

Original Article

Analysis of sagittal morphology of angular kyphosis in adult patients with spinal tuberculosis

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Abstract: Background: Human spinal curvature, hip and knee extension, arch, and dynamic muscle systems form a unique sagittal shape and position relationship. Normal human sagittal curve enables the body in the most stable and minimum energy consumption state. Adult spinal tuberculosis had younger age of onset with a majority of vertebral tuberculosis. The most common deformity of vertebral tuberculosis is kyphosis. The body sagittal had morphological changes when tuberculous spondylitis kyphosis occurs. This study aims to understand the compensatory characteristics of sagittal morphology for angular kyphosis in adult patients with spinal tuberculosis. Methods: Adult patients with spinal TB were recruited and the following parameters were measured: Cobb angle, cervical lordosis (CL), thoracic kyphosis (TK), lumbar lordosis (LL), pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), and sagittal vertical axis (SVA). Results: Compared with normal values reported in the literature, more LL and less TK were achieved. The values of CL, PI, PT, and SS were not statistically different from that reported in the literature. The LL value was greater than the normal value reported ($P < 0.05$). The TK value was less than the normal value reported ($P < 0.05$). The values of CL, PI, PT, and SS showed no statistical difference compared to the normal values reported. Conclusion: Patients having angular kyphosis but sagittally compensated with normal SVA demonstrate a TK decrease, LL increase, and hyperextension of adjacent segments of the kyphotic spine, without pelvic compensation. Decompensated patients with positive SVA have characteristic pelvic retroversion, while patients with negative SVA have increased pelvic anteversion.

Keywords: Spinal tuberculosis, angular kyphosis, sagittal plane

Introduction

Human sagittal morphology and position is defined by spinal curvature, hip and knee extension, arch, and dynamic muscle systems. Normal sagittal morphology allows the body to stay in the most stable position with minimal expense of energy [1-4]. Sagittal equilibrium includes sagittal alignment in the spinal, pelvic, and lower limb areas. Their morphology and orientation correlate and interact with each other. Respective equilibrium and alignment in the spine, pelvis, and lower limb play important roles in maintaining global sagittal equilibrium [5].

Schwab et al. [6] have demonstrated that the quality of life for adults with spinal disease closely correlates with sagittal deformity versus coronal deformity. Mild sagittal imbalance can cause changes in quality of life, and severe imbalance shows a linear relationship to deteriora-

tion in quality of life. At present, spinal deformity surgery aims not only to correct spinal deformity but also to restore spinal sagittal balance [7-9]. Studying the change in sagittal alignment is important to decision making in deformity surgery and postoperative quality of life [10-12].

Kyphosis is the most common deformity in vertebral tuberculosis (TB). It accounts for the majority of spinal TB-related deformities, and is more frequently observed in young adults. The adjacent vertebrae are wedged together with marginal impaction, and gradually, angular kyphosis develops that involves a small number of vertebrae, exhibiting severe deformities. The effects of angular kyphosis on the spinal sagittal plane balance were obvious and might not only cause instability of the spinal sagittal plane but also cause damage to the spinal nerves, thus seriously affecting patients' quality of life.

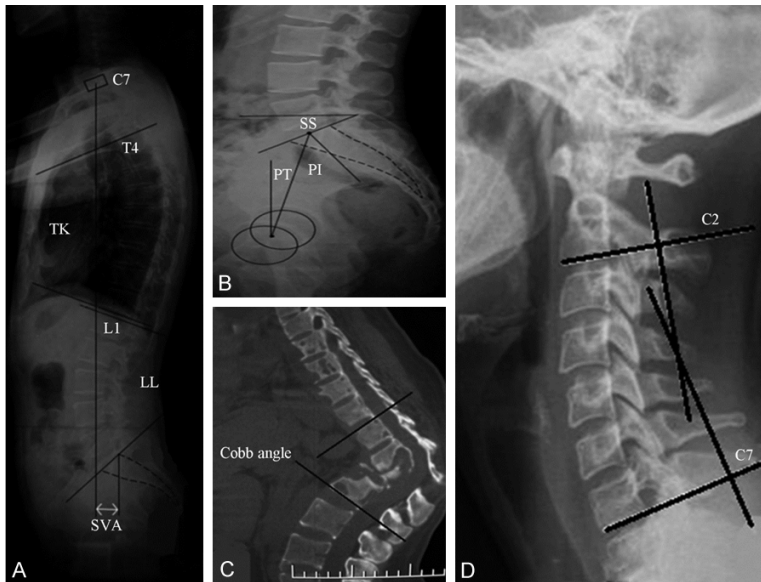


Figure 1. Measurement of spinopelvic parameters. A: ① TK: the angle between the superior endplate of T4 and the inferior endplate of T12; ② LL: the angle between the superior endplate of L1 and that of S1; ③ SVA: the distance between the C7 plumb line and the posterior-superior corner of S1 in the sagittal plane. When the plumb line is anterior to the posterior-superior corner of S1, SVA is positive, otherwise negative; B: ① PI: the angle between the perpendicular to the sacral plate at its midpoint and the line connecting this point to the middle axis of the femoral heads; ② PT: the angle between the line connecting mid-sacral plateau to the middle axis of the femoral heads and vertical line; ③ SS: the angle between the superior endplate of S1 and horizontal line; C: Cobb angle, defined as the angle between a line drawn parallel to the superior endplate of one vertebra above the fracture and a line drawn parallel to the inferior endplate of the vertebra one level below the fracture; D: CL, defined as the angle between perpendicular to the inferior endplate of C2 and C7.

