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Clinical, physical, and radiographic analyses of lumbar degenerative kyphosis and spondylolisthesis among community-based cohort.

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Concise title: Clinical and physical analyses of adult spinal deformity

Title

Clinical, Physical and Radiographic Analyses of Lumbar Degenerative Kyphosis and Spondylolisthesis Among Community-Based Cohort

[Structured Abstract]

Purpose To investigate longitudinal radiographic changes, and physical characteristics of lumbar degenerative kyphosis (LDK) and spondylolisthesis (DS).

Methods Two-hundred eighty nine community-based female subjects were recruited from population register and studied longitudinally for a mean 12.3 years. Upright entire spine radiographs were used to evaluate spinopelvic parameters including lumbar lordosis (LL), pelvic incidence (PI), and vertebral slip (% slip). Physical measurements included lumbar range of motion (ROM), isometric trunk muscle strength, and photometric gait posture using change in trunk inclination angle (dTIA).

Results Subjects' mean age (standard deviation; SD) was 56.9 (10.0) years at baseline and 68.5 (9.2) years at the final follow-up. Among 202 subjects who could perform instructed physical measurements, DS, defined as more than 5% slip, was found in 50 subjects (24.8%), and LDK, defined as LL of less than 1SD of mean value (<24.4°), was found in 24 subjects (11.9%). DS subjects showed significant weakness in trunk flexor strength (normal 282.5±73.0N vs. DS 245.5±75.5N, p=0.0219), and LDK subjects showed significant differences in; trunk extensor strength (normal 493.4±172.8N vs. LDK 386.3±167.6N, p=0.0066), ROM, and dTIA (normal 3.5±2.7° vs. LDK 7.6±4.8°, p<0.0001). PI was significantly larger in DS and smaller in LDK than normal subjects (normal 53.8±9.9° vs. DS 58.2±10.6°, p=0.0111; normal vs. LDK 48.4±9.2°, p=0.0191).

Conclusions Current study showed that DS was associated with reduced trunk flexor strength, which might increase pelvic anteversion, and LDK was associated with reduced extensor strength, ROM, and ambulatory kyphosis. Physical characteristics should be evaluated for successful management of adult spinal deformity.

Keywords: adult spinal deformity, sagittal spinal alignment, pelvic incidence, muscle weakness, gait posture

[Introduction]

Recent studies of adult spinal deformity (ASD), emphasizing the importance of pelvic parameters and sagittal balance, prompted the understanding of normal spinopelvic alignment, however, radiographic normative values are only one aspect of multifaceted degenerative conditions[10]. We have been investigating etiology of ASD using community-based cohorts, and Takemitsu et al. first reported comprehensive classification of lumbar degenerative kyphosis (LDK) in 1988[17]. Their study indicated that LDK patients showed severe histological atrophy in the back muscles and aggravated kyphosis during walk, along with radiographic degenerative changes. LDK was predominantly found in female farmers, and Takemitsu suggested overuse of back muscles, repeated minor injuries, and increased compartmental pressure during prolonged bending posture as causative factors.

Degenerative spondylolisthesis (DS) is another common spinal deformity among female population, and increased vertebral slope and sagittal facet morphology have been reported radiographically. Recent studies indicated the importance of pelvic incidence (PI), which showed positive correlation with lumbar lordosis and vertebral slope, and large PI was reported as a risk factor of de novo DS after 12-year follow-up of female subjects without baseline DS[1,3,4,6]. Contrary to LDK, physical characteristics among DS patients have not been well-documented. One study by Sinaki et al. showed that trunk flexion exercise was more favorable for reducing back pain than extension exercise among DS patients[16]. Their study implicated the importance of trunk flexor muscle, however, subsequent studies could not elucidate the relationship between DS and trunk muscle weakness. The purpose of this study was to investigate radiographic, clinical, and physical characteristics of LDK and DS among community-based female cohort.

