

Original article

Impact of appendicular and trunk skeletal muscle mass and back extensor strength on sagittal spinal alignment in Japanese women without vertebral fracture



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ABSTRACT

Objectives: Progressive and generalized loss of skeletal muscle mass (SMM) and strength are characteristics of sarcopenia. However, the impact of appendicular and trunk SMM and back extensor strength (BES) on spinal sagittal alignment remains unclear. Herein, we investigate the relationship between these factors and spinal sagittal alignment.

Methods: In total, 202 women without vertebral fractures (median age, 66.9 years; interquartile range, 61.4–71.9 years) were analyzed at an orthopedic outpatient clinic. Pelvic incidence (PI), lumbar lordosis (LL), sagittal vertical axis (SVA), and pelvic tilt (PT) were measured on whole spine radiographs. Body mass index (BMI), appendicular and trunk relative SMM index, and BES were also evaluated. These measurements were compared between spinal sagittal alignment groups using the Mann–Whitney U test. Finally, the factors contributing to abnormal alignment were analyzed using multiple logistic regression analysis.

Results: BES was significantly lower in all abnormal sagittal alignment groups, as defined by PI–LL ($\geq 10^\circ$), SVA (≥ 4 cm), and PT ($\geq 20^\circ$) (all $P < 0.001$). On multivariate analysis, BES was a contributing factor for abnormal PI–LL ($P < 0.001$), SVA ($P = 0.001$), and PT ($P < 0.001$). Conversely, a decrease in appendicular and trunk relative SMM index did not statistically affect abnormal spinal sagittal alignment.

Conclusions: BES was associated with changes in spinal sagittal alignment; however, SMM, which is often used for diagnosing sarcopenia, did not affect spinal sagittal alignment.

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1. Introduction

Sagittal spinal malalignment in adults is one of the most important problems faced by spine surgeons [1–4] because age-related spinal deformities, especially kyphosis, negatively affect the quality of life (QOL) [1,4,5] and postural balance [6], and increases the risk for falls in elderly people and osteoporotic patients [7]. Generally, degenerative kyphosis is associated with back muscle atrophy and decreased back extensor strength (BES) [8,9]. In addition, decreases in lumbar lordosis (LL), spinal range of motion (ROM), and BES are closely associated with worsening of QOL [5,10].

Spinal sagittal alignment has been studied using several methods [11]. Sagittal vertical axis (SVA) is the most common method of evaluating global sagittal balance. A positive sagittal spinal balance based on SVA has a negative effect on health status scores, such as in the Scoliosis Research Society patient questionnaire, Short Form-12, and the Oswestry Disability Index, in adults with spinal deformity [1,2].

In 1989, Rosenberg proposed the definition of “sarcopenia” as an age-related decrease in muscle mass [12]. After that, sarcopenia was defined as “a syndrome characterized by progressive and generalized loss of skeletal muscle mass (SMM) and strength with a risk of adverse outcomes such as physical disability, poor quality of life, and death” by the European Working Group on Sarcopenia in Older People [13]. In fact, sarcopenia has been reported to have a relationship with functional impairment, physical disability, and risk of falls [14–17]. More recently, the prevalence of sarcopenia

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was shown to be higher in patients who have undergone orthopedic surgery than in those who have not [18].

However, to the best of our knowledge, the effect of appendicular and trunk SMM and BES on spinal sagittal alignment remains unclear. Therefore, generalized loss of skeletal muscle mass may affect sagittal spinal malalignment because of a decline in back SMM or decreased BES. This study aims to investigate the relationship between these factors and their impact on spinal sagittal alignment.

