綜　説

Spinal Deformity and the Musculoskeletal Cohort Study of the General Older Population

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Ⅰ Introduction

The proportion of adults aged 65 years or more in Japan has reached 28 % according to the 2019 Ministry of Internal Affairs and Communications Statistics Bureau Population Census. It is socially important to unveil the impact of aging and extend healthy life expectancy. One of the most important factors diminishing healthy life expectancy is the aging of motor organs, such as the bones, joints, nerves, and muscle tendons. In recent years, corrective surgeries for spinal postural abnormalities in the sagittal plane of the spine have been performed in older adults across Japan since it was reported that such disorders are associated with impaired walking and mobility, respiratory and digestive symptoms, and low back pain[1)2)]. However, little research exists on the epidemiology, pathogenesis, evaluation methods, and treatment effects on gait and mobility for spinal postural abnormality in order to establish treatment guidelines.

In this paper, we review the history of spinal postural abnormalities and discuss the Obuse Study, a musculoskeletal cohort study of agricultural community residents conducted by our department in conjunction with the Rehabilitation Center, New Life Hospital, and the Obuse town office.

Ⅱ History of Spinal Postural Abnormality Studies

In 2001, Simmons described two types of adult spinal deformities : degenerative lumbar scoliosis with no or minimal rotational deformity (Type I), and degenerative lumbar scoliosis, which is often secondary to pre-existing scoliosis and exhibits a large rotational deformity with substantial loss in lumbar lordosis (LL) (Type II). These deformities require different bracing and correction methods, with Type I usually necessitating a short brace and Type II requiring correction with a longer brace using sagittal plane reconstruction[3)].

In 2005, Aebi et al. defined adult scoliosis as a spinal deformity with a Cobb angle of 10 degrees or more in the coronal plane at the end of growth[4)]. They also classified postural abnormalities of the spine after bone maturation into three types based on etiology[4)]. Type I scoliosis is the most common type of deformity and is defined as primary degenerative scoliosis or de novo scoliosis. The curve in Type I scoliosis is essentially a continuous progression of anterior vertebral body deviation with asymmetrical degeneration of the intervertebral discs accompanied by rotation with the fulcrum at the facet joint on one side. Type I scoliosis is more common in primary degenerative scoliosis than in secondary degenerative idiopathic curves[5)]. Type II scoliosis is considered a remnant of congenital or idiopathic scoliosis. Idiopathic

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curves from other etiologies of secondary degeneration exist in several forms depending on the type of treatment previously given. Type III scoliosis is considered a deformity caused by lumbosacral lesions, lower extremity disease, and osteoporosis[6]. Degenerative idiopathic scoliosis, which is more prevalent in the surgically treated lumbar or thoracolumbar spine, is associated with lower functional scores after Harrington surgery, worse Oswestry disability index scores, and increased Modic change[7].

Also, in 2005, Schwab et al. proposed a radiographic classification method based on the degree of L1-S1 lordotic angle and the coronal plane obliquity of L3 in standing radiographs[8]. Ninety-eight adult patients with scoliosis were included in the study and followed for a minimum of 2 years. Although the Cobb angle did not correlate with visual analogue scale (VAS) scores or general health status (36-Item Short-Form Health Survey)[9], significant associations were identified between L3 coronal plane obliquity, L1-S1 lordotic angle, and VAS results ($p<0.05$). Mean VAS pain scores were 27.7 for Type I scoliosis, 43.3 for Type II scoliosis, and 47.1 for Type III scoliosis (Type I vs. Type III : $p<0.05$). The operative rate (i.e., failure of conservative treatment, including orthotics, physical therapy, and pharmacological treatment, for at least 3 months) was 0 % for Type I, 9 % for Type II, and 22.7 % for Type III ($p=0.002$)[8].

