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Clinical Study

Adult spinal deformity and its relationship with hip range of motion: a cohort study of community-dwelling females

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Abstract

BACKGROUND CONTEXT: Adult spinal deformity affects lower extremity alignment with compensation in joint range of motion (ROM) and alignment of the hip.

PURPOSE: To investigate the relationship between sagittal spinopelvic alignment and the ROM of the hip joint and the femoral oblique angle (FOA).

STUDY DESIGN: Cross-sectional, observational cohort study of community-dwelling Japanese women.

METHODS: The study group included 158 women, enrolled in our ongoing prospective cohort study, with upright spine radiographs and physical measurements obtained for all participants. Radiographic spinopelvic parameters included measurement of thoracic kyphosis, lumbar lordosis (LL), sagittal vertical axis (SVA), sacral slope, pelvic incidence, and pelvic tilt (PT). FOA parameters were measured on hip radiographs and hip ROM included external and internal rotation and extension. The association between spinopelvic parameters, the FOA, and hip joint ROM was evaluated using Spearman's correlation analysis.

RESULTS: External rotation of the hip was correlated with LL (R=0.179, p=.024), PT (R=−0.273, p=.001) and SVA (R=−0.215, p=.007), with the FOA being correlated with the SVA (R=0.502, p<.001).

CONCLUSIONS: The decrease in hip external rotation with adult spinal deformity might reflect a structural modification in spinopelvic alignment. An increase in FOA was associated with an increase in SVA, indicative of a sagittal malalignment in the decompensated phase of adult spinal deformity.

Keywords: Alignment; External rotation; Extremity; Femoral oblique angle; Hip joint; Pelvis; Posture; Range of motion; Spine deformity

Introduction

Recently, studies have shown that progression of adult spinal deformity (ASD) is related to a decline in quality of life (QOL) related to pain and disability [1−3]. Moreover, ASD is associated with changes in gait and an increased risk of falling [4−7]. Reports of the use of surgical treatment for ASD have increased. Of note, understanding the normative changes in spinal alignment that occur with age is of primary importance for planning surgery. The aging spine is associated with disc degeneration [8], muscle weakness [9] and reduced bone quality [10]. The resulting degenerative spinal deformities usually start with a decrease in lumbar lordosis (LL), which is primarily compensated for pelvic retroversion and modified alignment of the lower extremities [11]. Barry et al reported that compensation mechanisms to maintain spinal balance with

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increasing deformity involve the cervical spine and pelvis as well as the hip, knee, and ankle joints [12]. Among these compensations, pelvic retroversion induces an anterior opening of the acetabulum, which might alter the kinematics of the hip joint and possibly lead to secondary hip joint osteoarthritis[13]. This might also increase the risk of hip dislocation in patients who have undergone a total hip replacement[14]. Therefore, it is important to investigate the changes that occur in the hip joint as a compensation to changes in spinopelvic alignment.

The resulting degenerative spinal deformities usually is influenced by various factors, including muscle strength, spinal range of motion (ROM) and alignment, and ROM of the lower limbs. However, many studies have focused on radiological examination with little attention to muscle strength and ROM. Kobayashi et al reported an association between lumbar degenerative kyphosis and decreased trunk extensor muscle strength and active and passive lumbar spine ROM, indicative of the importance of nonradiological parameters of ASD [15]. Nonradiological factors are also important to evaluate the impact of the compensation mechanism on the hip joint. A biomechanical study showed that restriction in external hip rotation is associated with retroversion of the pelvis, although the effect of a posterior inclination of the pelvis on hip ROM has not been evaluated in clinical practice [16]. Therefore, it is not clear whether ASD affects the ROM of the lower limbs, specifically of the hip joint, which is adjacent to the spinopelvic segment. Accordingly, our aim in this study was to investigate the relationship between radiological spinopelvic alignment and ROM of the hip joint among community-based Japanese women.

