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Inter-segmental coordination of the spine is altered during lifting in patients with ankylosing spondylitis

A cross-sectional study

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Abstract

The abnormal inter-segmental coordination of the spine during lifting could be used to monitor disease progression and rehabilitation efficacy in patients with ankylosing spondylitis (AS). This study aimed to compare the inter-segmental coordination patterns and variability of the spine during lifting between patients with AS (n = 9) and control (n = 15) groups.

Continuous relative (CRP) and deviation (DP) phases between each segment of the spine (two lumbar and three thorax segments) and lumbosacral joint were calculated. The CRP and DP curves among participants were decomposed into few functional principal components (FPC) via functional principal component analysis (FPCA). The FPC score of CRP or DP of the two groups were compared, and its relationship with the indexes of spinal mobility was investigated.

Compared with the control group, the AS patients showed more anti-phase coordination patterns in each relative upper spine segment and lumbosacral joint. In addition, either less or more variation was found in the coordination of each relative lower spine segment and lumbosacral joint during different time periods of lifting for these patients. Some cases were considerably related to spinal mobility.

the inter-segmental coordination of the spine was altered during lifting in AS patients to enable movement, albeit inefficient and might cause spinal mobility impairment.

Abbreviations: AS = ankylosing spondylitis, BASDAI = bath ankylosing spondylitis metrology index, CI = confidence interval, CRP = continuous relative phase, DP = deviation phase, FPC = functional principal components, FPCA = functional principal component analysis, Hz = Hertz, L1 = the first lumbar, L3 = the third lumbar, L5 = the fifth lumbar, L5S1 = lumbosacral joint angle, LBP = low back pain, LLa = lower lumbar angle, MTa = middle thoracic angle, NRS = neurobehavioral rating scale, T10 = the tenth thorax, T2 = the second thorax, T6 = the sixth thorax, TLa = thoracolumbar angle, UK = United Kingdom, ULa = upper lumbar angle, US = United States, UTa = the upper thoracic angle, VAS = visual analog scale.

Keywords: ankylosing spondylitis, lifting, motor coordination, spine mobility

1. Introduction

The effects of ankylosing spondylitis (AS) on spine and sacroiliac joints[1] lead to structural and functional impairments[2] and a decreased quality of life.[3] Imaging techniques have substantially changed the management of this disease.[2] Motion capture analysis of daily life activities is necessary[3,4] to provide accurate and reliable real-time kinematic data and gain insights into AS patient-specific movement characteristics. Lifting is a type of back pain-related activity of daily living.[5] Analyzing abnormal lifting-related motion in AS patients can be used to monitor disease progression and rehabilitation efficacy.

Monitoring the abnormality of inter-segmental coordination during lifting in AS patients is one of important aspect. Trunk or lower limb coordination, such as lumbar and pelvic (or hip),[6–10] upper and lower lumbar,[9] hip and knee,[10,11] ankle and knee[11] in patients with low back pain (LBP) was investigated during lifting and other similar tasks (including flexion/extension). However, the aberrant characteristics of inter-segmental coordination remain unclear.[10] Limited studies focused on spine segments, especially on the inter-segmental coordination of the spine involved in the motion of thoracic regions that seem to be affected in AS patients.[3] Dividing the lumbar[12,13] and thoracic[14,15] region into detailed parts is important to these kind researches.

Certain studies focused on the effects of aberrant inter-segmental coordination on the severity of back pain in patients with LBP during functional movements. Esposito, Wilken[16] indicated that the altered trunk and pelvic coordination during walking may lead to LBP. Pranata et al[10] proposed that the

Editor: Jose Muyor.

The authors have no conflicts of interest to disclose.

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How to cite this article: Lin H, Seerden S, Zhang X, Fu W, Vanwanseele B. Inter-segmental coordination of the spine is altered during lifting in patients with ankylosing spondylitis: a cross-sectional study. Medicine 2020;99:5(e18941).

Received: 11 July 2019 / Received in final form: 26 December 2019 / Accepted: 27 December 2019

http://dx.doi.org/10.1097/MD.0000000000018941

increased anti-phase of lumbar and pelvic coordination is related to the enlarged disability of patients with LBP during lifting. Abnormal inter-segmental coordination is commonly considered a risk factor for developing back pain. Zehr et al[5] reported that continuous relative phase (CRP) of thorax and pelvic coordination can discriminate between lifting techniques according to biomechanical risk criteria. For AS patients, spinal mobility impairment is affected by spinal inflammation and structural damage in the early and later stages respectively[17]; however, the latter still needs to be verified. To our knowledge, the relationship between abnormal inter-segmental coordination of the spine and spinal mobility impairment has not been investigated.