One year later, Schwab et al. presented a new classification system for spinal postural abnormalities based on clinically significant associations of radiographic parameters through prospective studies[10]. Their sixth group was modified to include deformities in the sagittal plane only[10]. The classification also took into account an index of global balance. Around the same time, the Scoliosis Research Society (SRS) introduced a classification system with the goals of accurately classifying adult spinal postural abnormalities and providing a framework to help develop evidence-based approaches for the management of those conditions[11].

In 2008, Kuntz IV et al. proposed a neutral upright spinal alignment in asymptomatic volunteers[12]. The authors emphasized that global spinal alignment was maintained within a narrow range for horizontal gaze and balance of the spine over the pelvis and femoral head in asymptomatic volunteers despite large variations in the regional curve from the occiput to the pelvis[12].

Fig.1 shows the history of spinal postural abnormality studies.

Ⅲ　Pelvic Parameters in Spinal Postural Abnormalities

Dubousset et al. presented the concept of the cone of economy in 1994, which considered that standing posture was maintained in a cone with the foot as the fulcrum. The dimensions of the cone became smaller in a stable posture and larger in an unstable posture **(Fig. 2)**[13]. In patients with spinal postural

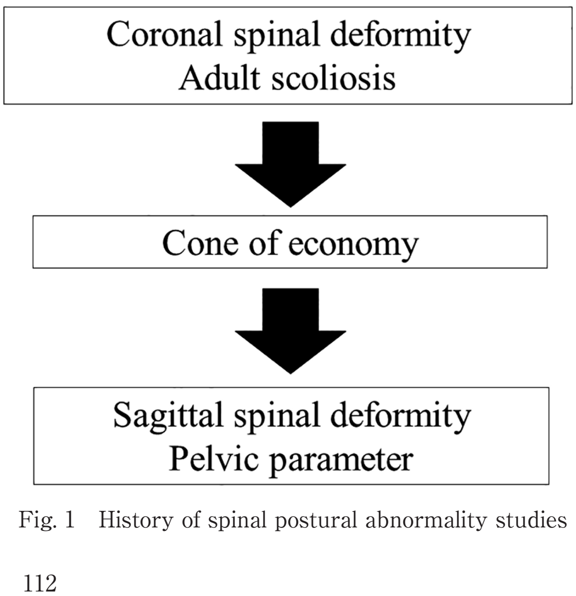

Fig. 1　History of spinal postural abnormality studies

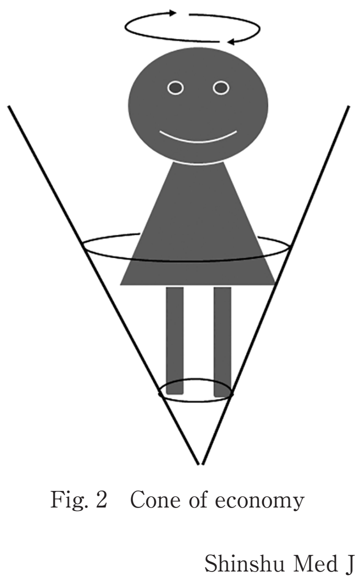

Fig. 2　Cone of economy

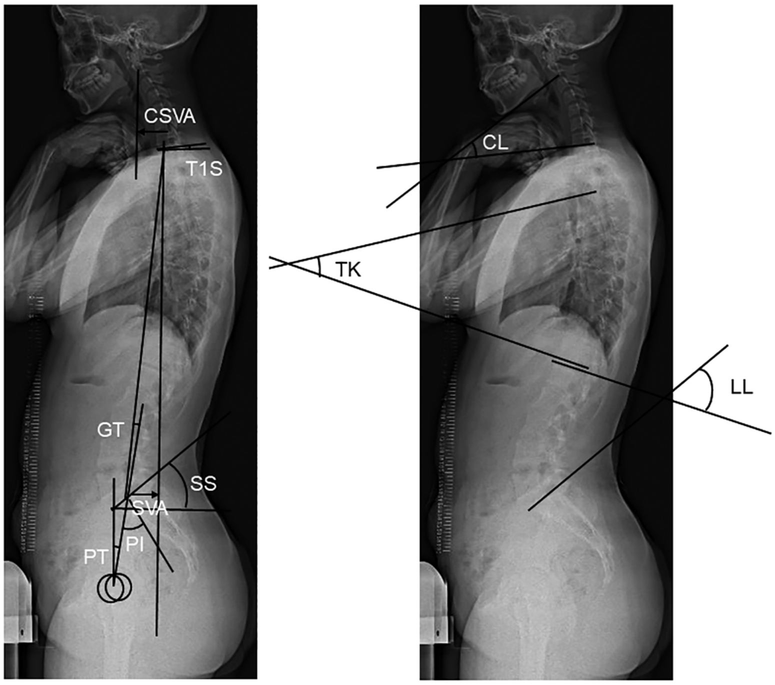

Fig. 3 Radiographic parameters of sagittal spinal alignment (adapted from Uehara 2019 [33])
Abbreviations : SVA, sagittal vertical axis ; GT, global tilt ; CL, cervical lordosis ; CSVA, cervical sagittal vertical axis ; T1S, T1 slope ; TK, thoracic kyphosis ; LL, lumbar lordosis ; SS, sacral slope ; PT, pelvic tilt ; PI, pelvic incidence.

abnormalities, increasing pelvic tilt (PT) and lower extremity compensatory functions are used to maintain the standing position in the cone[13]. In 1992, Duval-Beaupère et al. described three major pelvic sagittal parameters : pelvic incidence (PI), PT, and sacral slope (SS). They stated that LL should have a necessary angle according to PI and considered that the key to standing alignment was the pelvis **(Fig. 3)**[14,15]. In addition, they pointed out that a small PI was disadvantageous for an economical standing posture since it shortened the lever arm for the hip extensors to operate[14]. PI is a relatively constant morphological parameter of the pelvis, with only slight changes throughout adulthood. However, PI values vary widely even in healthy subjects[16-19], and recent studies have described PI changes with age, especially in women[20].