Materials and methods

This study is one component of our ongoing longitudinal cohort study, the Asahikawa observational study of Spinal Aging in a Prospective cohort (the ASAP study), which has been recruiting community-based volunteers. Participants are invited to the ASAP study using a population registry. The sample population for the ASAP study includes community-dwelling women, ≥50 years old, excluding those with a previous history of spinal surgery, hip joint replacement, neuromuscular disease, serious illness, or difficulty in performing physical assessments due to back pain or vertebral fracture. The ASAP study includes not only measurement of radiological parameters but also physical parameters of hip ROM.

The study was approved by the Ethical Review Board of our University. All participants provided written informed consent to have their data used for research purposes.

Full length standing spinal radiographs were obtained using a standard method, with participants standing in a relaxed posture, with knees maximally extended and arms supported on an arm rest. The following radiographic measurements were performed in the lateral view (Fig. 1): (1) thoracic kyphosis (TK; measured as the angle between the upper endplate of T4 and the lower endplate of T12); (2) LL (measured as the angle between the upper the endplate of L1and S1); (3) sagittal vertical axis (SVA; defined as the distance between a plumb line passing through C7 and the posterior edge of S1); (4) sacral slope (angle between a line drawn along the upper sacral endplate and the horizontal reference); (5) pelvic incidence (angle between a line through the center of the femoral head and the midpoint of the sacral table and a line perpendicular to the sacral table); (6) pelvic tilt (PT; angle between a line passing through the center of the femoral head and the midpoint of the sacral table and the vertical reference); and (7) femoral oblique angle (FOA; defined as the angle between the femoral axis and vertical line, as reported by Le Huec et al [16] and Cogniet et al [17], using the mean value of the right and left femur in the analysis). Measurement of the ROM was performed by the same physical therapist, and included hip extension, hip internal rotation (hip IR) and hip external rotation (hip ER). ROM was measured passively, using handheld goniometry, with the total ROM recorded for analysis. Handheld goniometry is a reliable measure of ROM, with a sufficiently high intratester reliability [18,19] and standard error of measurement of ±2° [20]. Measurement of hip extension was performed with the participant in a prone position. The reference axis of the goniometer was parallel to a line bisecting the trunk, with the moving axis parallel to a line connecting the center of the femur and the greater trochanter. Manual stabilization was applied to the lumbar vertebra and pelvis to prevent extraneous movement which would affect the endpoint of measurement. Measurement

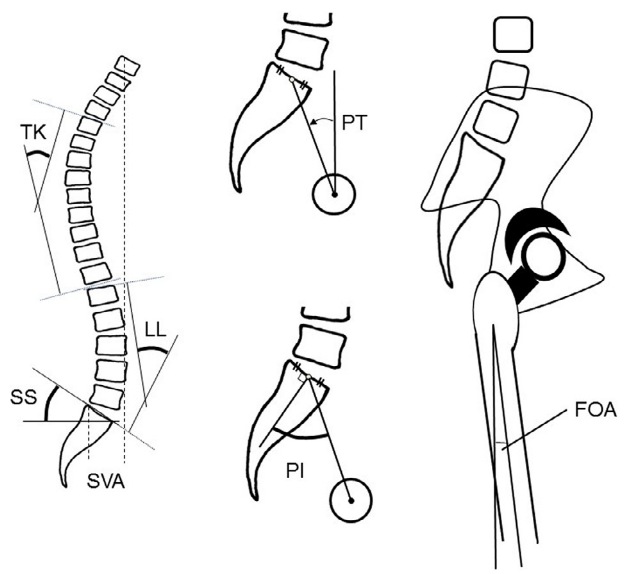

Fig. 1. Radiographic measurements of spinopelvic alignment, including: (left) thoracic kyphosis (TK), lumbar lordosis (LL), sacral slope (SS), and sagittal vertical axis (SVA); (center),pelvic incidence (PI) and pelvic tilt (PT);and (light)femoral oblique angle (FOA).

