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ORIGINAL ARTICLE

Sarcopenia is related to spinal sagittal imbalance in patients with spinopelvic mismatch

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Abstract

Purpose To clarify the relationship between sarcopenia and spinopelvic parameters.

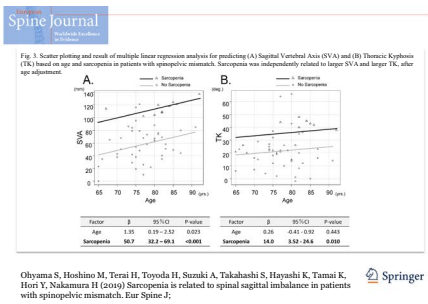
Methods Among outpatients of spine surgery department, 126 patients (mean age 77.2 years. M/F = 71/55) were included. We diagnosed patients with sarcopenia using the diagnostic algorithm of the Asian Working Group for Sarcopenia. Spinopelvic parameters and the prevalence of spinopelvic mismatch (pelvic incidence minus lumbar lordosis ≥ 10°) were investigated and compared between patients with and without sarcopenia. Furthermore, we compared the spinopelvic parameters between the Sarcopenia and No Sarcopenia groups under each condition of spinopelvic match and mismatch.

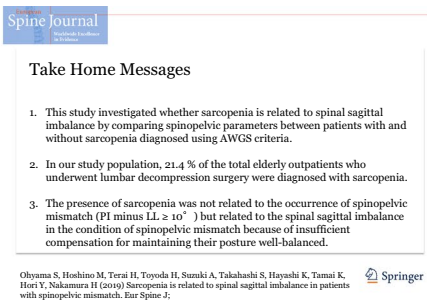
Results The prevalence of sarcopenia in this study was 21.4%. Overall, the spinopelvic parameters except thoracic kyphosis (TK) (Sarcopenia: 34.7°, No Sarcopenia: 24.3°, $p < 0.01$) were not significantly different between the Sarcopenia and No Sarcopenia groups. Prevalence of patients with spinopelvic mismatch was also not significantly different between the Sarcopenia and No Sarcopenia groups (37.0% vs. 42.4%, $p = 0.66$). Among patients without spinopelvic mismatch, there was no spinopelvic parameter with a significant difference between the 2 groups. However, among patients with spinopelvic mismatch, sagittal vertebral axis (SVA) (115.7 mm vs. 58.7 mm, $p < 0.01$) and TK (36.6° vs. 21.3°, $p < 0.01$) of the Sarcopenia group were significantly larger than those of the No Sarcopenia group. Moreover, sarcopenia was independently related to a significant increase in SVA ($\beta = 50.7$, $p < 0.01$) and TK ($\beta = 14.0$, $p < 0.01$) in patients with spinopelvic mismatch, after adjustment for age.

Conclusions Sarcopenia is related to spinal sagittal imbalance because of insufficient compensation by flattening thoracic kyphosis in patients with spinopelvic mismatch.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.





Keywords Sarcopenia · Sagittal imbalance · Spinopelvic mismatch · Spinopelvic parameters

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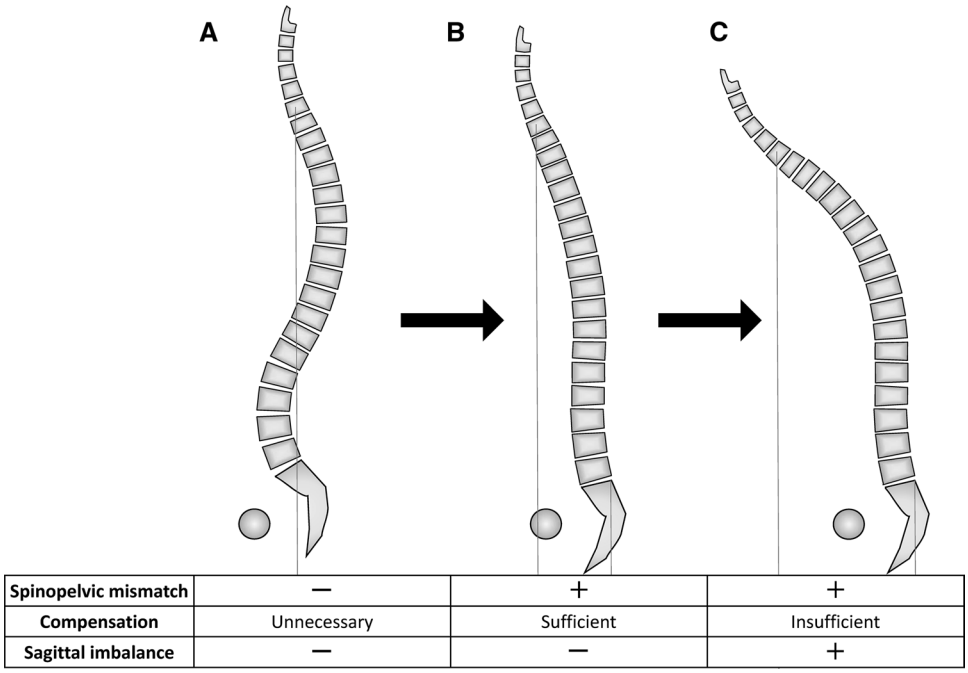