Related studies on LBP patients utilized the averaged CRP and deviation phase (DP) during the entire movement as indexes of inter-segmental coordination; however, such indexes exclude considerable information.[18] By contrast, certain works used the averaged CRP and DP across the subphase of movement[8,18]; these indexes showed detailed difference in inter-segmental coordination in the AS patients compared with that in healthy people. However, the difference still exists across the boundary of each subphase, as shown in the study by Silfies et al,[8] or during small time ranges within each subphase. Therefore, time-series analysis methods, such as functional data analysis, are needed to detect inter-segmental coordination at every time point of targeted motion.

Inter-segmental coordination of the spine is defined as a coordination set of the lumbosacral joint and another joint of the spine. According to this definition, the relationship among these spine joint motions can be observed as a whole on the basis of each relative motion with the lumbosacral joint, an important position connecting the spine and pelvis. This study aims to compare the inter-segmental coordination patterns and variability of the spine during lifting between AS patients and healthy controls, and further understand the relationship between its abnormal coordination patterns or variability and spinal mobility impairment. We hypothesize that certain parts of inter-segmental coordination of the spine will become anti-phase, either less or more variable, during different time periods of lifting in the AS patients. In addition, some of these abnormal aspects will be significantly related to spinal mobility impairment.

2. Methods

2.1. Protocol and registration

This study was carried out in full accordance with the *Declaration of Helsinki* on ethical principles for medical research involving human subjects, and was approved by the local ethical committee of university hospitals in Leuven (Ethics ID: S58067) Belgium.

2.2. Design

A cross-sectional study.

2.3. Participants

The study had 24 participants, including 9 patients with AS (8 males and 1 female) and 15 participants without AS (10 males and 5 females). The AS group met the modified New York criteria (bilateral 2–4 or unilateral 3–4 grades). The main inclusion criteria were as follows: (1) between the ages of 18 and 65 years, (2) free of any general physical or mental comorbidities unrelated to AS in the past 2 months, (3) BASDAI < 4 (0–10 scale), and (4) spinal pain on VAS or NRS BASDAI item $2 < 40$ mm (0–100 mm scale). The main exclusion criteria were as follows:

(1) peripheral arthritis and enthesitis,
(2) other inflammatory rheumatic or systemic comorbidity,
(3) any surgery of the spine or pelvis,
(4) lower limb surgery in the past 24 months or upper limb surgery in the past 12 months,
(5) any injuries/problems/comorbidity unrelated to AS.

Table 1

Basic participant characteristics of the AS and control groups.

	AS (n = 9) Mean ± SD	Control (n = 15) Mean ± SD	*P* values
Age (years)	53.9 ± 9.3	48.2 ± 14.46	.304
Gender (female, %)	9 (11%)	15 (33%)	.351
Height (m)	1.70 ± 0.05	1.76 ± 0.09	.950
Mass (kg)	72.6 ± 11.4	76.3 ± 14.7	.515
BMI (m/kg^2)	24.9 ± 3.4	24.4 ± 3.0	.739
BASMI	4.6 ± 1.6	1.1 ± 0.6	.000*

AS, ankylosing spondylitis; BASMI, Bath ankylosing spondylitis metrology index (0–10 scale); *Significant differences.

Table 1 shows that the AS and control groups had corresponding age, gender, height, mass, and BMI but significantly different BASMI. Table 2 indicates that the most impaired spinal segments (deepest blue) in the AS group are the middle thorax, thoracolumbar, and a portion of the upper lumbar as determined by the radiologic images.