Our study aimed to explore the change in sagittal morphology resulting from adult spinal tuberculous angular kyphosis and investigate the characteristics of compensatory mechanisms to facilitate clinical diagnosis and treatment. Through understanding the characteristics of the changes on the sagittal plane in adult patients with spinal tuberculous angular kyphosis, surgical procedures could be improved to correct the sagittal balance in these patients in future.

Materials and methods

General data

A total of 13 adult patients with spinal TB having angular kyphosis, including six male and seven female patients aged 20-56 years with mean age of 32.62, were recruited from our hospital between January 2013 and December 2014. There were 11 cases of thoracolumbar

TB, one each of thoracic and lumbar TB. Patients stood in a natural erect posture with shoulder ante flexion at 30°. Anteroposterior and lateral radiographs of the spine (including bilateral hip) were obtained in the weight-bearing position. This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of Xinjiang Medical University. Written informed consent was obtained from all participants.

Inclusion criteria: 1) patients with spinal tuberculous angular kyphosis patients; 2) age above 18 years; 3) no history of undergoing spine or hip surgery; 4) Cobb Angle >10°; and 5) kyphosis caused by other diseases.

Radiological measurement

Surgimap software was used to measure Cobb angle, cervical lordosis (CL), lumbar lordosis (LL), pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), and sagittal vertical axis (SVA) on lateral radiogram of the spine [13].

Sagittal spinopelvic parameters were measured as follows: 1) TK (the angle between the superior endplate of T4 and the inferior endplate of T12); 2) LL (the angle between the superior endplate of L1 and that of S1); 3) PI (the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the middle axis of the femoral heads); 4) PT (the angle between the line connecting the mid-sacral plateau to the middle axis of the femoral heads and vertical line); 5) SS (the angle between the superior endplate of S1 and the horizontal line); 6) SVA (the distance between the C7 plumb line and the posterior-superior corner of S1, SVA is positive, otherwise it is negative); 7) Cobb angle (the

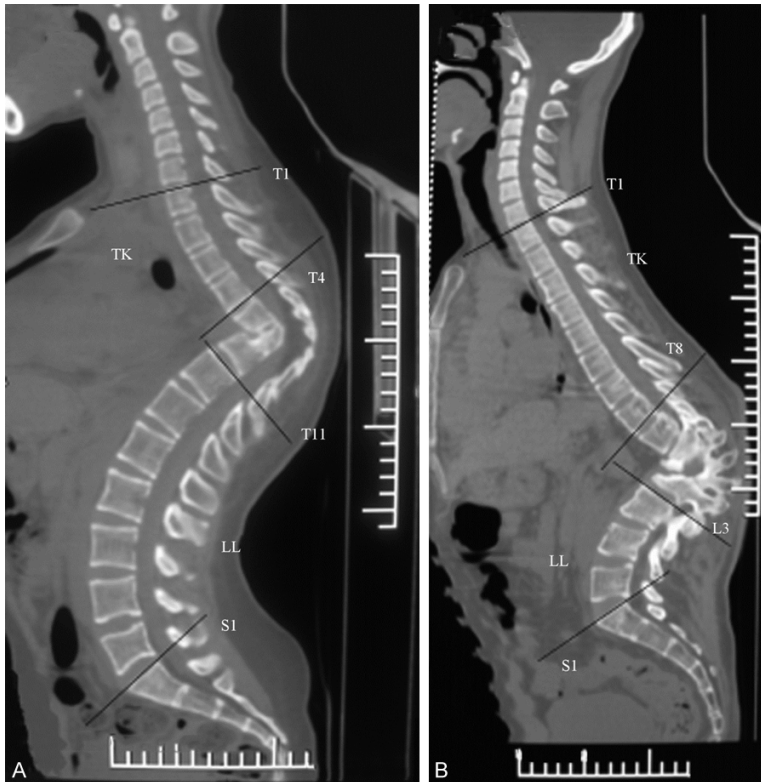


Figure 2. Patients with spinal TB kyphosis. Due to multiple adjacent vertebra that exhibit severe deformities wedging together with marginal impaction, only TK and LL in the segments adjacent to the deformity were measured for better understanding of compensatory mechanism in normal thoracic and lumbar spine. Thus, TK was defined as the angle between the superior endplate of T1 and the interior endplate of the upper vertebral body of the most tilted vertebral body of the top half of kyphosis, and LL was the angle between the superior endplate of the lower vertebral body of the most tilted vertebral body of the bottom half of kyphosis and the superior endplate of S1. A: Thoracic TB; B: Thoracolumbar TB.

angle between a line drawn parallel to the superior endplate of one vertebra above the fracture, and a line drawn parallel to the inferior endplate of the vertebra one level below the fracture); 8) CL (the angle between and perpendicular to the inferior endplate of C2 and C7 **Figure 1**).