According to the above findings, childbearing may be one of the reasons for high PI in women over 40 years of age ; as PI increases, LL must also increase proportionally to maintain vertical balance in the sagittal plane. PT and SS are posture-dependent values that vary with pelvic rotation on the hip axis. These three pelvic parameters are interrelated by the equation PI = PT + SS. Several studies have since shown that pelvic parameters and health-related quality of life are potentially related[1,21,22].

Ⅳ Indicators in Corrective Surgery

In 2012, the SRS revised its classification of spinal postural abnormalities by adding pelvic parameters (SRS-Schwab classification). In this revision, a deformity was described by its main coronal curve pattern and its degree using the Cobb angle, with three modifiers applied : the relationship between PI and LL (PI-LL), PT, and the anterior shift of the vertical axis of the sagittal plane of the seventh cervical vertebra (SVA). This provided an index of spinal pelvis parameters to surgeons to better define malalignment and correction goals. The theory of correction is that LL according to PI, thoracic kyphosis according to LL, and coordination of the lower extremities are required to maintain standing posture[23].

Since the publication of the SRS-Schwab classification as an index for corrective surgery, advances in spinal implants have led to a worldwide increase in fusion procedures for spinal postural abnormalities. However, there are few reports on optimal spinal alignment parameters in healthy individuals, and age-specific spinal deformity correction goals remain controversial[24)25)]. Furthermore, sagittal plane alignment in healthy individuals differs depending on ethnicity ; in a study comparing pelvic parameters in a population from Mexico, Caucasians, and Asians, both LL and SS were smaller in Asians[26)]. Arima et al. also reported that PI was largest in African-Americans and smallest in Asians, while LL was smallest in Asians[27)]. Several formulas for corrective indices in the Japanese have also been reported[28)-30)], and epidemiological studies on spinal posture in healthy volunteers currently exist[31)32)].

