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Pelvic Retroversion and Reduced Physical Function Are Associated With 10-Year Deterioration of Global Sagittal Alignment in a Community-Based Cohort

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Abstract

Background

Age-related deterioration of spinopelvic sagittal alignment is common in older adults, but its progression varies among individuals. This study aimed to identify baseline factors associated with 10-year deterioration of global sagittal alignment in a community-based cohort.

Methods

This longitudinal study included adults aged ≥ 50 years from a community-based cohort who underwent standing whole-spine radiography in 2012 and 2022. Participants with spinal fusion surgery, lower-extremity arthroplasty, or vertebral fracture at follow-up were excluded. Alignment deterioration was defined as an increase in sagittal vertical axis (SVA) of ≥ 50 mm. Baseline demographics, patient-reported outcomes (PRO), spinopelvic parameters, and physical function were compared between participants with and without deterioration. Associated factors were evaluated using logistic regression analysis.

Results

Among 135 participants, 19 showed deterioration of global sagittal alignment. Baseline sagittal vertical axis and patient-reported outcomes (PRO) were comparable between groups. However, participants with deterioration were older and had higher pelvic tilt (PT), lower sacral slope, lower prone trunk extension, and poorer sit-and-reach performance at baseline. Over 10 years, the deterioration group showed greater loss of lumbar lordosis, larger increases in sagittal vertical axis, and greater worsening of PRO. In multivariable logistic regression analysis, higher baseline PT was associated with subsequent deterioration.

Conclusions

In this 10-year community-based cohort, pelvic retroversion and reduced physical function were present before apparent sagittal imbalance or PRO decline. Combined assessment of spinopelvic alignment and physical function may help identify individuals at risk for future sagittal alignment deterioration.

Introduction

Age-related deterioration of spinopelvic sagittal alignment is an important clinical issue in older adults. With aging, lumbar lordosis tends to decrease, pelvic retroversion increases, and the trunk may gradually shift forward [1–5]. These changes can lead to global sagittal imbalance, which has been associated with pain, disability, impaired physical function, and reduced health-related quality of life[6–15]. Therefore, understanding the longitudinal process of sagittal alignment deterioration is important not only for the evaluation of adult spinal deformity but also for identifying older individuals at risk for future functional impairment.

Previous studies have demonstrated that sagittal spinopelvic parameters, including sagittal vertical axis (SVA), pelvic tilt (PT), pelvic incidence–lumbar lordosis (PI-LL) mismatch, and LL, are closely related to clinical symptoms and patient-reported outcomes (PROs) [6,8–10]. In addition, several community-based studies have shown that spinal sagittal alignment changes with aging and that deterioration of sagittal balance is associated with reduced back muscle strength, decreased physical performance, and impaired quality of life [16–21]. These findings suggest that sagittal alignment is influenced not only by spinal degeneration and structural changes but also by compensatory pelvic mechanisms and physical function[5,22–25].

However, age-related changes in sagittal alignment are variable among individuals. Although previous longitudinal studies have mainly described average age-related changes in sagittal parameters, some older adults show the deterioration of global sagittal alignment over time, whereas others maintain relatively stable alignment despite aging, as illustrated in Fig. 1. Therefore, evaluating only average longitudinal changes may obscure clinically important interindividual differences. Cross-sectional associations between sagittal alignment, muscle strength, and physical function have been reported; however, the baseline characteristics of individuals who subsequently develop sagittal alignment deterioration remain insufficiently understood. Because not all older adults experience progression of sagittal malalignment, identifying individuals at risk for future deterioration is important for risk stratification and for guiding targeted preventive interventions.

Therefore, this study aimed to identify baseline radiographic and physical functional factors associated with 10-year deterioration of global sagittal alignment in a community-based cohort.

Material & Methods

Study design and participants

This was a 10-year longitudinal study based on data from the Toei cohort, a community-based musculoskeletal cohort conducted in Toei Town, Aichi prefecture, Japan. Individuals were eligible for the present analysis if they were aged 50 years or older at baseline and underwent standing whole-spine radiography at both baseline in 2012 and follow-up in 2022. Participants were excluded if they had a history of spinal fusion surgery, lower-extremity arthroplasty, or vertebral fracture at follow-up that could affect sagittal alignment.