[Methods]

This study was a part of our ongoing longitudinal cohort study, Asahikawa observational study of Spinal Aging in Prospective cohort (the ASAP study), which has been recruiting adult volunteers from population register since 1983, whose baseline demographic data have been reported[1,7,8]. Follow-up study has been conducted since 1997 according to following criteria; included if baseline age of 40 years or older, healthy enough to walk independently to attend our program, available baseline and follow-up whole spine radiographs, and submitted written informed consent; excluded if history of spinal arthrodesis or joint replacement surgery, severe systemic or orthopaedic pathology requiring hospitalization or repetitive medical consultation. A final total of 289 Japanese female subjects were included and followed, and mean follow-up period was 12.3 (range 8-20) years. Entire spine radiographs were taken at the entry and at the final follow-up in relaxed standing posture with their arms supported and knees maximally extended. Digital image software was used to measure standard sagittal spinopelvic parameters including thoracic kyphosis (TK; between upper endplate of T4 and lower endplate of T12), lumbar lordosis (LL; between upper endplate of L1 and S1), sagittal vertical axis (SVA; distance of plumb lines through C7 and S1 posterior edge), sacral slope (SS; between upper sacral endplate and horizontal reference), pelvic tilt (PT; between the line through center of femoral head and midpoint of sacral table, and vertical reference), PI (between the line through center of femoral head and midpoint of sacral table, and the line perpendicular to sacral table), and percent slip (length of vertebral displacement divided by the length of vertebral endplate below) of each lumbar vertebra (Fig. 1). Measurements of spinopelvic parameters were in accordance with standard methods used in recent studies of ASD[10,13,15]. Clinical and physical evaluations by spine physicians and physical therapists were also conducted, and health-related quality of life scores (HRQOL, using Roland-Morris disability questionnaire), lumbar range of motion (ROM) evaluated by passive back extension (prone-press; distance of chin and floor at maximum lumbar extension at push-up with thighs attached to the floor) and active back extension test (BET; distance of sternal notch and floor at maximum active lumbar extension with thighs attached to the floor) were recorded. Trunk flexor and extensor muscle strengths were measured in a fixed sitting position using isometric dynamometer (GT350, OG Giken Co., Japan). Each participant repeated the measurement at least three times and best scores were used as flexor and extensor strength (Fig. 2). Gait posture was evaluated using photometric technique; each participant was instructed to walk 6-meter walkway with surface markers attached on C7 (or on prominent cervical spinous process) and on L4 (or on intercrestal line). Digital camcorder was used to measure the change in trunk inclination angle (dTIA), defined as the difference of angles subtended by the line through surface markers and the vertical reference between walk and rest. Each participant repeated dTIA measurement at least three-times and maximum difference was used. Most subjects showed increase in trunk inclination angle at walk, and dTIA was defined as positive for forward inclination (Fig. 3). Attending physician or physical therapist gave thorough explanation and demonstrations, if needed, upon each physical measurement. Subjects with difficulty in performing repeated physical measurements due to recent back pain, vertebral or non-vertebral fractures, clinical frailty or other medical conditions were excluded, and included only for radiographic measurements. Data of physical and clinical measurements were corrected at the latest visit, and used as cross-sectional data. Statistical analysis was performed using the StatView software (Abacus Concepts, Inc, Berkley, CA). Interclass comparison was done by analysis of variance, and p-value of less than 0.05 was considered as significant difference. Institutional review board approved the study, and written informed consent was mandatory for each participant upon enrollment.

[Results]

Longitudinal changes (mean±SD) of anthropometric and radiographic measurements of all 289 female subjects, from the age of 56.9±10.0 to 68.5±9.2 years, were as follows; body height from 150.7±5.6cm to 149.3±6.3cm, body weight from 54.5±7.0kg to55.7±8.6kg, TK from 31.1±13.1° to 32.0±16.0°, LL from 43.8±14.3° to 39.6±15.2°, SVA from 22.0±31.5mm to 30.9±42.8mm, SS from 34.0±10.4° to 30.6±12.7°, PT from 21.1±9.6° to 25.3±9.6°, and PI from 55.9±10.7° to 56.1±11.3° (Table 1). After excluding 87 subjects with difficulty in repeated physical measurements, physical measurements of eligible 202 subjects at the final follow-up were as follows; isometric trunk flexor muscle strength 268.4±75.1N, isometric trunk extensor muscle strength 455.3±174.1N, prone-press 26.3±6.5cm, BET 11.2±5.9cm, and dTIA 4.4±3.7°. Using the final radiographic measurements, DS was defined as more than 5% of percent slip, according to our previous study [1]. LDK has been diagnosed both radiographically and clinically, with aggravated kyphosis during walk. In the current study, we adopted radiographic definition of LDK for screening purpose; LL of less than 1SD of mean value (<24.4°). Among 202 subjects with full radiographic and physical evaluations, DS was found in 50 subjects (24.8%), and LDK was found in 24 subjects (11.9%).