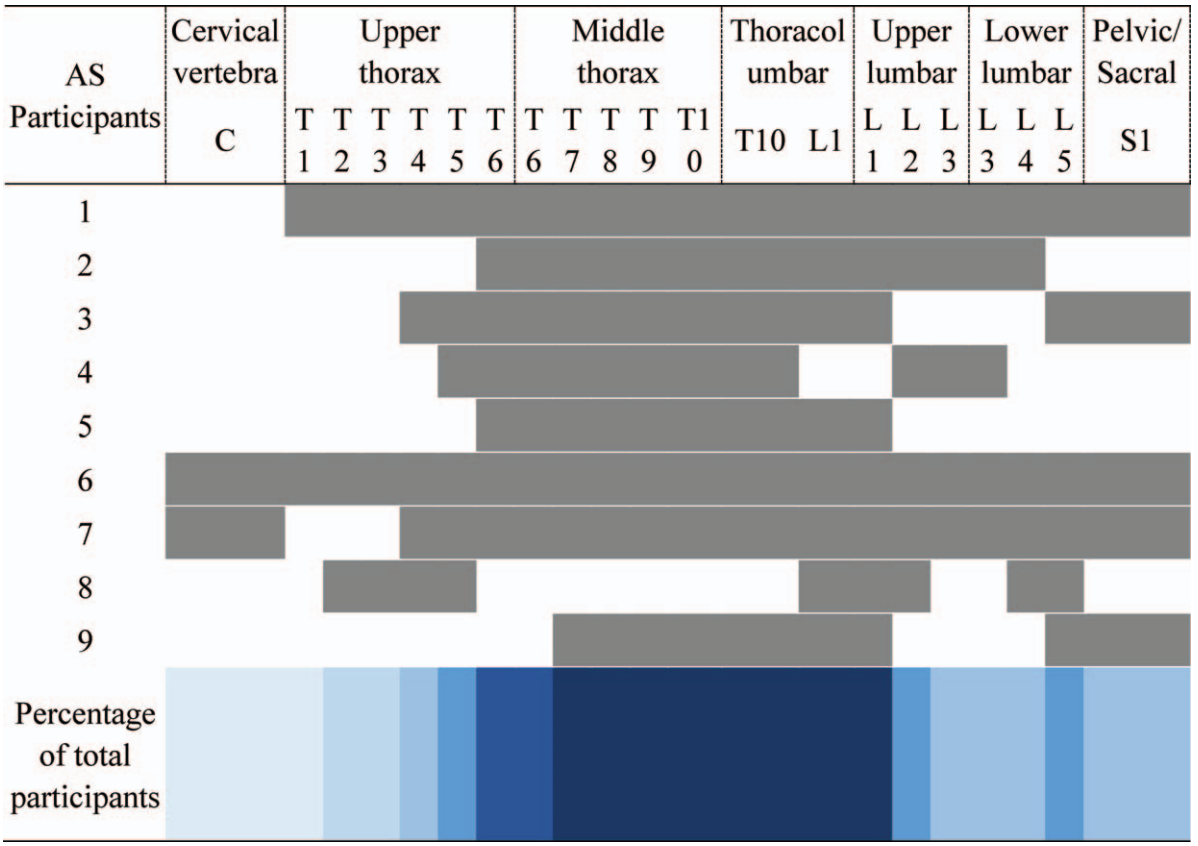
2.4. Experimental procedures

The participants were instructed to assume a standing position with both feet constantly in full contact with the floor. A transparent box with a fixed weight of 6 kg was placed in the center 15 cm from their toes. They were instructed to lift the box at a relaxed pace and with a comfortable technique until they reached a standing position. Three markers were placed on the corners of the top surface of the box to record the lifting technique's lift-off point and further motion. The movement was repeated three times, and the data were used for analysis. The kinematic data were collected by using 10 infrared Vicon MX motion capture cameras (VICON; Oxford, UK) with a sampling rate of 100 Hz and Vicon Nexus 2.4 software (Vicon Motion Systems, Oxford, UK).

A full-body kinematic model was set up by using the Vicon Bodybuilder 3.6.4. (Vicon Motion Systems, Oxford, UK) software added with a detailed multi-segment spine motion measure. Six sets of cluster markers were placed on the spinous processes of the second, sixth, and tenth thorax (T2, T6, and T10) and the first, third, and fifth lumbar (L1, L3, and L5) segments. The joint angles of the spinal regions were defined as the upper thoracic angle (UTa, T2 relative to T6), middle thoracic angle (MTa, T6 relative to T10), thoracolumbar angle (TLa, T10 relative to L1), upper lumbar angle (ULa, L1 relative to L3), lower lumbar angle (LLa; L3 relative to L5) and lumbosacral joint angle (L5S1; L5 relative to Vicon plug-in-gait pelvic/sacral segment). A set of cluster markers has three sticks, each possessing a marker on the tip and a virtual marker in the center to form its X-, Y-, and Z-axes.

Table 2

Fused vertebrae (gray regions) of each AS participant.



The percentage of total participants presents the frequency of the fused vertebrae among AS participants, and the darkening of blue indicates the increasing frequency of ankylosed vertebral areas. AS, ankylosing spondylitis.

2.5. Data analysis

The kinematic data were labeled and gap-filled via the Vicon Nexus 2.4 software. The angular displacement and angular velocity data of flexion/extension were derived from the same software and filtered with a fourth-order zero-phase shift low-pass Butterworth filter with a 6 Hz cut-off frequency in MATLAB R2017b (Mathworks Inc., Natick, MA). The beginning or ending of the task was the time point when the trunk angular velocity exceeded or returned under the cut-off line of 5% of its maximum, respectively.[19]

Angular displacement and velocity data were normalized to −1 to +1 intervals via the equations used by Hamill et al.[20] Phase angle = $\tan^{-1}$ (normalized angular velocity/normalized angular displacement) was calculated for each data point over the entire cycle. A two-quadrant inverse-tangent function was used to reveal the phase angles and avoid discontinuities. The CRP curve was plotted by subtracting the phase angles of each spine joint angle from L5S1 at every data point. The DP curve was the standard deviation of the CRP curves at every data point among the repetitive trials for each subject.