Radiographic assessment

Standing whole-spine lateral radiographs were obtained at baseline and at the 10-year follow-up. Radiographs were taken in a standardized standing position. The following sagittal spinopelvic parameters were measured: thoracic kyphosis (TK; angle from the upper endplate of T5 to the lower endplate of T12), lumbar lordosis(LL; upper endplate of L1 to upper endplate of S1), upper lumbar lordosis (uLL; upper endplate of L1 to upper endplate of L4), lower lumbar lordosis (loLL; upper endplate

of L4 to upper endplate of S1), sacral slope(SS), pelvic tilt(PT), pelvic incidence(PI), PI-LL mismatch, and SVA.

Definition of global sagittal alignment deterioration

The primary outcome was longitudinal deterioration of global sagittal alignment over 10 years. Alignment deterioration was defined as an increase in sagittal vertical axis of ≥ 50 mm (ΔSVA≥50mm) between baseline and follow-up, as anterior trunk displacement of this extent was considered to represent clear worsening of whole-spine sagittal alignment. Participants were divided into two groups according to the presence or absence of alignment deterioration: (the deterioration group and the maintenance group.)

Patient-reported outcomes and physical function

Patient-reported outcomes (PROs) were evaluated using the Oswestry Disability Index (ODI) and EuroQol five-dimensional questionnaire (EQ-5D) at baseline and follow-up. Physical function was assessed at baseline using prone trunk extension, sit-and-reach test, functional reach test, and one-leg standing time with eyes open. Prone trunk extension was used as an indicator of trunk extensor function. Sit-and-reach test was used to assess flexibility of the spine and hamstring. The functional reach test measures the maximal forward reach distance from a standing position and was used to assess dynamic balance and fall risk, and one-leg standing time with eyes open was used to assess static balance.

Statistical analysis

Continuous variables are presented as mean ± standard deviation, and categorical variables are presented as number or percentage. Continuous variables were compared using Student’s t-test or the Mann–Whitney U test, as appropriate. Categorical variables were compared using the chi-square test or Fisher’s exact test. A p value < 0.05 was considered statistically significant.

Ten-year changes in radiographic parameters and patient-reported outcomes were calculated as follow-up values minus baseline values and compared between groups.

Logistic regression analysis was performed to identify baseline factors associated with global sagittal alignment deterioration. Variables included in the logistic regression model were selected based on clinical relevance and the results of univariate analyses. Because the number of participants with deterioration was limited, only a restricted number of clinically relevant variables were entered into the model. Odds ratios and 95% confidence intervals were calculated.

Receiver operating characteristic (ROC) curve analysis was performed for baseline factors associated with global sagittal alignment deterioration to evaluate their discriminative ability. The area under the curve (AUC) was calculated, and the optimal cutoff value was determined using the Youden index.

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 28 (IBM Corp., Armonk, NY, USA).

Results

A total of 135 participants were included. Among them, 19 participants (14.1%) demonstrated deterioration of global sagittal alignment, defined as an increase in SVA of ≥ 50 mm over 10 years, and 116 participants (85.9%) were classified as the maintenance group.

Baseline characteristics

Demographic characteristics and PROs are shown in Table 1. Participants with alignment deterioration were significantly older than those without deterioration (72.2 ± 4.0 vs. 67.9 ± 6.5 years, p = 0.005). There were no significant differences between the groups in sex, height, body weight, body mass index, or PROs.

Table 1
Demographic characteristics and Patient-reported outcomes

N	**deteriorated**			**maintained**			**P-value**
	19			**116**			
Sex (F/M)	13 / 6			76 / 40			1
Age (years)	**72.2**	**±**	**4.0**	**67.9**	**±**	**6.5**	**0.005***
Height (cm)	152.5	±	10.2	156.2	±	8.0	0.076
Weight (kg)	54.3	±	11.9	55.0	±	10.1	0.783
BMI (kg/m^2)	23.2	±	2.9	22.5	±	22.5	0.369
ODI (%)	8.4	±	0.89	9.3	±	10.5	0.721
EQ-5D	0.89	±	0.16	0.85	±	0.15	0.401
*Statistically significant							
BMI: body mass index							
ODI: Oswestry Disability Index							

Radiographic parameters and physical function are summarized in Table 2. The deterioration group had significantly lower SS than the maintenance group (27.4 ± 10.7° vs. 32.6 ± 8.4°, p = 0.017) and significantly higher PT (21.2 ± 9.0° vs. 16.1 ± 7.2°, p = 0.007). In contrast, PI, LL, TK, PI-LL, and SVA did not differ significantly between the groups.