2. Methods

2.1. Subjects

The study was approved by the ethics committees of the Akita University Graduate School of Medicine (No. 1970). In total, 424 female patients aged 40 years and older who visited a single orthopedic outpatient clinic between July 2008 and April 2016 were retrospectively examined. The patients routinely underwent whole-body and regional (lumbar spine and total hip) dual-energy X-ray absorptiometry (DXA) (QDR 4500A; Hologic, Waltham, MA, USA) to measure lumbar spine (L2–L4) bone mineral density (BMD), as well as lateral whole-spine radiography in the upright position and isometric BES measurement in the prone position using a strain-gauge dynamometer (DPU-1000 N Digital Force Gauge; Imada, Toyohashi, Japan) (Fig. 1). This BES measurement method was reported to be highly reliable (intra-class correlation coefficient: 0.988, 95% confidence interval: 0.964–0.996, standard error of measurement: 1.3 kg, minimum detectable change: 3.6 kg) [19]. Subjects with a history of spinal instrumentation surgery, prevalent vertebral fractures (defined as changes in the semi-quantitative reading of ≥ 1 on the lateral whole-spine radiograph) [20], or paralysis; inability to walk for any reason (ie, myelopathy, paralysis, severe osteoarthritis, etc.); inability to perform isometric BES measurement due to any diagnosis of low back pain; and inadequate medical records and clinical examinations were excluded. Finally, a total of 202 subjects (median age: 66.9 years; interquartile range: 61.4–71.9 years) were analyzed.

2.2. Estimation of SMM

Appendicular SMM, which was calculated as the sum total of the SMM of the 4 extremities, and trunk SMM were measured using a

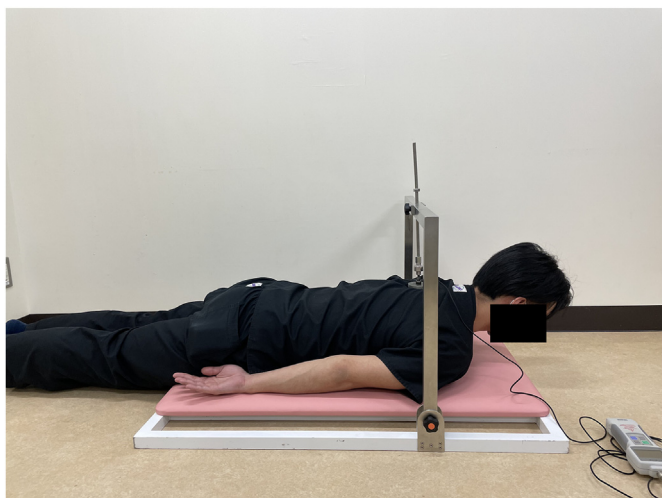


Fig. 1. Isometric back extensor strength measurement in the prone position.

DXA device (QDR 4500A; Hologic, Waltham, MA, USA). The color image in Fig. 2 shows the relative amounts of fat, lean, and bone tissue. SMM was assumed to include all tissues except fat and bone [21,22]. DXA has also been previously validated [23,24]. In addition, intra-center coefficients of variation were reported to be within the range of the manufacturer acceptable values (BMD: 1.40%, fat mass: 0.89%, lean mass: 0.76%) [25]. Relative SMM index of the extremities or trunk was derived from the appendicular SMM or PT in kilograms, and the index was divided by the square of the height in meters, in line with previous studies [21,26]. The relative SMM index of all limbs was used for analysis because this method is used for the diagnosis of sarcopenia [27].

2.3. Measurement of sagittal spinal alignment

All data were obtained from lateral whole-spine radiographs, where the pelvis is positioned upright with fists-on-clavicles without any external support. Radiographic parameters included in the analysis were as follows: thoracic kyphosis (TK) (T4–T12); LL (T12–S1); pelvic incidence (PI), which is the angle between a line perpendicular to the sacral plate at its midpoint and a line connecting this point to the femoral head axis; SVA, which is the distance between the C7 plumbline and the posterosuperior corner of S1; and pelvic tilt (PT), which is the angle between the vertical and the line from the center of the bicoxofemoral axis and the midpoint of the sacral endplate. A PI–LL angle $\geq 10^\circ$, SVA ≥ 4 cm, or PT $\geq 20^\circ$ were considered abnormal [28]. The respective intra- and inter-observer agreement rates on whole-spine radiographs were reported in the literature as follows: PI, 0.84 and 0.79; LL, 0.89 and 0.83; SVA, 0.99 and 0.99; and PT, 0.98 and 0.96 [29].

