Original article

Characteristics and reference values of fat mass index and fat free mass index by bioelectrical impedance analysis in an adult population

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SUMMARY

Background & aims: We aim to examine the influence of sex, age, region and ethnicity on fat mass index (FMI) and fat free mass index (FFMI), and to establish FMI and FFMI reference values in Chinese adults.
Methods: A stratified cluster sampling method was adopted to enroll Chinese participants in this cross-sectional study. Questionnaire surveys and medical examinations were performed to collect data, and body composition parameters were measured by bioelectrical impedance analysis. FMI and FFMI were calculated as the ratio of fat mass and fat free mass to the square of height. Differences in mean values for parameters were tested by Student's *t*-test or one-way analysis of variance. Reference values of FMI and FFMI were obtained using the percentiles method.
Results: A total of 8959 multiethnic healthy Chinese adults were included in the analysis. Males had higher mean FFMI (males, 18.6 ± 1.6 kg/m^2; females, 15.7 ± 1.1 kg/m^2, $P < 0.001$) but lower mean FMI (males, 5.1 ± 2.1 kg/m^2; females, 7.8 ± 2.8 kg/m^2, $P < 0.001$) than did female participants regardless of age and ethnicity. For both sexes, FMI (Male: Bouyei, 4.2 ± 1.8 kg/m^2; Uygur, 5.8 ± 2.2 kg/m^2, $P < 0.001$; Female: Bouyei, 6.7 ± 2.3 kg/m^2; Uygur, 9.0 ± 3.2 kg/m^2, $P < 0.001$) and FFMI (Male: Bouyei, 17.8 ± 1.4 kg/m^2; Uygur, 19.4 ± 1.6 kg/m^2, $P < 0.001$; Female: Bouyei, 15.1 ± 1.0 kg/m^2; Uygur, 16.3 ± 1.1 kg/m^2, $P < 0.001$) were lowest in Bouyeis and highest in Uygurs. FMI and FFMI values increased with age until they peaked in the 30–39 year age group in males and after the age of 40 years in females for all ethnic groups. Reference values (5th–95th percentile) of FMI and FFMI were presented according to gender, age, region and ethnicity.
Conclusion: The body composition of Chinese population differs in different age, sex, ethnicity and region subgroups. Practitioners and future studies may need to consider different reference values for FMI and FFMI in Chinese adults among Han, Bouyei and Uygur populations; these values can serve as indices for evaluating nutrition status and identifying abnormalities in body composition.

1. Introduction

Fat mass index (FMI) and fat free mass index (FFMI) were first put forward by VanItallie and colleagues in 1990 [1]. FMI and FFMI can recognize whether the excess or deficit of body weight is due to the change of fat mass (FM) or fat free mass (FFM) or both. In addition, FMI and FFMI provide information about actual body composition that may better reflect nutrition status [2]. Compared with the absolute FM and FFM, height-adjusted index, FMI and FFMI make it possible to compare the body compositions of people with different body sizes precisely.

Owing to its convenience of measurement, body mass index (BMI) is the most common clinical method used to determine underweight and overweight. However, BMI has been doubted by an increasing number of studies, because the respective contributions of FM and FFM are not taken into account [3–5]. Body composition is the relative proportion of muscle, fat, bone, water and other vital components of the body. It has also been demonstrated that individuals with the same body weight or BMI may have completely diverse compositions [6], which lead to differences in risk, prognosis or mortality of disease in different clinical settings [7–10]. Using BMI to evaluate nutritional status or detect undernutrition is inadequate in some specific populations [1,7], for example, athletes, elder people and hospitalized patients.

Currently, there are many methods available for measuring body composition, including bioelectrical impedance analysis (BIA), dual-energy X-ray absorptiometry (DXA) and indirect estimations such as skin-fold measurements and waist circumference. Owing to its convenience, efficiency and safety, BIA is widely implemented to evaluate body composition in clinical practice and epidemiological studies [11].

Both FMI and FFMI have been reported to be associated with clinical outcomes. In cross-sectional studies, increased FMI has shown positive associations with the prevalence of metabolic syndrome [12] and length of hospital stay [13]. Meanwhile, low FFMI has been shown to be related to increased mortality in elderly people [14–16] and longer length of hospital stay [13,17]. Thus, reference values of FMI and FFMI can help us detect abnormalities in clinical practice.

Recent studies have already reported reference values of FMI and/or FFMI for American [18,19], European [2,20–22], Australian [23] or Korean populations [24]. However, body composition has been shown to vary among different populations and races. There is no universal reference data to be applied, and it is necessary to provide reference values of body composition indicators for Chinese population. Lu et al. [25] first established reference values for FMI and FFMI in Chinese adults in Beijing. However, as is known, China is a multinational country composed of 56 ethnicities. Due to the multiplicity of ethnic culture, conventions and character, body composition is very likely to vary among ethnic groups. To address these research gaps, we aimed to establish reference values of FMI and FFMI measured by BIA for multiethnic Chinese adults, including those of Han, Bouyei and Uygur ethnicity, and to identify the determinants of body composition and how it changes with age.