Table 2
Radiographic parameters and physical function at baseline

TK (°)	**deteriorated**	**maintained**	**P-value**
	32.8 ± 12.0	**30.8 ± 11.2**	**0.472**
LL (°)	39.5 ± 18.5	43.7 ± 13.5	0.233
upper LL (°)	12.3 ± 14.3	14.3 ± 11.6	0.484
lower LL (°)	27.2 ± 14.2	30.0 ± 8.3	0.235
SS (°)	**27.4 ± 10.7**	**32.6 ± 8.4**	**0.017**
PT (°)	**21.2 ± 9.0**	**16.1 ± 7.2**	**0.007**
PI (°)	48.7 ± 10.2	48.7 ± 9.4	0.992
PI - LL (°)	10.7 ± 18.0	5.2 ± 11.4	0.08
SVA (mm)	36.6 ± 38.3	31.8 ± 30.3	0.541
Prone trunk extension (cm)	**30.5 ± 8.9**	**35.3 ± 8.8**	**0.027**
Sit and reach test (cm)	**13.2 ± 8.0**	**18.6 ± 7.6**	**0.005**
One-leg standing with eye open (sec)	48.3 ± 16.9	48.2 ± 18.0	0.971
Functional reach test (cm)	35.8 ± 5.9	38.9 ± 6.4	0.051
*Statistically significant			
TK: thoracic kyphosis, LL: lumbar lordosis,			
SS: sacral slope, PT: pelvic tilt,			
PI: pelvic incidence, SVA: sagittal vertical axis			

Regarding physical function, the deterioration group had significantly lower prone trunk extension (30.5 ± 8.9 cm vs. 35.3 ± 8.8 cm, p = 0.027) and lower sit-and-reach test (13.2 ± 8.0 cm vs. 18.6 ± 7.6 cm, p = 0.005). Functional reach test tended to be lower in the deterioration group, although the difference did not reach statistical significance. One-leg standing time with eyes open did not differ significantly between the groups.

Ten-year changes in radiographic parameters and patient-reported outcomes

longitudinal changes in radiographic parameters and PROs are presented in Table 3. Compared with the maintenance group, the deterioration group demonstrated a significantly greater reduction in lumbar

lordosis (-16.0 ± 15.5° vs. -3.0 ± 8.0°, $p < 0.001$). Both uLL and loLL declined more substantially in the deterioration group. The deterioration group also showed a significantly greater increase in PI-LL mismatch (15.7 ± 10.2° vs. 3.8 ± 7.6°, $p < 0.001$) and SVA (73.6 ± 29.8mm vs. -1.6 ± 33.1mm, $p < 0.001$).

Table 3
Longitudinal changes in radiographic parameters and Patient-reported outcomes

TK 5/12 (°)		**deteriorated**	**maintained**	**P value**
	2012	**32.84 ± 12.0**	**30.8 ± 11.2**	**0.472**
	2022	33.9 ± 16.3	33.3 ± 12.6	0.863
	Δ	1.1 ± 10.9	2.5 ± 7.5	0.467
LL L1/S1 (°)	2012	27.2 ± 14.2	30.0 ± 8.3	0.235
	2022	23.1 ± 15.4	30.1 ± 8.5	**0.004**
	Δ	-4.1 ± 8.5	0.15 ± 5.8	**0.006**
upper LL L1/4 (°)	2012	12.314.3	14.3 ± 11.6	0.484
	2022	2.5 ± 13.2	10.7 ± 12.9	**0.012**
	Δ	-9.7 ± 14.7	-3.7 ± 9.2	**0.017**
lower LL L4/S1 (°)	2012	27.2 ± 14.2	30.0 ± 8.3	0.235
	2022	23.1 ± 15.4	30.1 ± 8.5	**0.004**
	Δ	-4.1 ± 8.5	0.2 ± 5.8	**0.006**
SS (°)	2012	27.4 ± 10.7	32.6 ± 8.4	**0.017**
	2022	21.3 ± 11.0	27.9 ± 10.1	**0.01**
	Δ	-6.1 ± 6.3	-4.7 ± 5.4	0.321
PT (°)	2012	21.2 ± 9.0	16.1 ± 7.2	**0.007**
	2022	27.9 ± 11.6	21.7 ± 9.4	**0.012**
	Δ	6.7 ± 6.2	5.6 ± 5.2	0.429
PI (°)	2012	48.7 ± 10.2	48.7 ± 9.4	0.992
*Statistically significant				
TK: thoracic kyphosis, LL: lumbar lordosis,				
SS: sacral slope, PT: pelvic tilt,				
PI: pelvic incidence, SVA: sagittal vertical axis				
BMI: body mass index, ODI: Oswestry Disability Index				
EQ-5D: EuroQol five-dimensional questionnaire				