Ⅴ Overview of the Obuse Study

Led by then-Professor Kato, the Department of Orthopaedic Surgery of Shinshu University School of Medicine established the Obuse Study, a cohort population study of Japanese residents in agricultural areas, in 2014. The investigation aimed to study the degree and frequency of age-related changes to bones, joints, and muscle tendons as a collaborative effort among Shinshu University (Department of Orthopaedic Surgery and Rehabilitation Center), the local government, and town hospitals[33)-43)].

To create the Obuse cohort, we randomly selected 1,297 of 5,352 townspeople aged 50-89 years in the resident registry of Obuse town, Nagano Prefecture, and sent them information on the proposed musculoskeletal examinations. A total of 412 people, approximately 50 men and 50 women across four age groups (50s, 60s, 70s, and 80s), who agreed to the testing were included in the study. Standing lateral radiographs and physical function measurements of the whole spine were taken. Reference values for each parameter of sagittal spinal column alignment for each age group and gender were calculated from the standing lateral radiographs. The Dunnett test was used to determine the extent to which changes in alignment occurred, and from which age in reference to values obtained for the 50-year-old participants. Physical function measurements included the following : knee flexion/extension muscle strength, grip strength, one-leg standing time, the stand-up test, and the two-step test.

Ⅵ Obuse Study : Analysis of Sagittal Spinal Alignment Parameters[33)]

The mean and standard deviation (SD) of each parameter for each age group and gender are shown in **Table 1**. In the sagittal plane global alignment of the spine, SVA became larger and spinal alignment shifted anteriorly with age in both men and women. Statistical examination showed that SVA was significantly shifted forward in men in their 80s and in women in their 70s as compared with the values of subjects in their 50s. This was especially pronounced in women, with SVA in the 80s age group shifting anteriorly by an average of 66 mm versus the 50s age group **(Fig. 4)**. The changes in cervicothoracic alignment parameters by age were clearly different between genders. In men, anterior shift of the cervical spine was evident from the age of 60 years **(Fig. 5)**. In women, decreased lumbar kyphosis and posterior PT occurred at a younger age than in men. The decrease in PT appeared roughly 10 years before that in male subjects **(Fig. 6)**. An increase in thoracic kyphosis angle was significant only in men over 70 years of age, although the increase was 4 to 6 degrees in both sexes **(Fig. 5)**.

The Obuse Study revealed several key findings : ① a decrease in LL in both men and women, with a significant decrease in women ; ② a decrease in sacral tilt in both men and women, with a significant decrease in women ; ③ a significant change in SS in women, with changes occurring approximately 10 years earlier than in men ; and ④ clear evidence of age-related alignment changes in the cervical spine. There was a clear difference between genders in cervical spine sagittal alignment changes due to aging, with a marked anterior shift in men.

Ⅶ Obuse Study : Relationship between Spinal Postural Abnormalities and Motor Function[34)]

The relationships between sagittal plane parame-

Table 1 Spinal sagittal alignment parameters of the Obuse Study cohort (adapted from Uehara 2019 [33])

