Internal Medicine
The Japanese Society of Internal Medicine
doi: 10.2169/internalmedicine.5792-20
Intern Med 60: 1191-1196, 2021
http://internmed.jp

【 ORIGINAL ARTICLE 】

Which Is a Better Skeletal Muscle Mass Index for the Evaluation of Physical Abilities: The Present Height or Maximum Height?

Ken-ichiro Tanaka[1-3], Yuki Morisato[4], Hirofumi Nakajima[4], Keizo Kanasaki[2], Toshitsugu Sugimoto[5] and Ippei Kanazawa[3,6]

Abstract:

Objective Sarcopenia and osteoporosis often coexist in older adults. Sarcopenia is diagnosed using the skeletal muscle mass index (SMI), which is calculated as the appendicular skeletal muscle mass (ASM)/(present height)^2, although patients with osteoporosis frequently have a loss of body height. We therefore investigated whether the present height or maximum height is more useful for calculating the SMI in the evaluation of physical abilities.

Methods We conducted a cross-sectional study to investigate the association of the SMI with physical abilities, such as the grip strength and gait speed, in 587 postmenopausal women. The SMI was evaluated using whole-body dual-energy X-ray absorptiometry (DXA). The SMI [(ASM)/(present height)^2], modified SMI (mSMI) [(ASM)/(maximum height)^2], and SMI difference (ΔSMI) (mSMI-SMI) were calculated.

Results Age and body mass index (BMI)-adjusted regression analyses showed that the SMI (β=0.30, p< 0.001 and β=0.14, p=0.034) and mSMI (β=0.40, p<0.001 and β=0.29, p<0.001) were positively associated while the ΔSMI was negatively associated with the grip strength and gait speed (β=-0.15, p<0.001 and β=-0.24, p<0.001, respectively). Furthermore, the age, BMI, and presence of osteoporotic fractures-adjusted logistic regression analyses showed that a low mSMI (<5.4 kg/m^2) was significantly associated with a low grip strength (<18 kg) and slow gait speed (1.0 m/s) [odds ratio (OR)=2.45, 95% confidence interval (CI)=1.52-3.95 per SD increase, p<0.001; and OR=1.73, 95% CI=1.01-2.96, p=0.042, respectively], although a low SMI showed no such relationship (p=0.052 and p=0.813, respectively).

Conclusion The mSMI using the maximum height is more useful for evaluating physical abilities than conventional SMI estimation in postmenopausal women.

Key words: sarcopenia, skeletal muscle mass index, maximum height, physical ability, grip strength, gait speed

(Intern Med 60: 1191-1196, 2021)
(DOI: 10.2169/internalmedicine.5792-20)

Introduction

Sarcopenia and osteoporosis are both aging-related diseases associated with the deterioration of muscle and bone strength, resulting in frailty among older adults. There are several common factors, including genetic factors, vitamin D insufficiency/deficiency, glucocorticoid use, and sex hormone decline. Previous studies have shown that muscle and bone metabolism are associated with each other, and a strong relationship exists between sarcopenia and osteoporosis, which has recently come to be known as osteosarcopenia (1-3). As sarcopenia and osteoporosis have become worldwide social issues with the aging of the global popula-

[1]Department of Internal Medicine, Matsue Memorial Hospital, Japan, [2]Department of Internal Medicine 1, Shimane University Faculty of Medicine, Japan, [3]Shimane BMD Laboratory, Japan, [4]Nakashima Hospital, Japan, [5]Eikokai Ono Hospital, Japan and [6]Kanazawa Diabetes and Osteoporosis Clinic, Japan

Received: July 5, 2020; Accepted: October 12, 2020; Advance Publication by J-STAGE: November 23, 2020

Correspondence to Dr. Ippei Kanazawa, ippeikanazawa@kanazawa-doc.com

tion, preventing and treating these conditions are important.

