.1 ± 1.2	10.6 ± 0.7
6	381	121.4 ± 5.6	23.6 ± 4.5	15.9 ± 2.1	7.7 ± 2.6	15.9 ± 2.3	15.1 ± 2.2	5.9 ± 1.1	1.4 ± 0.2	4.5 ± 0.9	5.2 ± 1.5	10.7 ± 0.9
7	362	126.3 ± 5.8	25.8 ± 4.6	16.1 ± 2.1	8.0 ± 2.7	17.4 ± 2.2	16.6 ± 2.2	6.7 ± 1.1	1.5 ± 0.2	5.2 ± 0.9	5.0 ± 1.5	10.9 ± 1.0
8	331	132.4 ± 6.6	29.7 ± 6.3	16.8 ± 2.5	9.4 ± 3.7	20.0 ± 3.1	19.0 ± 3.0	7.9 ± 1.5	1.7 ± 0.3	6.2 ± 1.2	5.3 ± 1.9	11.4 ± 1.1
9	340	138.0 ± 7.4	33.0 ± 7.8	17.2 ± 2.7	10.6 ± 4.2	22.4 ± 3.9	21.4 ± 3.8	9.1 ± 1.9	1.9 ± 0.4	7.1 ± 1.5	5.5 ± 1.9	11.7 ± 1.2
10	302	144.1 ± 8.5	36.3 ± 8.2	17.3 ± 2.6	11.4 ± 3.9	25.1 ± 4.7	23.9 ± 4.6	10.3 ± 2.2	2.2 ± 0.5	8.1 ± 1.7	5.4 ± 1.6	12.0 ± 1.5
11	290	150.8 ± 8.5	43.9 ± 10.6	19.1 ± 3.3	14.0 ± 5.5	29.9 ± 5.5	28.6 ± 5.3	12.5 ± 2.5	2.6 ± 0.5	9.8 ± 2.0	6.1 ± 2.1	13.1 ± 1.6
12	295	155.8 ± 7.5	47.7 ± 10.0	19.6 ± 3.4	14.9 ± 5.6	32.8 ± 5.2	31.3 ± 5.0	13.6 ± 2.4	2.8 ± 0.5	10.8 ± 2.0	6.1 ± 2.1	13.4 ± 1.6
13	270	158.8 ± 6.4	50.2 ± 9.8	19.8 ± 3.2	16.1 ± 5.6	34.5 ± 4.9	32.9 ± 4.7	14.3 ± 2.3	2.9 ± 0.5	11.3 ± 1.9	6.4 ± 2.1	13.7 ± 1.5
14	301	159.9 ± 6.3	51.8 ± 8.5	20.2 ± 2.9	16.8 ± 5.1	35.4 ± 4.5	33.7 ± 4.3	14.5 ± 2.1	3.0 ± 0.4	11.5 ± 1.7	6.5 ± 1.8	13.8 ± 1.4
15	486	160.4 ± 5.6	54.1 ± 9.1	21.0 ± 3.1	18.5 ± 5.3	36.0 ± 4.8	34.1 ± 4.7	14.7 ± 2.4	3.0 ± 0.5	11.7 ± 1.9	7.2 ± 1.9	13.9 ± 1.5
16	574	160.5 ± 5.7	54.4 ± 8.8	21.1 ± 3.0	19.1 ± 5.5	35.6 ± 4.6	33.7 ± 4.4	14.3 ± 2.2	3.0 ± 0.5	11.4 ± 1.8	7.4 ± 2.0	13.8 ± 1.4
17	722	160.6 ± 5.9	54.3 ± 7.5	21.0 ± 2.6	18.4 ± 4.9	35.8 ± 4.3	33.9 ± 4.1	14.3 ± 2.1	3.0 ± 0.5	11.3 ± 1.7	7.1 ± 1.8	13.8 ± 1.3

Data are means ± standard deviations. ASM, appendicular skeletal muscle mass; BMI, body mass index; FFM, fat free mass; FFMI, fat free mass index; FM, fat mass; FMI, fat mass index; LLSM, lower limb skeletal muscle mass; ULSM, upper limb skeletal muscle mass.

and insulin resistance.[4–7] In addition, high skeletal muscle mass has been shown to improve bone health through biomechanical stress and multiple myokines.[8] Studies have shown that about 40% of bone growth after birth is determined by muscle development.[9] Skeletal muscle mass, like bone mineral density,[10] increases with age across childhood and adolescence. Therefore, growth curves of skeletal muscle mass in youth need to be established using percentile charts due to the dynamic nature of growth. The growth curves for muscle mass indices can be used to assess the muscle development in healthy children and adolescents and monitor loss of muscle in participants with muscle-related metabolic diseases.

Multiple approaches such as magnetic resonance imaging, computed tomography, dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance are available for assessment of skeletal muscle. Among them, DXA has been recommended as the preferred detection technology for assessing skeletal muscle loss due to its low radiation, accuracy and strong clinical feasibility.[11,12] Several reference curves for skeletal muscle for youths have been established in UK[13] and South Korea.[14] However, these reference values are limited by their small sample sizes and absence of data for individuals with age <5 years. To date, there is no reference data of skeletal muscle mass for Chinese youths. Therefore, using large-scale population-based data from the China Child and Adolescent Cardiovascular Health (CCACH) Study, we aimed to establish reference values of skeletal muscle measured by DXA for Chinese children and adolescents.