Fig. 1 Schematic images of the course toward spinal sagittal imbalance. **a** Balanced spine without spinopelvic mismatch, **b** balanced spine with sufficient compensation for spinopelvic mismatch, and **c** imbalanced spine without sufficient compensation for spinopelvic mismatch

Introduction

Sarcopenia, defined as an age-related loss of muscle mass and function [1], is becoming a great concern in super-aged societies as a risk factor leading to adverse events, such as a decline in the quality of life [2] and death [3]. According to the diagnostic algorithm of sarcopenia defined by the European Working Group on Sarcopenia in Older People (EWGSOP) [4] in 2010 and the Asian Working Group for Sarcopenia (AWGS) [5] in 2014, sarcopenia has been widely reported to be related with various diseases [6–9]. In the research field of spine surgery, sarcopenia was reported to be a risk factor for vertebral fractures [10] and to induce worse performance in patients with lumbar canal stenosis [11].

Spinal sagittal imbalance, which induces low back pain and poor quality of life in elderly people [12], was also one of the greatest concerns in the field of spine surgery. The causal pathway of spinal sagittal imbalance was reported to be insufficient compensation for spinopelvic mismatch secondary to a decrease in lumbar lordosis [13] (Fig. 1). Muscular factors, such as back extensor muscle strength [14] and paraspinal muscle volume, [15] were reported to be related to a decrease in lumbar lordosis and spinal sagittal imbalance; however, what causes or accelerates spinopelvic mismatch and spinal sagittal imbalance still remains unclear.

We hypothesized that sarcopenia was relevant to the occurrence of spinopelvic mismatch and spinal sagittal imbalance. There are a few studies that have reported that sarcopenia is related to adult spinal deformity [16]; however, to our knowledge, no study has compared the spinopelvic parameters between patients with sarcopenia and patients without sarcopenia. Furthermore, there has been no report on the relationship between sarcopenia strictly diagnosed using EWGSOP or AWGS and the pathology of spinal disease.

The purpose of this study is to clarify whether sarcopenia is related to spinopelvic mismatch or spinal sagittal imbalance by comparing the spinopelvic parameters between patients with and without sarcopenia diagnosed using AWGS criteria on outpatients of spine clinic.

Methods

COI and IRB statements

This study was a retrospective analysis of prospectively collected data of spine clinic outpatients. The study protocol was approved by the Institutional Review Board of our institution (No. 3170). No funds were received in support of this work.

Study population

From August 2015 to March 2016, we continuously recruited our spine clinic outpatients who were aged 65 or more and who agreed to screening for sarcopenia. For assessing the spinopelvic parameters of patients with similar backgrounds, we included patients who had undergone microscopic or

micro-endoscopic lumbar decompression surgery for lumbar spinal canal stenosis and patients who exceeded 1-year post-surgery. We excluded the patients who were not able to walk by themselves, had any metal implants in the body, had vertebral fracture, or had complaint of neurological deficit. Finally, 126 patients (mean age 77.2 years, male/female = 71/55) were enrolled in this study.

Measurements

On the last day of visit to the clinic, we measured the patients' body mass index (BMI), lumbar Japanese Orthopaedic Association (JOA) score, hand-grip strength, usual gait speed, and muscle mass. All the patients underwent whole spine radiography.

Hand-grip strength

Hand-grip strength was measured using a dynamometer (T.K.K.5401, TAKEI, Japan). Two trials for each hand were carried out, and we recorded the highest value for diagnosing sarcopenia [5].

Usual gait speed

Patients were asked to walk at their usual pace after an examiner's "Start" command over an 8-m course and to stop just past the finish line. The examiners measured the time to pass through 8 m, except the first and last meters, which equates to the 6 central meters. Usual gait speed (m/s) was calculated using the time for the 6-m walk [17].

Muscle mass

Muscle mass was measured using a bioelectrical impedance analysis (BIA) machine (MC980A, TANITA, Japan). Appendicular skeletal muscle mass (ASM) was calculated as the sum of the skeletal muscle masses of the arms and legs. Skeletal muscle mass index (SMI) was defined as ASM divided by height in meters squared (ASM/height^2) [18].

Radiological evaluation

Patients were instructed to stand in a comfortable position with their hands resting on their clavicle. From the radiograph, the following spinopelvic parameters were measured: pelvic incidence (PI): the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the axis of the femoral heads [19], lumbar lordosis (LL): the Cobb angle from the upper endplate of L1 to the lower endplate of S1 [20], sagittal vertebral axis (SVA): the horizontal distance from the C7 plumb line originating at the middle of the C7 vertebral body to the posterior superior endplate of S1 [12], thoracic kyphosis (TK): the Cobb angle from the upper endplate of T4 to the lower endplate of T12 [21], and pelvic tilt (PT): the angle between the line connecting the midpoint of the sacral plate to the axis of the femoral heads and the vertical axis [22]. In this study, SVA was used as an index of spinal sagittal imbalance. From the sagittal modifier of SRS-Schwab classification [23], when PI minus LL is 10° or more, it is defined as spinopelvic mismatch.