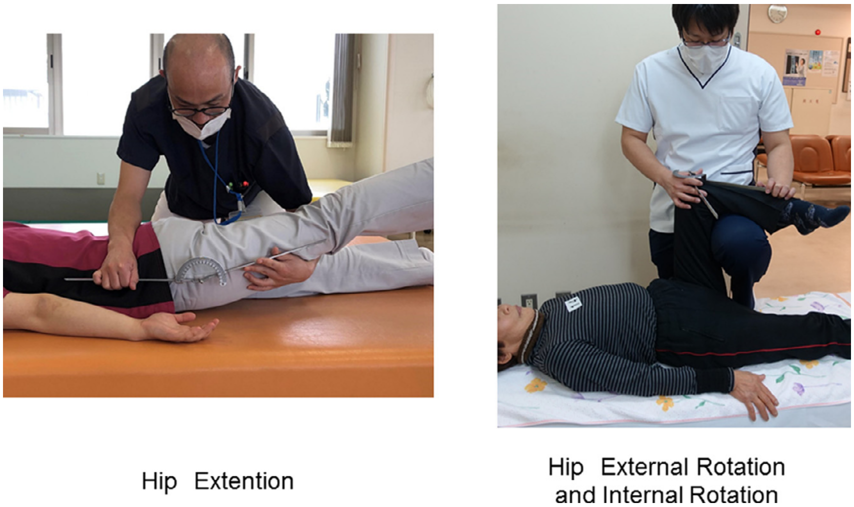

Fig. 2. Measurement of the range of motion (ROM) of the hip. Hip external rotation and internal rotation were measured in the supine position, with the hip and knee in 90˚ of flexion (right). Hip extension was measured in the prone position (left).

of hip IR and ER was performed with the participant in a supine position, with the hip and knee flexed to 90˚. The reference axis was parallel to a vertical line originating at the center of the patella and the moving axis was aligned with the midline of the crus. Again, support and stabilization were provided to prevent extraneous movements. ROM was times, and the average score was used for analysis (Fig. 2).

Statistical analysis

All statistical analyses were performed using SPSS Statistics version12 (IBM, Tokyo, Japan).All data are expressed as a mean and standard deviation (SD).The normal distribution of the variables was verified using the Shapiro-Wilk test. As measurement variables were found to have a non-normal distribution, Spearman's correlation was used to evaluate the association between spinopelvic parameters and ROM of the hip joint and the FOA. Two subanalyses were performed, one with regard to ER and the other to the FOA, to evaluate the association between changes in spinopelvic parameters with ASD and hip ROM and alignment. For both subanalyses, the ER and FOA were subdivided into three groups, as follows: reduced group (<mean−1/2 SD); standard group (mean±1/2 SD); and increased group (>mean+1/2 SD). Between group differences in measured parameters were evaluated using a one-way analysis of variance (ANOVA), with the Games-Howell test post hoc test. A p value <.05 was considered as a significant difference.

Results

The study group included 158 women (mean age, 67.2 years; range, 60−85 years). Radiographic measurements are reported in Table 1, with the correlation coefficients between hip ROM measurements and the spinopelvic parameters summarized in Table 2.1. The highest correlation was identified between the spinopelvic parameters and hip ER, with a lower correlation to hip extension. The group cutoffs of ER for subanalysis were as follows: reduced group, hip ER <77 (n=47); standard group, hip ER 78−90˚ (n=73) and increased group, hip ER >91˚ (n=38) (Table 2.2). Comparison of the radiological parameters among the three groups revealed a significant correlation between a reduced hip ER and a decrease in LL and an increase in PT and SVA (compared to the standard and increased ER group; Fig. 3−5).

Table 1
Radiographic measurements and range of motion of the hip joint for the 158 female participants

Variable	Mean (SD)
Thoracic kyphosis (˚)	28 (13)
Lumbar lordosis (˚)	37 (17)
Sacral slope (˚)	27 (10)
Pelvic incidence (˚)	52 (11)
Pelvic tilt (˚)	25 (10)
Sagittal vertical axis (mm)	22 (40)
Femoral oblique angle (˚)	7 (4)
Hip extension (˚)	44(15)
Hip internal rotation (˚)	73 (16)
Hip external rotation (˚)	84 (14)

SD, standard deviation.