2. Materials and methods

2.1. Study population

This study was a part of the China National Health Survey, a cross-sectional population-based survey conducted in various areas in China. Detailed methodological information was reported previously [26,27]. Briefly, we used a stratified cluster sampling method to enroll subjects aged 18−80 years old from Guizhou Province (Han and Bouyei) in 2012 and from Xinjiang Uygur Autonomous Region (Han and Uygur) in 2013 in China. Ethnic status was determined based on information provided on the identification card of each subject. Participants with incomplete data or self-reported neoplastic, cardiac, respiratory, liver, renal or hematological disease or other chronic diseases that may significantly influence body composition were excluded. In the analysis, we further excluded participants with BMI < 14 kg/m² and BMI > 36 kg/m². These participants were excluded because body composition of these severely underweight or obese subjects measured by BIA may be inaccurate [22]. The study was approved by Institutional Review Board of the Institute of Basic Medical Sciences, Chinese Academy of Medical Sciences and written informed consent was obtained from all subjects.

2.2. Data collection

All participants were required to maintain their regular lifestyle for at least one week and fast overnight, for more than 8 h, before conducting the survey. Trained staff provided questionnaire investigation for participants following a standardized procedure. Physical examination was performed by medical staff. Height was measured without shoes to the nearest 0.1 cm using a stadiometer. Weight was measured to the nearest 0.1 kg using the BIA device as a weight scale. Body composition was measured using a body composition analyzer (BC-420, Tanita, Japan). A single frequency (50 kHz), leg-to-leg pressure contact electrode BIA system was used for impedance measurements. This method had been validated, with magnetic resonance imaging [28] and DXA, however, no rigorous agreement analyses were performed in the previous studies. There was a strong relationship between body fat percentage (%BF) derived from the present BIA system and that derived from DXA ($r = 0.90$ and 0.91 for males and females, respectively) according to studies conducted by the manufacturer. The device was calibrated daily with a standard according to manufacturer's instruction [29]. Height, sex, age and other characteristics of subjects were input into the system by the staff. After removal of socks, heavy clothing and metal objects, subjects were told to stand up straight on the contact electrodes of the analyzer with hands hanging naturally. The proprietary equations not supplied by the manufacturer were used to estimate body composition parameters. FM, FFM and %BF values of each subjects were calculated and recorded by the system. BMI, FMI and FFMI were calculated as body weight, FM and FFM in kilograms divided by the square of height in meters.

2.3. Statistical analysis

Continuous data are described as means with standard deviation (SD) and differences in mean values were tested by Student's t-test. All analyses were conducted separately by sex. The following four ethnic categories were used in the analysis: Han in Guizhou, Han in Xinjiang, Bouyei in Guizhou and Uygur in Xinjiang. One-way analysis of variance with Least Significant Difference (LSD) test was used to compare the body composition indices between each ethnic group and age category. The 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentile values of FMI and FFMI were calculated according to sex, region, ethnicity and age. All statistical analyses were conducted using SPSS (version 19.0), with two-sided significance determined as $P < 0.05$.

We calculated the statistical power using the methods for estimating the mean in the population. The maximum available sample size in our analysis was 8959. We used 0.05 as the two-sided probability of type I error. The mean FMI and FFMI in the whole population were 6.7 ± 2.8 and 16.9 ± 2.0, respectively. Based on the above parameters, we have more than 99% statistical power to find the two-sided 95% confidence intervals of the reference values

smaller than 0.34 for FMI and 0.84 for FFMI. We believed that the statistical power was large enough for us to conduct the data analysis for the reference values of FMI and FFMI. Power analysis was conducted using PASS (version 11).

3. Results

3.1. Characteristics of subjects

A total of 8959 subjects (3627 males and 5332 females) aged 18–80 years (46.2 ± 13.7 years) were included in these analyses. Demographic and anthropometric characteristics for males and females are summarized in Table 1. On average, males were older, taller, heavier and had higher FFM (means ± SD, 51.3 ± 7.3 vs 37.3 ± 4.5 kg) and FFMI (means ± SD, 18.6 ± 1.6 vs 15.7 ± 1.1 kg/m^2) than did females. Conversely, %BF (means ± SD, 20.7 ± 5.7 vs 32.1 ± 6.4%), FM (means ± SD, 14.1 ± 6.0 vs 18.5 ± 7.0 kg) and FMI (means ± SD, 5.1 ± 2.1 vs 7.8 ± 2.8 kg/m^2) were significantly higher in female individuals than in male individuals.