Due to multiple adjacent vertebra that exhibit severe deformities wedging together with marginal impaction, only TK and LL in the segments adjacent to the deformity were measured for a better understanding of compensatory mechanisms in normal thoracic and lumbar spine. Thus, TK was defined as the angle between the superior endplate of T1 and interior endplate of the upper vertebral body of the most tilted vertebral body of the top half of kyphosis, and LL was the angle between the superior endplate of

the lower vertebral body of the most tilted vertebral body of the bottom half of kyphosis and the superior endplate of S1 (**Figure 2**).

Statistical analysis

Data were analyzed with SPSS17.0. Sagittal spinopelvic parameters were presented as mean \pm SE and compared with normal values reported in the literature using a t-test.

Results

Sagittal spinopelvic parameters in 13 cases of spinal tuberculous angular kyphosis (**Table 1**) were compared with normal values reported in the literature (**Table 2**) [14]. Lumbar lordosis was $66.62 \pm 18.496^\circ$, more than the value reported ($48.2 \pm 9.6^\circ$) in the literature ($P < 0.05$); TK was $-1.77 \pm 12.524^\circ$, less than the value reported ($27.8 \pm 11.4^\circ$) in the literature ($P < 0.05$). The values of CL ($16.6 \pm 12.231^\circ$), PI ($47.00 \pm 12.193^\circ$), PT ($17.69 \pm 10.995^\circ$) and SS ($29.08 \pm 10.436^\circ$) were not statistical-

ly different from those reported in the literature [14, 15].

Discussion

A normal erect position requires cervical lordosis, thoracic kyphosis, lumbar lordosis, anterior pelvic tilt, and leg extension. On sagittal radiography, the C7 plumb line (C7PL) is located at the posterior-superior corner of S1. Sagittal balance is achieved when the distance between C7PL and the posterior-superior corner of S1 is within ± 2.5 cm.

There is significant interaction between each segment of the spine. Cervical lordosis, thoracic kyphosis, lumbar lordosis, pelvic rotation, and lower limb flexion and extension are considered physiological adjustments for adapta-

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Table 1. Sagittal parameters in spinal TB patients with angular kyphosis

No.	Gender	Age/years	Location	CL/°	LL/°	TK/°	PI/°	PT/°	SS/°	Cobb angle/°	SVA/mm
1	Female	30	T12	19	55	-3	37	35	2	91	75
2	Female	38	T12	0	92	-2	47	16	31	84	-37
3	Male	29	T12	12	97	-2	43	10	33	105	16
4	Male	26	T12L1	35	81	-21	36	-1	37	90	91
5	Female	28	T12L1	0	76	-19	27	8	19	90	-21
6	Female	30	L1	21	80	-11	41	15	26	93	0
7	Male	44	L1	15	70	-3	53	21	32	55	20
8	Male	54	T12L1	24	32	17	49	27	22	34	23
9	Male	21	T6-7	23	53	-8	36	5	29	68	-15
10	Female	56	L2-3	29	48	20	56	13	43	24	25
11	Female	22	T10-11	3	57	-5	73	35	38	37	25
12	Male	20	T11	32	68	0	59	22	36	75	4
13	Female	26	L1	3	57	14	54	24	30	32	-5

Table 2. Comparison of spinopelvic parameters between spinal TB patients with angular kyphosis and normal values reported in the literature

Data source	n (cases)	Age/years	LL/°	TK/°	PI/°	PT/°	SS/°
Our study	13	32.62±11.920	66.62±18.496*	-1.77±12.524*	47.00±12.193	17.69±10.995	29.08±10.436
Literature [14]	260	34.3±12.6	48.2±9.6	27.8±11.4	44.6±11.2	11.2±7.8	32.5±6.5

*: Correlation is significant at the 0.05 level.