Variability of the CRP and DP curves among participants was decomposed into few functional principal components (FPC) by using the functional principal component analysis (FPCA). The functions of this method were developed by Ramsay and Silverman[21] via MATLAB software (Mathworks Inc., Natick, MA). Similar to the method utilized by Ryan et al,[22] B-splines and the least-squares (goodness of fit) approach were used by adding a roughness penalty to fit the CRP or DP curve into $x_i(s)$. Then, $x_i(s)$ were decomposed into few functional principal components (F_i) with certain weight functions ($\beta(s)$) via FPCA, and the requirements of each FPC explained the variance above 5%.[23] The FPC score was calculated by using Formula (1). A multiplication of each FPC was added and subtracted to the overall mean to reveal the influence of these components on the mean curve.

$$F_i = \int \beta(s) x_i(s) \quad (1)$$

2.6. Statistical analysis

Shapiro-Wilk and Levene's tests were utilized to verify the normal distribution of data and homogeneity of variance. Independent samples t tests were applied to compare the basic participant characteristics (except for gender, which was compared by Chi-square test) and FPC score between the AS and control groups. If the data were not normally distributed, then Mann-Whitney U test was performed instead of independent samples t test to explore the difference between the 2 groups. Finally, Pearson product–moment correlation analysis was applied to explore the relationship between the FPC score and spinal mobility impairment. All statistical analyses were performed with SPSS 20.0 (SPSS Science, Chicago, IL).

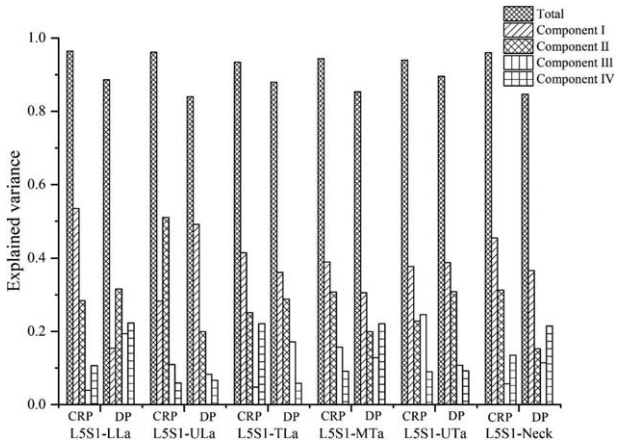


Figure 1. Explained variance of CRP or DP curve FPC during lifting.

3. Results

3.1. Explained variance of FPC

The CRP or DP curves of all participants during lifting were decomposed into 4 FPCs. Figure 1 shows that the total explained variance of four FPCs of the CRP curves was above 0.85 (mean = 0.95, the smallest = 0.93, the largest = 0.96), except for ULa and L5S1 DP, and was nearly obtained by the DP curves (mean = 0.87, the smallest = 0.84, the largest = 0.90). Therefore, the use of 4 FPCs to represent all CRP or DP curves is reasonable. Furthermore, nearly all FPC explained variance of the CRP or DP curves were above 0.05, except for the CRP FPC III of LLa and L5S1 (0.040), TLa, and L5S1 (0.048), which were excluded for further analysis.

3.2. FPC score difference between the groups

Table 3 reveals that the FPC score of the CRP curves for AS group were significantly higher than that for the control group in MTa and L5S1 FPC IV (explained variance = 0.09, mean difference = 110.05, P = 0.028, 95% confidence interval (CI) [13.07,207.03]), UTa and L5S1 FPC IV (explained variance = 0.09, mean difference = 120.22, P = .000, 95% CI [80.44,160.01]), and neck and L5S1 FPC I (explained variance = 0.46, mean difference = 123.92, P = .040, 95% CI [6.17,241.67]) and significantly lower than that of the control group in neck and L5S1 FPC II (explained variance = 0.31, mean difference = −95.09, P = .048, 95% CI [−203.17, −15.42]). Therefore, the AS patients exhibited more anti-phase in coordination of each relative upper spine segments and L5S1 in special FPC, including the least impaired parts of the spine, compared with the control group.