TK 5/12 (°)		deteriorated	maintained	P value
	2012	**32.84 ± 12.0**	**30.8 ± 11.2**	**0.472**
	2022	49.2 ± 10.2	49.3 ± 10.4	0.948
PI-LL (°)	2012	10.7 ± 18.0	5.2 ± 11.4	0.08
	2022	26.4 ± 23.4	9.1 ± 13.2	**<0.001**
	Δ	15.7 ± 10.2	3.8 ± 7.6	**<0.001**
SVA (mm)	2012	36.6 ± 38.3	31.8 ± 30.3	0.541
	2022	110.2 ± 54.2	30.2 ± 41.9	**<0.001**
	Δ	73.6 ± 29.8	-1.6 ± 33.1	**<0.001**
ODI (%)	2012	4.00 [0.00, 31.00]	6.00 [0.00, 62.00]	0.563
	2022	24.00 [4.00, 44.00]	7.00 [0.00, 47.00]	**<0.001**
EQ-5D	2012	1.00 [0.58, 1.00]	0.78 [0.48, 1.00]	0.458
	2022	0.69 [0.60, 1.00]	0.77 [0.48, 1.00]	**0.009**
Height (cm)	2012	152.5 ± 10.2	156.2 ± 8.0	0.076
	2022	149.5 ± 11.1	154.4 ± 8.2	**0.023**
	Δ	-2.9 ± 1.8	-1.7 ± 1.4	**0.001**
*Statistically significant				
TK: thoracic kyphosis, LL: lumbar lordosis,				
SS: sacral slope, PT: pelvic tilt,				
PI: pelvic incidence, SVA: sagittal vertical axis				
BMI: body mass index, ODI: Oswestry Disability Index				
EQ-5D: EuroQol five-dimensional questionnaire				

PROs deteriorated more substantially in the deterioration group, with a greater increase in ODI (13.2 ± 12.8% vs. 2.6 ± 11.0%, p < 0.001) and a greater decrease in EQ-5D (-0.16 ± 0.16 vs. -0.03 ± 0.17%, p = 0.003) than in the maintenance group.

Logistic regression and ROC analysis

Logistic regression analysis was performed to evaluate baseline factors associated with deterioration of global sagittal alignment (Table 4). Higher baseline PT was identified as a factor associated with deterioration (Odds ratio, 1.07; 95% confidence interval, 1.00–1.15; p = 0.04). Age, prone trunk extension, and sit-and-reach test were not independently associated with deterioration in the multivariable model.

Table 4
Logistic regression analysis for global sagittal alignment deterioration

Variable	Odds ratio	95%CI	P value
Age	1.07	0.97–1.19	0.16
Pelvic Tilt (2012)	**1.07**	**1.00-1.15**	**0.04**
Prone trunk extension	0.97	0.89–1.05	0.41
Sit and reach test	0.94	0.89–1.01	0.086
*Statistically significant			

ROC curve analysis was performed to evaluate the discriminative ability of baseline PT for global sagittal alignment deterioration. The AUC was 0.685 (95% confidence interval, 0.547–0.823; p = 0.010). The optimal cutoff value was 19.5°, with a sensitivity of 57.9% and specificity of 73.3% (Fig. 2).

Case presentation

Representative cases are shown in Figs. 3 and 4. These cases illustrate that 10-year changes in global sagittal alignment vary among individuals. In particular, the case with subsequent deterioration already showed greater pelvic retroversion, smaller uLL, and reduced trunk extensor function at baseline, whereas the case with preserved alignment showed smaller PT, greater uLL, and better trunk extension.

Figure 3 shows a 74-year-old female who demonstrated deterioration of global sagittal alignment over 10 years. At baseline(A), she had relatively high PT, reduced uLL, and low prone trunk extension, suggesting pelvic retroversion, limited upper lumbar compensation, and reduced trunk extensor function. Over 10 years(B), LL decreased from 33° to 15°, uLL decreased from 12° to 0°, SVA increased from 50.9 mm to 128 mm, and PI–LL mismatch increased from 12° to 31°.

Figure 4 shows a 72-year-old woman with preserved global sagittal alignment over 10 years. At baseline (A), she had lower PT, greater uLL, and better prone trunk extension than the deteriorated case. Over 10 years (B), LL was maintained from 50° to 55°, uLL was maintained from 22° to 25°, SVA remained stable from 54.2 mm to 45.3 mm, and PI–LL mismatch improved from 6° to 1°.