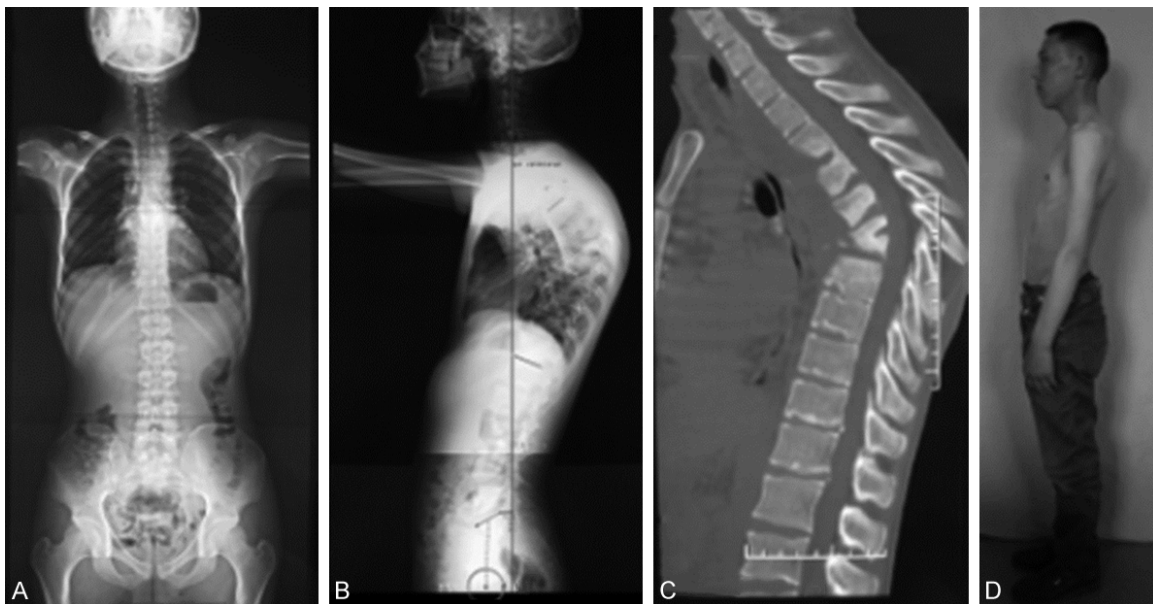


Figure 3. Patient with TB present in T6 and T7 vertebral bodies. A and B: Were anteroposterior and lateral X-ray films of whole spine, which revealed TK reduction of adjacent segments and global lordosis involving thoracolumbar and lumbar segments to limit an anterior body tilt for compensation with negative SVA. Compensatory pelvic retroversion was not observed. C: Was thoracic CT. D: Was lateral picture of patient, which showed hip and knee extension without compensatory flexion.

tion. Theoretically, an increase in PT results in an increase in LL, followed by an increase in TK

which consequently increases CL. However, although a change in PL causes LL alteration, it

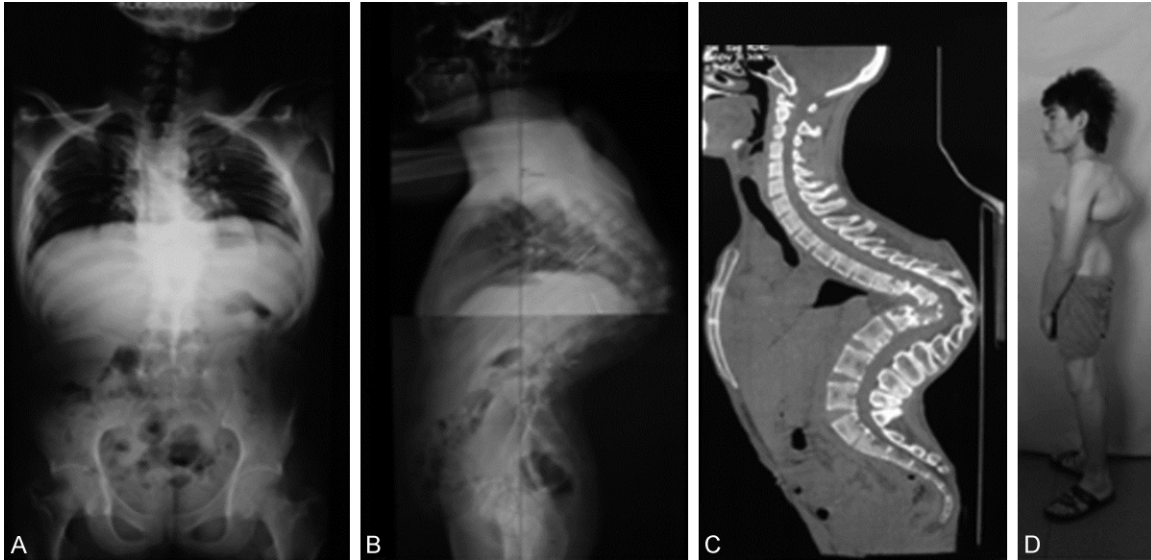


Figure 4. Patient with TB present in L12 vertebral body. A and B: Were anteroposterior and lateral X-ray films of whole spine, showing thoracolumbar TB sagittally compensated with positive SVA. LL increased and TK decreased with normal cervical curvature and without compensatory pelvic retroversion. C: Was whole spine CT. D: Was lateral picture of patient with hip and knee extension; no compensatory flexion was observed.

is not significantly associated with TK and CL, indicating a complicated relationship between the pelvis and cervical structure.