Physical, clinical, and radiographic parameters were compared among DS, LDK, and normal subjects without DS or LDK (Fig.4). DS subjects showed significantly weaker trunk flexor muscle strength than normal subjects (normal 282.5±73.0N vs. DS 245.5±75.5N, p=0.0219; LDK 261.3±77.7N). LDK subjects, compared to normal subjects, showed significant differences in; trunk extensor muscle strength (normal 493.4±172.8N vs. LDK 386.3±167.6N, p=0.0066; DS 448.7±170.9N), ROM (prone-press normal 27.2±6.0cm vs. LDK 23.6±8.2cm, P=0.0146; DS 25.6±6.1cm / BET normal 12.0±5.5cm, LDK 5.4±5.3cm, P<0.0001; DS 11.2±5.4cm), dTIA (normal 3.5±2.7° vs. LDK 7.6±4.8°, p<0.0001; DS 5.1±3.9°), HRQOL (normal 1.4±2.6 vs. LDK 5.2±6.0, p=0.0015; DS 1.2±2.8). PI was significantly larger in DS and smaller in LDK than normal subjects (normal 53.8±9.9° vs. DS 58.2±10.6°, p=0.0111; normal vs. LDK 48.4±9.2°, p=0.0191)

[Discussions]

Current study showed that DS was associated with large PI and reduced trunk flexor muscle strength by 13%, and LDK was associated with reduced extensor muscle strength by 22%, along with reduced ROM, increased trunk inclination during walk, and worse HRQOL.

In a prospective randomized study, Sinaki et al. divided 48 DS patients with back pain into trunk flexion exercise group and trunk extension exercise group[16]. After 3 months, the rate of back pain reduced to 27% in flexion exercise group and to 67% in extension exercise group. The overall recovery rate after 3 years was 62% for the flexion group and 0% for the extension group. Their study indicated the importance of trunk flexion exercise when prescribing physical therapy for DS patients, however, magnitude of trunk flexor attenuation with DS was not documented.

Sanderson et al. reported that history of pregnancy was related to increased incidence of DS[14]. They reviewed medical record of 949 women, and those who had borne children showed 28% incidence of DS compared to 16.7% among nullparous women with statistical significance (p=0.043). Their retrospective study could not elucidate the mechanism of muscle weakness and the development of DS, however, they proposed that weakened abdominal muscle during pregnancy might be a causative factor, along with joint laxity, and increased lumbar load equivalent to 22° of trunk inclination during pregnancy.

Current study could clarify statistically significant reduction of isometric trunk flexor muscle strength by 13% with DS, using susceptible female subjects with comparable background, and related mechanism should be that reduced trunk flexor strength reduced pull-up force onto pelvic insertion, which might increase anteversion of pelvis and vertebral slope (Fig. 5). Anatomically, subject with large PI exhibits large pelvic ROM. Reported equation of PI=SS+PT [15] showed that maximum value of SS depends on the magnitude of PI, and subjects with large PI and weak flexor muscle are susceptible to increased SS and vertebral slope, resulting in increased sheer stress and risk of vertebral slip. Female subjects with large PI and reduced trunk flexor muscle should be recognized as a prominent risk of developing DS, and trunk flexor exercise should be beneficial for this type of patients.

LDK was associated with small PI and reduced back extensor muscle strength and aggravated kyphotic posture during walk, which substantiated previous study that LDK was associated with back muscle attenuation and histological muscle fiber atrophy suggesting 'compartment syndrome' of back muscles, along with worsening kyphosis after distant walk [17]. Ambulatory kyphosis with LDK, expressed as 2.2-fold increase in dTIA, proposed limited relevance of static spinopelvic radiographs, and clinical and physical evaluation of "dynamic kyphosis" during activities should be included for better management of senile kyphotic deformity.

Contrary to DS, controversy exists about LDK and PI. Lee JH et al. reported that PI was high up to 65.8° in Takemitsu type-1 LDK, characterized as flat back deformity[9]. Bae

JS et al. reported the number of LDK patients were 25.6% in low PI (≤ 45°) and 29.6% in high PI (>60°), studying 172 symptomatic LDK patients[2]. Radiographic studies indicated that small PI is usually associated with small LL, however, clinical studies by Le Huec or others indicated that small LL with large PI, or 'mismatched' kyphosis, to be more difficult to treat[11,12]. Aforementioned studies using symptomatic patients might include more number of clinically problematic 'mismatched' kyphosis with large PI compared to studies using community-based volunteers.