2.4. Statistical analysis

All data are expressed as medians with interquartile range. Comparisons between normal and abnormal sagittal alignment groups were performed using the Mann–Whitney U test. Spearman's rank correlation coefficient was used for the analysis of correlations between BES and appendicular and trunk relative SMM index. Finally, variables with probability values < 0.20 on univariate analyses were included in the multiple logistic regression analysis to identify factors associated with PI–LL, SVA, and PT. All data were analyzed using SPSS version 25.0 for Mac (IBM Corp., Armonk, NY, USA). The significance level was considered as $P < 0.05$.

3. Results

Table 1 shows the baseline characteristics of all included patients. Table 2 shows comparisons between normal and abnormal sagittal alignment groups on PI–LL, SVA, and PT. BES was significantly lower in all the abnormal sagittal alignment groups defined by PI–LL, SVA, and PT (all $P < 0.001$). BMI and appendicular relative SMM index ($P = 0.003$) and trunk relative SMM index ($P = 0.002$) were significantly higher, and lumbar spine BMD ($P = 0.005$) was significantly lower in the abnormal sagittal alignment group defined by PT (Table 2).

Significant correlations were not found between BES and appendicular relative SMM index ($r = -0.066$, $P = 0.349$) and trunk relative SMM index ($r = 0.006$, $P = 0.938$).

BES was the only contributing factor for abnormal PI–LL ($\geq 10^\circ$) on univariate analysis (odds ratio [OR], 0.880; 95% confidence interval [CI], 0.822–0.942; $P < 0.001$) (Table 3). Age ($P = 0.006$), BMI ($P = 0.053$), and BES ($P < 0.001$) had P -values < 0.20 for abnormal SVA (≥ 4 cm) on univariate analysis; however, BES was the only remaining contributing factor for abnormal SVA on multivariate