Sex	Age(years)	N	SVA (mm)	GT (deg.)	CL (deg.)	CSVA (mm)	T1S (deg.)	TK (deg.)	LL (deg.)	SS (deg.)	PT (deg.)	PI (deg.)
Male	50s	50	6 (26)	13 (7)	10 (10)	23 (14)	25 (6)	25 (8)	44 (11)	33 (8)	12 (6)	45 (9)
	60s	53	9 (38)	17 (11)	9 (11)	28 (15)	27 (8)	29 (8)	45 (13)	31 (9)	14 (8)	45 (10)
	70s	55	22 (30)	19 (8)	13 (12)	29 (12)	29 (9)	31 (10)	45 (13)	33 (9)	16 (6)	49 (10)
	80s	45	57 (49)	29 (12)	14 (15)	31 (17)	31 (10)	31 (13)	38 (12)	28 (6)	21 (7)	49 (9)
	All	203	22 (41)	19 (11)	12 (12)	28 (15)	28 (8)	29 (10)	43 (12)	31 (8)	16 (7)	47 (10)
	Weighted*		17 (38)	18 (11)	11 (12)	27 (15)	28 (8)	29 (9)	44 (12)	32 (8)	15 (7)	46 (10)
Female	50s	47	−5 (26)	14 (8)	9 (10)	18 (11)	23 (7)	27 (9)	51 (11)	36 (8)	14 (6)	49 (9)
	60s	61	5 (30)	19 (11)	9 (9)	16 (8)	22 (7)	31 (10)	47 (14)	31 (10)	17 (8)	48 (11)
	70s	54	30 (36)	26 (11)	13 (11)	17 (11)	25 (10)	30 (11)	42 (14)	29 (9)	23 (10)	53 (11)
	80s	48	61 (60)	36 (16)	19 (12)	19 (16)	30 (14)	33 (19)	38 (20)	25 (11)	27 (11)	51 (11)
	All	210	22 (46)	23 (14)	12 (11)	17 (11)	25 (10)	30 (12)	45 (16)	30 (10)	20 (10)	50 (11)
	Weighted*		19 (45)	22 (14)	12 (11)	17 (11)	24 (10)	30 (12)	45 (16)	31 (10)	20 (10)	50 (11)

Values represent the mean standard deviation.
*based on the Japanese population composition of July 2017.
Abbreviations : SVA, sagittal vertical axis ; GT, global tilt ; CL, cervical lordosis ; CSVA,
cervical sagittal vertical axis ;
T1S, T1 slope ; TK, thoracic kyphosis ; LL, lumbar lordosis ; SS, sacral slope ; PT, pelvic tilt ; PI, pelvic incidence.

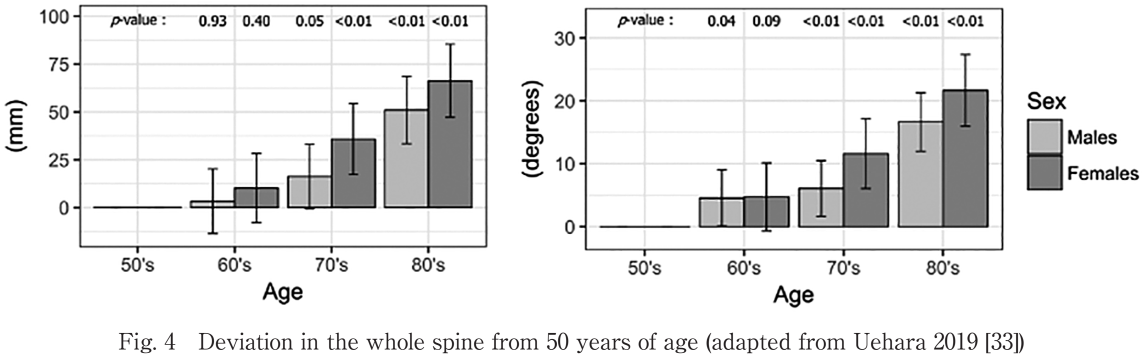

Fig. 4 Deviation in the whole spine from 50 years of age (adapted from Uehara 2019 [33])
Note : Error bars represent 95 % confidence intervals.
Abbreviations : SVA, sagittal vertical axis ; GT, global tilt.