Limitations of this study included that this was an observational study and could not elucidate the treatment regimen for each ASD condition, however, the characteristics of trunk muscle attenuation implied that abdominal muscle exercise should be appropriate for DS patients, and back muscle and ROM exercise should be appropriate for LDK. There has been no gold standard for measuring trunk muscle strength, ROM, or gait posture, however, used methods were in common clinical use especially among physical therapists, and provided enough statistical significance using largest-ever number of study subjects for physical evaluations with radiographic parameters. Currently ongoing studies include the assessment of instructed exercise by physical therapists onto longitudinal changes in physical and radiographic measurements, which should further clarify the impact of physical characteristics upon ASD, and should provide answers to above-mentioned limitations.

[Conclusion]

Current study showed that DS was associated with large PI and reduced trunk flexor muscle strength by 13%, supposedly leading to reduced capacity of maintaining pelvic retroversion. LDK was associated with reduced extensor muscle strength by 22%, active ROM by 55%, passive ROM by 13%, and increased ambulatory kyphosis by 117%. Physical characteristics should be an important factor as well as radiographic parameters, and distinctive radiographic, clinical and physical features should be considered for successful management of ever-increasing adult spinal deformity.

All the authors have no conflict of interest concerning this manuscript.

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[Legends]

FIGURE 1.

Radiographic measurements of thoracic kyphosis (TK; between upper endplate of T4 and lower endplate of T12), lumbar lordosis (LL; between upper endplate of L1 and S1), sagittal vertical axis (SVA; distance of plumb lines through C7 and S1 posterior edge), sacral slope (SS; between upper sacral endplate and horizontal reference), pelvic tilt (PT; between the line through center of femoral head and midpoint of sacral table and vertical reference), pelvic incidence (PI; between the line through center of femoral head and midpoint of sacral table and the line perpendicular to sacral table), and percent slip (length of vertebral displacement divided by the length of vertebral endplate below; S/V in percent). TK thoracic kyphosis, LL lumbar lordosis, SVA sagittal vertical axis, SS sacral slope, PT pelvic tilt, PI pelvic incidence.

FIGURE 2.

Physical measurements. A, passive lumbar ROM by prone-press (distance of chin and floor at maximal lumbar extension by push-up force). B, active lumbar ROM by back extension test (BET; distance of sternal notch and floor at active lumbar extension). C-D, trunk flexor and extensor muscle strength measured using isometric device (GT350, OG Giken Co., Japan). ROM range of motion.

FIGURE 3.

Photometric evaluation of gait posture using the difference of trunk inclination angle (dTIA). Trunk inclination angle was the angle subtended by the line through surface markers attached on C7 (or on prominent cervical spinous process) and on L4 (or on intercrestal line), and the line through vertical reference. Difference of trunk inclination angle (dTIA) between 6-meter walk and rest was used and defined as positive for forward inclination during walk. A, TIA at rest. B, TIA during 6-meter walk.

FIGURE 4.

Comparison of physical parameters among normal, DS, and LDK. Statistical interclass comparison was performed by analysis of variance. DS degenerative spondylolisthesis, LDK lumbar degenerative kyphosis, BET back extension test, dTIA difference of trunk inclination angle

FIGURE 5.