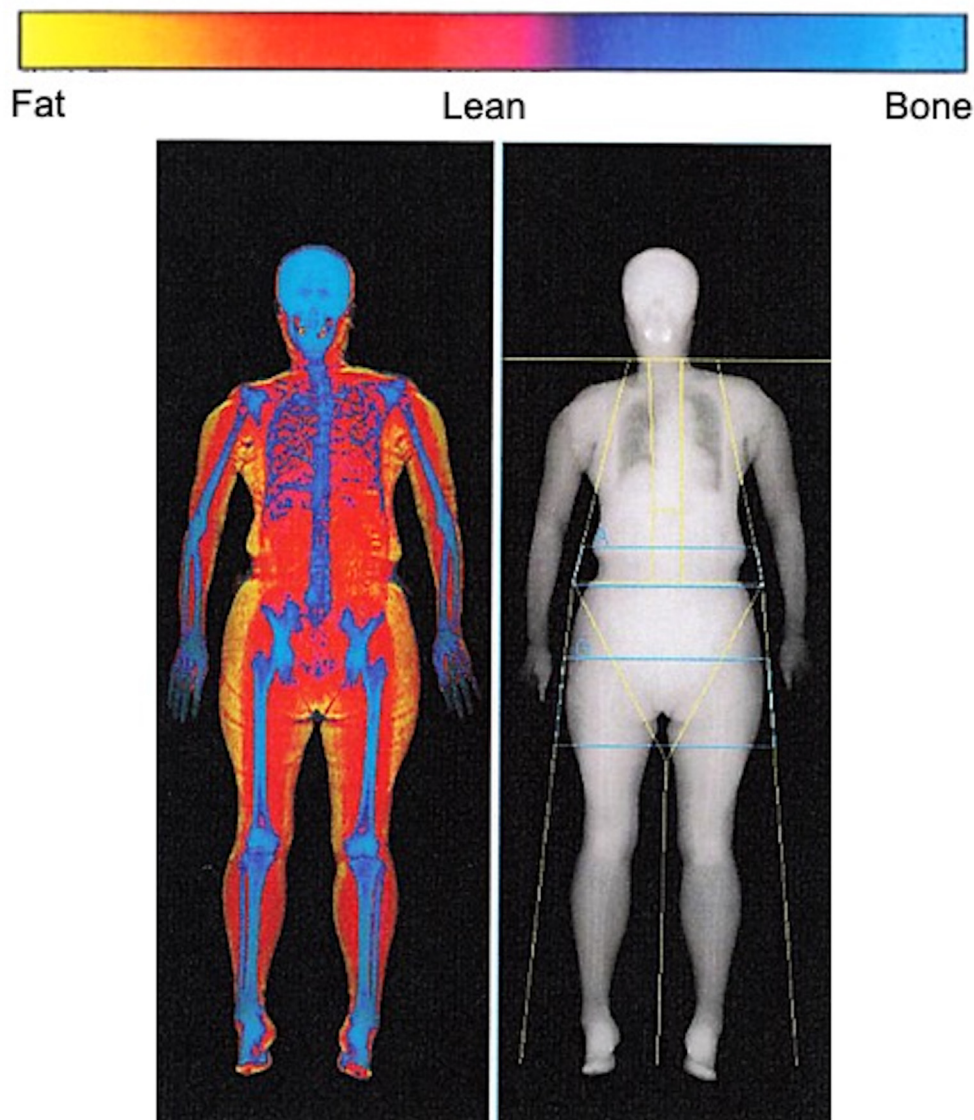


Fig. 2. Appendicular and trunk SMM measurement. The color image shows the relative amounts of fat, lean, and bone tissue.

Table 1
Characteristics of patients.

Variable	Median (interquartile range)
Age, yr	66.9 (61.4–71.9)
BMI, kg/m ²	21.4 (19.8–23.3)
Lumbar spine BMD, g/cm ²	0.71 (0.65–0.77)
Lumbar spine BMD, T-score	−2.51 (−3.07–−2.02)
Appendicular relative SMM index, kg/m ²	5.89 (5.53–6.33)
Trunk relative SMM index, kg/m ²	7.45 (6.85–7.97)
Back extensor strength, n	134.8 (95.1–175.2)
Thoracic kyphosis, °	33.3 (25.1–40.6)
Lumbar lordosis, °	51.6 (42.9–59.3)
PI, °	51.5 (45.5–60.1)
PI-LL, °	0.4 (−7.0–8.4)
SVA, cm	0.47 (−1.0–2.6)
PT, °	18.3 (13.0–23.9)

Values are expressed as medians (interquartile range).
BMI, body mass index; BMD, bone mineral density; SMM, skeletal muscle mass; PI, pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis; PT, pelvic tilt.

analysis (OR, 0.986; 95% CI, 0.977–0.994; P = 0.001) (Table 3). The P-values of age (P = 0.005), BMI (P = 0.041), lumbar spine BMD (P = 0.010), appendicular relative SMM index (P = 0.006), trunk relative SMM index (P = 0.008), and BES (P < 0.001) were <0.20, and lumbar spine BMD (OR, 0.016; 95% CI, 0.001–0.338; P = 0.008) and BES (OR, 0.904; 95% CI, 0.854–0.957; P < 0.001) were the contributing factors for abnormal PT (Table 3). Typical cases with a discrepancy between the relative SMM index and BES are shown in Fig. 3a and b. A 68-year-old female with normal sagittal alignment (PI-LL, −7.4°; SVA, 0.5 cm; PT, 9°) showed low appendicular and trunk relative SMM index (5.05 kg/m² and 6.47 kg/m², respectively) (a). However, her BES (253.8 N) was higher than the 75th percentile value (a). Conversely, a 70-year-old female with abnormal sagittal alignment (PI-LL, 32.2°; SVA, 8.1 cm; PT, 38°) showed high appendicular and trunk relative SMM index (5.77 kg/m² and 8.63 kg/m², respectively) (b). However, her BES (55.9 N) was lower than the 25th percentile value (b).

Table 2
Comparisons between normal and abnormal sagittal alignment.