Methods

Study population

The CCACH Study is a large-scale population-based cross-sectional study conducted during 2013–15, which was designed to select a representative sample of children and adolescents aged 3–18 years living in urban areas of China. The detailed information of the survey has been described elsewhere.[10] In brief, we firstly stratified China into five regions according to characteristics of climate, economic development and the residents' life habits. Then, we selected one or two capital cities from each region and included a total of seven cities (i.e. Beijing, Tianjin, Changchun, Jinan, Yinchuan, Shanghai and Chongqing). Next, several schools were randomly selected from

Table 2 Reference values of MMI (kg/m^2) among Chinese children and adolescents

Age (years)	L	S	Mean - 2 SD	Mean - SD	Mean	Mean + SD	Mean + 2 SD	Percentiles					
								P3	P10	P25	P75	P90	P97
Boys													
3	−0.553	0.059	9.05	9.57	10.15	10.78	11.47	9.11	9.42	9.75	10.56	10.97	11.38
4	−0.553	0.065	9.13	9.71	10.35	11.06	11.85	9.20	9.55	9.92	10.82	11.27	11.75
5	−0.553	0.073	9.25	9.91	10.64	11.46	12.39	9.32	9.71	10.14	11.18	11.71	12.27
6	−0.553	0.081	9.33	10.06	10.89	11.83	12.89	9.41	9.85	10.32	11.51	12.11	12.76
7	−0.553	0.088	9.42	10.23	11.14	12.20	13.41	9.51	9.99	10.51	11.84	12.52	13.26
8	−0.553	0.096	9.54	10.43	11.44	12.62	14.00	9.64	10.16	10.74	12.22	12.99	13.83
9	−0.553	0.103	9.68	10.65	11.77	13.09	14.66	9.79	10.36	10.99	12.64	13.51	14.46
10	−0.553	0.111	9.87	10.92	12.16	13.63	15.39	9.99	10.61	11.30	13.12	14.09	15.17
11	−0.553	0.117	10.17	11.31	12.67	14.29	16.26	10.30	10.97	11.73	13.73	14.81	16.01
12	−0.553	0.121	10.60	11.83	13.30	15.08	17.25	10.74	11.46	12.28	14.46	15.65	16.97
13	−0.553	0.123	11.12	12.44	14.01	15.92	18.26	11.27	12.04	12.92	15.26	16.53	17.96
14	−0.553	0.123	11.65	13.03	14.68	16.68	19.14	11.80	12.62	13.53	15.99	17.32	18.82
15	−0.553	0.122	12.09	13.50	15.19	17.24	19.75	12.24	13.08	14.02	16.53	17.90	19.43
16	−0.553	0.120	12.39	13.82	15.53	17.58	20.09	12.55	13.40	14.34	16.87	18.23	19.76
17	−0.553	0.118	12.63	14.05	15.75	17.78	20.26	12.78	13.63	14.57	17.08	18.43	19.94
Girls													
3	−0.387	0.062	8.43	8.95	9.52	10.13	10.80	8.49	8.80	9.13	9.92	10.31	10.72
4	−0.387	0.066	8.47	9.03	9.64	10.31	11.04	8.54	8.87	9.22	10.08	10.51	10.95
5	−0.387	0.073	8.53	9.15	9.84	10.60	11.44	8.60	8.97	9.37	10.34	10.83	11.34
6	−0.387	0.080	8.59	9.28	10.04	10.89	11.85	8.67	9.08	9.52	10.61	11.15	11.73
7	−0.387	0.087	8.68	9.43	10.27	11.22	12.30	8.76	9.21	9.69	10.90	11.51	12.16
8	−0.387	0.093	8.83	9.65	10.57	11.62	12.83	8.92	9.41	9.93	11.27	11.95	12.68
9	−0.387	0.099	9.05	9.94	10.95	12.11	13.45	9.15	9.68	10.25	11.71	12.47	13.28
10	−0.387	0.103	9.34	10.29	11.39	12.65	14.12	9.44	10.01	10.63	12.22	13.04	13.94
11	−0.387	0.106	9.67	10.69	11.86	13.22	14.81	9.78	10.38	11.05	12.76	13.64	14.61
12	−0.387	0.108	10.00	11.07	12.30	13.74	15.41	10.12	10.75	11.45	13.25	14.18	15.20
13	−0.387	0.108	10.28	11.38	12.65	14.13	15.86	10.40	11.05	11.77	13.62	14.59	15.64
14	−0.387	0.107	10.49	11.60	12.88	14.37	16.11	10.61	11.27	12.00	13.86	14.84	15.89
15	−0.387	0.105	10.62	11.73	13.00	14.48	16.20	10.75	11.40	12.13	13.98	14.94	15.98
16	−0.387	0.103	10.70	11.79	13.04	14.48	16.16	10.82	11.47	12.18	13.99	14.93	15.94
17	−0.387	0.100	10.76	11.83	13.04	14.45	16.06	10.88	11.51	12.20	13.97	14.88	15.86

MMI, muscle mass index; L, lambda; S, coefficient of variation; SD, standard deviation.

each city to ensure the representativeness of sex, age and socio-economic status.

All the students (n = 15 548) from the selected schools were invited, and a total of 11 457 participated in a clinical examination, including a questionnaire survey, anthropometric measurements and DXA scan. In the present study, we exclude 639 subjects who met the following criteria: (i) with physical disability or *in vivo* surgically implanted device and the brace; (ii) with extreme values of height (≥197.5 cm), weight (≥204 kg) or body mass index (BMI) (<mean - 3 SD or >mean + 3 SD); (iii) with chronic metabolic diseases (e.g. rheumatologic diseases, blood diseases and kidney diseases); (iv) with a recent acute illness; (v) professional athlete. Finally, a total of 10 818 individuals (5509 boys and 5309 girls) were included for data analysis.

This study was approved by the Ethics Committee of the Capital Institute of Pediatrics. The written informed consents were obtained from the participants and/or their parents.

