CLINICAL ARTICLE

Variation in Global Spinal Sagittal Parameters in Asymptomatic Adults with 11 Thoracic Vertebrae, four Lumbar Vertebrae, and six Lumbar Vertebrae

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Objective: To investigate the prevalence of 11 thoracic vertebrae (TVs), four lumbar vertebrae (LVs) and six LVs among asymptomatic Chinese volunteers, and the influence of spine variations on the global spinal sagittal parameters.

Methods: A total of 389 asymptomatic Chinese volunteers were recruited. Each subject underwent a full-spine X-ray examination with measurement of global spinal sagittal parameters. The radiographs were examined by a spine surgeon and a radiologist to determine the variation in the number of vertebrae. These parameters were used to compare individuals with five LVs to those with 11 TVs, four LVs, and six LVs.

Results: The study population included 12 individuals (3.1%) with seven cervical vertebrae (C) + 11 thoracic vertebrae (T) + five lumbar vertebrae (L), 8 (2.1%) with 7C + 11T + 6L, 8 (2.1%) with 7C + 12T + 4L, and 15 (3.9%) with 7C + 12T + 6L. Compared to the 7C + 12T + 5L individuals, those with 7C + 11T + 5L had significantly lower C_6–T_5 Cobb values ($P < 0.05$); 7C + 12T + 4L individuals had significantly greater thoracic inlet angles ($P < 0.05$) and significantly lower pelvic tilt ($P < 0.05$); individuals with 7C + 12T + 6L had significantly greater sacral slope, pelvic tilt, pelvic incidence, and L1–5 Cobb values (all $P < 0.05$), but significantly lower thoracic inlet angle ($P < 0.05$). There were no significant differences in any of the parameters examined between the 7C + 11T + 6L group and the 7C + 12T + 5L group.

Conclusions: Asymptomatic adults with 7C + 12T + 6L, 7C + 12T + 4L, and 7C + 11T + 5L presented with different spinal sagittal alignment compared to those with 7C + 12T + 5L. Compared to variation in the number of LVs, the variation in the number of TVs had less effect on global spinal sagittal parameters. Spinal surgeons and researchers should be aware of the effects of variation in numbers of TVs and LVs on global spinal parameters and sagittal balance.

Key words: 11 thoracic vertebrae; Four lumbar vertebrae; Chinese asymptomatic volunteer; Sagittal alignment parameter; Spine variations

Introduction

There have been many studies on the spinal morphology and alignment of asymptomatic Asian and Western subjects[1–6]. many studies have revealed the tremendous help of sagittal spine parameters on mechanisms and therapeutic strategies for spinal disease[1,3,6]. Spinopelvic alignment

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parameters are closely correlated with spine typing and spinal sagittal curve[3]. Pelvic incidence (PI) as a widely used anatomical parameter increases in childhood and adolescence, but is stable in adulthood[7]. There is an intrinsic relationship between PI, pelvic tilt(PT) and sacral slope (SS), namely, PI = PT + SS. PT and SS are also regarded as forceful indicators for determining pelvic location and are strongly related to spine sagittal curves[8]. Matching lumbar lordosis (LL) to pelvic incidence (PI) to within 10° is one of the key radiographic components associated with successful outcome in adult spinal deformity surgeries[9]. Therefore, one of the purposes of the surgeon's corrective surgery is to obtain an adequate LL to achieve a harmonious spinopelvic alignment (PI-LL 10°or less). In addition, occipitocervical alignment, cervicothoracic alignment, cervical parameters, thoracic parameters, and lumbar parameters also play an important role in the diagnosis and treatment of spinal imbalance or spinal diseases at their respective segments[2,4,6,8,10].

However, many of these studies do not consider variation in the number of vertebrae. Most people have 12 thoracic vertebrae (TVs) (T_1–T_{12}) and five lumbar vertebrae (LVs) (L_1–L_5). However, some asymptomatic individuals have variation in the number of TVs or LVs, including a reduced number of TVs due to bilateral 12th rib loss and lumbosacral transitional vertebrae[4,11–15]. The lumbosacral transitional vertebra (LSTV), which was first observed by Bertolotti in 1917, is the most frequent malformation of the lumbosacral region[15]. It is defined as either lumbarization of the highest sacral spinal segment (six LVs) or sacralization of the most inferior lumbar spinal segment (four LVs).

Yokoyama *et al.*[4] noted six LVs among normal volunteers, and identified differences in total sagittal parameters between six LVs and five LVs. Benlidayi *et al.*[15] reported that patients with LSTV had less sacral tilt, i.e., a more vertical sacrum. However, they ignored the fact that sometimes an increase in the number of LVs can be accompanied by a decrease in the number of TVs. That is, there are individuals with 11 TVs and six TVs at the same time.

There still remains a paucity of literature regarding global spinal parameters for individuals with variation in the number of vertebrae. Therefore, the purpose of this study is: (i) to explore the prevalence of 11 TVs, four LVs and six LVs among asymptomatic Chinese volunteers; (ii) to present the global spinal parameters from volunteers in eastern China; and (iii) to analyze the changes of global spinal parameters caused by variation of the number of lumbar and thoracic vertebrae.