The Asian Working Group for Sarcopenia (AWGS) recommended using the three items of skeletal muscle mass index (SMI), grip strength (muscle strength), and gait speed (physical function) for making a diagnosis of sarcopenia (4). The appendicular skeletal muscle mass (ASM) is measured by whole-body dual-energy X-ray absorptiometry (DXA) or total body electrical conductivity with a bioelectrical impedance analysis (BIA). The SMI is calculated as the ASM/(present height)^2 (4). A low SMI (<5.4 kg/m^2 for women) is used for the diagnosis of sarcopenia in Asians (4).

A major clinical feature of osteoporosis is height loss. Previous studies have shown that height loss increases the vertebral fracture risk and mortality (5, 6). Furthermore, Masunari et al. showed that height loss and vertebral fracture were independently associated with a deteriorated quality of life (7). Because height loss is related to activities of daily living, it is suggested that height loss is also associated with sarcopenia. However, if the SMI is calculated based on the present height, disregarding any height loss, it is likely to be overestimated. If this overestimated SMI is then used for the diagnosis of sarcopenia, many patients with sarcopenia will be misdiagnosed and won't receive therapeutic intervention.

We thus hypothesized that the modified SMI (mSMI) using the maximum body height might be more useful for evaluating physical abilities and conducted a cross-sectional study to investigate whether the SMI using the present height or maximum height showed a better association with the grip strength and gait speed.

Materials and Methods

Subjects

This is a cross-sectional study examining the association between muscle mass and physical abilities in postmenopausal women. Patients who visited or were admitted to Shimane University Hospital or Nakashima Hospital, except for those with dementia, renal dysfunction (estimated glomerular filtration rate <30 mL/min/1.73 m^2), nutritional derangements, malignant diseases, and infection, between 2008 and 2018 were screened. In this study, 587 postmenopausal women who underwent a physical examination, such as an assessment of the grip strength, gait speed, or body composition by whole-body DXA, to evaluate sarcopenia were included.

Anthropometric and biochemical measurements

The body height (cm) was measured with a Martin metal anthropometer to the nearest 0.1 cm according to the standard technique, and the maximum height was obtained by medical interview. Height loss was calculated as the difference between the self-reported maximum adult height and the actual measured height. The body weight (kg) was measured using a medical electronic scale and recorded with 0.05-kg precision with the subject wearing light clothes. The body mass index (BMI) was calculated as the weight/height^2 (kg/m^2). Biochemical markers were measured using standard methods, as previously described (8, 9). Grip strength was measured by a Smedley-type handheld dynamometer (Takei, Tokyo, Japan). Patients walked on a flat and straight surface at their normal walking pace. Two markers were used to indicate the start and end of a 2.4-m walking path, with a 2-m section to be traversed before passing the start marker, so that participants were walking at a comfortable pace by the time they reached the timed path. There is an approach run when measuring gait speed, and participants were asked to continue walking for an additional 2 m past the end of the path to ensure a consistent walking pace while on the timed path. The walking time was measured over a 6-m distance in seconds using a stopwatch, and the participants' gait speed (m/s) was calculated (10).

Measurements of muscle mass according to whole-body DXA

The lean body mass of the ASM was evaluated by whole-body DXA (QDR-4500; Hologic, Bedford, USA). The SMI was calculated as the ASM/(present height)^2, as previously described (4). In addition, the mSMI [(ASM)/(maximum height)^2] and SMI difference (ΔSMI) (SMI subtracted from mSMI) were calculated. We defined a low SMI as <5.4 kg/m^2, a low grip strength as <18 kg, and a slow walking speed as <0.8 m/s, which are the values used for diagnosing sarcopenia in Asians (4). The diagnostic criteria of sarcopenia in AWGS2019 was used for diagnosing sarcopenia (4).