Data collection

Weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, in lightweight clothing without shoes in a calibrated digital scale. Weight and height were measured twice, and the mean values were used to calculate BMI (calculated as weight in kilograms divided by height in metres squared). Whole body DXA scans (Hologic Discovery-A&W, Bedford, MA, USA) were performed to assess body composition (fat mass, fat free mass and bone mass) according to International Society of Clinical Densitometry's standard operating method.[11] Fat mass index (fat mass/height^2) and fat free mass index (fat free mass/height^2) were calculated. Whole body and four-limb muscle mass were calculated as fat free mass minus bone mass. Appendicular skeletal muscle mass (ASM) was calculated as the sum of the arms' and the legs' muscle mass, which is a good proxy for whole body skeletal muscle mass.[15] To account for the potential influence of body size or height, several muscle mass variables were calculated as below:

$$\text{muscle mass index (MMI)} = \text{whole body muscle mass/height}^2\ (\text{kg/m}^2),$$

$$\text{appendicular skeletal muscle mass index (ASMI)} = \text{ASM/height}^2\ (\text{kg/m}^2),$$

Table 3 Reference values of ASMI (kg/m^2) among Chinese children and adolescents

Age (years)	L	S	Mean - 2 SD	Mean - SD	Mean	Mean + SD	Mean + 2 SD	Percentiles					
								P3	P10	P25	P75	P90	P97
Boys													
3	−0.064	0.117	2.53	2.84	3.19	3.59	4.05	2.57	2.75	2.95	3.46	3.72	3.99
4	−0.064	0.117	2.75	3.08	3.46	3.90	4.38	2.79	2.98	3.20	3.75	4.03	4.32
5	−0.064	0.116	3.05	3.42	3.84	4.31	4.85	3.09	3.31	3.55	4.15	4.46	4.78
6	−0.064	0.116	3.32	3.73	4.18	4.70	5.28	3.37	3.61	3.87	4.52	4.86	5.21
7	−0.064	0.117	3.56	3.99	4.49	5.05	5.68	3.61	3.87	4.15	4.86	5.22	5.60
8	−0.064	0.120	3.76	4.23	4.77	5.38	6.08	3.81	4.10	4.40	5.18	5.57	5.99
9	−0.064	0.125	3.94	4.46	5.05	5.72	6.49	4.00	4.30	4.64	5.49	5.93	6.39
10	−0.064	0.130	4.12	4.68	5.33	6.08	6.93	4.18	4.52	4.88	5.82	6.31	6.82
11	−0.064	0.135	4.34	4.95	5.67	6.49	7.44	4.40	4.77	5.17	6.21	6.74	7.32
12	−0.064	0.138	4.60	5.27	6.05	6.95	8.00	4.68	5.07	5.51	6.65	7.23	7.87
13	−0.064	0.139	4.89	5.61	6.45	7.42	8.54	4.97	5.40	5.87	7.09	7.72	8.40
14	−0.064	0.138	5.16	5.92	6.79	7.81	8.98	5.25	5.69	6.19	7.46	8.12	8.83
15	−0.064	0.136	5.37	6.14	7.03	8.06	9.26	5.45	5.91	6.42	7.71	8.38	9.11
16	−0.064	0.134	5.49	6.26	7.16	8.18	9.37	5.58	6.04	6.54	7.83	8.50	9.22
17	−0.064	0.131	5.57	6.34	7.22	8.23	9.40	5.66	6.11	6.61	7.89	8.54	9.25
Girls													
3	−0.161	0.106	2.46	2.73	3.03	3.38	3.77	2.49	2.65	2.83	3.26	3.48	3.72
4	−0.161	0.108	2.60	2.89	3.21	3.59	4.01	2.63	2.80	2.99	3.46	3.70	3.96
5	−0.161	0.112	2.82	3.14	3.51	3.93	4.41	2.85	3.05	3.26	3.79	4.06	4.35
6	−0.161	0.115	3.02	3.38	3.79	4.26	4.79	3.06	3.27	3.51	4.10	4.40	4.72
7	−0.161	0.119	3.22	3.61	4.06	4.57	5.17	3.26	3.49	3.75	4.40	4.73	5.09
8	−0.161	0.122	3.41	3.84	4.33	4.89	5.55	3.46	3.71	3.99	4.70	5.07	5.46
9	−0.161	0.125	3.60	4.07	4.60	5.22	5.94	3.66	3.93	4.23	5.01	5.41	5.85
10	−0.161	0.127	3.80	4.30	4.87	5.54	6.32	3.86	4.15	4.48	5.31	5.75	6.22
11	−0.161	0.129	3.99	4.52	5.13	5.84	6.67	4.05	4.36	4.71	5.60	6.07	6.57
12	−0.161	0.129	4.15	4.70	5.34	6.09	6.96	4.21	4.54	4.90	5.83	6.32	6.85
13	−0.161	0.129	4.26	4.83	5.49	6.25	7.14	4.33	4.66	5.03	5.99	6.49	7.03
14	−0.161	0.128	4.33	4.90	5.56	6.33	7.22	4.40	4.73	5.11	6.07	6.56	7.10
15	−0.161	0.126	4.36	4.93	5.58	6.33	7.21	4.42	4.76	5.13	6.08	6.57	7.10
16	−0.161	0.123	4.36	4.92	5.56	6.29	7.14	4.43	4.75	5.12	6.04	6.52	7.04
17	−0.161	0.120	4.36	4.90	5.52	6.23	7.05	4.42	4.74	5.09	5.99	6.45	6.95

ASMI, appendicular skeletal muscle mass index; L, lambda; S, coefficient of variation; SD, standard deviation.

DOI: 10.1002/jcsm.12361

appendicular skeletal muscle mass weight ratio (ASMR) $= \text{ASM}/\text{weight} \times 100\%$,[11]

upper limb skeletal muscle index (ULSMI) $= \text{upper limbs skeletal muscle mass}/\text{height}^2\ (\text{kg}/\text{m}^2)$

and lower limb skeletal muscle mass index (LLSMI) $= \text{lower limbs skeletal muscle mass}/\text{height}^2\ (\text{kg}/\text{m}^2)$.