Kyphosis at any spinal segment can cause an abnormal forward-curved posture. To maintain sagittal balance, the following compensatory mechanisms are observed: hyperextension of adjacent segments, pelvic retroversion, hip hyperextension, and knee flexion. The compensatory change in the cervical spine is also shown to maintain head and gaze position. Compensatory mechanisms in patients with kyphosis are illustrated as follows [16]: 1) Reduction of thoracic kyphosis causes forward-curved posture. Reduction of thoracic kyphosis limits anterior translation of the axis of gravity and is typically observed in young patients with a flexible spine. Compensation was not significant in aging patients or in patients with ankylosing spondylitis due to a rigid spine; 2) Increase in LL can compensate for forward-leaning of the spine resulting from kyphosis; 3) Hyperextension of adjacent segments is a very common compensatory mechanism in kyphotic deformity. The loss of distal LL can be compensated by the increase of proximal lumbar or thoracic lordosis, which is common in multiple segments or adjacent segments; 4) Pelvic retroversion: pelvic incidence determines the global capacity of pelvis retro-

version, which is easily achieved for patients with a great pelvic incidence [17, 18]. Pelvic incidence increases with age and remains constant after skeletal maturity [19]. In fact, pelvic adjustment in adults depends on PT and SS [20]. The pelvis regulates sagittal balance through two mechanisms: First, PT and SS closely correlate with LL, and PI changes LL by modulating SS to regulate spinal alignment. Second, loss of lumbar curvature is compensated by PT change and corresponds to the posterior rotation of the pelvis around the femoral heads, similar to that during hip hyperextension, which causes a posterior body tilt allowing for compensation of anterior leaning body; 5) Change of CL: Cervical vertebra maintain head and horizontal gaze position, and limited cervical function will greatly influence daily activity and decreased quality of life. One study indicated that CL related to TK, SVA, PT, and T1 slant angle [21]; 6) Hip hyperextension and knee flexion: hip extension causes a posterior body tilt, and knee flexion results in posterior translation of the axis of gravity.

This study revealed the following characteristics of sagittal compensatory mechanism in patients with adult spinal TB having kyphosis: Kyphosis at any spinal segment in patients with spinal TB can cause hyperextension of adjacent segments. Hyperextension of adjacent spi-

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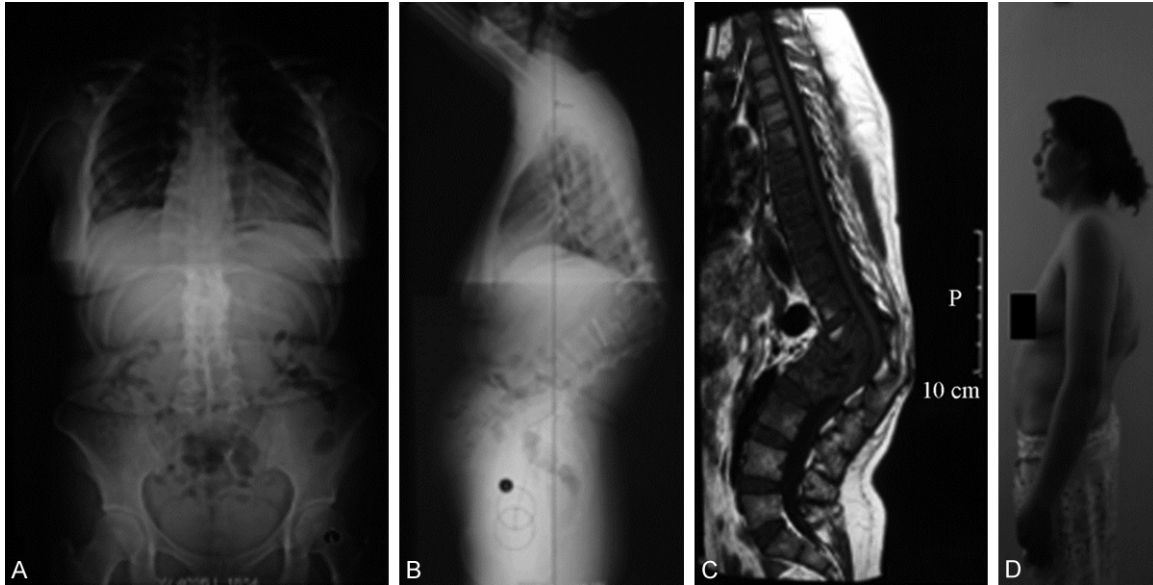


Figure 5. Patient with TB present in L1 vertebral body. A and B: Were anteroposterior and lateral X-ray films of whole spine, showing thoracolumbar TB with SVA of zero. LL increased and TK decreased with normal cervical curvature and without compensatory pelvic retroversion. C: Was whole spine MRI. D: Was lateral picture of patient.