The assessment of osteoporotic fractures

For the vertebral fracture assessment, lateral radiographic films of the thoracic and lumbar spine were taken during the same week as the serum collection for all subjects. The anterior, central, and posterior heights of each of the 13 vertebral bodies from T4 to L4 were measured. A vertebral fracture was diagnosed if at least one of three height measurements along the length of the same vertebra had decreased by >20% compared with the height of the nearest uncompressed vertebral body (11). For non-vertebral fracture assessments, only low-trauma fractures, i.e., those occurring as a result of falls from a standing height or lower, were considered. We included all fractures except for those of the hand, toes, metacarpals, face, and skull, as well as pathological fractures, such as bone metastasis and post-procedural fractures, based on clinical interviews.

Statistical analyses

Data are expressed as the mean±standard deviation (SD). To investigate correlations of the SMI and body height loss with background characteristics, simple regression analyses were performed. To adjust for the age, BMI, and body height loss, multiple regression analyses were performed. To investigate the association between the SMI and the presence of low physical abilities, logistic regression analyses

Table 1. Background Characteristics of Subjects.

Number of patients	587
Age (years)	74.6±9.9
Body height (cm)	149.2±6.5
Maximum body height (cm)	153.2±5.5
ΔBody height (cm)	4.0±3.9
Body weight (kg)	50.8±9.7
Body mass index (kg/m^2)	22.8±3.9
SMI (kg/m^2)	5.77±0.82
mSMI (kg/m^2)	5.46±0.82
ΔSMI (kg/m^2)	0.30±0.29
Albumin (g/dL)	4.0±0.5
ALT (IU/L)	29±26
Creatinine (mg/dL)	0.67±0.31
eGFR (mL/min/1.73m^2)	66.1±25.0
Grip strength (kg)	19.2±4.9
Gait speed (m/sec)	1.0±0.3
Number of patients with sarcopenia	98*, 166**
Number of patients with osteoporotic fractures	277

The values are mean±SD.

*: sarcopenia involving SMI, **: sarcopenia involving mSMI.

SMI: skeletal muscle mass index, Δbody height: subtracting body height from maximum body height, m (modified) SMI: calculated using maximum body height, ΔSMI: subtracting SMI from modified SMI, eGFR: estimated glomerular filtration rate

were used for a multivariate analysis to adjust for confounding factors. All analyses were carried out using the StatView software program (Abacus Concepts, Berkeley, USA). A p value <0.05 was considered significant.

Results

Simple correlations of the SMI, mSMI, and ΔSMI with background characteristics

Patient demographic characteristics, biochemical parameters, and indices of muscular and physical abilities are shown in Table 1. The numbers of patients with sarcopenia diagnosed based on the SMI and mSMI were 98 and 166, respectively. The number of patients with osteoporotic fractures was 277.

We examined the simple correlations of the SMI, mSMI, ΔSMI, and Δbody height with various parameters (Table 2). The SMI and mSMI were significantly and negatively correlated with the age (r=-0.20, p<0.001 and r=-0.39, p<0.001, respectively) and positively with the body weight (r=0.70, p <0.001 and r=0.75, p<0.001, respectively) and BMI (r=0.78, p<0.001 and r=0.74, p<0.001, respectively). Furthermore, the mSMI was significantly and positively correlated with the body height (r=0.14, p=0.001) and negatively with the Δbody height (r=-0.30, p<0.001). The ΔSMI was significantly and positively correlated with the age (r=0.56, p< 0.001), Δbody height (r=0.98, p<0.001), and BMI (r=0.13, p =0.003) and negatively with the body height (r=-0.60, p< 0.001) and body weight (r=-0.16, p<0.001). In contrast, the Δbody height was significantly and positively correlated with the age (r=0.58, p<0.001) and negatively with the body height (r=-0.54, p<0.001), body weight (r=-0.24, p<0.001), serum albumin level (r=-0.27, p=0.003), and eGFR (r=-0.10, p=0.041).