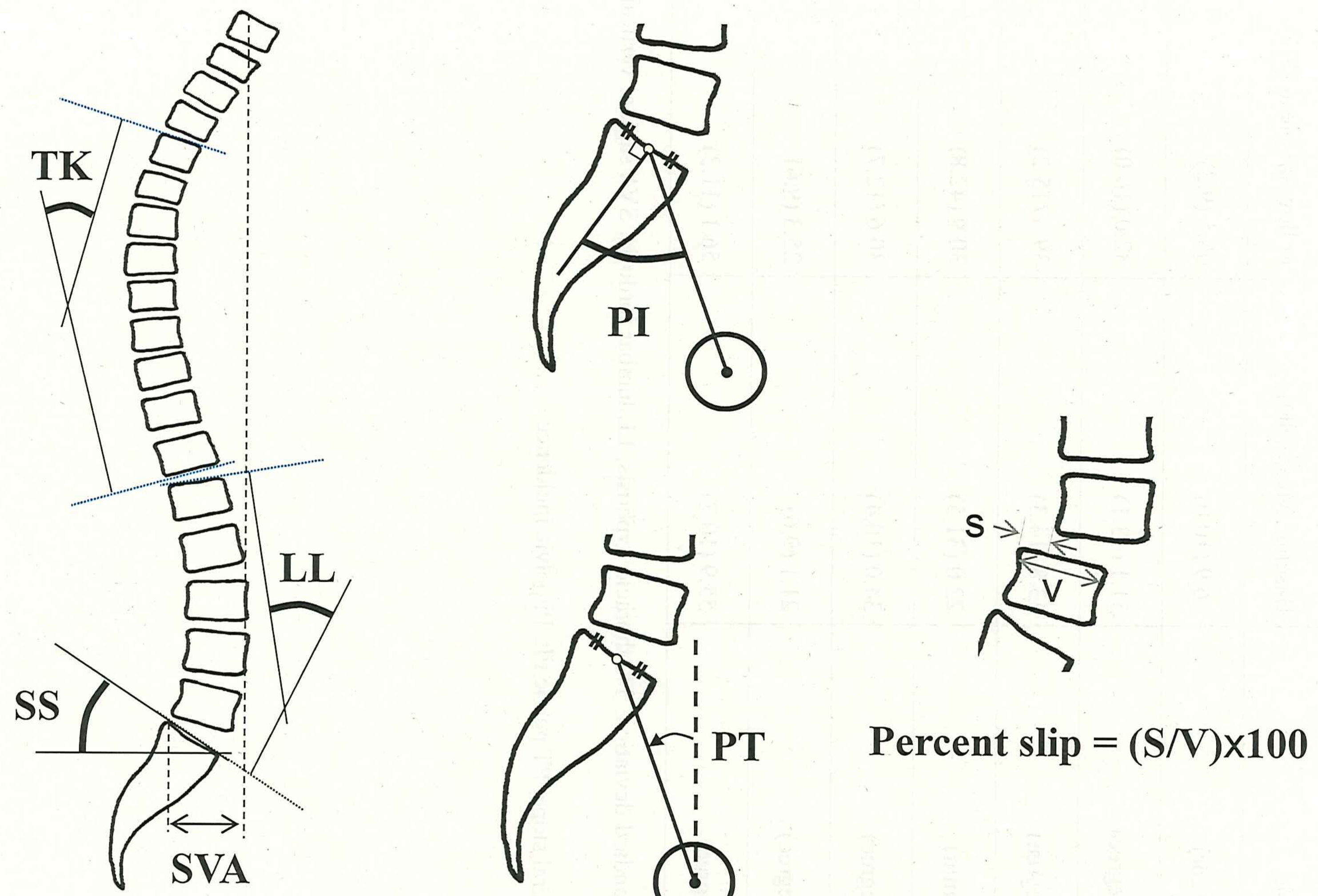
Proposed relationship between trunk flexor muscle and DS. Reduced trunk flexor muscle reduces pull-up force onto pelvic insertion, which might lead to increased anteversion of pelvis and vertebral slope. Subjects with large PI anatomically have large pelvic range of motion, thus increasing the risk of DS with reduced trunk flexor muscles. DS degenerative spondylolisthesis.

Table 1. Longitudinal changes of 289 female subjects.

Variable	Baseline Mean (SD)	Follow-up Mean (SD)
Age (year)	56.9 (10.0)	68.5 (9.2)
TK (degree)	31.1 (13.1)	32.0 (16.0)
LL (degree)	43.8 (14.3)	39.6 (15.2)
SVA (mm)	22.0 (31.5)	30.9 (42.8)
SS (degree)	34.0 (10.4)	30.6 (12.7)
PT (degree)	21.1 (9.6)	25.3 (9.6)
PI (degree)	55.9 (10.7)	56.1 (11.3)

SD standard deviation, TK thoracic kyphosis, LL lumbar lordosis, SVA sagittal vertical axis, SS sacral slope, PT pelvic tilt, PI pelvic incidence