Variable	Normal alignment	Abnormal alignment	P-value
PI-LL			
Number of patients	161	41	
Age, yr	67.4 (61.2–71.9)	66.7 (62.9–71.7)	0.654
BMI, kg/m ²	21.3 (19.8–23.3)	21.9 (20.1–23.3)	0.499
Lumbar spine BMD, g/cm ²	0.716 (0.651–0.770)	0.686 (0.625–0.751)	0.144
Lumbar spine BMD, T-score	–2.47 (–3.02––2.02)	–2.72 (–3.24––2.18)	0.144
Appendicular relative SMM index, kg/m ²	5.89 (5.45–6.32)	5.94 (5.60–6.34)	0.393
Trunk relative SMM index, kg/m ²	7.39 (6.82–7.87)	7.61 (7.14–8.03)	0.149
Back extensor strength, n	143.1 (103.9–184.2)	93.6 (61.7–122.7)	<0.001
SVA			
Number of patients	171	31	
Age, yr	66.4 (60.9–71.5)	68.0 (62.8–73.9)	0.005
BMI, kg/m ²	21.3 (19.8–23.1)	22.1 (20.0–25.0)	0.101
Lumbar spine BMD, g/cm ²	0.712 (0.650–0.769)	0.691 (0.624–0.800)	0.765
Lumbar spine BMD, T-score	–2.49 (–3.00––1.98)	–2.51 (–3.17––2.05)	0.765
Appendicular relative SMM index, kg/m ²	5.90 (5.52–6.32)	5.84 (5.63–6.40)	0.686
Trunk relative SMM index, kg/m ²	7.40 (6.84–7.89)	7.72 (7.06–8.08)	0.107
Back extensor strength, n	142.1 (102.4–181.8)	96.0 (66.6–128.9)	<0.001
PT			
Number of patients	110	92	
Age, yr	65.5 (60.1–71.3)	68.6 (63.4–73.0)	0.008
BMI, kg/m ²	20.8 (19.4–22.9)	22.3 (20.4–24.0)	0.004
Lumbar spine BMD, g/cm ²	0.730 (0.663–0.780)	0.687 (0.631–0.747)	0.005
Lumbar spine BMD, T-score	–2.36 (–2.92––1.93)	–2.71 (–3.18––2.21)	0.005
Appendicular relative SMM index, kg/m ²	5.80 (5.40–6.12)	6.01 (5.64–6.50)	0.003
Trunk relative SMM index, kg/m ²	7.30 (6.80–7.78)	7.59 (7.13–8.08)	0.002
Back extensor strength, n	150.9 (114.7–196.0)	112.7 (77.9–160.2)	<0.001

Values are expressed as medians (interquartile range).

Mann–Whitney U tests were used to compare two groups.

BMI: body mass index; BMD: bone mineral density; SMM: skeletal muscle mass; PI, pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis; PT, pelvic tilt.

Table 3
Multiple logistic regression analysis for abnormal PI-LL (PI-LL ≥ 10°), SVA (SVA ≥ 4 cm), and PT (PT ≥ 20°).

Variable	Univariate		Multivariate	
	OR (95% CI)	P-value	OR (95% CI)	P-value
PI-LL				
BMI	1.042 (0.928–1.170)	0.483		
Lumbar spine BMD	0.120 (0.003–4.212)	0.242		
Appendicular relative SMM index	1.246 (0.725–2.143)	0.426		
Trunk relative SMM index	1.256 (0.785–2.010)	0.342		
Back extensor strength	0.880 (0.822–0.942) ^a	<0.001		
SVA				
Age	1.082 (1.023–1.144)	0.006	1.060 (0.998–1.126)	0.057
BMI	1.132 (0.999–1.282)	0.053	1.135 (0.989–1.303)	0.071
Lumbar spine BMD	8.888 (0.285–277.401)	0.213		
Appendicular relative SMM index	1.169 (0.640–2.138)	0.611		
Trunk relative SMM index	1.331 (0.793–2.235)	0.280		
Back extensor strength	0.985 (0.977–0.993)	<0.001	0.986 (0.977–0.994)	0.001
PT				
Age	1.057 (1.017–1.099)	0.005	1.038 (0.994–1.083)	0.089
BMI	1.109 (1.004–1.225)	0.041	1.004 (0.838–1.201)	0.041
Lumbar spine BMD	0.020 (0.001–0.397)	0.010	0.016 (0.001–0.338)	0.008
Appendicular relative SMM index	1.918 (1.206–3.050)	0.006	1.326 (0.671–2.622)	0.417
Trunk relative SMM index	1.739 (1.153–2.620)	0.008	1.741 (0.802–3.778)	0.161
Back extensor strength	0.896 (0.851–0.944)	<0.001	0.904 (0.854–0.957)	<0.001

^a Back extensor strength was the only contributing factor for abnormal PI-LL without multivariate analysis.