Diagnosis of sarcopenia (AWGS criteria)

We diagnosed patients with sarcopenia using the diagnostic algorithm of AWGS [5]. In the AWGS algorithm, elderly people with low muscle mass (BIA method; SMI < 7.0 kg/m^2 in male and < 5.7 kg/m^2 in female), in addition to low hand-grip strength (hand-grip strength < 26 kg in men and < 18 kg in women) and/or slow walking speed (usual gait speed < 0.8 m/s) are diagnosed with sarcopenia (Fig. 2).

Statistical analysis

Patients diagnosed with sarcopenia were assigned to the Sarcopenia group, and others were assigned to the No Sarcopenia group. Continuous and categorical variables were compared between the Sarcopenia group and No Sarcopenia groups using the Mann–Whitney *U* test and Chi-squared test, respectively. According to the definition of spinopelvic mismatch described above, the prevalence of spinopelvic mismatch was compared between the Sarcopenia group and No Sarcopenia group. In each case with or without spinopelvic mismatch, we compared the spinopelvic parameters between the Sarcopenia group and No Sarcopenia group using the Mann–Whitney *U* test. Additionally, for spinopelvic parameters with significant differences, age-adjusted comparisons were made between the Sarcopenia group and No Sarcopenia group using multiple linear regression analysis. Statistical analyses were performed using statistical software SAS (version 9.4: SAS Institute Inc., Cary, North Carolina, the USA). All values are expressed as mean ± standard deviation with a statistical significance level set at $p < 0.05$.

Results

Prevalence of sarcopenia

Of the 126 patients, a total of 27 patients were diagnosed with sarcopenia using AWGS criteria. The prevalence of

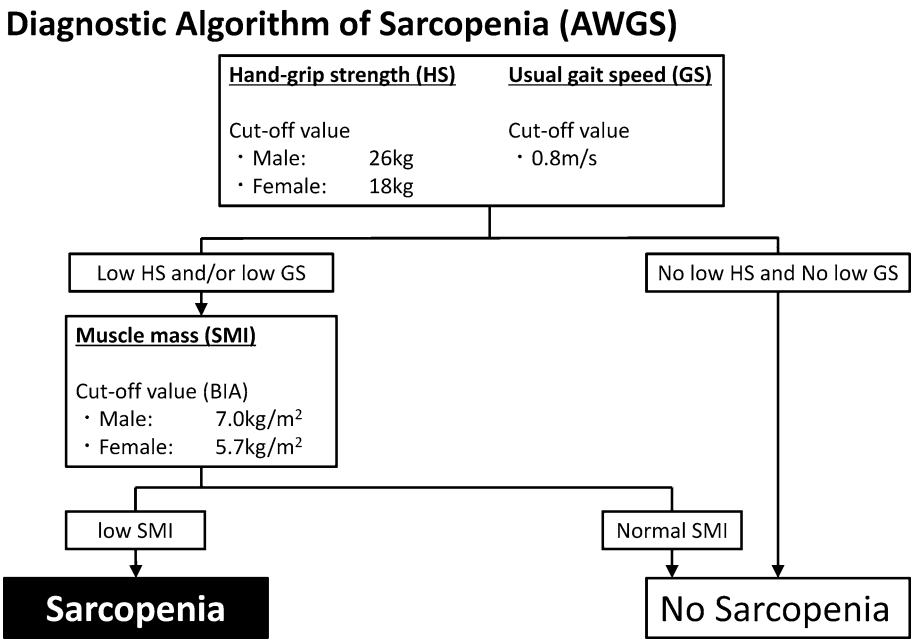


Fig. 2 Diagnostic algorithm of Sarcopenia, Asian Working Group for Sarcopenia (AWGS) Criteria. First, elderly patients are examined for their hand-grip strength and usual gait speed. When patients' hand-grip strength and usual gait speed exceed the cutoff value, they are diagnosed with no sarcopenia. Second, patients whose hand-grip strength and/or usual gait speed are less than the cutoff value are examined for their skeletal muscle mass. Finally, patients whose skeletal muscle mass is less than the cutoff value in addition to low hand-grip strength and/or low usual gait speed are diagnosed with sarcopenia

sarcopenia in this study group was 21.4%. Patients in the Sarcopenia group were significantly older than those in the No Sarcopenia group (81.7 years vs. 76.0 years, $p<0.01$). The Sarcopenia group showed lower BMI (19.9 kg/m^2 vs. 24.1 kg/m^2, $p<0.01$), hand-grip strength (16.8 kg vs. 24.9 kg, $p<0.01$), gait speed (0.80 m/s vs. 0.95 m/s, $p<0.01$), and SMI (5.92 kg/m^2 vs. 7.48 kg/m^2, $p<0.01$) than the No Sarcopenia group. However, there was no significant difference in the lumbar JOA score between the 2 groups (23.1 points vs. 24.4 points, $p=0.12$) (Table 1).