The FPC score of the DP curves for the AS group was significantly higher than that of the control group in UTa and L5S1 FPC III (explained variance = 0.08, mean difference = 17.26, P = .035, 95% CI [1.34,30.50]) and TLa and L5S1 FPC IV (explained variance = 0.22, mean difference = 38.09, P = .025, 95% CI [9.67,84.24]) and significantly lower than that of the control group in TLa and L5S1 FPC IV (explained variance = 0.06, mean difference = −18.09, P = .018, 95% CI [−3.42, −36.42]). Therefore, the patients exhibited less variability in coordination of each relative lower spine segment and L5S1 in special FPC, including the most impaired parts of the spine.

3.3. Time-dependent variability between the groups in FPC

High CRP in the AS group was found

1) during 20% to 53% movement, with the highest at 35% movement (62° difference) in MTa and L5S1 FPC IV;
2) during 31% to 60% movement, with the highest at 40% movement (33° difference) in UTa and L5S1 FPC IV;
3) during 26% to 64% movement, with the highest at 46% movement (80° difference) in neck and L5S1 FPC I; and
4) during 48% to 92% movement, with the highest at 67% movement (46° difference) in neck and L5S1 FPC II (Fig. 2).

Therefore, the CRP of these relative upper segments of the spine and L5S1 was higher in the patient group mainly during the first half of lifting, except for the neck and L5S1, which covered the second half of lifting.

Table 3

Means and standard deviations of the FPC score of the CRP or DP curves of the two groups.

	Component I		Component II		Component III		Component IV	
	AS	Control	AS	Control	AS	Control	AS	Control
CRP								
L5S1–LLa	34.33 ± 161.90	−20.60 ± 153.64	11.49 ± 166.46	−6.90 ± 71.62	−6.53 ± 56.60	3.92 ± 32.11	−1.65 ± 61.84	1.00 ± 75.86
L5S1–ULa	−0.19 ± 123.94	0.11 ± 101.26	4.37 ± 145.79	−2.62 ± 148.84	−20.30 ± 84.51	12.18 ± 53.59	2.67 ± 72.24	−1.60 ± 30.96
L5S1–TLa	−29.12 ± 92.33	17.47 ± 177.82	−31.92 ± 62.05	19.15 ± 139.19	−2.11 ± 40.34	3.51 ± 68.1	9.67 ± 123.98	−16.12 ± 86.11
L5S1–MTa	34.67 ± 247.69	−20.80 ± 260.10	88.16 ± 203.95	−52.90 ± 224.39	3.72 ± 155.89	−2.23 ± 167.34	68.78 ± 129.10*	−41.27 ± 99.02
L5S1–UTa	33.99 ± 216.05	−20.39 ± 101.68	−47.00 ± 178.29	28.20 ± 51.75	−8.83 ± 165.26	5.30 ± 96.05	75.14 ± 59.73*	−45.08 ± 34.85
L5S1–Neck	77.45 ± 170.37*	−46.47 ± 109.13	−71.95 ± 157*	43.17 ± 66.18	0.03 ± 48.85	−0.02 ± 54.43	−9.83 ± 103.17	5.90 ± 63.98
DP								
L5S1–LLa	11.30 ± 28.30	−6.78 ± 34.60	−13.81 ± 75.55	8.29 ± 14.22	−12.85 ± 44.51	7.71 ± 30.66	−0.75 ± 24.40	0.45 ± 47.35
L5S1–ULa	13.76 ± 48.25	−8.26 ± 54.63	5.76 ± 54.36	−3.45 ± 10.21	11.54 ± 15.2*	−6.93 ± 22.14	4.95 ± 27.27	−2.97 ± 12.69
L5S1–TLa	18.92 ± 96.73	−11.35 ± 31.73	−3.17 ± 13.99	1.9 ± 72.39	9.58 ± 51.31	−5.75 ± 39.85	−15.01 ± 6.15*	9.01 ± 21.62
L5S1–MTa	10.89 ± 96.39	−6.54 ± 59.86	9.45 ± 39.03	−5.67 ± 70.04	−4.68 ± 46.49	2.81 ± 50.09	32.00 ± 74.87*	−19.2 ± 47.54
L5S1–UTa	19.07 ± 66.30	−11.44 ± 49.38	3.60 ± 26.7	−2.16 ± 61.72	2.03 ± 29.25	−1.22 ± 31.46	−3.77 ± 27.03	2.26 ± 28.74
L5S1–Neck	19.07 ± 66.30	−11.44 ± 49.38	3.60 ± 26.7	−2.16 ± 61.72	2.03 ± 29.25	−1.22 ± 31.46	−3.77 ± 27.03	2.26 ± 28.74

AS = ankylosing spondylitis; *Significant difference between the AS and control groups.