Materials and Methods

Study Design

This study was performed in accordance with the principles of the Declaration of Helsinki and was approved by our institutional review board (2016 Clinical Research Ethics Review No. 10). A cohort of 427 asymptomatic Chinese adults was recruited between 27 May 2016 and 13 April 2018. The exclusion criteria were as follows: age <18 years; lameness or unequal length of lower limbs; apparent scoliosis (Cobb angle >10° in coronal position); history of trauma of the spine, pelvis, or lower extremity; history of hip or knee arthroplasty and spine, pelvis, or lower limb surgery; complaints of back pain, neck pain, or limb numbness caused by degenerative diseases of the spine, such as disc herniation, spinal canal stenosis, and lumbar spondylolisthesis; strabismus or torticollis affecting balance; history of neuromuscular disorders or congenital abnormalities; or pregnancy or preparation for pregnancy. All individuals were of Chinese ethnicity. Informed consent was obtained from each volunteer prior to enrollment in this trial. The volunteers were

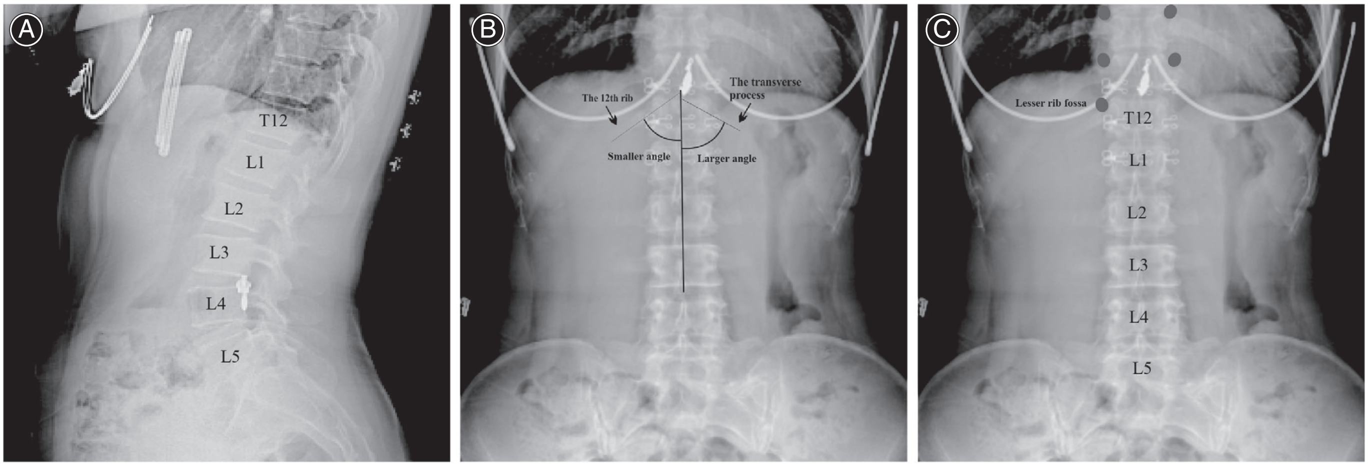

Fig. 1 An example of a unilateral 12th rib to distinguish the poorly developed 12th rib from the first lumbar transverse process. (A) The poorly developed rib could not be viewed in the lateral X-ray image. (B) A smaller example of a unilateral 12th rib to distinguish the poorly developed 12th rib from the first lumbar rib vertebrae angle (RVA) between the rib and the anterior midline of vertebral body in the posteroanterior view. (C) There was a "lesser rib fossa" at the junction of ribs and vertebrae in the posteroanterior view.

TABLE 1 Definition, measurement method and clinical significance of the parameters