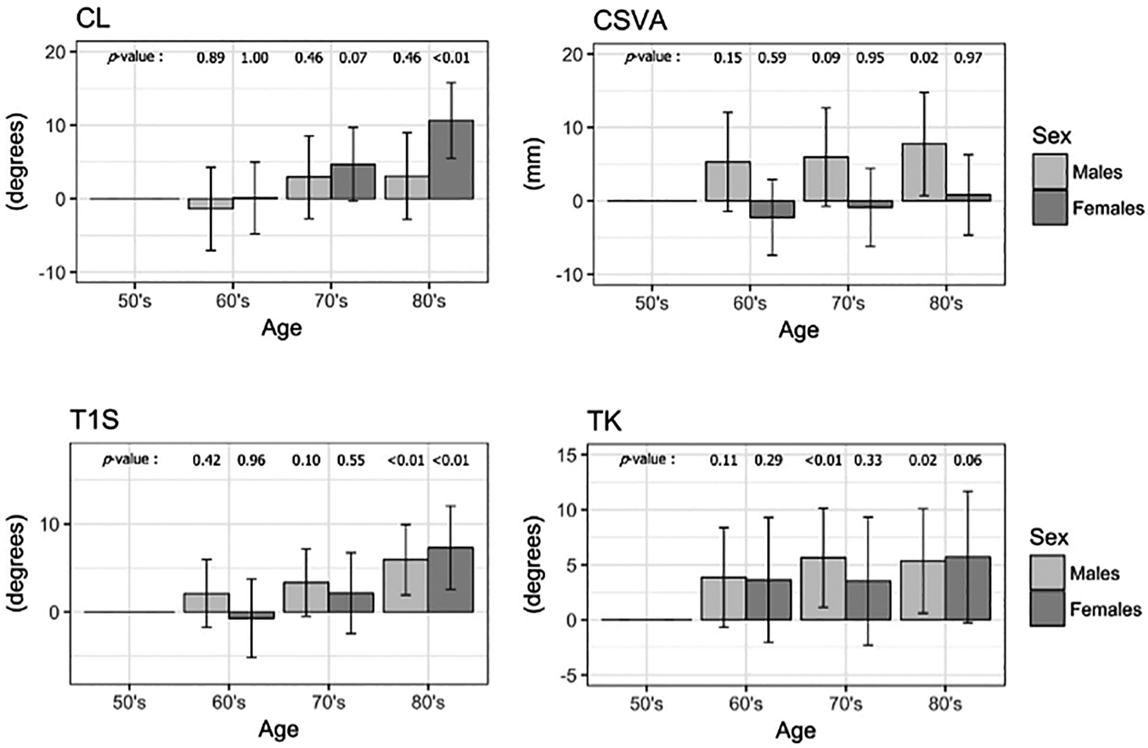

Fig. 5 Deviation in the cervical and thoracic spine from 50 years of age (adapted from Uehara 2019 [33])
Note : Error bars represent 95 % confidence intervals.
Abbreviations : CL, cervical lordosis ; CSVA, cervical sagittal vertical axis ; T1S, T1 slope ; TK, thoracic kyphosis.