Association between the SMI and physical abilities

Both the SMI and mSMI were significantly and positively correlated with the grip strength (r=0.29, p<0.001 and r= 0.41, p<0.001, respectively). The correlation coefficient of the mSMI and grip strength was larger than that of the SMI and grip strength (0.41 vs. 0.29). Furthermore, the mSMI was significantly and positively correlated with the gait speed (r=0.14, p=0.003), although the SMI was not. The ΔSMI was significantly and negatively correlated with the grip strength and gait speed (r=-0.35, p<0.001 and r=0.47, p <0.001, respectively). In addition, the Δbody height was significantly and negatively correlated with the grip strength and gait speed (r=-0.37, p<0.001 and r=-0.47, p<0.001, respectively).

Regarding the multiple regression analyses (Table 3), age- and BMI-adjusted regression analyses showed that the SMI (β=0.30, p<0.001 and β=0.14, p=0.034) and mSMI (β=0.40, p<0.001 and β=0.29, p<0.001) were positively associated with the grip strength and gait speed. The correlation coefficient of the mSMI and grip strength was larger than that of the SMI and grip strength and gait speed (0.40 vs. 0.30 and 0.29 vs. 0.14, respectively). The ΔSMI was significantly and negatively associated with the grip strength and gait speed (β=-0.15, p<0.001 and β=-0.24, p<0.001, respectively). In addition, the Δbody height was significantly and negatively associated with the grip strength and gait speed (β=-0.16, p< 0.001 and β=-0.24, p<0.001, respectively). Furthermore, the positive association of the SMI (β=0.33, p<0.001 and β= 0.20, p=0.001) and mSMI (β=0.36, p<0.001 and β=0.20, p= 0.002) with the grip strength and gait speed remained significant after additional adjustment for the Δbody height.

Association between a low SMI and the presence of a low physical ability

Next, to examine the association between the presence of a low SMI and low physical abilities, logistic regression analyses were performed (Table 4). A low SMI and mSMI were significantly and positively associated with a low grip strength (<18 kg) [odds ratio (OR)=1.55, 95% confidence interval (CI)=1.07-2.24 per SD increase, p=0.022; and OR= 3.15, 95% CI=2.15-4.62 per SD increase, p<0.001, respectively]. Furthermore, age- and BMI-adjusted logistic regression analyses showed that a low mSMI and SMI were significantly and positively associated with a low grip strength (OR=2.44, 95% CI=1.52-3.93, p<0.001 and OR=1.65, 95% CI=1.01-2.57, p=0.047, respectively). In contrast, age- and BMI-adjusted logistic regression analyses showed that a low mSMI was significantly and positively associated with a slow gait speed (<1.0 m/s) (OR=1.75, 95% CI=1.03-2.97, p =0.040), whereas a low SMI was not (OR=1.08, 95% CI= 0.63-1.84, p=0.785). In addition, the positive association of

Table 2. Correlations between SMIs and Various Parameters.

	SMI		mSMI		ΔSMI		Δbody height	
	r	p	r	p	r	p	r	p
Age (years)	-0.20	<0.001	-0.39	<0.001	0.56	<0.001	0.58	<0.001
Body height (cm)	-0.07	0.138	0.14	0.001	-0.60	<0.001	-0.54	<0.001
Maximum body height (cm)	-0.05	0.243	-0.04	0.328	-0.02	0.592	0.07	0.103
Δbody height (cm)	0.04	0.389	-0.30	<0.001	0.98	<0.001	-	-
Body weight (kg)	0.70	<0.001	0.75	<0.001	-0.16	<0.001	-0.24	<0.001
Body mass index (kg/m^2)	0.78	<0.001	0.74	<0.001	0.13	0.003	0.00	0.986
Albumin (g/dL)	0.04	0.707	0.07	0.527	-0.19	0.091	-0.27	0.003
ALT (IU/L)	-0.01	0.861	-0.02	0.685	0.03	0.522	0.03	0.528
Creatinine (mg/dL)	0.06	0.574	0.07	0.553	-0.02	0.875	0.02	0.802
eGFR (mL/min/1.73 m^2)	-0.05	0.285	-0.02	0.755	-0.09	0.066	-0.10	0.041
Grip strength (kg)	0.29	<0.001	0.41	<0.001	-0.35	<0.001	-0.37	<0.001
Gait speed (m/s)	-0.06	0.221	0.14	0.003	-0.47	<0.001	-0.47	<0.001