Statistical analysis

All data analyses were performed with SAS 9.4 software (SAS Institute Inc., Cary, NC, USA). Continuous variables were presented as mean ± standard deviation (SD). Smoothed percentile curves for muscle mass indices including MMI, ASMI, ASMR, ULSMI and LLSMI were constructed in boys and girls separately using the lambda-mu-sigma (LMS) method (LMS Chart Maker Pro Version 2.54, Medical Research Council, London, UK), which converted skewed distribution to normal using the maximum likelihood method and adjusted the curves of median (*M*), the coefficient of variation (*S*) and the Box–Cox power (*L*) and smoothed the percentile curves of muscle mass indices by cubic natural smoothing spline functions.[16,17] Percentile curves of muscle mass indices were plotted with Origin Pro 2017.

Z values can be calculated by the following equation:

$$Z = \frac{\left(\frac{X}{M}\right)^L - 1}{LS}, (L \neq 0)$$

where X is the muscle mass indices, L is the power transformation, M is the median value and S is the population SD. Percentiles were obtained from z-scores, for example, z-scores of -1.645, -1.282, 0, 1.282 and 1.645 correspond to the 5th, 10th, 50th, 90th and 95th percentiles, respectively.

Results

A total of 10 818 children and adolescents were included in this study, and their characteristics were presented in Table 1. The selected characteristics included height, weight, BMI, fat mass, fat free mass, muscle mass, ULSM, LLSM, fat

Table 4 Reference values of ASMR among Chinese children and adolescents

Age (years)	L	S	Mean - 2 SD	Mean - SD	Mean	Mean + SD	Mean + 2 SD	Percentiles					
								P3	P10	P25	P75	P90	P97
Boys													
3	1.455	0.096	16.77	18.93	20.98	22.94	24.83	17.03	18.33	19.61	22.31	23.48	24.61
4	1.398	0.098	18.05	20.42	22.68	24.86	26.96	18.34	19.76	21.17	24.16	25.46	26.72
5	1.318	0.101	19.66	22.31	24.87	27.35	29.75	19.98	21.58	23.16	26.55	28.03	29.47
6	1.243	0.105	20.64	23.52	26.32	29.05	31.72	20.98	22.72	24.44	28.17	29.81	31.41
7	1.171	0.11	21.14	24.22	27.24	30.2	33.11	21.51	23.36	25.21	29.24	31.03	32.77
8	1.113	0.115	21.55	24.83	28.08	31.29	34.45	21.94	23.91	25.9	30.25	32.18	34.07
9	1.087	0.119	21.66	25.11	28.54	31.93	35.28	22.07	24.14	26.23	30.82	32.87	34.88
10	1.113	0.122	21.63	25.23	28.78	32.28	35.73	22.06	24.22	26.39	31.14	33.25	35.32
11	1.208	0.123	22.04	25.84	29.53	33.13	36.64	22.5	24.78	27.05	31.97	34.13	36.23
12	1.38	0.122	22.97	27.03	30.88	34.56	38.09	23.46	25.91	28.31	33.38	35.57	37.68
13	1.626	0.117	24.18	28.51	32.46	36.14	39.59	24.72	27.33	29.83	34.97	37.13	39.19
14	1.932	0.11	25.24	29.72	33.65	37.19	40.44	25.81	28.53	31.05	36.07	38.13	40.07
15	2.274	0.103	25.85	30.32	34.08	37.37	40.32	26.43	29.15	31.6	36.34	38.23	39.99
16	2.629	0.095	26.04	30.37	33.88	36.88	39.52	26.61	29.25	31.58	35.95	37.65	39.22
17	2.986	0.088	26.03	30.17	33.42	36.14	38.5	26.59	29.12	31.3	35.3	36.83	38.24
Girls													
3	0.463	0.107	16.26	18.25	20.38	22.63	25.01	16.49	17.68	18.93	21.89	23.29	24.72
4	0.463	0.108	17.1	19.2	21.45	23.82	26.33	17.34	18.6	19.92	23.03	24.51	26.02
5	0.463	0.108	18.43	20.71	23.14	25.71	28.42	18.7	20.06	21.49	24.85	26.46	28.09
6	0.463	0.108	19.56	21.98	24.56	27.3	30.18	19.84	21.28	22.8	26.39	28.09	29.83
7	0.463	0.108	20.46	22.99	25.7	28.56	31.58	20.75	22.26	23.86	27.61	29.39	31.22
8	0.463	0.108	21.22	23.85	26.65	29.61	32.74	21.52	23.09	24.74	28.63	30.48	32.36
9	0.463	0.107	21.91	24.6	27.47	30.51	33.72	22.22	23.83	25.52	29.5	31.4	33.33
10	0.463	0.106	22.52	25.24	28.15	31.22	34.46	22.83	24.46	26.17	30.2	32.11	34.07
11	0.463	0.104	22.97	25.69	28.58	31.64	34.86	23.28	24.91	26.62	30.62	32.53	34.47
12	0.463	0.101	23.23	25.89	28.72	31.71	34.85	23.53	25.13	26.8	30.72	32.58	34.47
13	0.463	0.098	23.29	25.86	28.58	31.45	34.47	23.58	25.12	26.73	30.5	32.29	34.1
14	0.463	0.094	23.14	25.59	28.17	30.9	33.75	23.42	24.88	26.42	30	31.69	33.4
15	0.463	0.091	22.8	25.11	27.54	30.1	32.78	23.06	24.44	25.89	29.25	30.84	32.45
16	0.463	0.087	22.39	24.57	26.86	29.26	31.76	22.65	23.95	25.3	28.46	29.95	31.46
17	0.463	0.084	22.04	24.09	26.25	28.5	30.85	22.28	23.5	24.78	27.76	29.15	30.57

ASMR, appendicular skeletal muscle mass weight ratio; L, lambda; S, coefficient of variation; SD, standard deviation.