PI: pelvic incidence; LL: lumbar lordosis; SVA: sagittal vertical axis; PT: pelvic tilt; BMI: body mass index; BMD: bone mineral density, SMM: skeletal muscle mass; OR: odds ratio; CI: confidence interval.

4. Discussion

Contrary to our expectations, a decrease in both appendicular and trunk relative SMM index did not affect sagittal spinal malalignment in the multivariate analysis. The most probable reason for this is that BES did not correlate with appendicular and trunk SMM. A discrepancy between muscle strength and function and SMM has consistently been shown in previous studies. Possible causes

include the decline in muscle quality because of decreased fiber size and number, an alteration in contractile properties, fat infiltration, increase in collagen, and impaired neurological modulation [30].

According to the InCHIANTI study by Cesari et al. [31], calf muscle density (hazard ratio [HR], 0.78; 95% CI, 0.69–0.88), muscle area (HR, 0.75; 95% CI, 0.66–0.86), and fat area (HR, 0.82; 95% CI, 0.73–0.92) were significant risk factors associated with mortality in

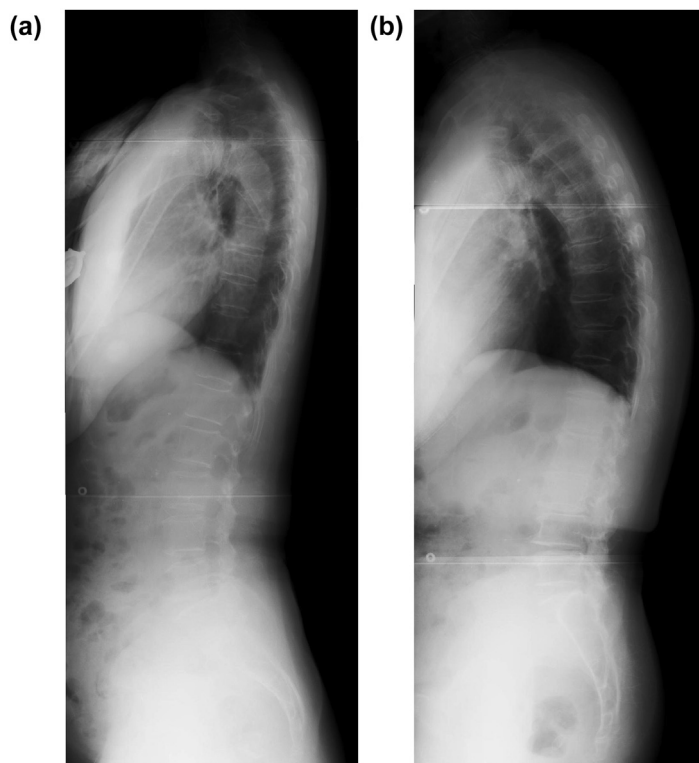


Fig. 3. A 68-year-old female with normal sagittal alignment (a). Radiological and physiological assessments were as follows: appendicular relative SMM index, 5.05 kg/m²; trunk relative SMM index, 6.47 kg/m²; PI-LL, -7.4°; SVA, 0.5 cm; PT, 9°; BES, 253.8 N. A 70-year-old female with abnormal sagittal alignment (b). Radiological and physiological assessments were as follows: appendicular relative SMM index, 5.77 kg/m²; trunk relative SMM index, 8.63 kg/m²; PI-LL, 32.2°; SVA, 8.1 cm; PT, 38°; BES, 55.9 N.