Parameter	Description and definition	Clinical significance
Occipital Slope (°)	The angle between McRae's line and the horizontal line	Craniocervical parameters(reflecting occipital tilt)
$C_{0\text{-}2}$ Cobb angle (°)	The angle between McRae's line and the lower endplate of C_2	Cervical parameters(reflecting cervical curvature)
$C_{2\text{-}7}$ Cobb angle (°)	The angle between the C_2 lower endplate and the C_7 lower endplate	
$C_{1\text{-}7}$ Cobb angle (°)	The angle between the line linking the inferior anterior arch and the inferior posterior arch of the atlas and the C_7 lower endplate.	
$C_{2\text{-}7}$ SVA (mm)	The distance between a plumbline dropped from the centroid of C_2 and the posterior superior corner of C_7	
ARA C_2–C_7 (°)	The angle between Jackson's physiologic stress lines drawn at the C_2 and C_7 posterior body margins	
Cervical tilt (°)	The angle between two lines, both originating from the center of the T_1 upper endplate, with one being vertical to the T_1 upper endplate and the other passing through the tip of the dens	Cervicothoracic parameters;TS = cervical tilting pluscranial tilting(reflecting inclination of the cervical spine)
Cranial tilt (°)	The angle between two lines, both originating from the center of the T_1 upper endplate, with one passing through the dens and the other being a vertical line	
T_I Slope (°)	The angle between a horizontal plane and a line parallel to the T_1 upper end plate	Thoracic Inlet Parameters;TIA = TS + NT. (To reflect cervical and thoracic junction curvature andpredict physiological alignment of the cervicalspine.)
Neck Tilt (°)	The angle between two lines both originating from the upper end of the sternum, with one being a vertical line and the other connecting to the center of the T1 upper endplate	
Thoracic Inlet Angle (°)	The angle between a line originating from the center of the T_1 upper endplate and perpendicular to the T1 upper endplate and a line from the center of the T1 upper endplate and the upper end of the sternum	
C_6-T_5 Cobb angle (°)	The angle between the superior endplate of C_6 and the inferior endplate of T_5	Thoracic parameters(reflecting Thoracicl curvature)
$T_{5\text{-}12}$ Cobb angle (°)	The angle between the superior endplate of T_5 and the inferior endplate of T_{12}	
Thoracic Kyphosis (°)	The angle between the superior endplate of T_1 and the inferior endplate of T_{12}	
L_I Slope (°)	The angle between a horizontal plane and a line parallel to the L_1 upper end plate	Lumbar parameters(reflecting Lumbar curvature)
$L_{1\text{-}5}$ Cobb angle (°)	The angle between the superior endplate of L_1 and the inferior endplate of L_5	
Sacral Slope (°)	The angle formed by a line drawn along the endplate of the sacrum and a horizontal reference	Spinopelvic alignment.PI=SS + PT.(The important parameters basis ofRoussouly classification; To predictphysiological alignment of thethoracic and lumbar spine.)
Pelvic Tilt (°)	The angle formed by a line drawn from the midpoint of the sacral endplate to the center of the bicoxofemoral axis and vertical plumbline	
Pelvic Incidence (°)	The angle formed by a line originating from the center of the sacral endplate and perpendicular to the S_1 upper endplate and a line drawn between the center of the femoral head and the center of the sacral endplate	
PI-LL (°)	Pelvic Incidence minus $L_{1\text{-}5}$ Cobb angle	Achieving a harmonious spinopelvicalignment (PI-LL 10°or less) is instructive for both long and short segment fusion for adult spinal deformity
C_7 SVA (mm)	The horizontal offset from the posterosuperior corner of S_1 to the vertebral body of C_7	Sagittal balance parameters(Reflecting the sagittal balance of spine; The normal value is between plus and minus 50 mm)

given a free full-spine photograph and X-ray report, including the chest, lungs, spine, and abdomen, in return for their participation.

Forty volunteers who had an incomplete number of X-ray images or who met the exclusion criteria after radiography were excluded. Ultimately, 389 asymptomatic subjects were included in the study.

Radiographic Analyses

Anteroposterior and lateral radiographs were acquired for all volunteers with their arms in the fists-on-clavicles position, the head in the neutral position, and the knees and hips fully extended. The radiographs were examined by a spine surgeon and a radiologist who had independently reviewed several hundred whole-spine images prior to this review. The following parameters were measured from each lateral whole-spine standing radiograph: occipital slope (OS), $C_{0–2}$ Cobb angle ($C_{0–2}$ Cobb), $C_{2–7}$ Cobb angle ($C_{2–7}$ Cobb), $C_{1–7}$ Cobb angle ($C_{1–7}$ Cobb), $C_{2–7}$ sagittal vertical axis ($C_{2–7}$ SVA), absolute rotation angle C_2–C_7 (ARA C_2–C_7), cervical tilt, cranial tilt, T_1 slope (TS), neck tilt (NT), thoracic inlet angle (TIA), thoracic kyphosis (TK), C_6–T_5 Cobb angle (C_6–T_5 Cobb), $T_{5–12}$ Cobb angle (T_5–T_{12} Cobb), L_l Slope (LS), $L_{1–5}$ Cobb angle ($L_{1–5}$ Cobb), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), and C_7 sagittal vertical axis (C_7 SVA). Examples of the parameters have previously been as described[2,4,16].