Discussion

In this 10-year community-based cohort study, 14.1% of participants developed deterioration of global sagittal alignment. Participants with subsequent deterioration already had pelvic retroversion and reduced physical function at baseline, despite comparable SVA and PROs. During follow-up, they showed greater loss of lumbar lordosis, greater increases in PI–LL mismatch and SVA, and worsening PROs. These findings suggest that compensatory pelvic retroversion and impaired physical function may represent early features preceding apparent sagittal imbalance and clinical worsening.

Age-related changes in sagittal alignment have been reported in previous longitudinal studies. Takeda et al. showed that aging is associated with loss of lumbar lordosis and anterior shift of the trunk over long-term follow-up [1]. Oe et al. also suggested that age-related sagittal alignment deterioration may begin with pelvic changes before progression of spinal malalignment becomes apparent[3]. The present findings are consistent with these reports.

In the present cohort, participants with later SVA deterioration had higher PT and lower SS despite comparable baseline SVA. With progressive loss of lumbar lordosis, this compensatory mechanism may become insufficient, leading to anterior trunk shift. Schwab et al. established PT, SVA, and PI–LL mismatch as sagittal modifiers in the SRS-Schwab classification and further demonstrated that these parameters are associated with disability in adult spinal deformity [7,8]. Although the present study was based on a community cohort rather than a surgical deformity population, higher baseline PT may represent a compensated stage before apparent sagittal imbalance develops.

Physical function may also play an important role in the maintenance of sagittal alignment. In this study, participants with SVA deterioration had lower prone trunk extension and lower sit-and-reach test at baseline. Prone trunk extension may reflect trunk extensor function, whereas sit-and-reach test may reflect flexibility of the spine and hamstring. Takahashi et al. reported that back muscle and lower-extremity strength are related to compensatory mechanisms of sagittal alignment in older adults [16]. Imagama et al. reported that spinal sagittal alignment is related to body balance, muscle strength, physical ability, and fall risk in middle-aged and elderly men[17]. These findings support the concept that maintenance of sagittal alignment depends on not only structural spinal changes but also the physical capacity required to maintain upright posture.

The longitudinal changes observed in this study suggest that SVA deterioration has clinical relevance. Participants with later deterioration showed greater reductions in lumbar lordosis and greater increases in PI–LL mismatch and SVA over 10 years, accompanied by worsening ODI and EQ-5D. Increased SVA, PT, and PI–LL mismatch have been associated with pain, disability, and reduced health-related quality of life in adult spinal deformity. Moreover, changes in SRS-Schwab sagittal modifiers have been linked to clinically meaningful changes in HRQOL [6,8–10]. Although the present cohort differed from surgical adult spinal deformity populations, the concurrent worsening of sagittal parameters and PROs suggests that age-related SVA deterioration may be clinically meaningful in a community-based population, particularly in individuals with reduced compensatory reserve.

These findings may help identify individuals at risk for future sagittal imbalance at an early stage. Baseline PT may serve as a simple radiographic marker of pelvic compensation, whereas prone trunk extension and sit-and-reach test may reflect physical reserve for maintaining upright posture. Previous studies have suggested that pelvic changes, trunk and lower-extremity muscle function, and spinopelvic morphology are involved in age-related sagittal compensation [3,5,22–25]. In the present study, a baseline PT of approximately 20° was suggested as a possible reference value for identifying individuals at risk for subsequent sagittal alignment deterioration. However, the discriminative ability of PT alone was modest, indicating that pelvic retroversion by itself is insufficient to fully distinguish individuals who will deteriorate from those who will maintain alignment. Therefore, combined assessment of spinopelvic parameters and physical function may help identify older adults at risk for future sagittal imbalance before SVA progression or PRO decline becomes evident. In particular, physical function a potentially modifiable and may represent a clinically important target for preventive exercise-based interventions in individuals at increased risk.

This study has several limitations. First, the number of participants with SVA deterioration was relatively small, which limited the number of variables included in the logistic regression model. Second, although prone trunk extension and sit-and-reach test were used as functional measures, direct assessments of back extensor strength, muscle mass, and muscle quality were not available. Third, lower-extremity alignment, hip and knee contracture, and dynamic postural compensation were not fully evaluated. These factors may influence global sagittal balance.

In conclusion, this 10-year community-based cohort study showed that deterioration of global sagittal alignment occurred in 14.1% of participants. Participants with subsequent SVA deterioration had pelvic retroversion and reduced physical function at baseline, despite comparable SVA and PROs. These findings suggest that pelvic compensation and reduced physical function may appear before sagittal imbalance and may help identify older adults at risk for age-related sagittal alignment deterioration.