The correlation coefficients between the spinopelvic parameters and the FOA are reported in Table 3.1, showing a correlation between the FOA and the SVA. The group FOA cutoffs for subanalysis were as follows: reduced group, FOA<6˚ (n=58); standard group, FOA6−9˚ (n=53); and increased group, FOA>9˚ (n=47) (Table 3.2).The correlation between the FOA and an increased SVA was

Table 2.1
Spearman correlation of the range of motion of the hip joint and radiological parameters

Variables	Thoracic kyphosis	Lumbar lordosis	Sacral slope	Pelvic incidence	Pelvic tilt	Sagittal vertical axis
Hip extension	0.170*	0.199*	0.108	0.121	−0.035	−0.029
Hip internal rotation	−0.016	0.143	0.140	0.059	−0.120	0.035
Hip external rotation	−0.012	0.179*	0.241*	−0.074	−0.273†	−0.215†

* Statistically significant correlation coefficient ($p<.05$).
† Statistically significant correlation coefficient ($p<.01$).

Table 2.2
Radiographic measurements of subdividing three hip ER Group

Variable	Reduced group (ER<77) N=47	Standard group (78−90) N=73	Increased group (91<ER) N=38
Thoracic kyphosis	27 (16)	31 (12)	26 (9)
Lumbar lordosis	31 (21)	40 (15)	40 (14)
Sacral slope	24 (12)	28 (9)	31 (9)
Pelvic incidence	53 (11)	51 (10)	52 (12)
Pelvic tilt	30 (13)	24 (9)	22 (8)
Sagittal vertical axis	34 (49)	21 (39)	12 (32)

Mean(SD).

significant greater for the increased FOA group, compared to the reduced and standard FOA groups (Fig. 6).

Discussion

To our knowledge, this is the first study to examine the relationship between sagittal spinopelvic alignment and ROM of the hip joint and the FOA in an asymptomatic population. Our study revealed a stronger correlation between changes in spinopelvic parameters and hip ER than either hip IR or flexion. Specifically, on subanalysis for the three ER subgroups, a decrease in hip ER was associated with a reduced LL and increased PT and SVA, indicative of an influence of ASD on hip ER. Similarly, on hip alignment, the SVA was highest for the increased FOA subgroup. Using the sacrofemoral angle as a parameter, which is a modified parameter of the FOA, Takemitsuet al first reported that lumbar degenerative kyphosis influenced the alignment and mechanics of the pelvis and hip joint [21]. In addition, Barry et al described a compensatory mechanism