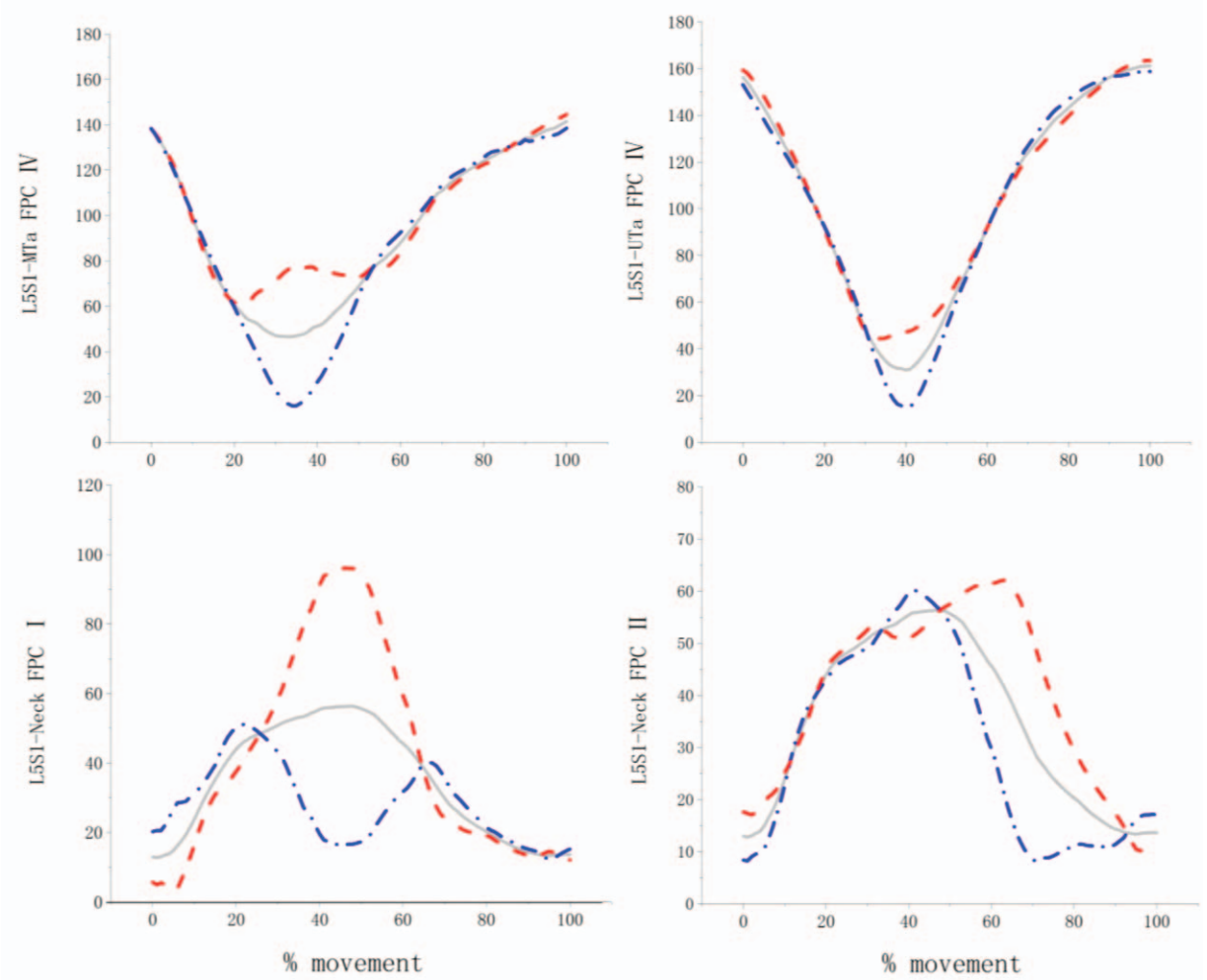


Figure 2. Time-dependent CRP variability in FPC with significant difference between the 2 groups (The red dashed and blue dash–dot curves represent the CRP in the AS and control groups, respectively; whereas the gray curve indicates the means of the two groups.).

The DP in the AS group was low during 17% to 41% movement, with the lowest value occurring at 35% movement (18° difference) in ULa and L5S1 FPC III; and during 61% to 89% movement, with the lowest at 72% movement (8° difference) in TLa and L5S1 FPC IV (Fig. 3). Therefore, the low DP variability of ULa and L5S1 in AS patients existed during the first half of lifting and that of TLa and L5S1 was observed during the second half of lifting.