Table 1 Comparison of patients' background data between Sarcopenia and No Sarcopenia

	Sarcopenia $N=27$	No Sarcopenia $N=99$	P
Age (years)	81.7 ± 5.4	76.0 ± 6.0	**< 0.01**
Female (%)	59.3%	39.4%	0.08
BMI (kg/m^2)	19.9 ± 1.5	24.1 ± 3.0	**< 0.01**
Hand-grip strength (kg)	16.8 ± 6.9	24.9 ± 8.9	**< 0.01**
Gait speed (m/s)	0.80 ± 0.23	0.95 ± 0.27	**< 0.01**
SMI (kg/m^2)	5.92 ± 0.67	7.48 ± 1.20	**< 0.01**
Lumbar JOA score (pts)	23.1 ± 3.2	24.4 ± 3.6	0.12

Data are presented as mean ± standard deviation

P values with significant differences are shown in bold

Mann–Whitney *U* test for continuous variables and Chi-squared test for categorical variables were used to compare groups

BMI body mass index, *SMI* skeletal muscle mass index, *JOA score* Japanese Orthopaedic Association scoring system

Comparison of spinopelvic parameters between Sarcopenia and No Sarcopenia groups

Spinopelvic parameters except TK (Sarcopenia: 34.7°, No Sarcopenia: 24.3°, $p<0.01$) were not significantly different between the Sarcopenia group and No Sarcopenia groups (Table 2). The prevalence of patients with spinopelvic mismatch (PI minus LL ≥ 10°) was 37.0% (10 of 27 patients) in the Sarcopenia group and 42.4% (42 of 99 patients) in the No Sarcopenia group (Table 2). There was no significant difference between the Sarcopenia group and No Sarcopenia groups ($p=0.66$).

Patients without spinopelvic mismatch (PI minus LL < 10°)

Among patients without spinopelvic mismatch (PI minus LL < 10°), there was a significant difference regarding age between the Sarcopenia group (81.3 years) and No Sarcopenia groups (75.3 years, $p<0.01$). However, there was no significant difference in the spinopelvic parameters between the 2 groups (Table 3).

Patients with spinopelvic mismatch (PI minus LL ≥ 10°)

When limiting patients with spinopelvic mismatch (PI minus LL ≥ 10°), the mean age of the Sarcopenia group (81.6 years) was significantly higher than that of the No Sarcopenia group (77.0 years, $p<0.01$). Regarding spinopelvic parameters, the mean SVA of the Sarcopenia group

Table 2 Comparison of the spinopelvic parameters between Sarcopenia and No Sarcopenia

	Sarcopenia $N=27$	No Sarcopenia $N=99$	P
Spinopelvic parameters			
PI (°)	48.5 ± 9.5	48.9 ± 11.1	0.82
LL (°)	37.3 ± 14.6	35.3 ± 16.9	0.71
PI-LL (°)	11.2 ± 10.4	13.7 ± 14.1	0.51
SVA (mm)	60.1 ± 47.0	48.4 ± 30.7	0.21
TK (°)	34.7 ± 11.0	24.3 ± 13.9	**< 0.01**
Spinopelvic mismatch			0.66
PI-LL < 10° (n)	17	57	
PI-LL ≥ 10° (n)	10	42	

Data are presented as mean ± standard deviation

P value with significant difference is shown in bold

Mann–Whitney *U* test for continuous variables and Chi-squared test for categorical variables were used to compare groups

PI pelvic incidence, *LL* lumbar lordosis, *SVA* sagittal vertebral axis, *TK* thoracic kyphosis, *PT* pelvic tilt

Table 3 Comparison of the spinopelvic parameters between Sarcopenia and No Sarcopenia (in patients with PI minus LL < 10°)

	Sarcopenia $N=17$	No Sarcopenia $N=57$	P
Age (years)	81.3 ± 4.8	75.3 ± 5.7	**< 0.01**
Female (%)	64.7%	35.1%	0.05
Spinopelvic parameters			
PI (°)	49.9 ± 8.2	47.6 ± 10.3	0.43
LL (°)	45.7 ± 8.4	45.7 ± 10.9	0.98
PI-LL (°)	4.1 ± 4.3	1.9 ± 5.6	0.15
SVA (mm)	33.6 ± 11.4	37.4 ± 30.5	0.70
TK (°)	34.4 ± 11.4	28.9 ± 11.3	0.13
PT (°)	20.8 ± 7.3	18.3 ± 10.4	0.36

Data are presented as mean ± standard deviation

P value with significant difference is shown in bold

Mann–Whitney *U* test for continuous variables and Chi-squared test for categorical variables were used to compare groups

PI pelvic incidence, *LL* lumbar lordosis, *SVA* sagittal vertebral axis, *TK* thoracic kyphosis, *PT* pelvic tilt

(115.7 mm) was significantly larger than that of the No Sarcopenia group (58.7 mm, $p < 0.01$). The mean TK of the Sarcopenia group (36.6°) was also significantly larger than that of the No Sarcopenia group (21.3°, $p < 0.01$) (Table 4). Using multiple linear regression analysis for adjusting age, it was revealed that sarcopenia was independently related to the significant increase in SVA ($\beta = 50.7$, $p < 0.001$) and TK ($\beta = 14.0$, $p = 0.010$) (Fig. 3a, b).