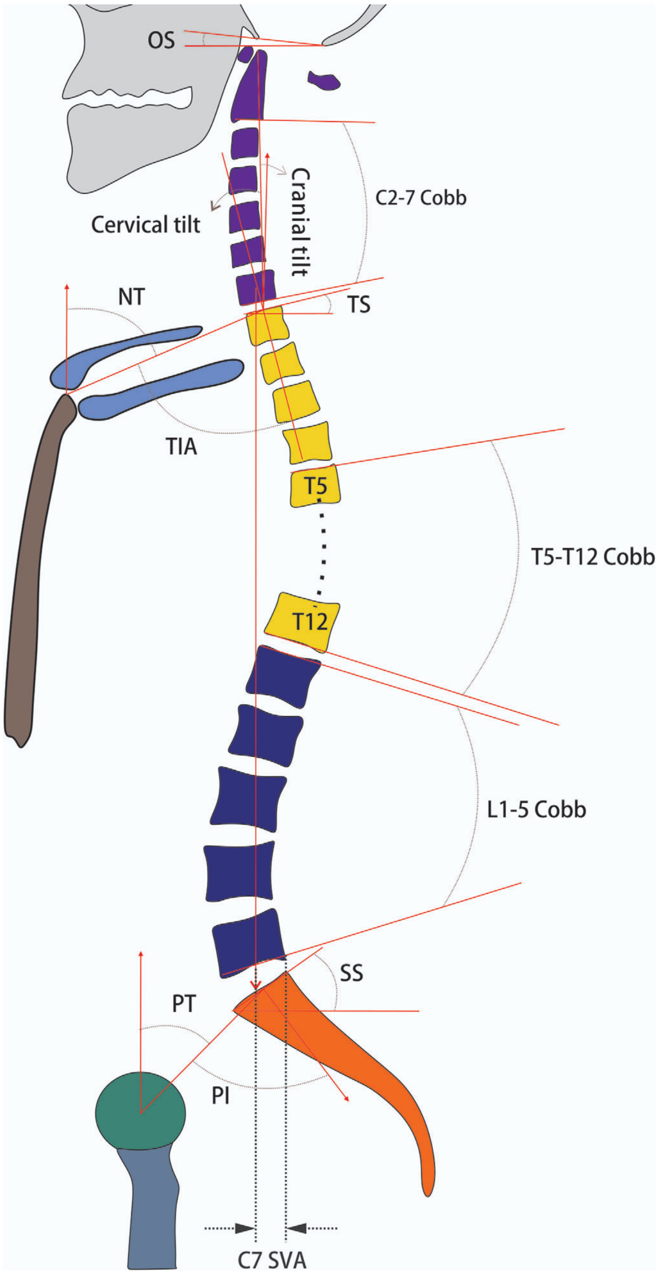

Fig. 2 Measurement methods of some spinal parameters.

All vertebrae with rib attachments, including bilateral or unilateral ribs, were counted as TVs. A vertebra was considered to be at the LV level only if it was not attached to the ribs[17]. The key to differentiating whether there were only 11 TVs was to distinguish the first lumbar transverse process from the 12th rib. Generally, the well-developed 12th rib can be viewed in lateral X-ray film. However, if the rib is not fully developed or too small, it is difficult to distinguish it from the first lumbar transverse process in either the lateral or posteroanterior view. It is possible to determine whether it is the 12th rib or the first lumbar transverse process from rib vertebrae angle (RVA) and the angle between the first lumbar transverse process and vertebral body (opening angle), and the presence or absence of "lesser rib fossa" in the posteroanterior view (Fig. 1). Spinal parameter measurements in individuals with 11 TVs were performed using the T_{11} as an indicator instead of T_{12}.

Individuals with four LVs were determined to have only four vertebrae and five intervertebral discs between the 12th thoracic vertebra and the sacrum. Spinal parameter measurements in individuals with four LVs were performed using L_4 as an indicator instead of L_5.

L6 was determined as present if all of the following criteria were fulfilled[4,18]: the L6 vertebral body appeared square or rectangular on lateral X-ray images, and obvious, well-formed disc material extending along the entire anteroposterior length of the sacrum was present between L6 and the sacral segment. Spinal parameter measurements in individuals with six LVs were performed using L6 as an indicator instead of L_5.

The definition, measurement method and clinical significance of each parameter are shown in Table 1. The measurement method of part of global spinal parameters (positive sign) is shown in Fig. 2.

TABLE 2 Comparison of global alignment parameters between 11TVs or 6LVs and normal

Parameter	7C + 12T + 5L	11TVs	6LVs
Number (%)	346 (89.4%)	20 (5.1%)	23 (5.9%)
Male/female	133/213	4/16	12/11
Age (years)	42.6 ± 13.2	41.6 ± 13.0	43.5 ± 13.7
BMI (kg/m^2)	22.6 ± 2.8	21.1 ± 2.2*	22.2 ± 2.7
Occipital slope (°)	13.6 ± 7.3	14.3 ± 7.1	16.5 ± 6.8
$C_{0\text{-}2}$ Cobb angle (°)	27.1 ± 8.1	26.3 ± 5.9	28.7 ± 9.2
$C_{2\text{-}7}$ Cobb angle (°)	6.3 ± 10.9	4.33 ± 10.1	5.1 ± 12.0
$C_{1\text{-}7}$ Cobb angle (°)	27.6 ± 11.2	26.1 ± 12.5	27.8 ± 12.3
$C_{2\text{-}7}$ SVA (mm)	16.7 ± 8.5	13.2 ± 6.4	14.9 ± 8.5
ARA C_2–C_7 (°)	8.2 ± 10.5	7.6 ± 9.6	6.3 ± 12.9
Cervical tilt (°)	8.7 ± 10.8	9.8 ± 8.1	10.2 ± 8.0
Cranial tilt (°)	5.0 ± 4.8	4.6 ± 4.2	4.8 ± 5.4
T_1 slope (°)	17.7 ± 6.2	16.0 ± 6.2	16.0 ± 7.1
Neck tilt (°)	52.1 ± 6.8	55.0 ± 8.1	51.6 ± 8.8
Thoracic inlet angle (°)	69.8 ± 8.2	70.9 ± 7.9	67.2 ± 10.1
C_6-T_5 Cobb angle (°)	9.8 ± 6.5	7.9 ± 5.3	10.0 ± 6.0
$T_{5\text{-}12}$ Cobb angle (°)	21.8 ± 7.8	22.7 ± 8.7	19.6 ± 8.7
Thoracic kyphosis (°)	34.2 ± 9.2	33.3 ± 9.3	31.1 ± 9.7
L_1 slope (°)	13.3 ± 5.4	14.5 ± 5.8	11.6 ± 4.9
$L_{1\text{-}5}$ Cobb angle (°)	35.3 ± 9.9	37.5 ± 8.6	41.7 ± 10.3*
Sacral slope (°)	38.2 ± 7.7	39.4 ± 6.6	41.6 ± 7.2*
Pelvic tilt (°)	9.7 ± 6.2	10.4 ± 6.0	15.4 ± 8.9*
Pelvic incidence (°)	47.3 ± 9.2	49.1 ± 10.6	56.6 ± 10.6*
PI-LL (°)	11.9 ± 9.1	11.7 ± 9.0	15.0 ± 10.1
C_7 SVA (mm)	10.3 ± 18.6	16.7 ± 33.5	14.8 ± 30.9