3.2. Differences according to region of origin and ethnicity

FMI and FFMI values in males and females by region and ethnicity are shown in Fig. 1. Among all ethnic groups, body composition parameters (%BF, FM, FFM, BMI, FMI and FFMI) were all highest in Uygurs and lowest in Bouyeis (Table 1). In particular, FMI and FFMI of people living in Xinjiang were significantly higher than those of people living in Guizhou, even if they are from the same ethnicity (Han). However, there was no statistically significant difference in FFMI between Uygur and Han males living in Xinjiang (19.4 ± 1.6 vs 19.4 ± 1.5 kg/m^2, $P = 0.839$). For males and females, statistically significant differences in FMI were observed among all ethnic groups (means ± SD, Male: Han in Xinjiang, 5.5 ± 2.0 kg/m^2; Uygur in Xinjiang, 5.8 ± 2.2 kg/m^2, $P = 0.002$; Female: Han in

Guizhou, 7.6 ± 2.5 kg/m^2; Han in Xinjiang, 7.9 ± 2.6 kg/m^2, $P = 0.012$; comparisons between other ethnic groups, $P < 0.001$). FFMI differed among all ethnicities ($P < 0.001$ each) with the exception of males in Xinjiang.

3.3. Changes of FMI and FFMI occurring with age

According to the international criteria regarding age classification [30], we separated subjects into three age groups as follows: the young (18–44 y), the middle-aged (45–59 y) and the old (60–80 y) at first. Table 2 summarizes the FMI and FFMI values grouped by sex, age category and ethnic group. There were statistically significant differences in FMI and FFMI among the three age groups within all ethnic groups, although no statistical significance was found between part of age subgroups. In addition, detailed results for values and statistical tests between subgroups are shown in Table 2.

All participants were further divided into specific age groups with a 10-year-interval except for the first group (18–29 age group), to demonstrate the trend in the change in FMI and FFMI as age increased (Fig. 2). For both genders and all ethnicities, curves for BMI, FMI and FFMI showed nearly the same changing patterns, rising to a peak and decreasing afterward. In particular, these body composition indicators peak mostly in the 30–39 age groups in males, but after 40 years of age in females. Peak values of FMI and FFMI occurred in the 60–69 age category among Han females in Xinjiang, whereas FMI of Bouyei declined rapidly ahead of the other ethnic populations. Males showed similar changing tendencies for BMI, FMI and FFMI across ethnic groups. All these body composition values increased in the youngest group and then remained stable over the next decade, with a subsequent decrease in the following age group. However, the same indicators of female counterparts among ethnic categories showed diverse curves.

Table 1
Anthropometric characteristics for male and female subjects grouped by region and ethnicity.

Variable	All ethnicities	Han in Guizhou	Han in Xinjiang	Bouyei in Guizhou	Uygur in Xinjiang	P
Male						
Number	3627	937	891	1067	732	
Age (years)	46.7 ± 14.2	47.1 ± 13.9	45.0 ± 13.2	49.5 ± 14.4	44.0 ± 14.4	a b c d f
Height (cm)	165.6 ± 7.3	164.1 ± 6.3	169.6 ± 6.3	160.9 ± 6.3	169.4 ± 6.2	a b c d f
Weight (kg)	65.4 ± 12.6	63.3 ± 10.4	71.8 ± 11.5	57.1 ± 9.9	72.5 ± 11.6	a b c d f
%BF (%)	20.7 ± 5.7	21.1 ± 5.5	21.5 ± 5.3	18.4 ± 5.4	22.3 ± 5.7	b c d e f
FM (kg)	14.1 ± 6.0	13.8 ± 5.4	15.9 ± 5.9	10.9 ± 4.9	16.7 ± 6.3	a b c d e f
FFM (kg)	51.3 ± 7.3	49.5 ± 5.7	55.8 ± 6.3	46.1 ± 5.6	55.8 ± 6.1	a b c d f
BMI (kg/m^2)	23.7 ± 3.6	23.5 ± 3.3	24.9 ± 3.4	22.0 ± 3.0	25.2 ± 3.6	a b c d f
FMI (kg/m^2)	5.1 ± 2.1	5.1 ± 2.0	5.5 ± 2.0	4.2 ± 1.8	5.8 ± 2.2	a b c d e f
FFMI (kg/m^2)	18.6 ± 1.6	18.3 ± 1.5	19.4 ± 1.5	17.8 ± 1.4	19.4 ± 1.6	a b c d f
Female						
Number	5332	1381	1243	1462	1246	
Age (years)	45.8 ± 13.4*	46.4 ± 14.2	44.8 ± 11.8	50.2 ± 13.7	40.9 ± 11.6	a b c d e f
Height (cm)	154.1 ± 6.7**	152.6 ± 5.9	157.5 ± 5.8	149.7 ± 5.7	157.4 ± 5.7	a b c d f
Weight (kg)	55.8 ± 10.7**	53.7 ± 9.0	59.3 ± 9.2	49.0 ± 8.3	62.6 ± 11.1	a b c d e f
%BF (%)	32.1 ± 6.4**	32.2 ± 5.9	32.2 ± 6.1	29.9 ± 6.0	34.5 ± 7.0	b c d e f
FM (kg)	18.5 ± 7.0**	17.7 ± 6.0	19.5 ± 6.5	15.1 ± 5.3	22.3 ± 8.0	a b c d e f
FFM (kg)	37.3 ± 4.5**	35.9 ± 3.7	39.7 ± 3.6	33.9 ± 3.6	40.3 ± 3.8	a b c d e f
BMI (kg/m^2)	23.4 ± 3.8**	23.0 ± 3.5	23.9 ± 3.5	21.8 ± 3.2	25.3 ± 4.2	a b c d e f
FMI (kg/m^2)	7.8 ± 2.8**	7.6 ± 2.5	7.9 ± 2.6	6.7 ± 2.3	9.0 ± 3.2	a b c d e f
FFMI (kg/m^2)	15.7 ± 1.1**	15.4 ± 1.0	16.0 ± 0.9	15.1 ± 1.0	16.3 ± 1.1	a b c d e f