Table 4 Comparison of the spinopelvic parameters between Sarcopenia and No Sarcopenia (in patients with PI minus LL ≥ 10°)

	Sarcopenia $n=10$	No Sarcopenia $n=42$	P
Age (years)	81.6 ± 6.5	77.0 ± 6.0	**< 0.01**
Female (%)	50.0%	45.2%	0.53
Spinopelvic parameters			
PI (°)	44.6 ± 10.1	49.5 ± 12.1	0.20
LL (°)	20.9 ± 8.7	25.6 ± 15.8	0.21
PI-LL (°)	23.7 ± 6.3	23.9 ± 11.5	0.51
SVA (mm)	115.7 ± 10.6	58.7 ± 28.2	**< 0.01**
TK (°)	36.6 ± 10.9	21.3 ± 14.8	**< 0.01**
PT (°)	25.0 ± 6.7	27.5 ± 9.3	0.35

Data are presented as mean ± standard deviation

P values with significant differences are shown in bold

Mann–Whitney *U* test for continuous variables and Chi-squared test for categorical variables were used to compare groups

PI pelvic incidence, *LL* lumbar lordosis, *SVA* sagittal vertebral axis, *TK* thoracic kyphosis, *PT* pelvic tilt

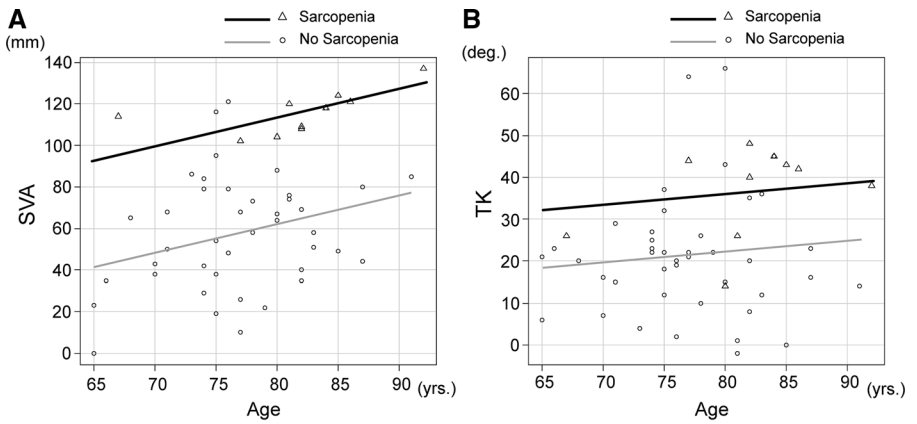
Discussion

In our study population, 21.4% of the all elderly outpatients who underwent lumbar decompression surgery were diagnosed with sarcopenia on the basis of the AWGS criteria. Yoshimura et al. reported that the prevalence of sarcopenia diagnosed using AWGS was 8.2% (men, 8.5%; women, 8.0%) among 1099 elderly people in Japan [24]. Despite the absence of present symptoms of lumbar canal stenosis, outpatients who had undergone lumbar decompression surgery seemed more likely to have sarcopenia than the general elderly population.

Overall, there was no significant difference regarding spinopelvic parameters except TK between the 2 groups. The incidence of spinopelvic mismatch among patients with sarcopenia and without sarcopenia was also not significantly different ($p = 0.66$). Spinopelvic mismatch caused by decrease in LL with aging, vertebral fractures, and disk degeneration was reported to be the key trigger of spinal sagittal imbalance (increase in SVA) [13]. Our result showed that sarcopenia was not related to the occurrence of spinopelvic mismatch.

Among patients without spinopelvic mismatch, all spinopelvic parameters were not significantly different between the 2 groups. Schwab et al. reported that if the patients' LL were maintained within the range of PI ± 9°, their posture was well balanced and there was spinopelvic harmony [22]. In that situation, they did not need any compensation to keep their posture balanced; therefore, the presence of sarcopenia was not related to spinopelvic parameters.

Among patients with spinopelvic mismatch, SVA and TK of the patients with sarcopenia were significantly larger than those of the patients without sarcopenia. Even



Factor	β	95%CI	P-value
Age	1.35	0.19 – 2.52	0.023
Sarcopenia	**50.7**	**32.2 – 69.1**	**<0.001**

Factor	β	95%CI	P-value
Age	0.26	-0.41 - 0.92	0.443
Sarcopenia	**14.0**	**3.52 - 24.6**	**0.010**

Fig. 3 Scatter plotting and result of multiple linear regression analysis for predicting **a** sagittal vertebral axis (SVA) and **b** thoracic kyphosis (TK) based on age and sarcopenia in patients with spinopelvic mismatch. Sarcopenia was independently related to larger SVA and larger TK, after age adjustment

after adjusting the age difference between the 2 groups using multilinear regression analysis, sarcopenia was significantly related to a larger SVA and a larger TK. When the spinopelvic mismatch occurred, for avoiding sagittal imbalance (increase in SVA), compensatory mechanisms such as pelvic retroversion (increase in PT), flattening of thoracic spine (decrease in TK) were recruited to pull back the center of their gravity line (decrease in SVA) [22, 25, 26]. From our result, PT was not significantly different whether patients had sarcopenia or not. So once spinopelvic mismatch occurred, patients with sarcopenia could not compensate their sagittal imbalance as much as patients without sarcopenia because of insufficient compensation especially by flattening of their thoracic spine (Fig. 4).