C, cervical vertebrae; *L*, lumbar vertebrae; LVs, lumbar vertebrae; *T*, thoracic vertebrae; TVs, thoracic vertebrae.; "7C + 12T + 5L" stands for volunteers with normal number of vertebrae; PI-LL, pelvic Incidence minus $L_{1\text{-}5}$ Cobb angle; * Compared with group 7C + 12T + 5L $P < 0.05$.

TABLE 3 Comparison of occipitocervical alignment and cervical balance parameters in different group

Parameter	7C + 11T + 5L	7C + 11T + 6L	7C + 12T + 4L	7C + 12T + 6L	7C + 12T + 5L	All
Number (%)	12 (3.1%)	8 (2.1%)	8 (2.1%)	15 (3.9%)	346 (89.4%)	389
Male/female	1/11	3/5	3/5	9/6	133/213	149/240
Age (year)	39.3 ± 14.4	44.9 ± 10.7	42.9 ± 15.4	42.8 ± 15.4	42.6 ± 13.2	42.5 ± 13.3
BMI (kg/m^2)	19.9 ± 2.2*	22.8 ± 1.5	21.8 ± 2.7	21.9 ± 3.1	22.6 ± 2.8	22.5 ± 2.8
Occipital slope (°)	13.8 ± 8.2	15.2 ± 5.5	17.8 ± 8.7	17.2 ± 9.5	13.6 ± 7.3	13.8 ± 7.4
$C_{0\text{-}2}$ Cobb angle (°)	27.6 ± 5.3	24.3 ± 6.6	30.2 ± 10.9	31.0 ± 9.7	27.1 ± 8.1	27.2 ± 8.2
$C_{2\text{-}7}$ Cobb angle (°)	2.0 ± 10.7	7.8 ± 8.8	4.6 ± 15.0	3.6 ± 13.4	6.3 ± 10.9	6.1 ± 11.0
$C_{1\text{-}7}$ Cobb angle (°)	22.7 ± 13.7	31.2 ± 8.7	28.3 ± 15.5	26.0 ± 13.8	27.6 ± 11.2	27.5 ± 11.4
$C_{2\text{-}7}$ SVA (mm)	13.0 ± 5.5	13.7 ± 8.0	16.2 ± 6.0	15.5 ± 8.9	16.7 ± 8.5	16.4 ± 8.4
ARA C_2–C_7 (°)	3.7 ± 8.9	13.4 ± 7.7	7.0 ± 11.8	2.54 ± 13.7	8.2 ± 10.5	7.9 ± 10.6

* Compared with group 7C + 12T + 5L $P < 0.05$.

TABLE 4 Comparison of cervicothoracic alignment and thoracic parameters in different group

Parameter	7C + 11T + 5L	7C + 11T + 6L	7C + 12T + 4L	7C + 12T + 6L	7C + 12T + 5L	All
Number (%)	12 (3.08%)	8 (2.06%)	8 (2.06%)	15 (3.86%)	346 (89.4%)	389
Male/female	1/11	3/5	3/5	9/6	133/213	149/240
Cervical tilt (°)	8.5 ± 9.2	11.8 ± 6.3	14.3 ± 8.8	9.3 ± 8.9	8.7 ± 10.8	8.9 ± 10.5
Cranial tilt (°)	4.5 ± 3.6	4.7 ± 5.3	3.9 ± 7.0	4.9 ± 5.6	5.0 ± 4.8	4.9 ± 4.8
T_1 slope (°)	15.3 ± 6.6	16.9 ± 5.8	19.8 ± 9.6	15.6 ± 7.9	17.7 ± 6.2	17.5 ± 6.3
Neck filt (°)	53.8 ± 6.5	56.8 ± 10.3	56.9 ± 10.7	48.8 ± 6.8	52.1 ± 6.8	52.2 ± 6.9
Thoracic inlet angle (°)	69.3 ± 6.6	73.3 ± 9.6	76.6 ± 11.4*	63.9 ± 9.0*	69.8 ± 8.2	69.7 ± 8.3
C_6-T_5 Cobb angle (°)	5.7 ± 4.6*	11.3 ± 4.4	9.5 ± 5.7	9.2 ± 6.7	9.8 ± 6.5	9.7 ± 6.5
$T_{5\text{-}12}$ Cobb angle (°)	25.4 ± 7.0	18.6 ± 9.8	23.0 ± 10.7	20.2 ± 8.5	21.8 ± 7.8	21.8 ± 7.9
Thoracic kyphosis (°)	35.0 ± 7.8	30.7 ± 11.1	36.8 ± 9.6	31.3 ± 9.3	34.2 ± 9.2	34.0 ± 9.2

* Compared with group 7C + 12T + 5L $P < 0.05$.