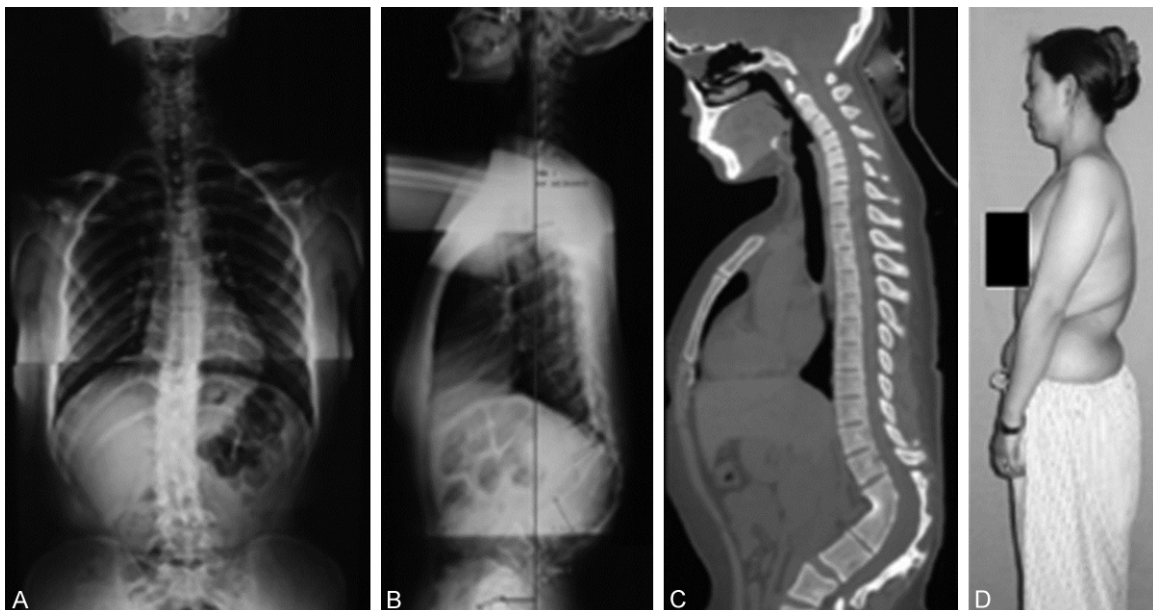


Figure 6. Patient with TB present in T12 and L1 vertebral bodies. A and B: Were anteroposterior and lateral X-ray films of whole spine, showing thoracolumbar TB sagittally compensated with negative SVA. LL increased, TK decreased and cervical curvature reduced without compensatory pelvic retroversion. C: Was whole spine CT. D: Was lateral picture of patient with hip and knee extension; no compensatory flexion was observed.

nal segments was observed in all of the patients with spinal TB in our research. Thoracic TB kyphosis inevitably induces changes in cervical and lumbar vertebra, thoracolumbar TB in thoracic and lumbar vertebra, and lumbar TB in thoracic vertebra and pelvis.

The change of the non-adjacent segments, namely segments with intervals, in patients with spinal TB with kyphosis depends on the compensatory status of adjacent segments. When kyphosis is compensated by hyperextension of adjacent segments in young patients

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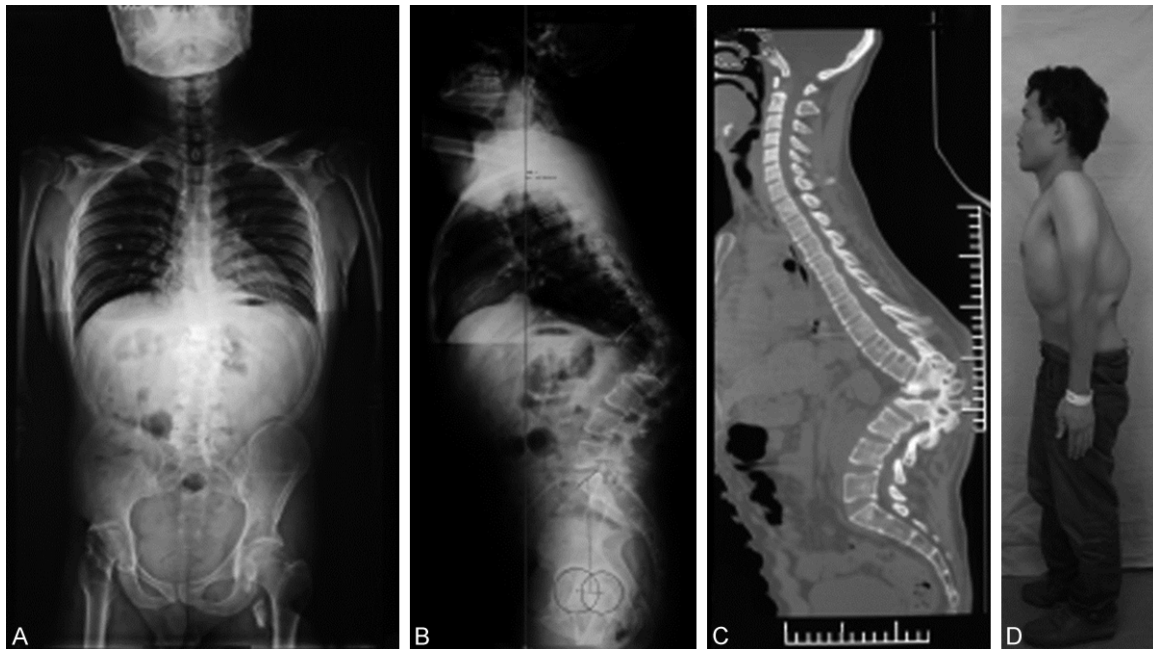