In summary, the presence of sarcopenia was not related to the occurrence of spinopelvic mismatch but to spinal sagittal imbalance in the presence of spinopelvic mismatch because of insufficient compensation for maintaining a balanced posture.

Spinal sagittal imbalance induces worse quality of life among elderly people. Although correction surgery for adult spinal deformity including spinal sagittal imbalance was reported to be effective [27], there are still problems such as a high complication rates [28] and high medical costs [29]. Therefore, it is important to elucidate methods to prevent spinal sagittal imbalance. Our results reveal the possibility that prevention of sarcopenia might be effective in preventing spinal sagittal imbalance.

Strength of our study

Regarding the relationship between sarcopenia and spinal deformity, Eguchi et al. reported that the prevalence of sarcopenia and serum pentosidine level among patients with

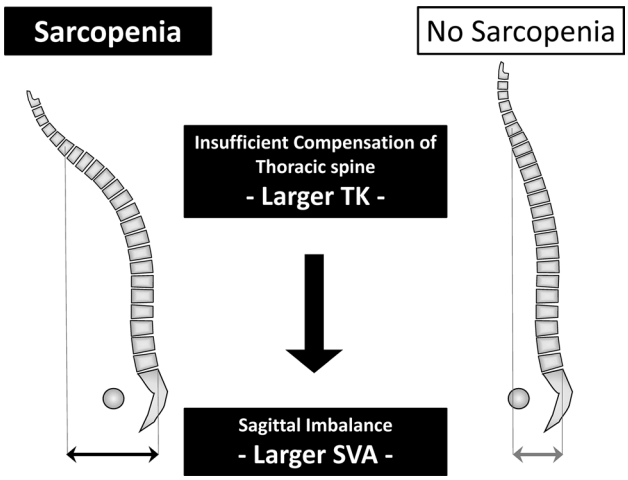


Fig. 4 Schematic images comparing postures of patients in the Sarcopenia and No Sarcopenia groups, in patients with spinopelvic mismatch. The patients in the Sarcopenia group could not compensate for their sagittal imbalance as much as the patients in the No Sarcopenia group because of insufficient compensation by flattening of their thoracic spine

degenerative lumbar scoliosis (DLS) were higher than those without DLS [16, 30]. And they reported that high serum pentosidine level was associated with severity of coronal and sagittal malalignment [30]. However, those studies were not directly compared the spinopelvic parameters between patients with sarcopenia and without sarcopenia. Therefore, to our knowledge, our study is the first to report the relationship of sarcopenia with spinopelvic parameters and reveal that sarcopenia is relevant to spinal sagittal imbalance.

Furthermore, the definition of sarcopenia in our study strictly followed the AWGS diagnostic algorithm. Unlike other research fields, most of the reports in the research field of spine surgery defined sarcopenia as just a reduction in

muscle mass [10, 16, 30, 31]. For researching the influence of sarcopenia in an aged society, it is important to define sarcopenia under the same, widely used diagnostic criteria [4, 5]. Our study satisfied that, so it is also meaningful in this respect.

Limitation of our study

This study has several limitations. First, we could not detect whether sarcopenia was the "cause" of spinal sagittal imbalance or the "result" of spinal sagittal imbalance due to the cross-sectional nature of our study. Further studies, such as longitudinal studies, are needed. Second, we could not assess the sagittal alignment of the lower extremity due to lack of full-length radiographs like the EOS imaging system [32]. Knee flexion was reported to be one of the important compensatory mechanisms [33]. Finally, our study population included patients who had undergone microscopic or micro-endoscopic lumbar decompression surgery. It is unknown whether this result can be generalized to all elderly people. However, the patients we targeted had no neurological deficit, no metal implants, and no vertebral fractures. Therefore, among the spine clinic outpatients, the patients we recruited were considered suitable subjects to evaluate spinal sagittal alignment and balance.

Conclusions

This study investigated whether sarcopenia was related to spinal sagittal imbalance by comparing spinopelvic parameters between patients with and without sarcopenia. In conclusion, sarcopenia is not independently related to spinopelvic mismatch; however, it is independently related to spinal sagittal imbalance because of insufficient compensation by flattening thoracic kyphosis in patients with spinopelvic mismatch.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study protocol was approved by the Institutional Review Board of our institution (No. 3170).