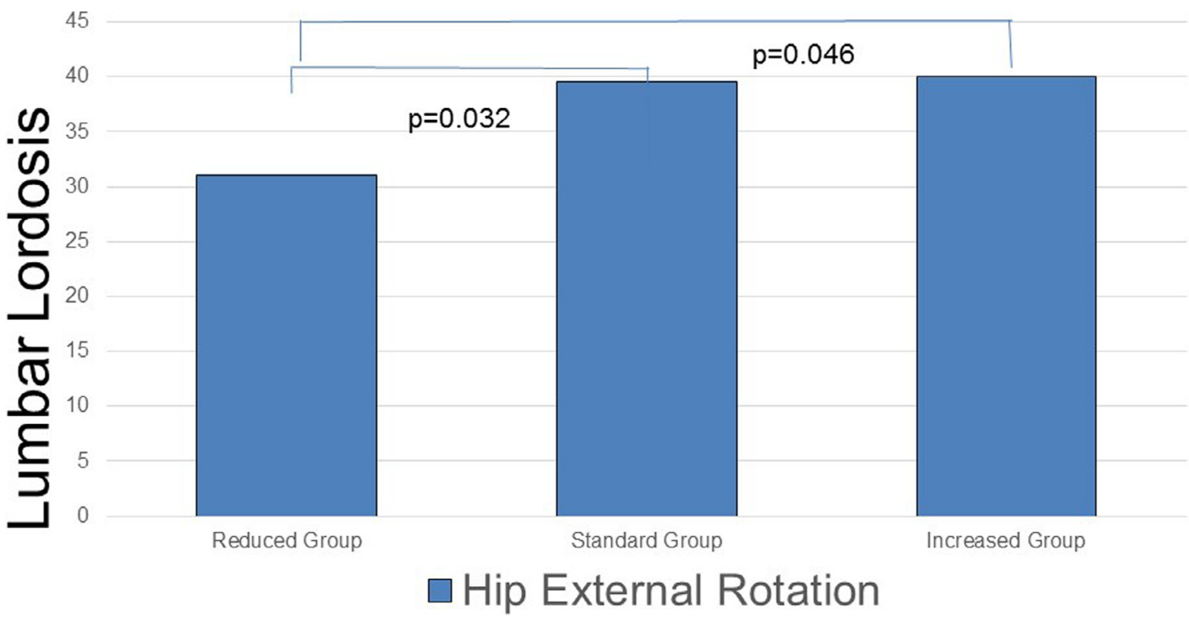

Fig. 3. Comparison of the radiological parameters of lumbar lordosis (LL) among the three hip external rotation (hip ER) groups (reduced, standard, and increased).

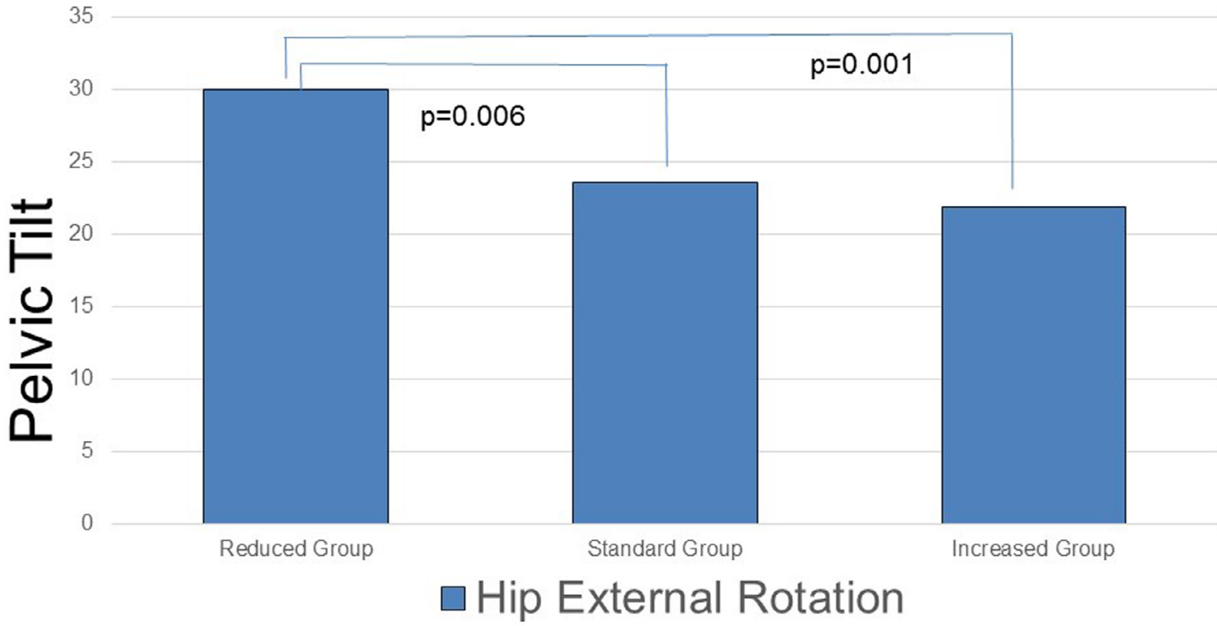

Fig. 4. Comparisons of the radiological parameters of pelvic tilt (PT) among the three hip external rotation (hip ER) groups (reduced, standard and increased).

for spinal deformity, which includes adaptation at the level of the cervical spine, pelvis, hip, knee, and ankle joints [12]. The specific compensation for sagittal spinopelvic malalignment at the level of the lower limbs has been investigated in several studies, with the EOS imaging technique (EOS imaging, Paris, France) being widely used in this regard due to the detailed imaging information it provides. Lafage et al described lower limb compensation strategies relative to the SVA, while Ferrero et al evaluated lower limb compensation strategies relative to spinopelvic parameters [22,23].