Figure
FIGURE 1



FUGURE 2

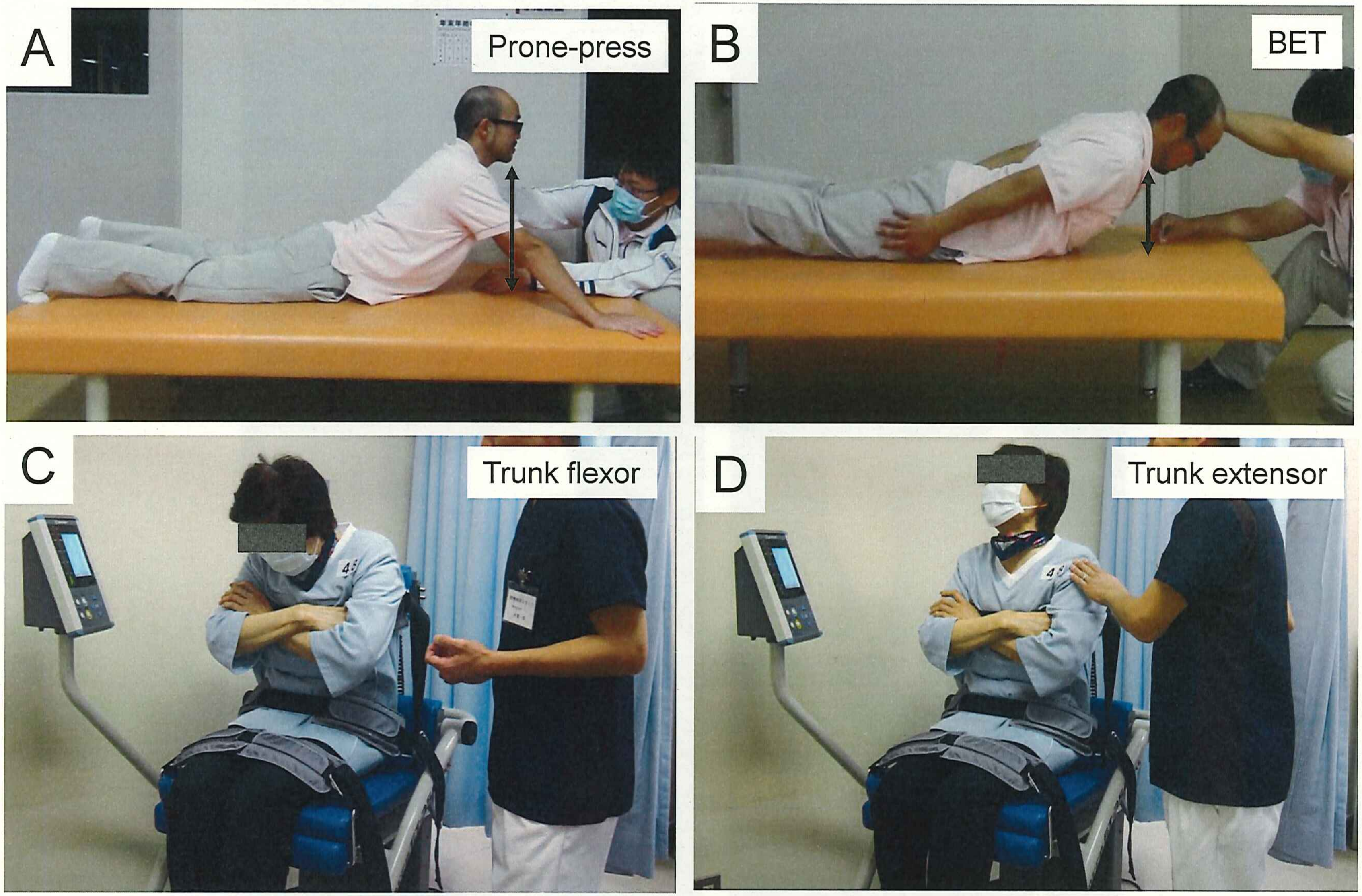