Declarations

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Conflict of interest: Competing interests SO worked in a donation-endowed laboratory in the Division of Geriatric Musculoskeletal Health. The remaining authors declare no conflicts of interest.

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Author contributions: Y.M. drafted the manuscript and performed the main analyses. Y.Y. contributed to the conception and design of the study and supervised the project. All authors contributed to data interpretation, critically reviewed the manuscript, and approved the final version of the manuscript.

Ethical approval

We conducted this study in compliance with the principles of the Declaration of Helsinki. The study protocol was approved by the institutional review board of our institution (approval number 23-210). The requirement for informed consent was waived because of the retrospective nature of this study.

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Figures

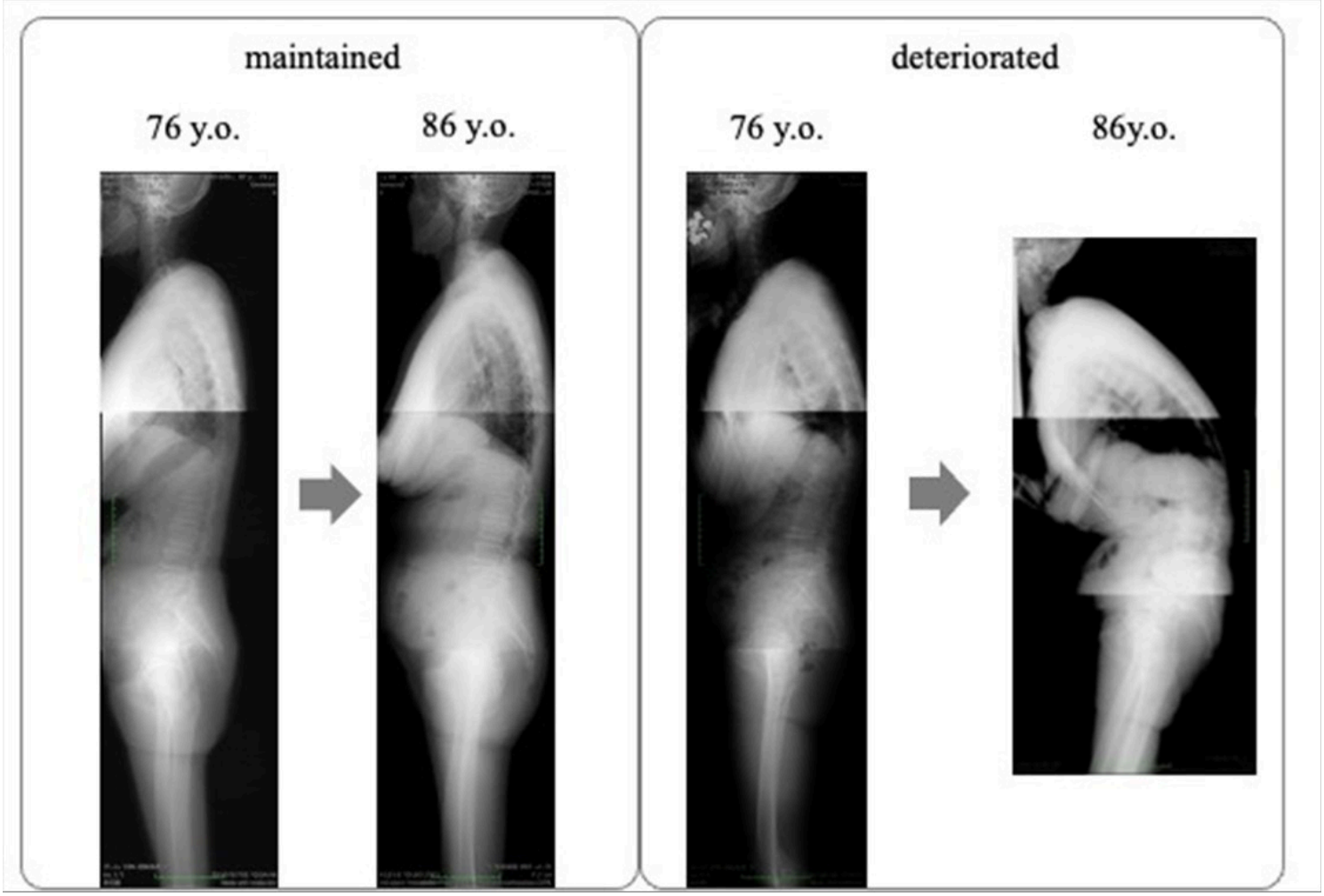


Figure 1

Whole-spine radiographs showing two different patterns of 10-year sagittal alignment change.