Figure 7. Patient with TB present in T12 and L1 vertebral bodies. A and B: Were anteroposterior and lateral X-ray films of whole spine, showing thoracolumbar TB decompensated with positive SVA. CL and LL increased, TK decreased with compensatory pelvic retroversion. C: Was whole spine CT. D: Was lateral picture of patient.

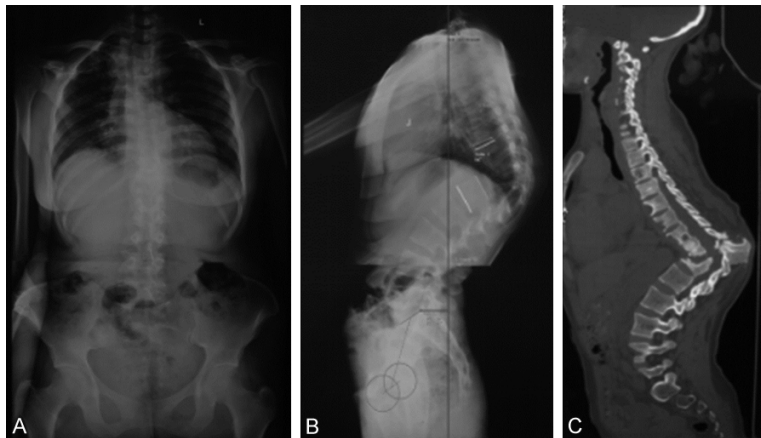


Figure 8. Patient with TB present in T12 vertebral body. A and B: Were anteroposterior and lateral X-ray films of whole spine, showing thoracolumbar TB decompensated with negative SVA. LL increased and TK decreased without compensatory pelvic retroversion. C: Was whole spine CT.

with spinal TB with a flexible spine and inconspicuous spinal degenerative disease, pelvic retroversion is not observed. Decompensated patients with positive SVA are characterized by pelvic retroversion, while patients with negative SVA have increased pelvic anteversion. In this study, spinal sagittal imbalance was only compensated by pelvic retroversion without knee flexion.

In our study, a 21-year-old patient with TB in the T6 and T7 vertebral bodies and flexible spine showed TK decrease in the adjacent segments and global lordosis involving thoracolumbar and lumbar segments to limit anterior body tilt through compensation with a negative SVA (Figure 3). Other compensatory mechanisms, such as posterior pelvic tilt of adjacent segments and knee flexion, were not observed. There were 11 cases of thoracolumbar spinal TB, including eight cases sagittally compensated with normal SVA, and three decompensated cases. Among eight compensated cases, SVA was positive in five cases (Figure 4), zero in one case (Figure 5) and negative in one case (Figure 6).

In this study, eight compensated patients with normal SVA are characterized by LL increase and TK decrease without pelvic retroversion or knee flexion. Among three decompensated

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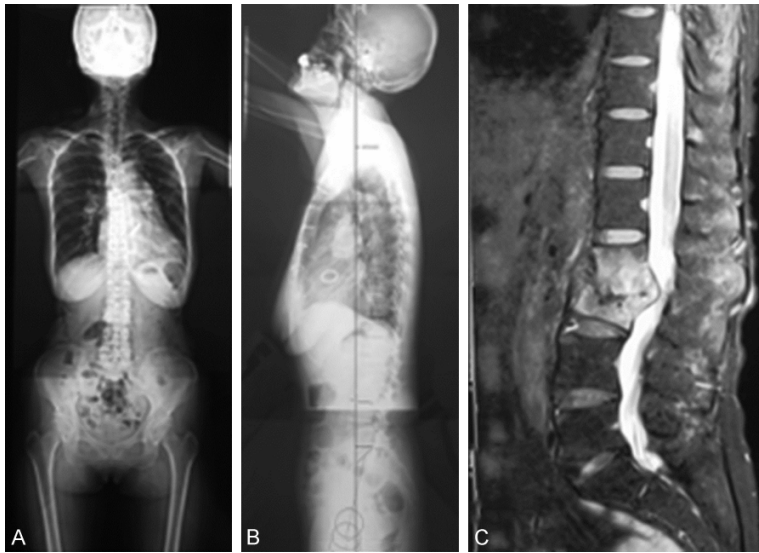


Figure 9. Patient with TB present in L2 and L3 vertebral bodies. A and B: Were anteroposterior and lateral X-ray films of whole spine, showing thoracolumbar TB sagittally compensated with positive SVA. TK decreased and lower LL increased without compensatory pelvic retroversion. C: Was whole spine MRI.

