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Correlation of cervical and thoracic inlet sagittal parameters by MRI and radiography in patients with cervical spondylosis

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Abstract

To investigate the relationship between cervical and thoracic sagittal alignment parameters measured by magnetic resonance imaging (MRI) and x-ray in patients with cervical spondylosis

Data from 120 symptomatic patients who presented with cervical spondylosis between April 2015 and January 2016 were retrospectively analyzed. Patients received both a cervical MRI and a cervical radiograph during a single visit. The thoracic inlet angle (TIA), T1 slope (T1S), neck tilt (NT), C2-C7 angle (C2-C7), and C2-C7 sagittal vertical axis (C2–7 SVA) were assessed. Pearson correlation coefficient, paired *t* test, and linear regression models were used to analyze parameters obtained by cervical MRI and radiography.

The difference in mean thoracic inlet angle x-ray (TIAX) and thoracic inlet angle MRI (TIAM) (TIAM–TIAX) ($0.72 \pm 5.82°$) was not significant ($P > .05$). There were significant differences in mean T1 slope x-ray (T1SX) and T1 slope MRI (T1SM) (T1SM-T1SX) ($-2.55 \pm 6.14°$), mean neck tilt x-ray (NTX) and neck tilt MRI (NTM) (NTM-NTX) ($3.26 \pm 6.01°$), mean C2-C7 angle x-ray (C2–7X) and C2-C7 angle MRI (C2–7 M) (C2–7M-C2–7X) ($-3.57 \pm 10.00°$), and mean C2-C7 sagittal vertical axis X ray (C2–7 SVAX) and C2-C7 sagittal vertical axis MRI (C2–7 SVAM) (C2–7 SVAM-C2–7 SVAX) (-4.50 ± 1.26 mm) (all $P \leq .001$). There were positive correlations between TIAM and TIAX ($r = 0.807$), T1SM and T1SX ($r = 0.581$), NTM and NTX ($r = 0.759$), cervical loidosis MRI and cervical loidosis x-ray ($r = 0.666$), and SVAM and SVAX ($r = 0.226$).

MRI may be useful to evaluate thoracic inlet and sagittal alignment parameters in patients with cervical spondylosis. Patients with cervical spondylosis may have a relatively low capacity for compensation in the cervical region.

Abbreviations: C2–7M = C2-C7 angle on MRI, C2–7SVAM = C2–7SVA on MRI, C2–7SVAX = C2–7SVA on x-ray, C2–7X = C2-C7 angle on x-ray, C2-C7 SVA = C2-C7 sagittal vertical axis, MRI = Magnetic resonance imaging, NT = Neck tilt, NTM = NT on MRI, NTX = NT on x-ray, T1S = T1 slope, T1SM = T1S on MRI, T1SX = T1S on x-ray, T1UEP = The T1 upper endplate, TIA = Thoracic inlet angle, TIAM = TIA on MRI, TIAX = TIA on x-ray.

Keywords: cervical spine, correlation, MRI, radiography, sagittal parameters

1. Introduction

In humans, maintenance of postural balance without external support requires minimal effort.[1] Conversely, sagittal imbalance is important in the pathogenesis of degenerative spine diseases, influencing the planning of perioperative care and determining clinical outcomes.[2–4] Cervical spine disorders may interfere with sagittal alignment, inducing a compensatory mechanism that result in higher energy expenditure and increased muscular forces, fatigue, and pain.[5] Indeed, several studies have shown that lumbar-pelvic sagittal alignment is significantly correlated with health-related quality of life.[6,7]

In 2012, Lee et al[8] reported that thoracic inlet, cervical spine, and cranial parameters, including the thoracic inlet angle (TIA), neck tilt (NT), cervical tilt, and cranial tilt, were related to cervical alignment. Subsequent studies have shown that cervical and thoracic inlet alignment are associated with cervical degenerative diseases, and may be preoperative radiological risk factors.[9–12] Radiographic measurement of spinal alignment is regarded as gold standard of diagnosis.[13–16] However, it is not possible to accurately quantify parameters responsible for balance in the cranial–cervical–thoracic regions by x-ray, in particular, in obese individuals, as overlapping soft and bony tissues reduce visibility of the sternum contour and C7 vertebra.