DOI: 10.1002/jcsm.12361

mass index and fat free mass index. Overall, all values of these variables increased with age for both sexes, except that fat mass index increased before age 10 years and then showed a decreasing trend thereafter. Boys vs. girls had higher mean values of BMI, fat free mass, fat free mass index, muscle mass but lower mean values of fat mass and fat mass index at each age.

Tables 2–6 presented reference values for mean, mean ± 1 SD and mean ± 2 SD, as well as the 3th, 10th, 25th, 75th, 90th and 97th percentiles for all muscle mass indices at each age for boys and girls. Figures 1 and 2 presented the smoothed LMS curves for mean, mean ± 1 SD and mean ± 2 SD for all muscle mass indices for both boys and girls. Overall, boys vs. girls had consistently higher values of all these indices at each given age.

Muscle mass index showed an increasing trend with age for both boys and girls. For boys, MMI increased slightly before age 9 years and then increased rapidly until 15 years and slowed down thereafter. For girls, MMI increased slightly before age 8 years, increased rapidly until 14 years and remained stable thereafter.

The trend of ASMI increased rapidly until age 16 years and then increased slightly for boys; by contrast, for girls, ASMI increased consistently before age 14 years but showed a slightly decreasing trend after that. LLSMI showed similar trend with ASMI for both boys and girls. For ULSMI, boys had higher values than girls, and the gap between sexes became wider with increasing age. For boys, ULSMI increased slightly before age 10 years, then increased dramatically until 14 years and increased slowly again thereafter. For girls, ULSMI increased slightly before age 9 years, and then increased at a greater rate until 13 years, but stopped increasing thereafter.

For ASMR, boys and girls showed different increasing trend patterns. In boys, ASMR showed a slightly increasing trend from age 3 years to age 10 years, but then increased more rapidly until 14 years. However, after age 14 years, ASMR showed a slight decreasing trend. In contrast, in girls, ASMR increased rapidly from age 3 years to age 12 years but showed a moderate decrease during age 12–17 years.

Discussion

To our knowledge, this is the first study to develop sex-specific and age-specific percentile reference values for

Table 5 Reference values of ULSMI (kg/m^2) among Chinese children and adolescents

Age (years)	L	S	Mean - 2 SD	Mean - SD	Mean	Mean + SD	Mean + 2 SD	Percentiles P3	P10	P25	P75	P90	P97
Boys													
3	0.285	0.112	0.74	0.84	0.94	1.05	1.16	0.75	0.81	0.87	1.01	1.08	1.15
4	0.285	0.112	0.77	0.87	0.97	1.08	1.21	0.78	0.84	0.90	1.05	1.12	1.19
5	0.285	0.112	0.81	0.91	1.01	1.13	1.26	0.82	0.88	0.94	1.09	1.17	1.24
6	0.285	0.112	0.83	0.93	1.04	1.17	1.30	0.84	0.90	0.97	1.12	1.20	1.28
7	0.285	0.114	0.84	0.95	1.06	1.19	1.33	0.85	0.92	0.98	1.15	1.23	1.31
8	0.285	0.118	0.85	0.97	1.09	1.22	1.37	0.87	0.93	1.01	1.18	1.26	1.35
9	0.285	0.124	0.86	0.98	1.12	1.26	1.42	0.88	0.95	1.03	1.21	1.30	1.40
10	0.285	0.131	0.87	1.00	1.15	1.30	1.48	0.89	0.97	1.05	1.25	1.35	1.45
11	0.285	0.137	0.91	1.05	1.21	1.38	1.57	0.92	1.01	1.10	1.32	1.43	1.55
12	0.285	0.143	0.96	1.12	1.30	1.49	1.71	0.98	1.07	1.18	1.43	1.55	1.68
13	0.285	0.146	1.04	1.21	1.41	1.62	1.86	1.06	1.16	1.27	1.55	1.69	1.83
14	0.285	0.147	1.11	1.30	1.51	1.75	2.01	1.14	1.25	1.37	1.67	1.82	1.97
15	0.285	0.145	1.18	1.37	1.59	1.84	2.11	1.20	1.32	1.44	1.76	1.91	2.07
16	0.285	0.143	1.22	1.42	1.64	1.89	2.16	1.24	1.36	1.49	1.81	1.96	2.13
17	0.285	0.141	1.25	1.45	1.67	1.92	2.19	1.27	1.39	1.52	1.84	1.99	2.16
Girls													
3	0.138	0.109	0.69	0.77	0.86	0.96	1.07	0.70	0.75	0.80	0.93	0.99	1.05
4	0.138	0.110	0.69	0.77	0.86	0.96	1.07	0.70	0.75	0.80	0.93	0.99	1.06
5	0.138	0.112	0.69	0.78	0.87	0.97	1.09	0.70	0.75	0.81	0.94	1.00	1.07
6	0.138	0.116	0.70	0.79	0.89	1.00	1.12	0.71	0.76	0.82	0.96	1.03	1.10
7	0.138	0.120	0.71	0.80	0.91	1.02	1.15	0.72	0.78	0.84	0.98	1.06	1.13
8	0.138	0.124	0.72	0.82	0.93	1.05	1.18	0.73	0.79	0.85	1.01	1.09	1.17
9	0.138	0.127	0.74	0.84	0.96	1.09	1.23	0.75	0.81	0.88	1.04	1.12	1.21
10	0.138	0.131	0.76	0.87	0.99	1.13	1.28	0.77	0.84	0.91	1.08	1.17	1.26
11	0.138	0.133	0.79	0.90	1.04	1.18	1.35	0.80	0.87	0.95	1.13	1.23	1.32
12	0.138	0.135	0.82	0.94	1.08	1.23	1.41	0.83	0.90	0.98	1.18	1.28	1.39
13	0.138	0.137	0.84	0.97	1.12	1.28	1.46	0.86	0.93	1.02	1.22	1.33	1.44
14	0.138	0.137	0.86	0.99	1.14	1.30	1.49	0.88	0.95	1.04	1.25	1.36	1.47
15	0.138	0.138	0.87	1.00	1.15	1.32	1.51	0.88	0.96	1.05	1.26	1.37	1.48
16	0.138	0.138	0.87	1.00	1.15	1.32	1.51	0.88	0.96	1.05	1.26	1.37	1.48
17	0.138	0.138	0.87	1.00	1.15	1.31	1.50	0.88	0.96	1.04	1.26	1.36	1.48

L, lambda; S, coefficient of variation; SD, standard deviation; ULSMI, upper limb skeletal muscle index.