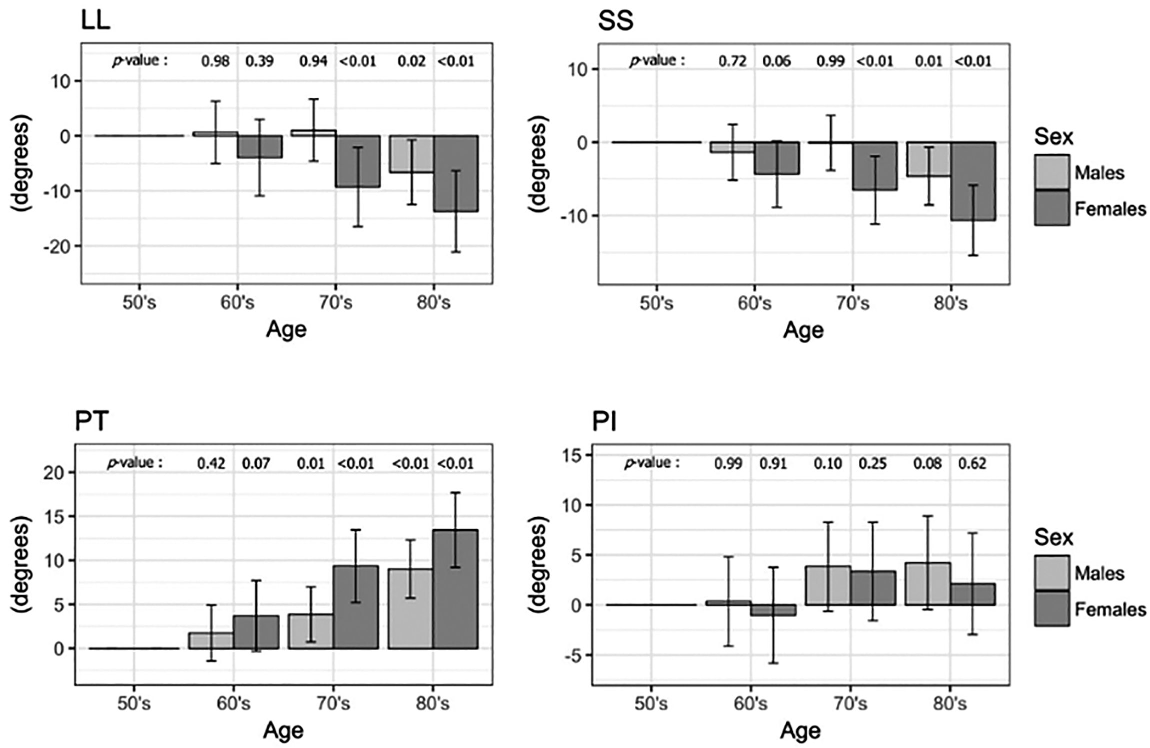

Fig. 6 Deviation in the lumbopelvic region from 50 years of age (adapted from Uehara 2019 [33])
Note : Error bars represent 95 % confidence intervals.
Abbreviations : LL, lumbar lordosis ; SS, sacral slope ; PT, pelvic tilt ; PI, pelvic incidence.