TABLE 5 Comparison of spinopelvic alignment and lumbar parameters in different group

Parameter	7C + 11T + 5L	7C + 11T + 6L	7C + 12T + 4L	7C + 12T + 6L	7C + 12T + 5L	All
Number (%)	12 (3.08%)	8 (2.06%)	8 (2.06%)	15 (3.86%)	346 (89.4%)	389
Male/female	1/11	3/5	3/5	9/6	133/213	149/240
L_1 Slope (°)	16.6 ± 5.5	11.4 ± 5.1	13.5 ± 4.2	11.7 ± 4.9	13.3 ± 5.4	13.3 ± 5.4
$L_{1\text{-}5}$ Cobb angle (°)	37.3 ± 6.1	37.7 ± 11.9	32.9 ± 8.5	43.8 ± 9.0*	35.3 ± 9.9	35.6 ± 10.0
Sacral slope (°)	38.1 ± 3.7	41.3 ± 9.5	37.6 ± 6.2	41.8 ± 6.1*	38.2 ± 7.7	38.4 ± 7.6
Pelvic tilt (°)	8.6 ± 6.1	13.0 ± 5.1	4.5 ± 5.4*	16.6 ± 10.4*	9.7 ± 6.2	10.0 ± 6.6
Pelvic incidence (°)	45.8 ± 7.7	54.1 ± 12.8	41.3 ± 8.2	58.1 ± 9.3*	47.3 ± 9.2	47.6 ± 9.5
PI-LL (°)	8.5 ± 9.5	16.4 ± 6.1	8.4 ± 8.2	14.2 ± 11.8	11.9 ± 9.1	11.9 ± 9.2
C_7 SVA (mm)	17.4 ± 28.9	15.8 ± 41.7	16.6 ± 14.3	14.3 ± 25.2	10.3 ± 18.6	11.1 ± 20.0

PI-LL, pelvic Incidence minus L1-5 Cobb angle.; * Compared with group 7C + 12T + 5L $P < 0.05$.

Statistical Analysis

The SPSS 19.0 statistical software package (SPSS, Chicago, IL) was used for statistical analyses. For comparison of parameters between the two groups, we applied the independent samples t test, Mann–Whitney U test, or chi square test as appropriate. All data are presented as the means ± standard deviations (SDs), and differences were considered statistically significant at $P < 0.05$.

Results

Study Population and X-ray Images of Each Group

The 389 volunteers ranged in age from 22 to 70 years, with a mean age of 42.5 years. They included 20 (5.1%) with 11 TVs, eight (2.1%) with four LVs, and 23 (5.9%) with six LVs. Eight individuals had an atypical number of both thoracic[11] and lumbar[6] vertebrae. No hemivertebra deformities were found in any of the volunteers.

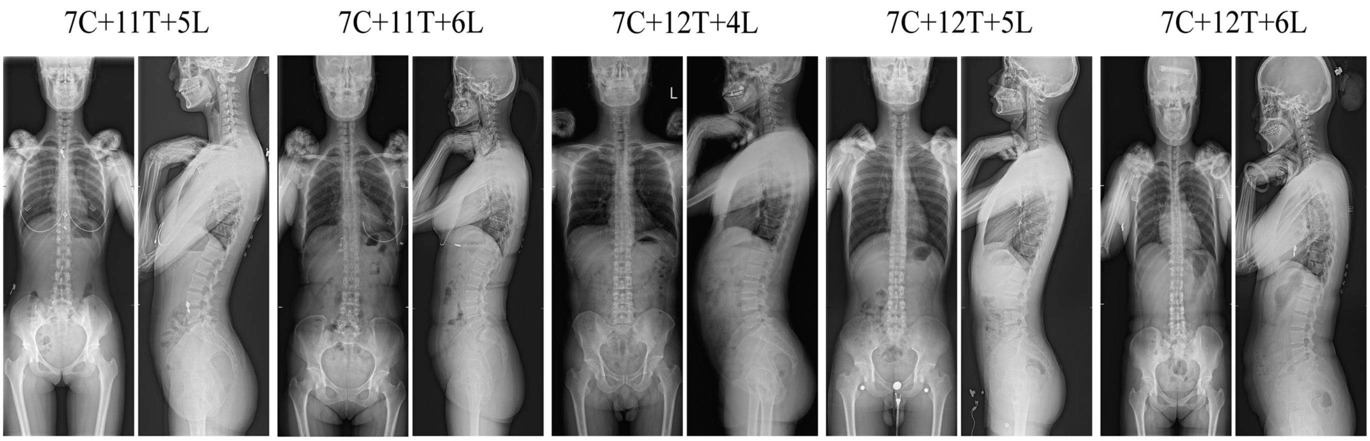

Fig. 3 Full-spine X-ray images of each group.