By contrast, the DP in the control group was lower

(1) during 60% to 80% movement, with the lowest at 64% movement (8° difference) in ULa and L5S1 FPC III;
(2) during 15% to 32% movement, with the lowest at 23% movement (12° difference) in TLa and L5S1 FPC IV;
(3) during 0% to 48% movement, with the lowest at 25% movement (16° difference); and
(4) during 70% to 93% movement, with the lowest at 82% movement (16° difference) in MTa and L5S1 FPC IV (Fig. 3).

Therefore, the lower DP variability of TLa and L5S1 and MTa and L5S1 in healthy people existed during the first half of lifting and that of ULa and L5S1 and TLa and L5S1 occurred during the second half of lifting.

3.4. Relationships between the FPC score and spinal mobility indexes

The high FPC score of the CRP curves in L5S1 and UTa FPC IV and L5S1 and neck FPC I was significantly related to low spinal mobility (Table 4). The high anti-phase of these aspects of inter-segmental coordination of the spine led to reduced spinal mobility.

The high FPC score of the DP curves in L5S1 and ULa FPC III and the low FPC score in L5S1 and TLa FPC IV were significantly related to low spinal mobility (Table 4). The decreased variability of L5S1 and ULa coordination during the first half of lifting and L5S1 and TLa coordination during the second half of lifting are attributed to low spinal mobility. Moreover, the high variability of L5S1 and ULa coordination during the second half of lifting and the L5S1 and TLa coordination during the first half of lifting reduced the spinal mobility.

4. Discussion

Compared with healthy people, the AS patients showed more anti-phase in coordination of each relative upper spine segment (neck and upper and middle thorax) and lumbosacral joint. The

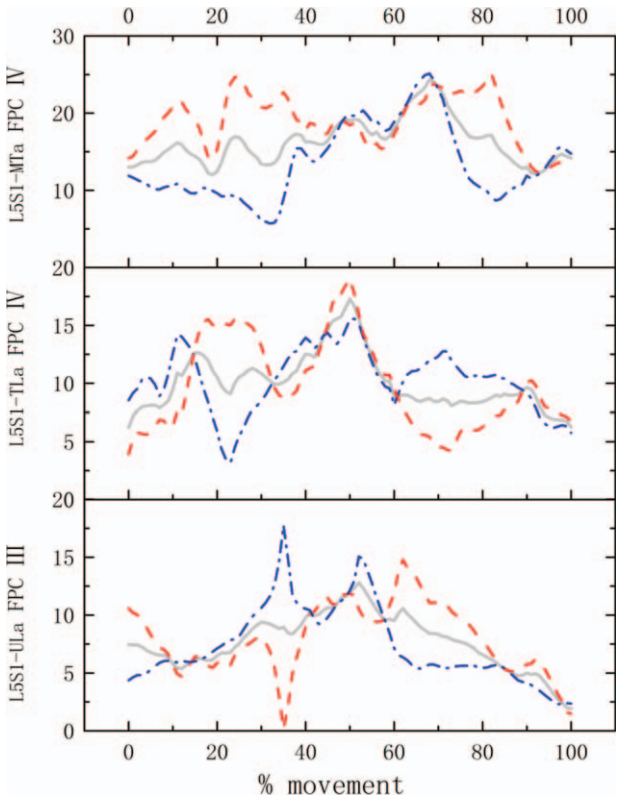


Figure 3. Time-dependent DP variability in FPC with significant difference between the 2 groups (The red dashed and blue dash–dot curves represent the DP in the AS and control groups, respectively; whereas the gray curve indicates the means of both groups.).

patients were either less or more variable in the coordination of each relative lower spine segments (middle thorax, thoracolumbar, and upper lumbar) and lumbosacral joint during different time periods of lifting. In addition, certain areas in the abnormal inter-segmental coordination of the spine in the AS patients had significant correlation with spinal mobility impairment.

This study revealed that the coordination of the upper lumbar and lumbosacral joint during the first half of lifting was less variable in AS patients. The motion of the two segments was coupled for the common task to stabilize the spine extensively as protection for the injured segments[9,24] and for other reasons.[25] This finding is consistent with previous studies on patients with LBP indicating that the variability in coordination of lumbar and pelvis is reduced during flexion-extension tasks.[7,9] In the present study, similar results were observed during the first half of lifting when the extension of trunk accelerated to the highest velocity, and then the spine needed increased stability. Furthermore, the motion of the upper lumbar was controlled to stabilize the spine in our participants, which may due to the one have larger range of motion than that of the lower lumbar.[12,15] Moreover, such controlled motion compensated for the instability of the most injured thoracolumbar and middle thorax, where were in a more controlled motion in healthy participants (Figure 3).