References

1. Rosenberg IH (1997) Sarcopenia: origins and clinical relevance. J Nutr 127:990S–991S. https://doi.org/10.1093/jn/127.5.990S
2. Trombetti A, Reid KF, Hars M, Herrmann FR, Pasha E, Phillips EM, Fielding RA (2016) Age-associated declines in muscle mass, strength, power, and physical performance: impact on fear of falling and quality of life. Osteoporos Int 27:463–471. https://doi.org/10.1007/s00198-015-3236-5
3. Brown JC, Harhay MO, Harhay MN (2016) Sarcopenia and mortality among a population-based sample of community-dwelling older adults. J Cachexia Sarcopenia Muscle 7:290–298. https://doi.org/10.1002/jcsm.12073
4. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel JP, Rolland Y, Schneider SM, Topinkova E, Vandewoude M, Zamboni M, European Working Group on Sarcopenia in Older P (2010) Sarcopenia: European consensus on definition and diagnosis: report of the European Working Group on Sarcopenia in Older People. Age Ageing 39:412–423. https://doi.org/10.1093/ageing/afq034
5. Chen LK, Liu LK, Woo J, Assantachai P, Auyeung TW, Bahyah KS, Chou MY, Chen LY, Hsu PS, Krairit O, Lee JS, Lee WJ, Lee Y, Liang CK, Limpawattana P, Lin CS, Peng LN, Satake S, Suzuki T, Won CW, Wu CH, Wu SN, Zhang T, Zeng P, Akishita M, Arai H (2014) Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. J Am Med Dir Assoc 15:95–101. https://doi.org/10.1016/j.jamda.2013.11.025
6. Lee DW, Choi EY (2016) Sarcopenia as an independent risk factor for decreased BMD in COPD patients: Korean National Health and Nutrition Examination Surveys IV and V (2008–2011). PLoS ONE 11:e0164303. https://doi.org/10.1371/journal.pone.0164303
7. Wang T, Feng X, Zhou J, Gong H, Xia S, Wei Q, Hu X, Tao R, Li L, Qian F, Yu L (2016) Type 2 diabetes mellitus is associated with increased risks of sarcopenia and pre-sarcopenia in Chinese elderly. Sci Rep 6:38937. https://doi.org/10.1038/srep38937
8. Han P, Yu H, Ma Y, Kang L, Fu L, Jia L, Chen X, Yu X, Hou L, Wang L, Zhang W, Yin H, Niu K, Guo Q (2017) The increased risk of sarcopenia in patients with cardiovascular risk factors in Suburb-Dwelling older Chinese using the AWGS definition. Sci Rep 7:9592. https://doi.org/10.1038/s41598-017-08488-8
9. Souza VA, Oliveira D, Barbosa SR, Correa J, Colugnati FAB, Mansur HN, Fernandes N, Bastos MG (2017) Sarcopenia in patients with chronic kidney disease not yet on dialysis: analysis of the prevalence and associated factors. PLoS ONE 12:e0176230. https://doi.org/10.1371/journal.pone.0176230
10. Hida T, Shimokata H, Sakai Y, Ito S, Matsui Y, Takemura M, Kasai T, Ishiguro N, Harada A (2016) Sarcopenia and sarcopenic leg as potential risk factors for acute osteoporotic vertebral fracture among older women. Eur Spine J 25:3424–3431. https://doi.org/10.1007/s00586-015-3805-5
11. Park S, Kim HJ, Ko BG, Chung JW, Kim SH, Park SH, Lee MH, Yeom JS (2016) The prevalence and impact of sarcopenia on degenerative lumbar spinal stenosis. Bone Joint J 98-B:1093–1098. https://doi.org/10.1302/0301-620X.98B8.37623
12. Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F (2005) The impact of positive sagittal balance in adult spinal deformity. Spine (Phila Pa 1976) 30:2024–2029
13. Diebo BG, Ferrero E, Lafage R, Challier V, Liabaud B, Liu S, Vital JM, Errico TJ, Schwab FJ, Lafage V (2015) Recruitment of compensatory mechanisms in sagittal spinal malalignment is age and regional deformity dependent: a full-standing axis analysis of key radiographical parameters. Spine (Phila Pa 1976) 40:642–649. https://doi.org/10.1097/BRS.0000000000000844
14. Sinaki M, Itoi E, Rogers JW, Bergstralh EJ, Wahner HW (1996) Correlation of back extensor strength with thoracic kyphosis and lumbar lordosis in estrogen-deficient women. Am J Phys Med Rehabil 75:370–374
15. Katzman WB, Miller-Martinez D, Marshall LM, Lane NE, Kado DM (2014) Kyphosis and paraspinal muscle composition in older men: a cross-sectional study for the Osteoporotic Fractures in Men (MrOS) research group. BMC Musculoskelet Disord 15:19. https://doi.org/10.1186/1471-2474-15-19