The spinal parameters for individuals with 11 TVs, four LVs, six LVs, and typical numbers of vertebrae are presented in Tables 2–5. –5. Based on the above results, the volunteers were divided into five groups: 7C + 11T + 5L group (12 cases), 7C + 11T + 6L group (eight cases), 7C + 12T + 4L group (eight cases), 7C + 12T + 5L group (346 cases), and 7C + 12T + 6L group (15 cases). X-ray images of each group are shown in Fig. 3.

Comparison of Global Alignment Parameters between 11TVs or 6LVs and Normal

Individuals with 11TVs had significantly lower body mass index (BMI) than individuals with 7C + 12T + 5L ($P < 0.05$). SS, PT, PI, and L_{1-5} Cobb values were significantly greater (all $P < 0.05$) in the 6LVs group than in the 7C + 12T + 5L group. Above is shown in Table 2.

Comparison of Global Alignment Parameters among Different Groups

Furthermore, according to Tables 3–5, Individuals with 7C + 11T + 5L had significantly lower body mass index (BMI) and C_6–T_5 Cobb values than individuals with 7C + 12T + 5L ($P < 0.05$). However, there was no correlation between BMI and C_6–T_5 Cobb value (Poisson $r = -0.470$, $P = 0.123$). The 7C + 12T + 4L group had a significantly greater TIA value ($P < 0.05$) and significantly lower PT value ($P < 0.05$) than the 7C + 12T + 5L group. SS, PT, PI, and L_{1-5} Cobb values were significantly greater (all $P < 0.05$), while the TIA value was significantly lower ($P < 0.05$) in the 7C + 12T + 6L group than in the 7C + 12T + 5L group. There were no significant differences in any of the parameters examined between the 7C + 11T + 6L group and 7C + 12T + 5L group.

Discussion

Variation in the Number of Vertebrae and the Advancing of the Resulting Changes in Spinal Parameters

About 10%–30% of adults have some form of spinal abnormality with a genetic cause, including a reduction in the number of TVs due to bilateral 12th rib loss and lumbosacral transitional vertebrae[4,11–15,19]. Previous studies have indicated that six LVs and four LVs have incidence rates of 6.1%–17.4%[4,15] and 13.1%–16.8%[20] in the asymptomatic population, respectively. In addition, approximately 5%–8% of "normal" individuals lack a pair of ribs/TVs[11,21]. In the present study, we found that 10.6% of the asymptomatic population had an atypical number of thoracic and/or LVs. Among all volunteers, 3.1% were included in the 7C + 11T + 5L group, 2.1% in the 7C + 11T + 6L group, 2.1% in the 7C + 12T + 4L group, and 3.9% in the 7C + 12T + 6L group. LSTV was present in 8.0%, and 5.1% of volunteers had 11 TVs. Although our results differ from some previous studies, they are consistent with other reports[11,21]. Previous studies on parameters and sagittal balance have all focused on asymptomatic individuals[2–4,22]. However, many of these studies have ignored the important question of whether spinal parameters can be accurately measured when there is variation in the number of vertebrae among patients[2,3,22]. Yokoyama *et al.*[4] determined that, compared to individuals with 5 LVs, those with six LVs present with markedly different sagittal alignment. However, Yokoyama *et al.* did not distinguish between 7C + 12T + 6L and 7C + 11T + 6L individuals. Furthermore, there have been no reports on the relations between 11 TVs, four LVs, and total sagittal parameters.

Changes of Global Spinal Parameters Caused by Variation of Lumbar Vertebrae Number

Our results do not differ from the spinal sagittal parameters reported previously in individuals with 7C + 12T + 5L[4]. However, we found that individuals with 7C + 12T + 6L and 7C + 12T + 4L showed marked differences in sagittal parameters compared to those with 7C + 12T + 5L. This appears to be related to the fact that the L_6 vertebra is embryologically derived from S_1 and L_4 due to L_5 sacralization. Mahato *et al.*[23] reported that the occurrence of LSTV is greatly influenced by the functional requirements of the upright position of the human vertebral column. If a sacral mass is small in its overall dimensions, specifically in its load-bearing areas, it will biologically adapt to incorporate the L_5 vertebra to enhance its load-bearing capacity (L_5 sacralization). The converse may occur if the sacral mass is capable of competent load bearing, even at its lower segments, because this would set the S_1 segment free (S_1 lumbarization). Therefore, in individuals with 7C + 12T + 6L, the sacrum is tilted more forward than normal, and the hip joints are positioned more posteriorly. By contrast, in individuals with 7C + 12T + 4L, the sacrum is tilted further to the rear than normal, and the hip joints are positioned more anteriorly. PI, PT, and SS are three important pelvic parameters for evaluating the sagittal spinopelvic balance. PI is a morphological parameter, and PT and SS are positional parameters related to the orientation of the pelvis. This explains why PI, SS, and PT became larger in individuals with 7C + 12T + 6L and smaller in individuals with 7C + 12T + 4L. Similar principles can also explain why the PI-LL of six LVs is greater than that of normal and four LVs. PI-LL is one of the key factors associated with successful outcome in adult spinal deformity surgeries. Obtaining an adequate LL to achieve a harmonious spinopelvic alignment (PI-LL 10°or less) is very important for surgeon's corrective surgery. We found that PI-LL increased with the increase of the number of LVs. The rotation of the pelvis around the axis of the femoral head is a main mechanism involved in regulating the sagittal balance of the spine. Therefore, cervicothoracic parameters, including TS, NT, and TIA, vary with rotation of the pelvis. Compared to 7C + 12T + 5L, we found that TIA was significantly smaller in individuals with 7C + 12T + 6L and significantly larger in individuals with 7C + 12T + 4L. Sacralization can alter the loading regime at the lower spine and can create asymmetrical forces at adjacent structures. This could lead to herniation degeneration of the disc above the transitional vertebra. Previous studies have reported a link between LSTV and lower back pain[4,20]. Moreover, Schwab *et al.*[23] investigated the relationships between spinopelvic parameters and back pain, and their results showed that increases in PT, PI, and C_7 SVA are important factors with adverse effects on quality of life (QOL) due to back pain. However, Dar *et al.*[20] found no association between the presence of sacralization and spondylolisthesis. Considering the treatment of symptomatic LSTV cases, it is important to adequately understand sagittal alignment in LSTV cases. The spinal alignment and sagittal balance parameters in individuals with 7C + 12T + 4L and 7C + 12T + 6L could be used as references in such cases.