SMI: skeletal muscle mass index, mSMI: modified SMI, ΔSMI: SMI difference, Δbody height: height loss

Table 3. Association between SMIs and Physical Abilities.

		SMI		mSMI		ΔSMI		Δbody height	
		β	p	β	p	β	p	β	p
Grip strength (kg)	Model 1	0.20	<0.001	0.39	<0.001	-0.56	<0.001	-0.14	<0.001
	Model 2	0.30	<0.001	0.40	<0.001	-0.15	<0.001	-0.16	<0.001
	Model 3	0.33	<0.001	0.36	<0.001	-0.25	<0.001		
Gait speed (m/sec)	Model 1	-0.05	0.229	0.03	0.519	-0.27	<0.001	-0.26	<0.001
	Model 2	0.14	0.030	0.29	<0.001	-0.24	<0.001	-0.24	<0.001
	Model 3	0.20	0.001	0.20	0.002	-0.43	0.050		

Multiple regression analyses were adjusted as follows:

Model 1 adjusted for age

Model 2 adjusted as for age and BMI

Model 3 adjusted as for age, BMI, and Δbody height.

SMI: skeletal muscle mass index, mSMI: modified SMI, ΔSMI: SMI difference, Δbody height: height loss

Table 4. Association of Low SMIs with the Presence of Low Physical Abilities.

	SMI (<5.4 kg/m^2)		mSMI (<5.4 kg/m^2)		Height loss (≥ 4.0 cm)	
	OR (95% CI)	p	OR (95% CI)	p	OR (95% CI)	p
Grip strength (<18 kg)						
Crude	1.55 (1.07-2.24)	0.022	3.15 (2.15-4.62)	<0.001	3.26 (2.27-4.67)	<0.001
Model 1	1.70 (1.13-2.57)	0.081	2.31 (1.53-3.48)	0.003	1.35 (0.88-2.08)	0.172
Model 2	1.65 (1.01-2.57)	0.047	2.44 (1.52-3.93)	<0.001	1.66 (1.00-2.75)	0.050
Model 3	1.64 (1.00-2.68)	0.052	2.45 (1.52-3.95)	<0.001	1.65 (0.99-2.74)	0.053
Gait speed (<1.0 m/s)						
Crude	0.61 (0.41-0.92)	0.017	1.39 (0.93-2.07)	0.103	4.84 (3.26-7.19)	<0.001
Model 1	0.64 (0.41-1.01)	0.053	0.96 (0.61-1.50)	0.851	2.36 (1.50-3.70)	<0.001
Model 2	1.08 (0.63-1.84)	0.785	1.75 (1.03-2.97)	0.040	2.22 (1.40-3.53)	<0.001
Model 3	1.07 (0.62-1.82)	0.813	1.73 (1.01-2.96)	0.042	2.24 (1.41-3.56)	<0.001

Logisitic regression analyses were adjusted as follows:

Model 1 adjusted for age

Model 2 adjusted as for age and BMI

Model 3 adjusted as for age, BMI, and presence of osteoporotic fractures.

SMI: skeletal muscle mass index, mSMI: modified SMI, OR: odds ratio, CI: confidence interval

a low mSMI with a low grip strength and slow gait speed remained significant after additional adjustment for the presence of osteoporotic fractures (OR=2.45, 95% CI=1.52-3.95, p<0.001 and OR=1.73, 95% CI=1.01-2.96, p=0.042, respectively).