Changes in lower extremity alignment affect other factors, including muscle power and volume, joint movement and soft tissue tension [24−26]. In this regard, however, studies on the modified ROM of the lower limb due to sagittal spinopelvic malalignment have been limited. Jung and

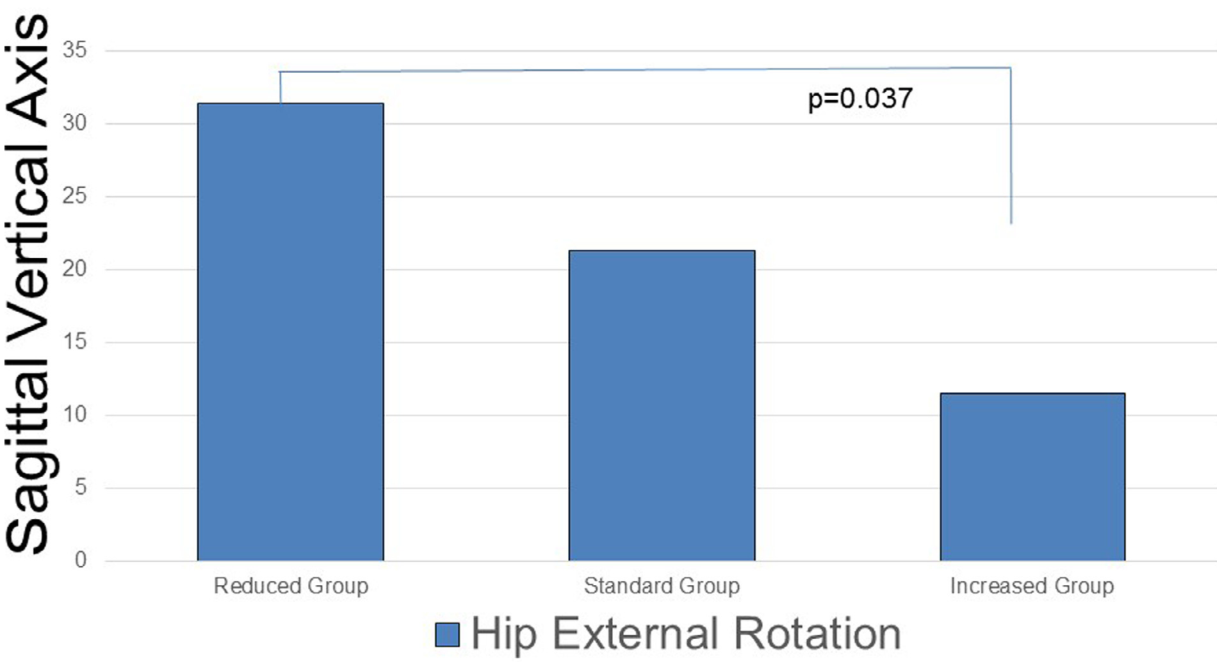

Fig. 5. Comparisons of the radiological parameters of the sagittal vertical axis (SVA) among the three hip external rotation (hip ER) groups (reduced, standard and increased).

Table 3.1
Spearman correlation between radiological parameters and femoral oblique angle

Parameter	Correlation coefficient	p value
Thoracic kyphosis	−0.064	.428
Lumbar lordosis	−0.441	<.001†
Sacral slope	−0.453	<.001†
Pelvic incidence	−0.166	.037*
Pelvic tilt	0.269	.01*
Sagittal vertical axis	0.502	<.001†

* Statistically significant correlation coefficient (p<.05).
† Statistically significant correlation coefficient (p<.01).