16. Eguchi Y, Suzuki M, Yamanaka H, Tamai H, Kobayashi T, Orita S, Yamauchi K, Suzuki M, Inage K, Fujimoto K, Kanamoto H, Abe K, Aoki Y, Toyone T, Ozawa T, Takahashi K, Ohtori S (2017) Associations between sarcopenia and degenerative lumbar scoliosis in older women. Scoliosis Spinal Disord 12:9. https://doi.org/10.1186/s13013-017-0116-0
17. Cesari M, Kritchevsky SB, Newman AB, Simonsick EM, Harris TB, Penninx BW, Brach JS, Tylavsky FA, Satterfield S, Bauer DC, Rubin SM, Visser M, Pahor M (2009) Added value of physical performance measures in predicting adverse health-related events: results from the Health, Aging And Body Composition Study. J Am Geriatr Soc 57:251–259. https://doi.org/10.1111/j.1532-5415.2008.02126.x
18. Baumgartner RN, Koehler KM, Gallagher D, Romero L, Heymsfield SB, Ross RR, Garry PJ, Lindeman RD (1998) Epidemiology of sarcopenia among the elderly in New Mexico. Am J Epidemiol 147:755–763
19. Legaye J, Duval-Beaupere G, Hecquet J, Marty C (1998) Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 7:99–103
20. Schwab F, Lafage V, Boyce R, Skalli W, Farcy JP (2006) Gravity line analysis in adult volunteers: age-related correlation with spinal parameters, pelvic parameters, and foot position. Spine (Phila Pa 1976) 31:E959–E967. https://doi.org/10.1097/01.brs.0000248126.96737.0f
21. Vialle R, Levassor N, Rillardon L, Templier A, Skalli W, Guigui P (2005) Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. J Bone Jt Surg Am 87:260–267. https://doi.org/10.2106/JBJS.D.02043
22. Schwab F, Patel A, Ungar B, Farcy JP, Lafage V (2010) Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. Spine (Phila Pa 1976) 35:2224–2231. https://doi.org/10.1097/BRS.0b013e3181ee6bd4
23. Bess S, Schwab F, Lafage V, Shaffrey CI, Ames CP (2013) Classifications for adult spinal deformity and use of the Scoliosis Research Society-Schwab Adult Spinal Deformity Classification. Neurosurg Clin N Am 24:185–193. https://doi.org/10.1016/j.nec.2012.12.008
24. Yoshimura N, Muraki S, Oka H, Iidaka T, Kodama R, Kawaguchi H, Nakamura K, Tanaka S, Akune T (2017) Is osteoporosis a predictor for future sarcopenia or vice versa? Four-year observations between the second and third ROAD study surveys. Osteoporos Int 28:189–199. https://doi.org/10.1007/s00198-016-3823-0
25. Lafage V, Schwab F, Patel A, Hawkinson N, Farcy JP (2009) Pelvic tilt and truncal inclination: two key radiographic parameters in the setting of adults with spinal deformity. Spine (Phila Pa 1976) 34:E599–E606. https://doi.org/10.1097/BRS.0b013e3181aad219
26. Barrey C, Roussouly P, Perrin G, Le Huec JC (2011) Sagittal balance disorders in severe degenerative spine. Can we identify the compensatory mechanisms? Eur Spine J 20(Suppl 5):626–633. https://doi.org/10.1007/s00586-011-1930-3
27. Smith JS, Lafage V, Shaffrey CI, Schwab F, Lafage R, Hostin R, O'Brien M, Boachie-Adjei O, Akbarnia BA, Mundis GM, Errico T, Kim HJ, Protopsaltis TS, Hamilton DK, Scheer JK, Sciubba D, Ailon T, Fu KM, Kelly MP, Zebala L, Line B, Klineberg E, Gupta M, Deviren V, Hart R, Burton D, Bess S, Ames CP, International Spine Study G (2016) Outcomes of operative and nonoperative treatment for adult spinal deformity: a prospective, multicenter, propensity-matched cohort assessment with minimum 2-year follow-up. Neurosurgery 78:851–861. https://doi.org/10.1227/NEU.0000000000001116
28. Smith JS, Shaffrey CI, Klineberg E, Lafage V, Schwab F, Lafage R, Kim HJ, Hostin R, Mundis GM Jr, Gupta M, Liabaud B, Scheer JK, Diebo BG, Protopsaltis TS, Kelly MP, Deviren V, Hart R, Burton D, Bess S, Ames CP, Group obotISS (2017) Complication rates associated with 3-column osteotomy in 82 adult spinal deformity patients: retrospective review of a prospectively collected multicenter consecutive series with 2-year follow-up. J Neurosurg Spine 27:444–457. https://doi.org/10.3171/2016.10.SPINE16849
29. Yagi M, Ames CP, Keefe M, Hosogane N, Smith JS, Shaffrey CI, Schwab F, Lafage V, Shay Bess R, Matsumoto M, Watanabe K, International Spine Study G (2018) A cost-effectiveness comparisons of adult spinal deformity surgery in the United States and Japan. Eur Spine J 27:678–684. https://doi.org/10.1007/s00586-017-5274-5
30. Eguchi Y, Toyoguchi T, Inage K, Fujimoto K, Orita S, Yamauchi K, Suzuki M, Kanamoto H, Abe K, Norimoto M, Umimura T, Koda M, Furuya T, Aoki Y, Takahashi K, Ohtori S (2018) Pentosidine concentration is associated with degenerative lumbar scoliosis in older women: preliminary results. Eur Spine J 27:597–606. https://doi.org/10.1007/s00586-017-5370-6
31. Koshimizu H, Sakai Y, Harada A, Ito S, Ito K, Hida T (2018) The impact of sarcopenia on cervical spine sagittal alignment after cervical laminoplasty. Clin Spine Surg 31:E342–e346. https://doi.org/10.1097/bsd.0000000000000657
32. Ilharreborde B, Steffen JS, Nectoux E, Vital JM, Mazda K, Skalli W, Obeid I (2011) Angle measurement reproducibility using EOS three-dimensional reconstructions in adolescent idiopathic scoliosis treated by posterior instrumentation. Spine (Phila Pa 1976) 36:E1306–E1313. https://doi.org/10.1097/BRS.0b013e3182293548
33. Obeid I, Hauger O, Aunoble S, Bourghli A, Pellet N, Vital JM (2011) Global analysis of sagittal spinal alignment in major deformities: correlation between lack of lumbar lordosis and flexion of the knee. Eur Spine J 20(Suppl 5):681–685. https://doi.org/10.1007/s00586-011-1936-x

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