Data were presented as mean ± SD or number.
%BF, body fat percentage; FM, fat mass; FFM, fat free mass; BMI, body mass index; FMI, fat mass index; FFMI, fat free mass index.
*$P < 0.05$, **$P < 0.001$ vs male subjects.
a, $P < 0.05$ for the difference between Han in Guizhou and Han in Xinjiang.
b, $P < 0.05$ for the difference between Han in Guizhou and Bouyei in Guizhou.
c, $P < 0.05$ for the difference between Han in Guizhou and Uygur in Xinjiang.
d, $P < 0.05$ for the difference between Han in Xinjiang and Bouyei in Guizhou.
e, $P < 0.05$ for the difference between Han in Xinjiang and Uygur in Xinjiang.
f, $P < 0.05$ for the difference between Bouyei in Guizhou and Uygur in Xinjiang.
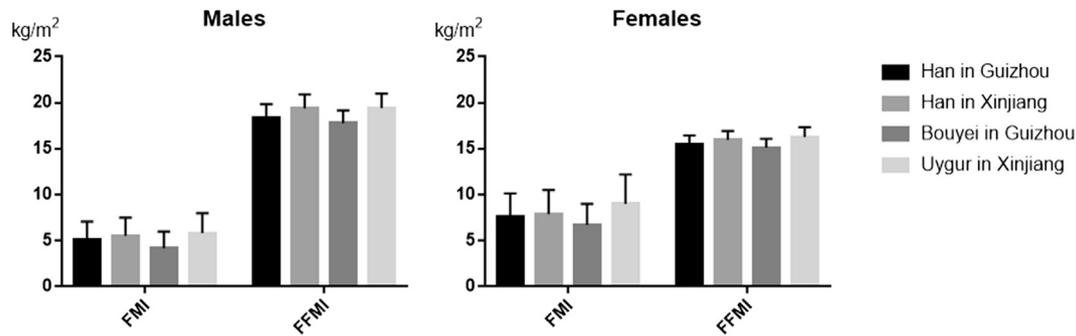
Fig. 1. FMI and FFMI in males and females according to region of origin and ethnicity.

Table 2
FMI and FFMI for male and female subjects grouped by age and ethnic group.

	FMI (kg/m^2)				FFMI (kg/m^2)			
	Age (years)				Age (years)			
	18–44	45–59	60–80	P	18–44	45–59	60–80	P
Male								
Number of subjects	1721	1158	748		1721	1158	748	
Han in Guizhou	5.1 ± 2.0	5.4 ± 2.0	4.8 ± 1.8	a, c	18.5 ± 1.6	18.4 ± 1.5	17.9 ± 1.3	b, c
Han in Xinjiang	5.4 ± 2.1	5.8 ± 1.8	5.4 ± 1.9	a	19.5 ± 1.6	19.4 ± 1.4	19.0 ± 1.4	b, c
Bouyei in Guizhou	4.5 ± 1.8	4.5 ± 1.8	3.5 ± 1.5	b, c	18.1 ± 1.4	18.0 ± 1.3	17.1 ± 1.2	b, c
Uygur in Xinjiang	5.6 ± 2.2	6.2 ± 2.1	5.8 ± 2.1	a	19.4 ± 1.7	19.6 ± 1.4	19.1 ± 1.5	b, c
Female								
Number of subjects	2668	1717	947		2668	1717	947	
Han in Guizhou	6.9 ± 2.4	8.3 ± 2.4	8.2 ± 2.6	a, b	15.3 ± 1.0	15.6 ± 1.0	15.4 ± 1.0	a, b, c
Han in Xinjiang	7.2 ± 2.4	8.5 ± 2.5	9.1 ± 3.1	a, b, c	15.9 ± 0.9	16.2 ± 0.9	16.0 ± 1.0	a
Bouyei in Guizhou	6.8 ± 2.1	7.1 ± 2.5	6.1 ± 2.2	b, c	15.2 ± 0.9	15.3 ± 1.0	14.8 ± 0.9	b, c
Uygur in Xinjiang	8.3 ± 3.1	10.4 ± 2.9	10.1 ± 3.2	a, b	16.1 ± 1.1	16.6 ± 0.9*	16.3 ± 1.1	c