One participant maintained relatively stable global sagittal alignment over 10 years, whereas another participant demonstrated deterioration with anterior trunk shift. These cases illustrate that age-related sagittal alignment changes are not uniform among individuals.

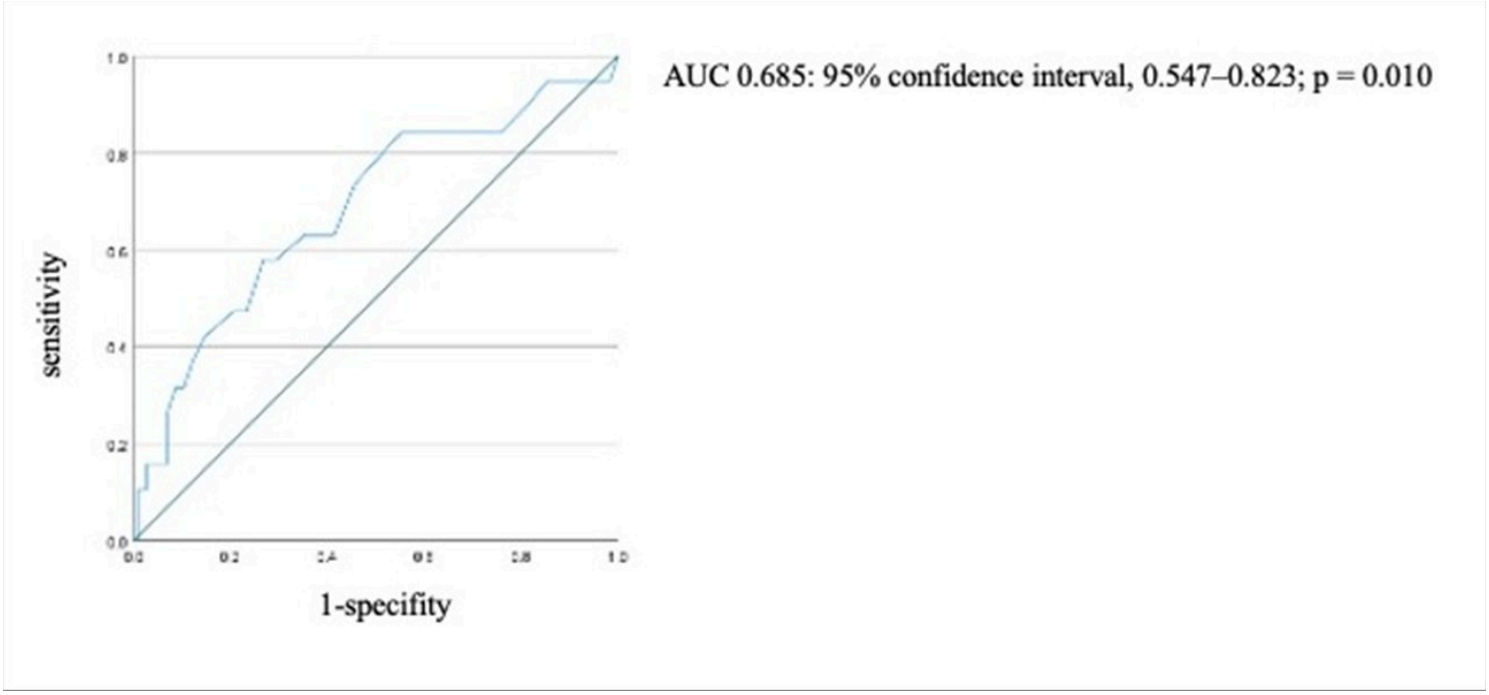


Figure 2

Receiver operating characteristic (ROC) curve of baseline pelvic tilt for global sagittal alignment deterioration.

ROC curve analysis was performed to evaluate the discriminative ability of baseline pelvic tilt for deterioration of global sagittal alignment. The area under the curve was 0.685. The optimal cutoff value was 19.5°, with a sensitivity of 57.9% and specificity of 73.3%.



Figure 3

Representative case with deterioration of global sagittal alignment over 10 years.

A 74-year-old woman showed deterioration of global sagittal alignment during the 10-year follow-up. At baseline (A), she had relatively high PT, reduced uLL, and low prone trunk extension. Over 10 years (B), LL

decreased from 33° to 15°, uLL decreased from 12° to 0°, SVA increased from 50.9 mm to 128 mm, and PI–LL mismatch increased from 12° to 31°.