Table 6 Reference values of LLSMI (kg/m^2) among Chinese children and adolescents

Age (years)	L	S	Mean - 2 SD	Mean - SD	Mean	Mean + SD	Mean + 2 SD	Percentiles					
								P3	P10	P25	P75	P90	P97
Boys													
3	−0.050	0.135	1.72	1.96	2.25	2.57	2.94	1.75	1.89	2.05	2.46	2.67	2.90
4	−0.050	0.132	1.91	2.18	2.49	2.84	3.25	1.94	2.10	2.27	2.72	2.95	3.20
5	−0.050	0.129	2.18	2.48	2.82	3.22	3.66	2.22	2.39	2.59	3.08	3.34	3.61
6	−0.050	0.127	2.44	2.76	3.14	3.56	4.05	2.47	2.67	2.88	3.42	3.70	3.99
7	−0.050	0.126	2.66	3.02	3.42	3.89	4.42	2.70	2.91	3.14	3.73	4.03	4.35
8	−0.050	0.128	2.86	3.24	3.68	4.19	4.77	2.90	3.13	3.38	4.02	4.35	4.70
9	−0.050	0.132	3.02	3.45	3.93	4.48	5.12	3.07	3.32	3.60	4.30	4.66	5.04
10	−0.050	0.136	3.19	3.65	4.18	4.79	5.49	3.24	3.51	3.81	4.58	4.98	5.41
11	−0.050	0.140	3.37	3.87	4.45	5.12	5.90	3.42	3.72	4.05	4.89	5.33	5.80
12	−0.050	0.142	3.58	4.12	4.75	5.47	6.32	3.64	3.96	4.31	5.22	5.70	6.21
13	−0.050	0.142	3.80	4.37	5.04	5.81	6.71	3.86	4.20	4.58	5.55	6.05	6.60
14	−0.050	0.141	3.99	4.59	5.28	6.09	7.02	4.06	4.41	4.81	5.81	6.34	6.90
15	−0.050	0.139	4.13	4.74	5.44	6.26	7.20	4.20	4.56	4.96	5.98	6.51	7.08
16	−0.050	0.136	4.21	4.82	5.52	6.33	7.26	4.28	4.64	5.03	6.05	6.58	7.15
17	−0.050	0.134	4.25	4.85	5.55	6.34	7.26	4.32	4.68	5.07	6.07	6.59	7.15
Girls													
3	−0.090	0.123	1.67	1.89	2.13	2.41	2.73	1.70	1.82	1.96	2.32	2.50	2.69
4	−0.090	0.124	1.82	2.05	2.32	2.63	2.98	1.85	1.98	2.14	2.53	2.72	2.94
5	−0.090	0.124	2.06	2.32	2.63	2.98	3.38	2.09	2.24	2.42	2.86	3.09	3.33
6	−0.090	0.126	2.26	2.55	2.89	3.28	3.73	2.29	2.47	2.66	3.15	3.40	3.67
7	−0.090	0.127	2.43	2.75	3.12	3.55	4.04	2.47	2.66	2.87	3.40	3.68	3.97
8	−0.090	0.128	2.60	2.95	3.35	3.81	4.34	2.64	2.85	3.07	3.65	3.95	4.28
9	−0.090	0.130	2.78	3.15	3.59	4.09	4.67	2.82	3.04	3.29	3.92	4.24	4.59
10	−0.090	0.131	2.95	3.36	3.83	4.36	4.99	3.00	3.24	3.50	4.18	4.53	4.91
11	−0.090	0.132	3.13	3.57	4.07	4.65	5.31	3.18	3.44	3.72	4.45	4.83	5.23
12	−0.090	0.132	3.29	3.75	4.27	4.88	5.58	3.34	3.61	3.91	4.67	5.07	5.50
13	−0.090	0.131	3.39	3.86	4.40	5.02	5.73	3.44	3.72	4.02	4.80	5.21	5.64
14	−0.090	0.130	3.44	3.91	4.45	5.07	5.78	3.49	3.77	4.07	4.85	5.26	5.69
15	−0.090	0.128	3.45	3.91	4.44	5.05	5.75	3.50	3.78	4.08	4.85	5.24	5.67
16	−0.090	0.125	3.44	3.89	4.40	4.99	5.67	3.49	3.75	4.05	4.79	5.17	5.58
17	−0.090	0.122	3.42	3.86	4.35	4.92	5.57	3.47	3.73	4.01	4.73	5.10	5.49