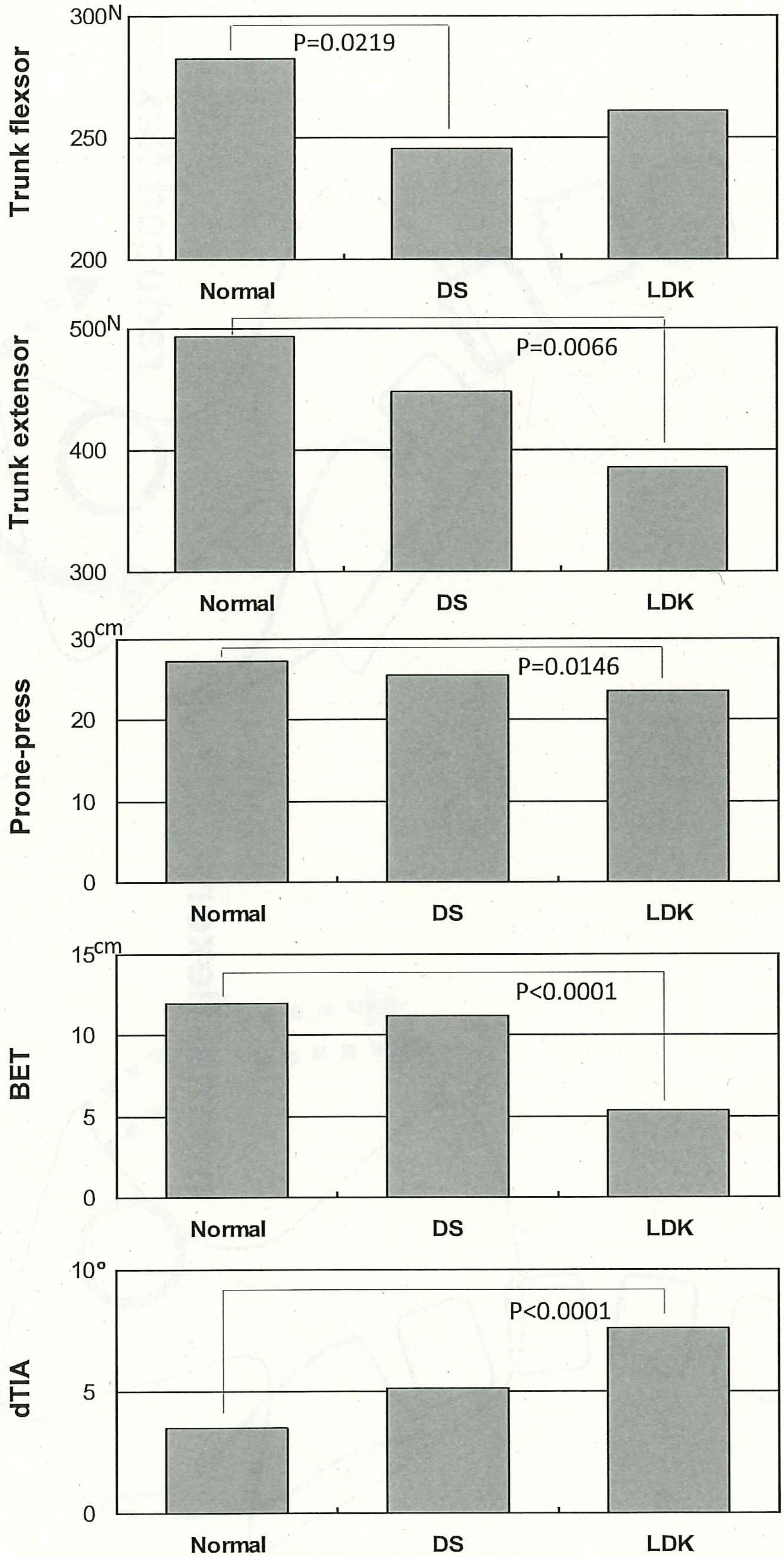