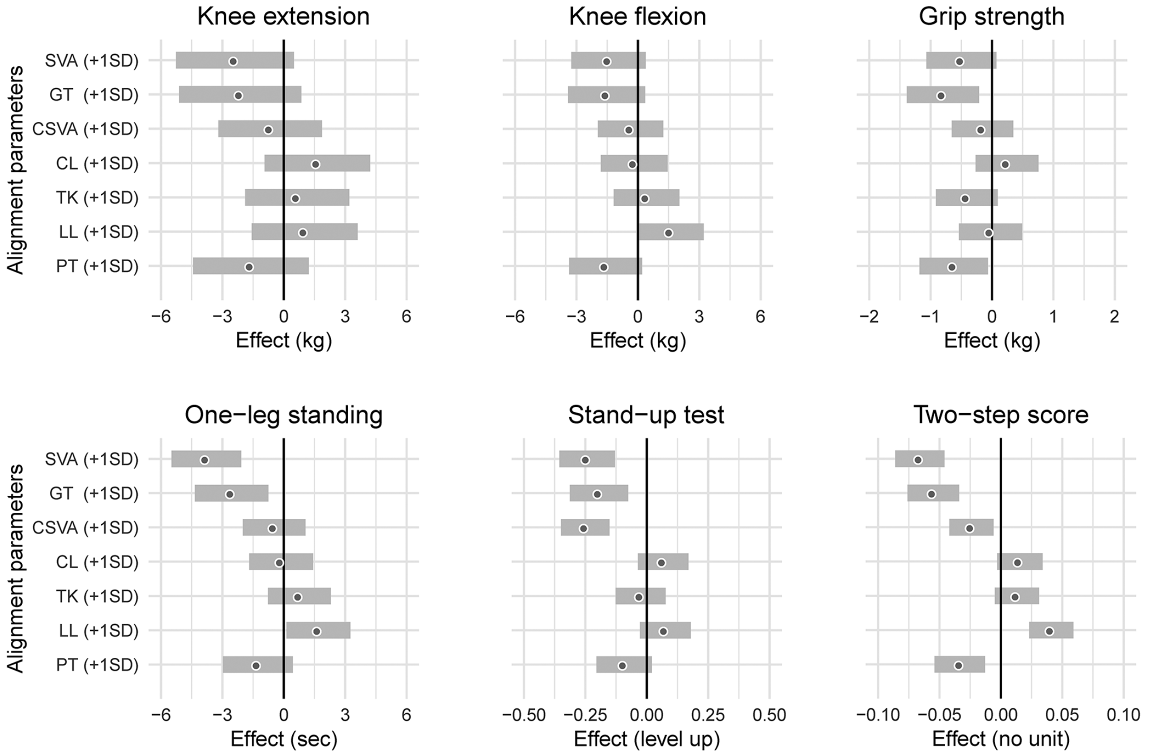

Fig. 7 Effect on physical performance tests of a +1 standard deviation shift of sagittal spinal alignment parameters (adapted from Tokida 2019 [34])

Note : Bands represent 95 % confidence intervals. All values were adjusted for age and sex.

Abbreviations : SVA, sagittal vertical axis ; GT, global tilt ; CSVA, cervical sagittal vertical axis ; CL, cervical lordosis ; TK, thoracic kyphosis ; LL, lumbar lordosis ; PT, pelvic tilt ; SD, standard deviation.

ters and physical function test values are shown in **Fig. 5**. Knee extension and flexion muscle strength were not remarkably associated with any sagittal plane parameter. Grip strength was significantly ($p<0.01$) associated with global tilt (GT) ($p<0.01$), an index of cervical sub-total alignment, with a mean of 0.8 kg (95 % confidence interval 0.2–1.4 kg) lower when GT was +1 SD (11 degrees for men and 14 degrees for women) greater than the mean. Similarly, larger PT was associated with lower grip strength ($p=0.02$). One-leg standing time was significantly related to SVA ($p<0.01$), GT ($p<0.01$), and LL ($p=0.03$), and was shorter when SVA or GT was larger or LL was smaller ; when SVA was deviated anteriorly by +1 SD (41 mm for men and 47 mm for women) from the mean, one-leg standing time was shorter by an average of 3.8 seconds (95 % confidence interval 2.1–5.5 seconds). The stand-up test was significantly associated with SVA ($p<0.01$), GT ($p<0.01$), and CSVA ($p<0.01$). Lastly, the two-step score was associated with several spinal column alignment parameters. Larger SVA, GT, CSVA, and PT all correlated with significantly lower scores ($p<0.01$ for all), while larger LL was associated with higher scores ($p<0.01$) **(Fig. 7)**.

The Obuse Study clearly showed that poor spinal sagittal alignment was associated with diminished motor function performance in the general older population. Since poor alignment can be easily visualized as a change in the appearance of standing posture, it may be applicable for use in population health screening. If a simple index for confirming spinal sagittal alignment in a standing posture and an evaluation method can be developed, it may be easier to detect older individuals in need of nursing care at an earlier stage to extend healthy life expectancy in Nagano Prefecture.

Ⅷ Conclusions

The Department of Orthopaedic Surgery of Shinshu University School of Medicine has been conducting a randomly selected exercise screening and epidemiological study (Obuse Study) of older people in cooperation with the Rehabilitation Center in Shinshu University Hospital, New Life Hospital, and the town office in Obuse, Nagano Prefecture, since 2014. The results indicate the presence of gender differences in the progression of spinal postural abnormalities with age. The worsening of spinal postural abnormalities may also be related to declines in motor function. In the second phase of the Obuse Study, longitudinal evaluations will analyze the changes in spinal posture over time to formulate prevention and intervention strategies for spinal postural abnormalities.

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