Table 3.2
Radiographic measurements of subdividing femoral oblique angle group

Variable	Reduced group (FOA<6) N=58	Standard group (6−9) N=53	Increased group (10<FOA) N=47
Thoracic kyphosis	29 (12)	31 (13)	26 (14)
Lumbar lordosis	45 (12)	40 (12)	25 (21)
Sacral slope	32 (7)	28 (8)	21 (12)
Pelvic incidence	55 (10)	50 (10)	50 (13)
Pelvic tilt	23 (8)	23 (9)	50 (13)
Sagittal vertical axis	3 (31)	16 (32)	52 (46)

Mean (SD).
SD, standard deviation; FOA, femoral oblique angle.

Yamasaki did report an important association between lower limb ROM and strength and physical performance [27] Specifically, lower extremity ROM and muscle strength were associated with physical performance, independent living and overall QOL [27]. Among the joints of the lower limbs, the hip is unique as a ball-and-socket joint (composed of the acetabulum of the pelvis and femoral head of the femur), with motion along the three anatomical planes, in addition to the combined motion of circumduction. As ASD influences pelvic retroversion, which causes acetabular anteversion and posterior acetabular impingement, then it makes sense that retroversion of the pelvis would limit femoral neck motion and, thus, hip ER (Fig. 7). Lazennec et al previously reported that a 1° of PT was associated with a 0.5° of acetabular anteversion [28]. Additionally, in their biomechanical study of total hip arthroplasty, Sato et al reported that changes in PT led to changes in the range of hip ER [29], with complete structural spinopelvic malalignment and pelvic retroversion resulting in a significant reduction in hip ER.

Yagi et al examined the gait patterns of patients with ASD, reporting abnormal gait patterns due to restrictions in the ROMs of the hip compared to healthy controls, with the extent of hip contracture correlating with the severity of

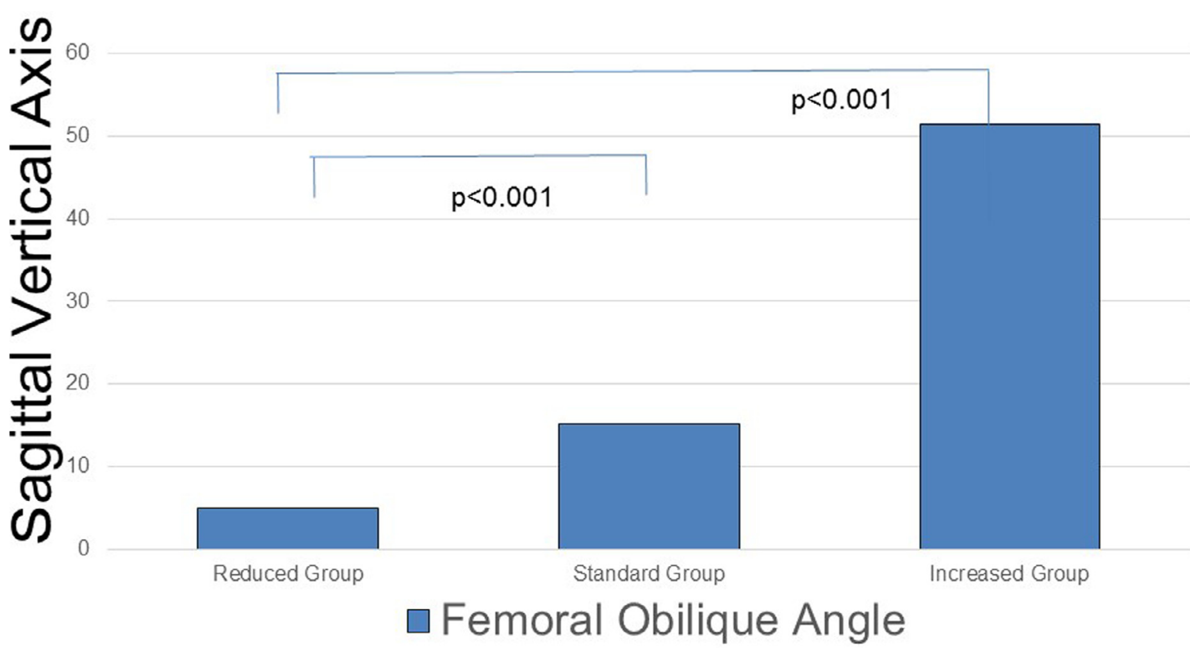

Fig. 6. Comparison of the radiological parameters of the sagittal vertical axis (SVA) among three femoral oblique angle (FOA) groups (reduced, standard and increased).