FIGURE 3

Figure



300N
250
200
Trunk flexsor
P=0.0219
Normal
DS
LDK
500N
400
300
Trunk extensor
P=0.0066
Normal
DS
LDK
30cm
20
10
0
Prone-press
P=0.0146
Normal
DS
LDK
15cm
10
5
0
BET
P<0.0001
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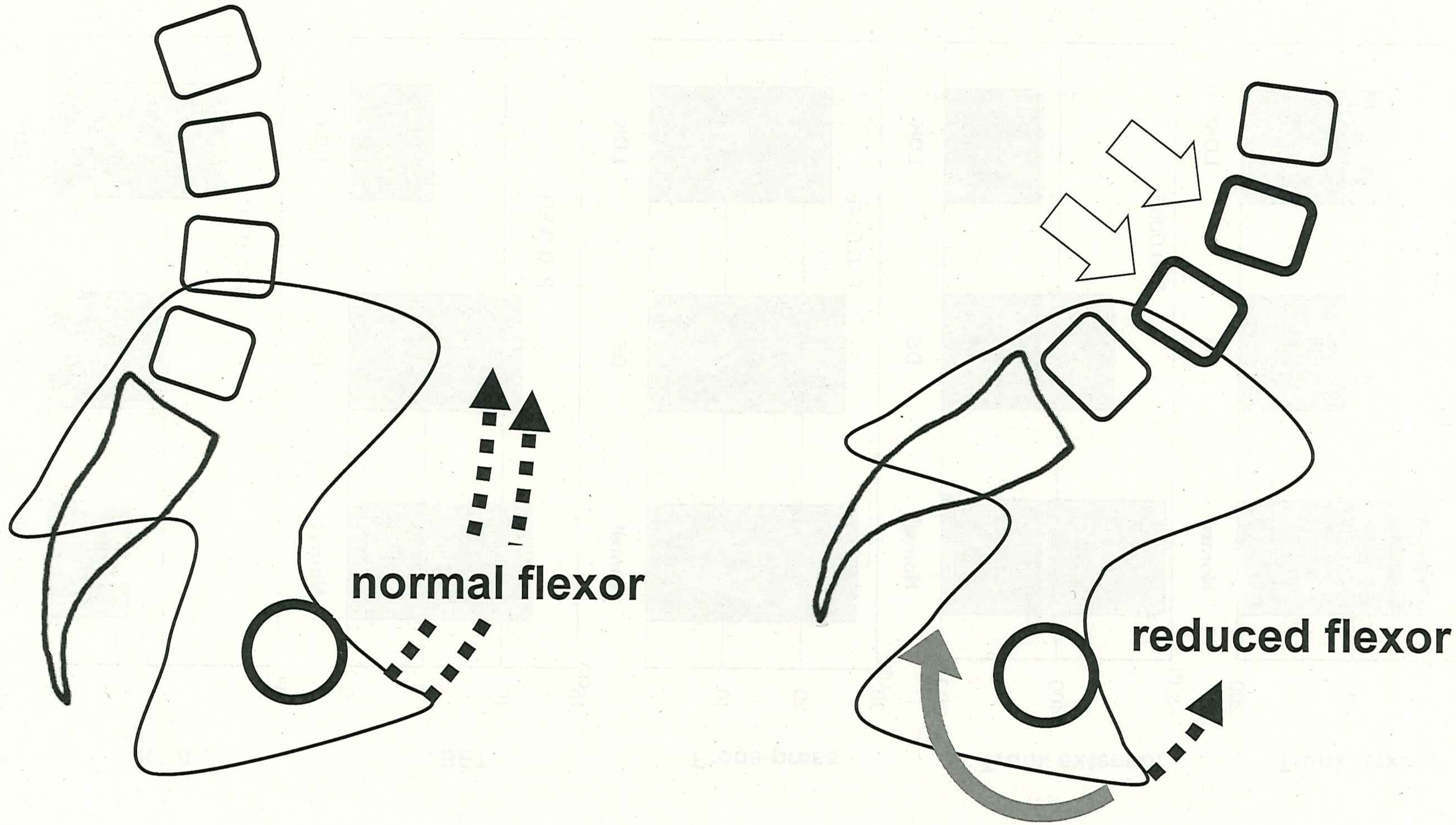
Figure
FIGURE 5



Table

TABLE 1. Longitudinal changes of 289 female subjects

Variable	Baseline mean (SD)	Follow-up mean (SD)
Age (year)	56.9 (10.0)	68.5 (9.2)
BH (cm)	150.7 (5.6)	149.3 (6.3)
BW (kg)	54.5 (7.0)	55.7 (8.6)
TK (degree)	31.1 (13.1)	32.0 (16.0)
LL (degree)	43.8 (14.3)	39.6 (15.2)
SVA (mm)	22.0 (31.5)	30.9 (42.8)
SS (degree)	34.0 (10.4)	30.6 (12.7)
PT (degree)	21.1 (9.6)	25.3 (9.6)
PI (degree)	55.9 (10.7)	56.1 (11.3)

BH body height, BW body weight, TK thoracic kyphosis, LL lumbar lordosis, SVA sagittal vertical axis, SS sacral slope, PT pelvic tilt, PI pelvic incidence