To address the limitations associated with x-ray, Park et al[17]and Jun et al[18]used 3-dimensional CT scans to evaluate cervical and thoracic sagittal alignment parameters. Notably, these radiographic procedures expose patients to repeat doses of ionizing radiation, which increases risk for health complications later in life.[19–21] More recently, the advantages of magnetic resonance imaging (MRI) in evaluation and diagnosis of degenerative spinal diseases have become apparent, as MRI does not involve radiation and provides clear vertebral visibility.[22] Increasingly, researchers have focused on the use of MRI images when assessing cervical and thoracic sagittal alignment parameters. In adolescent idiopathic

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scoliosis patients, Qiao et al[23] demonstrated that MRI was an optimal substitute for x-ray scans when measuring thoracic inlet alignment, with superior reliability. Currently, it is not clear how thoracic inlet alignment differs when measured by MRI in the supine position compared to x-ray in the upright position in patients with cervical spondylosis. The objective of this study was to investigate the relationship between cervical and thoracic sagittal alignment parameters measured by MRI and x-ray in patients with cervical spondylosis.

2. Materials and methods

2.1. Patient enrollment

Data from 120 symptomatic patients aged 15 to 77 years who presented with cervical spondylosis between April 2015 and January 2016 were retrospectively analyzed at our institution. Inclusion criteria were: Patients with neck pain, radiculopathy symptoms, and/or myelopathy; and patients that received both a cervical MRI and a cervical radiograph during a single visit. Exclusion criteria were: previous surgery on the cervical spine; 2) cervical spine deformity resulting from fracture, tumor, infection, or congenital abnormality; 3) neuromuscular disease, or inflammatory arthritis including ankylosing spondylitis and rheumatoid arthritis. Evaluators were blinded to patient demographic and clinical characteristics. This study was approved by the ethical review board at our institution. Written informed consent was obtained from each patient enrolled in this study.

2.2. Image information acquisition

Image information was obtained according to Jun et al.[24] For cervical MRI (Siemens 3.0T, AG, Germany), subjects were placed in a supine position, looking upward. Images covering a vertical area ranging from the orbit to the T1 vertebra and a horizontal area ranging from the maxilla to the occiput were obtained.

For x-ray, subjects were placed in an upright position, their hands by their sides, looking forward. Lateral radiographs of the cervical spine were obtained with the x-ray tube centered on the C3 or C4 intervertebral disc. The radiographic cassette was 180 cm (72 inches) from the tube, and radiographs were obtained without magnification.

2.3. Measurement of radiological parameters

The following parameters were analyzed on all images: TIA, T1 slope (T1S), NT, C2-C7 angle, and C2-C7 sagittal vertical axis (SVA). The TIA was defined as the angle formed by a line from the center of the T1 upper endplate (T1UEP) vertical to the T1UEP and a line connecting the center of the T1UEP and the upper end of the sternum. The T1S was defined as the angle formed between a line along the horizontal plane and the T1UEP. NT was defined as the angle formed by a vertical line passing through the upper sternum and a line connecting the center of the T1UEP and the upper sternum. The C2-C7 angle was measured by the Cobb method. It was defined as the angle between the horizontal line of the C2 lower endplate and the horizontal line of the C7 lower endplate, with "+" indicating lordosis and "−" indicating kyphosis. C2-C7 SVA was defined as the horizontal offset from the center of the odontoid process (dens) to the center of the vertebral body of C7, with "+" indicating the dens was behind the center of the C7 vertebra and "−" indicating the dens was in front of the center of the C7 vertebra (Fig. 1).