In addition, the association between body height loss ≥4.0 cm and low physical abilities was examined. The presence of body height loss was significantly and positively associated with a slow gait speed after adjusting for the age, BMI, and presence of osteoporosis (OR=2.36, 95% CI=1.50-3.70, p<0.001, OR=2.22, 95% CI=1.40-3.53, p<0.001 and OR=2.24, 95% CI=1.41-3.56, p<0.001, respectively).

Discussion

Muscle strength consists of the muscle function and muscle mass, indicated by the SMI (4, 12). The SMI is an important parameter for diagnosing sarcopenia (4). In the present study, we evaluated the usefulness of the mSMI as an indicator of sarcopenia in postmenopausal women. Simple and age-adjusted regression analyses showed that the mSMI is significantly and dominantly associated with physical abilities compared with SMI. Furthermore, logistic regression analyses showed that a low mSMI, but not SMI, was associated with a low grip strength. In addition, the ΔSMI was shown to be strongly associated with physical abilities. Thus, this is the first study to show that the mSMI is an important parameter for evaluating a subject's physical abilities, with our findings suggesting that body height loss should be considered when physical abilities and sarcopenia are evaluated in older adults.

To our knowledge, there have been no studies focusing on the utility of the height loss-modified SMI (mSMI) in evaluating a subject's physical abilities. A small cross-sectional study recently reported that the prevalence of presarcopenia was higher when its presence was evaluated by the arm span-adjusted SMI than by the SMI in 55 older Japanese women (62-95 years old) (13). Previous studies have reported that the arm span indicates the maximum height (14, 15). Thus, the prevalence and risk of sarcopenia may be underestimated if the SMI is determined without regard for any potential body height loss. Of note, the measurement of the arm span may be affected by postural changes, and a medical interview for assessing the maximum height is usually easier to perform than measuring the arm span. Thus, when the SMI is calculated in older adults, body height loss should be considered important information.

In the present study, the associations of the SMI and mSMI with gait speed were found to be the opposite of each other in logistic regression analyses. However, the inverse association between a low SMI and slow gait speed disappeared after adjusting for age, suggesting that the inverse association between a low SMI and slow gait speed without adjustment may not be important.

Body height loss is usually seen in older adults. Indeed, in the present study, the mean body height loss was 4.0 cm in postmenopausal women with a mean age of 74.6 years old. Height loss is associated with various complaints and diseases. Height loss often occurs in older adults with osteoporosis and vertebral fracture (16). However, even in the absence of bone metabolic disease, height loss increases with age due to postural changes caused by age-related phenomena and other diseases, such as osteoarthritis. In particular, atrophy of the muscle-related body attitude exacerbates height loss, and postural changes subsequently reduce the physical ability and cause muscle weakness. In the present study, the mSMI was found to be more useful for diagnosing sarcopenia than the SMI in postmenopausal women. If height loss is not considered in the management strategy of sarcopenia, we may miss detecting sarcopenic patients who need medical treatment. Indeed, height loss and the ΔSMI were shown to be significantly associated with the gait speed, although neither the SMI nor mSMI showed any such association. Therefore, we must consider potential height loss when estimating the SMI in order to diagnose sarcopenia.

Several limitations associated with the present study warrant mention. First, the sample size was not large enough to draw definite conclusions. Second, we obtained the maximum height by medical interview. Although a previous study showed that height loss due to the recalled maximum height was useful for predicting the loss of bone mineral density in 457 older adults in Tehran (17), the recalled maximum height may not be accurate. Third, we only investigated the relationship in postmenopausal women. We therefore need to examine it in male subjects. Finally, we need to conduct not only cross-sectional studies but also longitudinal ones to understand the causal relationship between the SMI estimated using the maximum height and physical abilities.

In conclusion, the present study suggested for the first time that the SMI estimated using the maximum height is useful for evaluating the physical abilities of postmenopausal women.