Data were presented as mean ± SD or number.
a, $P < 0.05$ for the difference between 18–44 and 45–59 age group.
b, $P < 0.05$ for the difference between 18–44 and 60–80 age group.
c, $P < 0.05$ for the difference between 45–59 and 60–80 age group.
Comparison of indices between each age group was performed by Least Significant Difference (LSD) test.

3.4. Reference values for FMI and FFMI

Tables 3 and 4 show sex-, age-, regional- and ethnic-specific distributions for FMI and FFMI respectively. In Guizhou Province, the reference values (5th–95th percentile) of FMI for males and females were 2.1–8.3 kg/m^2 and 4.1–12.0 kg/m^2, respectively, in Hans, while the ranges were 1.9–7.6 kg/m^2 and 3.5–10.7 kg/m^2, respectively, in Bouyeis. The reference values of FFMI in Han and Bouyei males ranged from 15.9 to 20.8 kg/m^2, and from 15.6 to 20.1 kg/m^2, respectively. In females, the FFMI percentiles were 18% lower than those in males. In Xinjiang Uygur Autonomous Region, the respective reference values of FMI were 2.2–8.8 kg/m^2 and 4.1–12.8 kg/m^2 for males and females of Han ethnicity. In Uygurs, 90% of males and females had an FMI between 2.2 and 9.3 kg/m^2, and between 4.0 and 14.8 kg/m^2, respectively. FFMI reference intervals were 14.4–17.5 kg/m^2 in Han females in Xinjiang and 14.4–17.9 kg/m^2 in Uygur females. FFMI reference values of Han males in Xinjiang were almost the same as those of Uygur males, which ranged from 16.7 to 21.9 kg/m^2.

4. Discussion

This cross-sectional study was based on a national population involving 8959 multiethnic Chinese adults and demonstrated that magnitude of changes in body composition measured by BIA varied according to sex, age, region and ethnicity. To the best of our knowledge, this is the first study providing sex-, age-, regional- and

ethnic-specific reference values of FMI and FFMI in multiple Chinese populations.

A considerable number of studies have found sex differences in the growth of body components or changes in body composition with aging [6,21,23–25,31]. As expected, we discovered that males showed a significantly higher absolute as well as height-adjusted FFM, while their female peers presented with significantly higher values of FM and FMI overall. Sex differences in body composition were also found within each ethnic and age group. This finding explains why we need to establish different reference values of FMI and FFMI for males and females, respectively.

The current study showed distinct differences in FMI and FFMI values between different age subgroups regardless of sex and ethnicity. Our results also demonstrated that FMI and FFMI declined earlier in males than those in females. These sex differences in changing patterns may be due to the small sample sizes of some subgroups in females. In addition, the rough division of age groups may lead to inaccurate changing tendencies between body composition parameters and age. Similarly to our findings, males reached their maximum FFMI or FMI earlier than did their female counterparts among Korean [24,32] and Chinese [25] participants in cross-sectional studies, despite differences in specific age at peak. Compared with those in another Chinese study, the participants in our study showed peak values of FMI and FFMI ten years earlier. This discrepancy may be due in part to the diverse background of the targeted population, such as ethnic status, exercise and living conditions. These diversities can result in heterogeneity
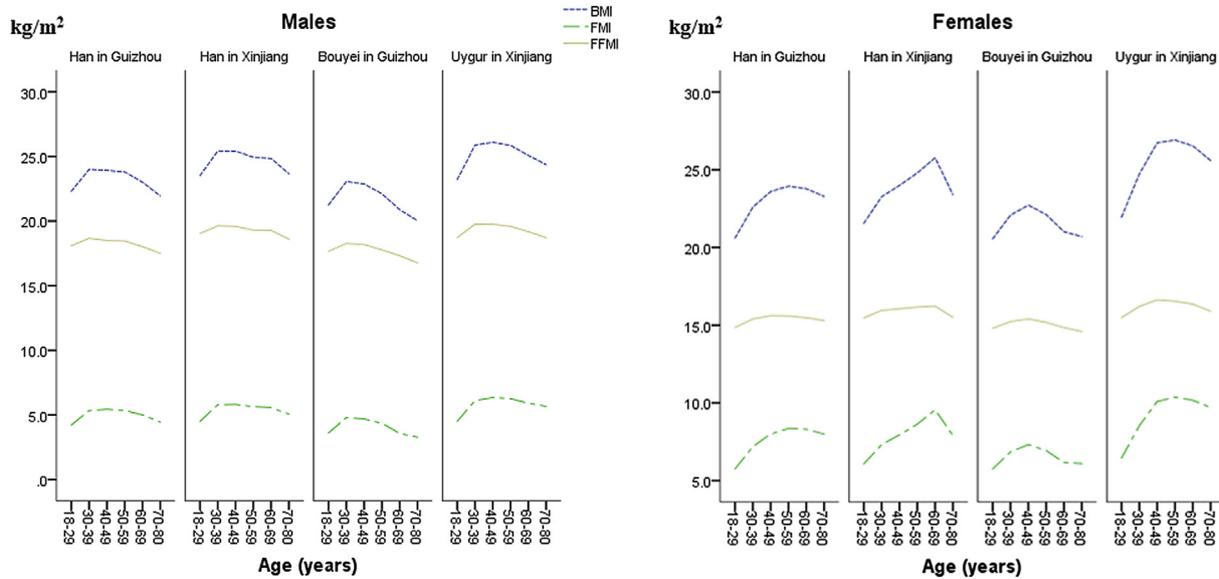
Fig. 2. Body composition indices (BMI, FMI and FFMI) in males and females by age and ethnic category.