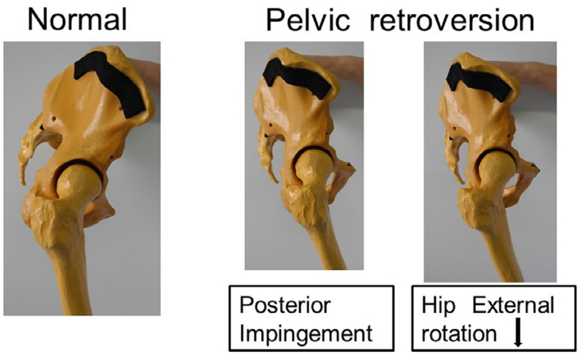

Fig. 7. Normal: spinopelvic model of a normal pelvis, with femoral neck anteversion. Pelvic retroversion: Adult model of spinal deformity, with the pelvic retroversion inducing a posterior impingement of the femoral neck. Hip external rotation is limited. If this structural malalignment is complete, then reduced hip external rotation occurs in patients with spinal deformity.

ASD [30]. If the pelvic retroversion becomes rigid, then structural changes occur in the hip joint, leading to limited hip ER, as we observed in our study.

Diebo et al reported that compensatory strategies for spinal malalignment in ASD were initiated in adjacent segments, with the primary adaptation for a decrease in LL occurring at the level of the pelvis [31] When compensation available at the pelvis is limited, then it becomes necessary for the femur to move anteriorly with increasing pelvic retroversion, which increases the FOA. Roussouly and Pinheiro-Franco reported that compensatory mechanisms were divided into three phases, namely normal, compensation, and decompensation [32]. The compensated phase did not include an increase in SVA, but did include an increase in PT. However, in the decompensation phase, the range of compensation at the level of the pelvis is limited, resulting in an increase in the FOA and appearance of anterior inclination of the trunk, which is the start of global sagittal malalignment. Therefore, the FOA is expected to be associated with the SVA, with an increase in the FOA being predictive of a global sagittal malalignment.

Le Huec et al described their use of a full balance integrated technique to evaluate sagittal alignment [16]. They describe the FOA as an important factor for the planning of surgical correction of ASD, with the FOA being included in the calculation of the preoperative index of correction. Mac-Thiong et al reported a correlation between the FOA and QOL, with the FOA being a useful parameter for evaluating sagittal alignment because it is easily measured [33].

In our study, ROM was measured by one physical therapist, using handheld goniometry, which has high intratester reliability. Inclinometers are increasingly being used in practice, owing to their ease of use compared to goniometers [34−35] and, thus, could provide an alternative to goniometry in future studies.

The limitations of our study should be acknowledged in the interpretation of results. First, we did not include all ROM parameters of the lower limb. These should be considered as a previous radiological study reported a correlation between ASD and knee and ankle angles [22]. Second, our study only included healthy Japanese women, with no history of spinal surgery and degeneration and no ASD. Therefore, our findings of the association between pelvis retroversion and decreased hip ER will need to be confirmed in patients with ASD. Third, it was found that ASD causes a change in the ROM of the hip joint, especially in ER. However, we did not the effects of this decrease in hip ER on performance in daily activities and gait restrictions. The association between ASD and clinical symptoms and performance of daily activities should be included in future studies.

In conclusion, with progressive ASD, adjustments occur at the level of the pelvis and the hip joint to maintain a balanced sagittal plane spinal posture. The extent of hip contraction, and associated decrease in hip ER, increases as a function of the extent of pelvis retroversion, with complete structure retroversion being associated with a significant reduction in the ROM in hip ER. An increase in FOA was associated with an increase on the SVA, which was expressed as global sagittal malalignment. Further studies are needed to expand our understanding of ASD and its relationship to the alignment and ROM of adjacent joints.

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