Changes of Global Spinal Parameters Caused by Variation of Thoracic Vertebrae Number

Most people have 12TVs (i.e., T_1–T_{12}). However, some individuals are missing a vertebra below T_{11}, with an incidence of 5%–8%[11,21]. The key to determining whether there are only 11 TVs is to distinguish the first lumbar transverse process from the 12th rib. If the rib is not fully developed or too small, it is difficult to distinguish from the first lumbar transverse process on either lateral or posteroanterior view. Two of the authors (a spine surgeon and a radiologist) used the method shown in Fig. 3 to determine the variation in the number of TVs and reached a consensus. We did not include any patients with cervical ribs or 13 TVs, as our selection criteria excluded these particular vertebrae variants. The incidence of cervical ribs varies from 0.05% to 8% in the general population, and they are rarely symptomatic in early childhood. However, in older children and adults, thoracic outlet syndrome or aneurysm formation can occur[11,24]. Supernumerary ribs, as seen in trisomy 21 syndrome, are rare variants[11,17]. Therefore, we excluded such variation in choosing adult asymptomatic volunteers. To the best of our knowledge, no previous studies have investigated the relationships between variation in the number of TVs and spinal sagittal parameters. In this study, we found that individuals with 7C + 11T + 5L had significantly lower BMI and C_6–T_5 Cobb values than individuals with 7C + 12T + 5L ($P < 0.05$). However, no correlations between BMI and C6–T5 Cobb values were found in the 7C + 11T + 5L group or in the total population. It is strange that the decrease in number of TVs did not significantly affect the TK value. This means that the reduction in the number of TVs had no significant effect on overall thoracic kyphosis, but had a significant effect on upper thoracic kyphosis. There were no significant differences in SS, PT, PI, or other parameters between the 7C + 11T + 5L group and the 7C + 12T + 5L group. Compared to variation in the number of LVs, the variation in the number of TVs had less effect on the global spinal sagittal parameters.

It is necessary to pay attention to the existence of individuals with six LVs and 11 TVs at the same time, which has not been discussed in previous reports. Previous studies have suggested that six LVs are mainly caused by lumbarization of the highest sacral spinal segment[14,15]. In this study, however, we found that six LVs may also be the result of the lowest thoracic vertebra segment lacking a pair of ribs. Interestingly, there were no significant differences in any spinal sagittal parameters examined between the 7C + 11T + 6L group and the 7C + 12T + 5L group. Even TK measurements in individuals with 11 TVs were performed using T11 as an indicator instead of T_{12} and L_{1-5} Cobb in individuals with six LVs were examined using L_6 as an indicator instead of L_5. This phenomenon should be explained in terms of measurement method and different curvature of the thoracolumbar segment and lumbosacral segment. However, there were too few samples in the 7C + 11T + 6L group, so we can only conservatively conclude that this type of spine variation has little effect on spinal parameters.

Limits

The present study had some limitations. First, the number of subjects with variation in the number of vertebrae was small. Second, the sacrum was tilted at about 40° in full-spine upright radiographs, and so it was difficult to evaluate L_6 or LSTV. Similarly, variation in the number of TVs may have been misjudged in unclear images. Regardless of the care taken in examining these radiographs, there may have been a certain amount of misdiagnosis. Therefore, it is necessary to consider the potential for misdiagnosis of T_{11}, L_4, or L_6 in upright radiographs. Importantly, it is questionable whether measurement of L_6, L_4, or T_{11} can be used as a marker to evaluate corresponding spinal parameters in individuals with six LVs, four LVs, or 11 TVs.

Conclusion

Asymptomatic adults with 7C + 12T + 6L, 7C + 12T + 4L, and 7C + 11T + 5L presented with different spinal sagittal alignment compared to those with 7C + 12T + 5L. Compared to variation in the number of LVs, the variation in the number of TVs had less effect on the global spinal sagittal parameters. Spinal surgeons and researchers should be aware of the effects of variation in the number of TVs and LVs on global spinal parameters and sagittal balance.

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