This study was approved by the ethics review boards of Shimane University Faculty of Medicine and Nakashima Hospital and complied with the Declaration of Helsinki.

The authors state that they have no Conflict of Interest (COI).

References

1. Kawao N, Kaji H. Interactions between muscle tissues and bone metabolism. J Cell Biochem **116**: 687-695, 2015.
2. Dent E, Morley JE, Cruz-Jentoft AJ, et al. International Clinical Practice Guidelines for Sarcopenia (ICFSR): Screening, Diagnosis and Management. J Nutr Health Aging **22**: 1148-116, 2018.
3. Kirk B, Zanker J, Duque G. Osteosarcopenia: epidemiology, diagnosis, and treatment-facts and numbers. J Cachexia Sarcopenia Muscle **11**: 609-618, 2020.
4. Chen LK, Woo J, Assantachai P, et al. Asian Working Group for Sarcopenia: 2019 Consensus Update on Sarcopenia Diagnosis and

Treatment. J Am Med Dir Assoc **21**: 300-307, 2020.

5. Masunari N, Fujiwara S, Kasagi F, Takahashi I, Yamada M, Nakamura T. Height loss starting in middle age predicts increased mortality in the elderly. J Bone Miner Res **27**: 138-145, 2012.

6. Huang C, Ross PD, Lydick E, Davis JW, Wasnich RD. Contributions of vertebral fractures to stature loss among elderly Japanese-American women in Hawaii. J Bone Miner Res **11**: 408-411, 1996.

7. Masunari N, Fujiwara S, Nakata Y, Nakashima E, Nakamura T. Historical height loss, vertebral deformity, and health-related quality of life in Hiroshima cohort study. Osteoporos Int **18**: 1493-1499, 2007.

8. Kanazawa I, Yamaguchi T, Sugimoto T. Serum insulin-like growth factor-I is amarker for assessing the severity of vertebral fractures in postmenopausal women with type 2 diabetes mellitus. Osteoporos Int **22**: 1191-1198, 2011.

9. Kanazawa I, Yamamoto M, Yamaguchi T, Sugimoto T. Effects of metformin and pioglitazone on serum pentosidine levels in type 2 diabetes mellitus. Exp Clin Endocrinol Diabetes **119**: 362-365, 2011.

10. Tsutsumimoto K, Doi T, Nakakubo S, et al. Association between anorexia of ageing and sarcopenia among Japanese older adults. J Cachexia Sarcopenia Muscle **11**: 1250-1257, 2020.

11. Genant HK, Wu CY, van Kujik C, Nevitt MC. Vertebral fracture assessment using a semiquantitative technique. J Bone Miner Res **8**: 1137-1148, 1993.

12. Barbat-Artigas S, Rolland Y, Zamboni M, Aubertin-Leheudre M. How to assess functional status: a new muscle quality index. J Nutr Health Aging **16**: 67-77, 2012.

13. Ono Y, Miyakoshi N, Kasukawa Y, et al. Diagnosis of presarcopenia using body height and arm span for postmenopausal osteoporosis. Clin Interv Aging **15**: 357-361, 2020.

14. Mohanty SP, Babu SS, Nair NS. The use of arm span as a predictor of height: a study of South Indian women. J Orthop Surg **9**: 19-23, 2001.

15. Jarzem PF, Gledhill RB. Predicting height from arm measurements. J Pediatr Orthop **13**: 761-765, 1993.

16. Kärkkäinen M, Rikkonen T, Kroger H, et al. Association between functional capacity tests and fractures: an eight-year prospective population-based cohort study. Osteoporos Int **19**: 1203-1210, 2008.

17. Moayyeri A, Ahmadi-Abhari S, Hossein-nezhad A, Larijani B, Soltani A. Bone mineral density and estimated height loss based on patients' recalls. Osteoporos Int **17**: 834-840, 2006.