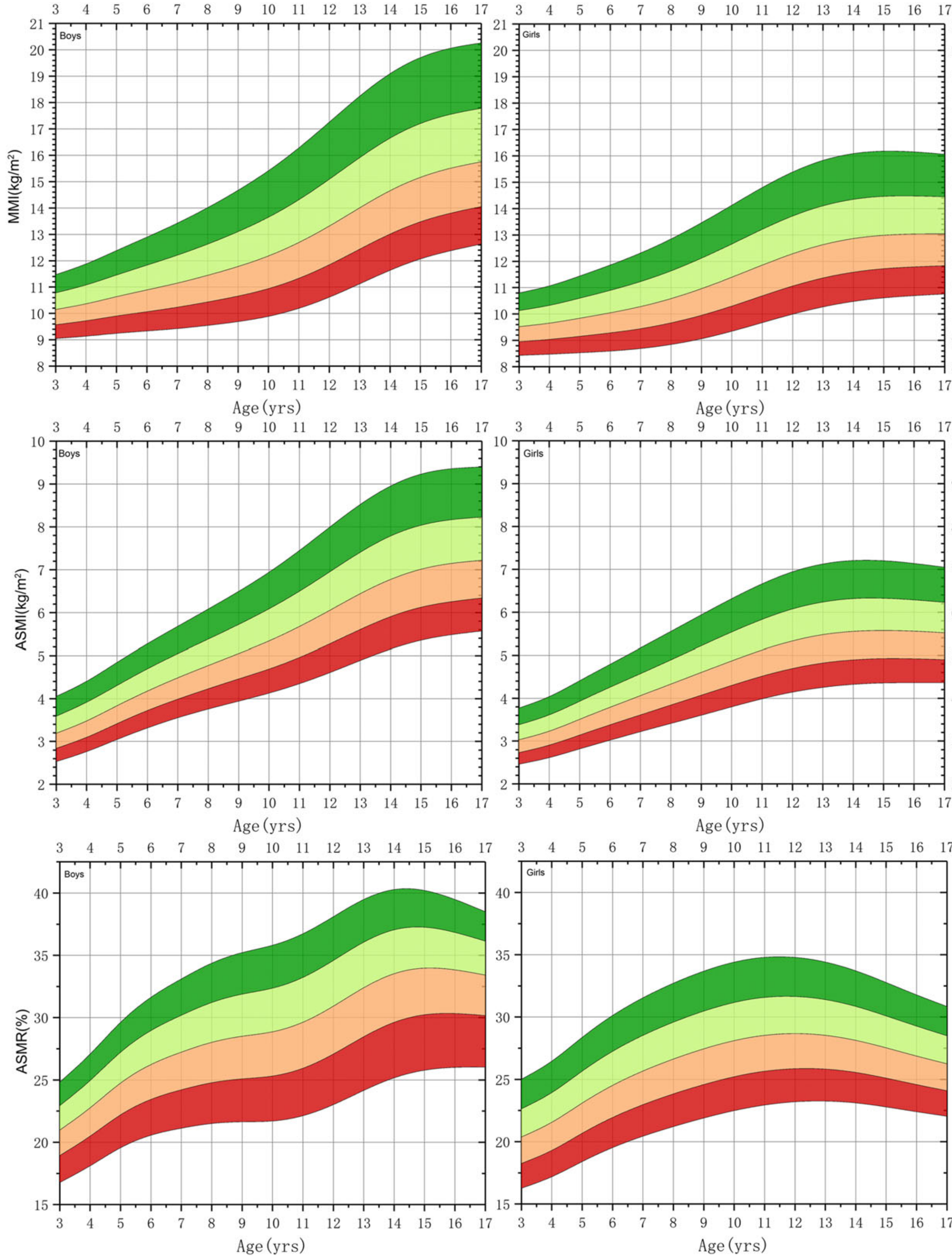
LLSMI, lower limb skeletal muscle mass index; L, lambda; S, coefficient of variation; SD, standard deviation.

muscle mass indices for Chinese children and adolescents aged 3–17 years using LMS method. These reference values can be potentially used for assessing the growth and development of skeletal muscle in Chinese children and adolescents in epidemiological and clinical settings.

It is well documented that skeletal muscle has many physiological functions through biomechanical stress and multiple myokines.[18] Studies have shown high muscle mass reduces the risk of osteoporosis and contributes to cardiovascular health in adults.[19–21] Maintaining optimal skeletal muscle mass in childhood may improve the peak muscle mass and bone strength and exert beneficial effects on cardiovascular health in adulthood. Therefore, establishing reference values for muscle mass is important for assessing muscle development during early growth. However, few studies have established the growth curve of skeletal muscle mass in children and adolescents. One prior study of 1985 Caucasian children aged 5–18.8 years created sex-specific reference curves for fat free mass and appendicular skeletal muscle mass measured using bioelectrical impedance. Another study of 1919 Korean children and adolescents aged 10–18 years established the reference values for DXA measured skeletal muscle mass. However, these reference values may be inapplicable for Chinese youths due to potential ethnicity disparity in muscle development. Compared with Korean boys, Chinese boys had similar BMI levels but lower ASMI. This difference might be explained by variation in genetics, economic status and diet habits. In addition, we found sex differences in growth patterns in skeletal muscle mass for Chinese children and adolescents. Although muscle mass indices increase rapidly during puberty for both sexes, boys vs. girls had a more rapid increase, especially for ASMI and ULSMI. This sex difference may be related to the different levels of hormone.