between these two studies. In contrast to the results described above, studies based on Australians and Italians showed different relationships between age and FMI or FFMI [21,23]. Overall, findings pertaining to changing patterns vary among studies, likely due to racial and geographical variations.

Age-related changes in body composition demonstrate that the significance of determining abnormalities in FMI and FFMI according to age group. For example, if we use the same criteria for adults from 18 to 80 years to detect nutritional status, people with a normal FMI may be misclassified as underweight or overweight, which could cause unnecessary intervention. More importantly, an appropriate FFMI lower limit can help us detect loss of FFMI earlier in subgroups of different ages, particularly elderly people, to prevent adverse outcomes by employing interventions immediately.

Racial differences in body composition, fat distribution and muscularity, have been reported previously [6,33–35]. Our data contains three ethnic populations (Han, Bouyei and Uygur) living in western China. We enrolled Hans from two regions, Guizhou and Xinjiang, but Bouyeis were all from Guizhou and Uygurs were only from Xinjiang. In the present study, we first analyzed ethnic status as a factor affecting FMI and FFMI among Chinese. A wide disparity in body composition was observed among Han, Bouyei and Uygur within each sex. In addition, Bouyeis showed significantly lower fat levels and FFM than did all other ethnic groups, while the parameters were highest in Uygurs, with or without adjusting for height. Moreover, Han living in the two regions exhibited completely different body composition. Our study also suggests that absolute FM and FFM and height-adjusted indicators of people living in

Table 3
Reference values of fat mass index percentiles in Chinese adults.

Ethnicity and age group (years)	Male								Female							
	N	P5	P10	P25	P50	P75	P90	P95	N	P5	P10	P25	P50	P75	P90	P95
All subjects	3627	2.0	2.5	3.5	5.0	6.5	7.8	8.6	5332	3.9	4.5	5.7	7.4	9.4	11.5	12.9
Han in Guizhou																
18−80	937	2.1	2.6	3.7	5.1	6.5	7.7	8.3	1381	4.1	4.7	5.8	7.3	9.2	11.0	12.0
18−44	426	1.9	2.5	3.5	5.1	6.5	7.7	8.3	648	3.8	4.2	5.3	6.4	8.2	10.2	11.4
45−59	306	2.4	3.0	3.9	5.4	6.8	8.0	8.8	440	4.9	5.3	6.6	8.0	9.8	11.3	12.2
60−80	205	2.1	2.5	3.6	4.9	6.0	7.0	7.8	293	4.3	5.0	6.4	8.0	9.9	11.5	12.7
Han in Xinjiang																
18−80	891	2.2	2.9	4.2	5.5	6.8	8.0	8.8	1243	4.1	4.9	6.0	7.5	9.5	11.4	12.8
18−44	476	1.9	2.7	3.9	5.4	6.8	8.3	9.1	654	3.8	4.4	5.6	6.9	8.6	10.4	11.6
45−59	295	2.7	3.3	4.6	5.8	7.0	8.0	8.8	443	4.9	5.6	6.7	8.3	9.8	11.8	13.0
60−80	120	1.8	3.0	4.3	5.4	6.5	7.6	8.4	146	4.6	5.1	6.8	8.9	10.9	13.1	15.3
Bouyei in Guizhou																
18−80	1067	1.9	2.2	2.9	3.8	5.3	6.8	7.6	1462	3.4	4.0	5.1	6.5	8.1	9.7	10.7
18−44	428	2.2	2.4	3.0	4.2	5.7	7.0	7.7	560	3.8	4.4	5.4	6.6	8.1	9.5	10.6
45−59	340	2.0	2.4	3.1	4.2	5.6	7.1	8.0	482	3.6	4.1	5.2	6.9	8.5	10.5	12.0
60−80	299	1.4	1.9	2.5	3.1	4.3	5.5	6.2	420	3.1	3.5	4.7	5.9	7.5	9.1	10.1
Uygur in Xinjiang																
18−80	732	2.2	2.8	4.2	6.0	7.4	8.4	9.3	1246	4.0	4.9	6.7	8.7	11.2	13.4	14.8
18−44	391	2.1	2.6	3.8	5.8	7.4	8.4	9.0	806	3.6	4.4	5.8	8.0	10.3	12.6	13.8
45−59	217	2.3	3.4	4.9	6.2	7.6	9.0	10.0	352	6.1	6.9	8.2	10.2	12.4	14.8	15.7
60−80	124	2.7	3.2	4.3	5.8	7.1	8.2	10.0	88	4.7	6.2	7.9	9.8	12.1	14.6	15.9