an unadjusted analysis of community-dwelling older adults. However, these significant associations disappeared after adjustment for potential confounders, and only walking speed was a significant risk factor (HR, 0.73; 95% CI, 0.60–0.88) for mortality on multivariate analysis. Ropponen et al. [32] investigated the relationship between quantitative and qualitative paraspinal muscle composition using magnetic resonance images and maximal isokinetic lifting performances. Their results indicated that correlation coefficients between quantitative (eg, paraspinal or psoas major muscle cross-sectional area) and qualitative muscle composition (eg, fat infiltration) measurements and isokinetic lifting force or work were low ($r = 0.02$ – 0.41). Furthermore, Miyakoshi et al. [33] investigated the factors contributing to spinal mobility in postmenopausal osteoporotic patients. On univariate analysis, age ($r = -0.412$), lumbar kyphosis angle ($r = -0.284$), BES ($r = 0.369$), lumbar paravertebral muscle thickness measured using ultrasound ($r = 0.227$), and the number of vertebral fractures ($r = -0.260$) significantly correlated with total spinal range of motion ($P < 0.05$). However, in the multiple regression analysis, BES showed the most significant correlation with spinal range of motion ($r = 0.308$, $P = 0.0216$). Results from these studies suggest that extremity and back SMM are less often related to muscle strength and function. Therefore, muscle strength and function must be strongly considered when predicting outcomes. However, some results from recent studies are different from our findings. Kim et al. [34] indicated that PT is significantly correlated with lumbar paraspinal muscle cross sectional area ($r = -0.502$, $p = 0.015$), and Park et al. [35] indicated that the paraspinal functional cross-sectional area, which is calculated by subtracting the fat tissue area from the cross-sectional area on magnetic resonance imaging, was lower in the sagittal imbalance group. Possible causes of these discrepancies could be the differences in radiological assessment methods or

patient selection biases.

Another possible issue is the effect of sarcopenia on osteoporotic vertebral fractures due to a decline in BES. Hida et al. [36] reported that risk factors for acute osteoporotic vertebral fracture were sarcopenia (OR, 1.96; $P < 0.001$) and leg SMM index (OR, 0.64; $P = 0.002$), in addition to other factors such as age, weight, and whole-body BMD, in a multivariate logistic regression analysis. However, they did not investigate the relationship between SMM and BES. To the best of our knowledge, few studies have investigated the effect of appendicular and trunk SMM and BES on spinal sagittal alignment. In our study, we excluded patients with vertebral fractures to clarify the effect of SMM on sagittal spinal alignment since it is affected by vertebral fractures [37]. In this study, the relative SMM index was not associated with the sagittal spinal alignment in Japanese women without vertebral fractures on multivariate analysis. This means that the relative SMM index measured by DXA is inadequate to predict the incidence of spinal kyphosis as a result of back muscle dysfunction, and BES should be assessed separately from SMM due to this discrepancy.

The current study has some limitations. First, sample selection may have been biased because all participants were patients at an orthopedic osteoporosis clinic. In addition, male patients were not included because almost all patients in the orthopedic osteoporosis clinic in this study were female. Second, we excluded patients with vertebral fractures for the reasons stated above; therefore, if patients with vertebral fractures had been included, results may have shown that vertebral fractures are the most significant contributor to sagittal spinal alignment.

5. Conclusions

Both appendicular and trunk relative SMM index did not

correlate with BES in osteoporotic women without vertebral fractures. Additionally, a decrease in SMM did not contribute to abnormal spinal sagittal alignment on multivariate analysis. BES was a significant contributor to abnormal spinal sagittal alignment defined by PI-LL, SVA, and PT. These results suggest that SMM measured using DXA is not a risk factor for abnormal sagittal spinal alignment, and BES should be assessed separately from SMM.

CRedit author statement

Daisuke Kudo: Conceptualization, Methodology, Investigation, Formal analysis, Writing - Original draft. **Naohisa Miyakoshi:** Writing - Reviewing & Editing. **Michio Hongo:** Supervision. **Yuji Kasukawa:** Formal analysis, Writing - Reviewing & Editing. **Yoshinori Ishikawa:** Supervision. **Takashi Mizutani:** Investigation. **Yoichi Mizutani:** Data Curation. **Yoichi Shimada:** Supervision.

Conflicts of interest

The authors declare no competing interests.

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