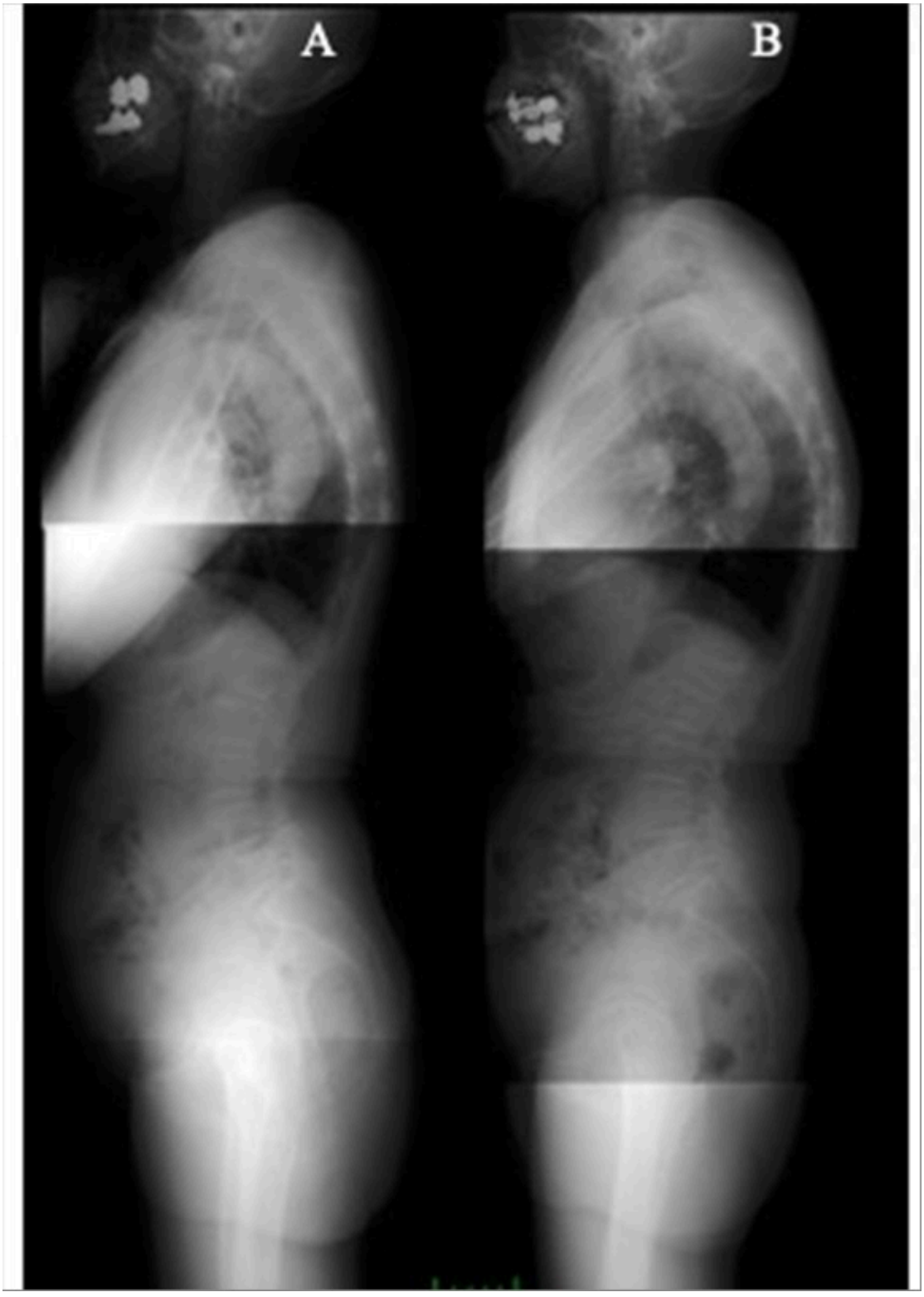


Figure 4

Representative case with preserved global sagittal alignment over 10 years.

A 72-year-old woman maintained global sagittal alignment during the 10-year follow-up. At baseline (A), she had lower PT, greater uLL, and better prone trunk extension than the deteriorated case. Over 10 years (B), LL was maintained from 50° to 55°, with preserved uLL and loLL. SVA remained stable from 54.2mm to 45.3 mm, and PI–LL mismatch improved from 6° to 1°.