Table 4
Reference values of fat free mass index percentiles in Chinese adults.

Ethnicity and age group (years)	Male								Female							
	N	P5	P10	P25	P50	P75	P90	P95	N	P5	P10	P25	P50	P75	P90	P95
All subjects	3627	16.0	16.5	17.5	18.6	19.8	20.8	21.4	5332	13.9	14.2	14.9	15.7	16.4	17.1	17.5
Han in Guizhou																
18—80	937	15.9	16.4	17.3	18.3	19.4	20.3	20.8	1381	13.8	14.2	14.7	15.4	16.1	16.8	17.1
18—44	426	15.8	16.4	17.4	18.5	19.5	20.5	21.0	648	13.6	14.1	14.5	15.2	15.9	16.7	17.2
45—59	306	16.1	16.4	17.4	18.4	19.5	20.4	20.8	440	14.1	14.3	15.0	15.6	16.3	16.8	17.1
60—80	205	15.5	16.1	16.9	17.9	18.8	19.6	20.0	293	13.6	14.1	14.7	15.5	16.1	16.7	17.0
Han in Xinjiang																
18—80	891	16.8	17.4	18.3	19.4	20.4	21.3	21.9	1243	14.4	14.8	15.4	16.0	16.7	17.2	17.5
18—44	476	16.7	17.4	18.3	19.5	20.5	21.6	22.1	654	14.3	14.7	15.3	15.9	16.5	17.1	17.5
45—59	295	17.0	17.6	18.6	19.4	20.4	21.1	21.5	443	14.8	15.1	15.6	16.2	16.8	17.3	17.6
60—80	120	16.2	17.4	18.2	19.1	20.2	20.5	21.0	146	14.1	14.4	15.3	16.1	16.8	17.3	17.5
Bouyei in Guizhou																
18—80	1067	15.6	16.0	16.8	17.7	18.7	19.6	20.1	1462	13.6	13.9	14.4	15.0	15.8	16.4	16.8
18—44	428	15.8	16.3	17.1	18.0	19.0	19.9	20.4	560	13.8	14.0	14.6	15.2	15.9	16.4	16.8
45—59	340	15.8	16.4	17.0	17.9	18.8	19.7	20.3	482	13.6	13.9	14.2	15.3	15.9	16.6	17.1
60—80	299	15.0	15.4	16.3	17.1	18.0	18.6	19.3	420	13.2	13.6	15.3	14.7	15.3	16.0	16.3
Uygur in Xinjiang																
18—80	732	16.7	17.3	18.3	19.5	20.5	21.4	21.9	1246	14.4	14.8	15.5	16.3	17.1	17.6	17.9
18—44	391	16.6	17.1	18.0	19.6	20.6	21.4	21.9	806	14.2	14.6	15.3	16.2	16.9	17.6	17.8
45—59	217	17.0	17.9	18.8	19.6	20.5	21.4	22.0	352	15.2	15.4	16.0	16.7	17.3	17.8	17.9
60—80	124	16.1	17.3	18.1	19.2	20.2	20.7	21.5	88	13.9	15.0	15.7	16.5	17.1	17.5	17.9

Xinjiang were higher than those of subjects living in Guizhou, regardless of sex and ethnicity. These regional and ethnic discrepancies in body composition may be explained by dietary status indicators such as energy intake and food proportion to some extent. For instance, people living in Xinjiang prefer to eat meat, which is considered a high energy-dense food, to store energy against the cold winter. A recent study conducted in southwest China identified a positive association between dietary energy density and body composition parameters (BMI, FMI, FFMI and other indicators of obesity like %BF) in both males and females, although direct causality was not demonstrated [36]. Another possible reason for ethnic differences in body composition is variations in other lifestyle factors, including physical labor, exercise and sedentary behavior. Physical activity was found to be a protective factor against an increase in FM in a large population-based study [37], and a longitudinal study showed that physical activity may prevent age-related FFM loss [31]. Moreover, substantial evidence revealed that regular physical activity was positively correlated with appendicular lean mass throughout adulthood [38]. These findings support our explanations for the effect of regional and ethnic factors on body composition to some degree; however, the specific mechanism by which ethnic diversity affects body composition in Chinese individuals requires further study.