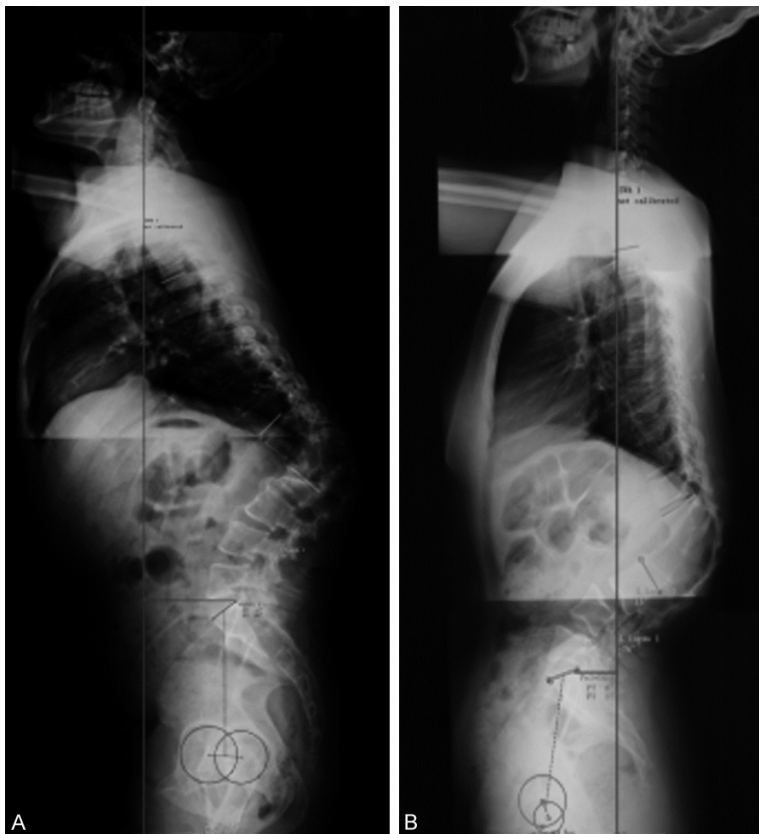


Figure 10. Change in CL in patient with spinal TB. A: Showed increased CL with positive SVA; B: Showed decreased CL with negative SVA.

patients with thoracolumbar TB, SVA was positive in two cases (**Figure 7**) and negative in one case (**Figure 8**). De-compensated patients with positive SVA showed compensatory LL increase, TK decrease, and pelvic retroversion, while patients with negative SVA had increased pelvic anteversion. One compensated patient (positive SVA) in our study with TB present in L2 and L3 vertebral bodies (**Figure 9**), close to the thoracolumbar segment, demonstrated reduction of TK and increase of lower LL without compensatory pelvic retroversion.

Change in cervical curvature is affected by multiple factors, including not only TB kyphotic segments, but also thoracic compensatory curvature, the shape and orientation of the thoracic inlet, and global SVA as well. The change in CL was complicated in this study. Locally, to maintain balance and keep an erect position and horizontal gaze, head and cervical alignment are influenced by thoracic curvature and the shape and orientation of the thoracic inlet, similar to the relation between PT and LL. In our research, the patient with TB present in T6 and T7 vertebral bodies (**Figure 3**) developed TK, which led to the increase in thoracic inlet angle, thus increasing CL to maintain gaze position. The greatest variation in the angle of CL was located at C1-C2 instead of the lower cervical vertebra. Similarly, the largest variation in angle of LL is located at L5-S1. Regarding global sagittal alignment, SVA

affects CL and is illustrated as follow: positive SVA results in CL increase, and negative SVA leads to CL decrease (**Figure 10**).

In conclusion, young patients with a flexible spine and inconspicuous spinal degenerative disease, having angular kyphosis but sagittally compensated with normal SVA, demonstrate TK decrease, LL increase and hyperextension of adjacent segments of the kyphotic spine, without pelvic compensation. Decompensated patients with positive SVA are characterized by pelvic retroversion, while patients with negative SVA have increased pelvic anteversion. Cervical lordosis has a complicated relationship with the shape and orientation of the thoracic inlet, as well as with SVA. All of the patients showed hip and knee extension without compensatory flexion.

Disclosure of conflict of interest

None.

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