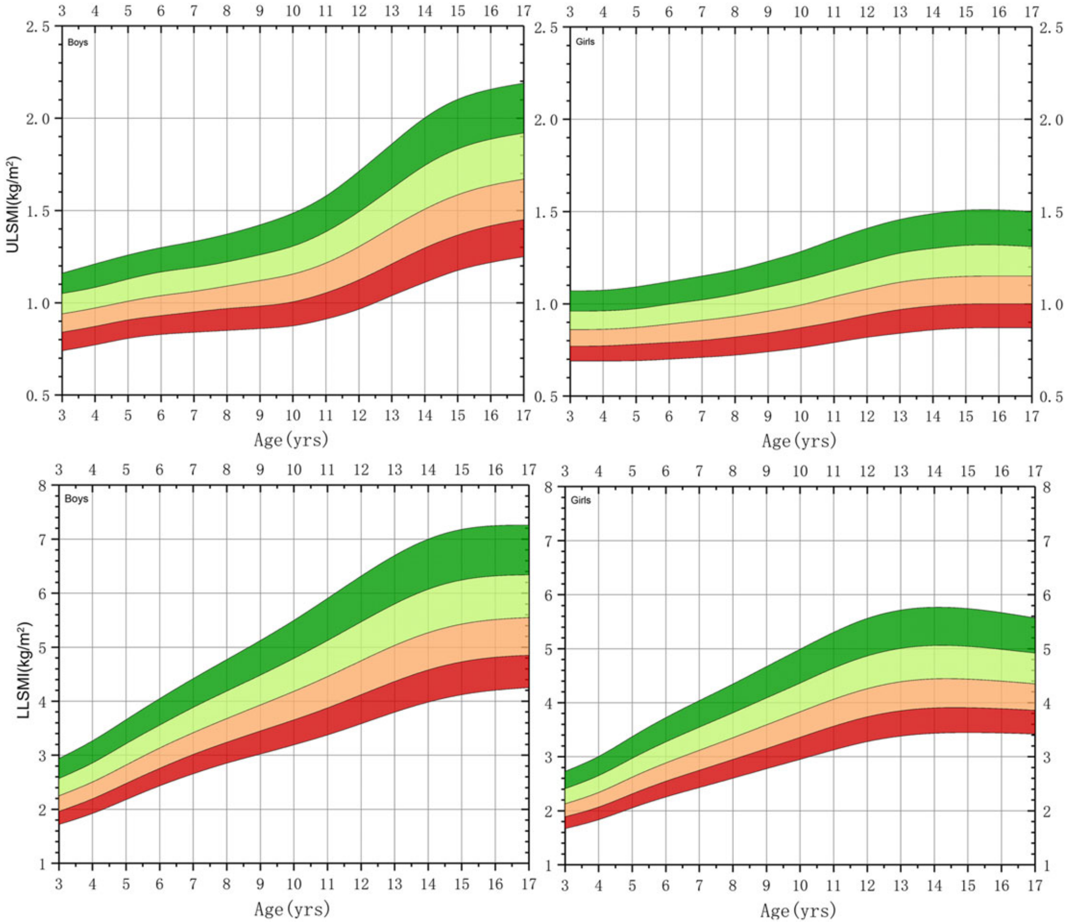
The reference values of skeletal muscle for Chinese children and adolescents can be used to assess the growth and development of skeletal muscle in healthy children and to monitor the loss of skeletal muscle in patients with some metabolic diseases, for example, severe malnutrition, wasting diseases and epilepsy. These reference data can also be used to evaluate the health risk and treatment effects in participants with bone-related diseases. In the elderly, the definition of sarcopenia is inconsistent. For example, Rosetta Study defined sarcopenia as SMI below mean minus 2 SD.[22] Another two studies defined sarcopenia based on sex-specific lowest 20% of study group.[23,24] Given great variation in the muscle mass during growth and development, we used sex-

Figure 1 Reference curves of MMI, ASMI and ASMR among Chinese children and adolescents. Red area: mean - 2 SD to mean - SD; yellow area: mean - SD to mean; cyan area: mean to mean + SD; green area: mean + SD to mean + 2 SD. ASMI, appendicular skeletal muscle mass index; ASMR, appendicular skeletal muscle mass weight ratio; MMI, muscle mass index; SD, standard deviation.



DOI: 10.1002/jcsm.12361

Figure 2 Reference curves of ULSMI and LLSMI among Chinese children and adolescents. Red area: mean-2 SD to mean-SD; yellow area: mean-SD to mean; cyan area: mean to mean + SD; green area: mean + SD to mean + 2 SD. LLSMI, lower limb skeletal muscle mass index; SD, standard deviation. ULSMI, upper limb skeletal muscle index.



specific and age-specific percentile values to evaluate healthy and abnormal skeletal muscle mass in the present study. Refer to the definition method for reference values of bone mineral density, skeletal muscle indices at ranges of mean to mean + SD and mean + SD to mean + 2 SD were defined as 'good' and 'excellent', respectively. Skeletal muscle indices at the range of mean - SD to mean and mean - 2 SD to mean - SD were defined as 'insufficient' and 'severe'.

The findings from the Physical Fitness and Health Research of Chinese school students from 1985 to 2010 showed that the trends in ULSMI and LLSMI were consistent with that of grip strength and distance of standing long jump. These findings indicated that physical activity may play a vital role in the development of skeletal muscle in youth. Therefore, children and adolescents are encouraged to engage in adequate physical activity.

Our study has several strengths. First, this study had a relatively large sample size of more than 10 000 Chinese children and adolescents. Secondly, DXA as the golden standard technology for assessment of skeletal muscle was applied in this study. Finally, the LMS curve smoothing method was used in this study to obtain growth curves at several specific percentiles. However, one limitation in the present study is that our study participants were from Chinese urban areas, and future studies involving rural children and adolescents are needed to reflect the whole spectrum of the youth population.

In conclusion, this study established sex-specific and age-specific percentile reference values for skeletal muscle mass for Chinese children and adolescents aged 3–17 years. These reference values may be an important tool for assessing muscle development and monitoring muscle-related diseases for Chinese youth.

Acknowledgements

We thank all the team members from seven centres attending in the CCACH Study for collecting data. We also thank all the participants in the present study. All authors declare that the submitted work has not been published before (neither in English nor in any other language) and that the work is not under consideration for publication elsewhere. All the authors certify that they comply with the ethical guidelines for publishing in the *Journal of Cachexia, Sarcopenia and Muscle*: update 2017.[25] The study was supported by grants from the National Key Research and Development Program of China (2016YFC1300101, 2016YFC0900602 and 2012BAI03B03) and the Beijing Leading Talent Grant (2009108 and 2011LJT07).

Conflict of interest

None declared.

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