In general, sex, age, ethnicity and original region influenced FMI and FFMI of the study population. The above-mentioned findings highlight the significance of establishing specific reference values for FMI and FFMI; these values can be useful for physicians in accessing nutritional status and evaluating underweight or overweight in clinical practice. Due to considerable differences in FMI and FFMI values among populations of different sex, age, ethnic and regional status, a unified criterion may not be effective in identifying potential diseases in entire populations. Thus, such a criterion would not be beneficial for increasing the effectiveness of disease prevention.

Increasing numbers of studies have also focused on height-adjusted indicators, FMI and FFMI, to eliminate the effect of height on body composition [19—25]. However, the vast majority of previous studies only provided sex- and age-associated reference values [21,23,24], and some presented BMI-specific values [3,22,25]. The reference values of BIA-measured FMI and FFMI were reported to be 2.7—11.8 and 18.2—22.3 kg/m^2 in Australian males and 4.8—19.4 and 13.7—17.5 kg/m^2 in their female peers, respectively [23]. These ranges were all higher than those of populations included in the present study, except for reference values of FFMI among Australian females. Compared with subjects of the same age range and with comparable BMI ranges from the UK Biobank dataset [22], Chinese subjects aged 45—59 years showed a lower FFMI at percentile five. Although Asians are more slender and have a higher body fat percentage than Caucasians for a given height or weight [39], differences in body composition between Chinese and other populations may not only be due to racial discrepancy with respect to body build. Moreover, differences in body composition measurement methods, such as the BIA device model or specific equations used, as well as variations in inclusion criteria and the age range of subjects, potentially lead to bias when making comparisons across different studies. Lu et al. [25] presented reference values for FMI and FFMI in a Chinese healthy check-up population from 18 to 92 years old. FMI and FFMI values were 1.99—7.75 kg/m^2 and 14.15—19.76 kg/m^2 in males and the values were most similar to those of Bouyei males in Guizhou in our study, whose mean BMI was also within the normal BMI range (18.5—23.9 kg/m^2). FFMI was 13.82—17.89 kg/m^2 for their female counterparts, consistent with our results for all female subjects with a mean BMI of approximately 23.4 kg/m^2. Thus, the common ground verifies the accuracy of our results. Participants in our study can represent the populations in Guizhou and Xinjiang well, owing to the stratified and cluster sampling method used in enrolling subjects. Authors of another Chinese study recruited only adults who underwent health check at a hospital health screening center, who are not as representative as our study populations. Another advantage of this study is that we considered different regions, especially remote areas, thus making the samples more representative based on population.

Some limitations are associated with the current study. First, due to the limited number of participants in specific subgroups, it may be inaccurate for evaluating changing tendency of body composition indicators in these subgroups. Second, the BIA method used in our study is unable to obtain regional fat deposits, which may be independent predictors of related disease risk. Third, body composition parameters (%BF, FM and FFM) were automatically calculated using unknown equations not supplied by the

manufacturer in the BIA system. It is necessary to test the validity of Tanita BC-420 and the internal BIA equations among Chinese in future studies. In addition, further agreement studies are needed to confirm the relationship between BIA-measured body composition values and those derived from other measurements. Finally, the present study addressed only three ethnicities and two regions; similar studies are needed to assess whether ethnic disparities are observed among other ethnicities, and to establish appropriate references values for other ethnic minority groups.

In conclusion, body composition varied according to sex, age, ethnicity and region of origin in Chinese population. The temporal trends in body composition parameters were different between males and females. Different temporal trends in FMI and FFMI were not obvious in males of different ethnicities; however, these differences were notable in females of different ethnicities. The sex-, age-, regional- and ethnic-specific FMI and FFMI reference values obtained in this study may be useful for obesity or underweight evaluation and nutritional assessment.

Authorship

Study conception and design: Hui Pan and Guangliang Shan; acquisition of data: Ke Xu, Xianxian Yuan, Meng Jin; analysis and interpretation of data: Yuelun Zhang, Meng Jin; drafting the manuscript: Meng Jin; critical revision of the manuscript: Hanze Du, Huijuan Zhu, Hui Pan. All authors have read and approved the final manuscript.

Conflict of interest

The authors have no conflicts of interest to disclose.

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