This study also showed that coordination of the upper thorax and the lumbosacral joint during the first half of lifting was highly anti-phase in the patients. The motion of thorax regions and lumbar–pelvic regions was greatly decoupled for different lifting tasks[26]; the former needed high participation in lifting object, and the latter required additional stabilization of the spine. The compensatory motion of thorax for the limited lumbar contribution to trunk motion was also observed in patients with LBP[6,9] and AS.[3] A previous study[10] found similar coordination patterns of lumbar and pelvis in LBP patients, including thorax segment in the definition of the lumbar angle. The results implied that the thorax marker configuration used to investigate the lumbar motion could explain the opposite viewpoints on the aberrant coordination of lumbar and pelvis in patients with LBP.

In the study, the AS patients had increased anti-phase in the coordination of neck and lumbosacral joint during the two phases of lifting. Similar to the thorax regions, neck motion was also released from the lumbar–pelvic regions. Neck extension during lifting increased the thoracic erector spinae activity.[27] Therefore, the increased neck extension would enhance the compensatory thorax extension mainly during the first half of lifting. This study also showed that the coordination of thoracolumbar and lumbosacral joint was less variable during the second half of lifting. The increased neck extension was then helpful to stabilize the thoracolumbar region, which can be a site for vertebral fractures.[28] The least flexion of the thoracolumbar among the thorax regions during flexion was also observed in the elderly,[14] who showed similar large thoracic kyphosis angle as the AS patients.

Our results revealed that apart from the limited motion of upper lumbar and thoracolumbar regions, the progression of

Table 4

Correlation coefficient between the FPC score and each index of spinal mobility in FPC with significant difference between the 2 groups.

	MS	TWL	MID	LF	CR
CRP					
L5S1–MTa FPC IV	−0.06	0.26	−0.23	−0.34	−0.10
L5S1–UTa FPC IV	−0.43*	0.58*	−0.76*	−0.72*	−0.69*
L5S1–neck FPC I	−0.47*	0.48*	−0.43*	−0.44*	−0.45*
L5S–-neck FPC II	0.46*	−0.34	0.29	0.43*	0.29
DP					
L5S1–ULa FPC III	−0.50*	0.46*	−0.48*	−0.27	−0.56*
L5S1–TLa FPC IV	0.54*	−0.50*	0.62*	0.51*	0.60*
L5S1–MTa FPC IV	−0.24	0.16	−0.42*	−0.27	−0.26

CR = cervical rotation, LF = LatFlex, MID = max intermalleolar distance, MS = Mod Schöber, TWL = tragus-to-wall Left.
* Significant correlation.

spinal mobility impairment might be associated with the compensatory motion of the neck and upper thorax. The overused muscle activity caused by the compensatory motion of the neck and thorax regions has been linked to neck and upper thorax pain.[27] The increased stiffness of the thoracolumbar[14,28] and lumbar[9,29–31] regions together with large compressive loads caused by lifting[32] might lead to excessive loads on the spine, and this phenomenon might play a major role in back disorders and pain[33] and structural damage.[3,4,34] Therefore, the results of our study supported the viewpoint that the altered movement patterns of the spine and hip might be a potential factor contributing to the development of adjacent segment destruction in AS patients.[3]

The following limitations must be addressed in this study. First, our study used a small sample size for patients. Second, the lifting weight was not set in several levels. Utilizing different levels of lifting weight might influence the lumbar participation to trunk motion[35] and the research on lumbar region. Third, the effect of inter-segmental coordination of the spine on its mobility impairment was proven indirectly by the correlation analysis of their relationship.

5. Conclusion

The inter-segmental coordination of the spine in the AS patients was altered to complete lifting tasks during special time. The motion of upper lumbar and thoracolumbar was more coupled with pelvis to provide stability to the trunk during the first and second half of lifting respectively. Moreover, the compensatory extension of neck and upper thorax for limited lumbar motion during first half of lifting, led to an enlarged extension range of the trunk. The compensatory extension of neck was benefited to keep stability of thoracolumbar during the second half of lifting. These abnormal aspects of inter-segmental coordination of the spine might affect disease progression.

Acknowledgments

Funding for this study was provided by Bijzonder Onderzoeksfonds KU Leuven (BOF): SPARKLE –Sensor-based Platform for the Accurate and Remote monitoring of Kinematics Linked to E-health #: IDO-13-0358; We graciously thank all other members of the SPARKLE group: K. De Vlam, R. Westhovens, W. Dankaerts, T. Swinnen, J. Geuens, L. Geurts, J. Lecoutere, R. Puers, V. Van den Abeele, S. Van Huffel and L. Billiet.

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Correction

This article was originally published without the full funding information. This has now since been added as an acknowledgements section.

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