2.4. Statistical analysis

SPSS version 22.0 (IBM SPSS, Armonk, NY) was used for statistical analyses. Parameters were measured independently on

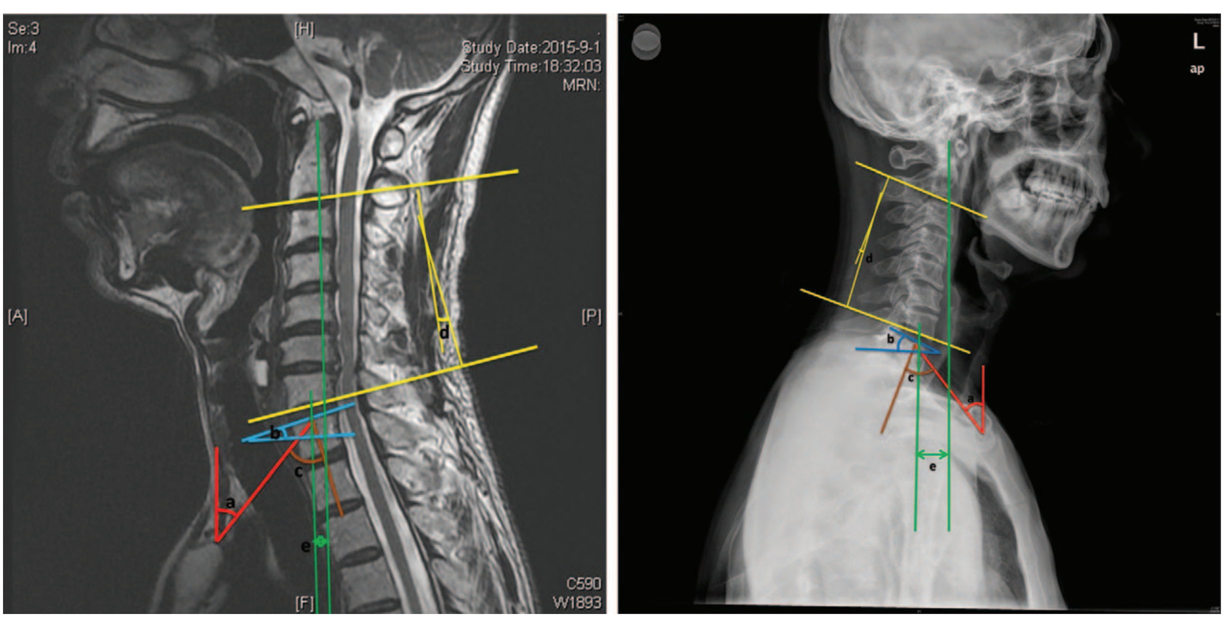

Figure 1. (a) Neck tilt (NT) was defined as the angle formed by a vertical line passing through the upper end of the sternum and a line connecting the center of the T1 upper endplate (T1UEP) and the upper end of the sternum. (b) The T1 slope was defined as the angle formed between the horizontal plane and the T1UEP. (c) Thoracic inlet angle (TIA) was defined as the angle formed by a line from the center of the T1UEP vertical to the T1UEP and a line connecting the center of the T1UEP and the upper end of the sternum. (d) The C2-C7 angle was measured by the Cobb method It was defined as the angle between the horizontal line of the C2 lower endplate and the horizontal line of the C7 lower endplate, with "+" indicating lordosis and "−" indicating kyphosis. (e) C2-C7 SVA was defined as the horizontal offset from the center odontoid process (dens) to the center of the vertebral body of C7, with "+" indicating the dens was behind the center of the C7 vertebra and "–" indicating the dens was in front of the center of the C7 vertebra. SVA = sagittal vertical axis, TIA = thoracic inlet angle, T1UEP = T1 upper endplate, NT = neck tilt.

2 different occasions, 1 week apart, by 2 observers who are attending surgeons in the field of spine surgery, with a Centricity RIS/FACS CE radiological system. The Pearson correlation coefficient, paired *t* test, and linear regression models were used to analyze correlations of parameters obtained by cervical MRI and radiograph. $P < .05$ was considered significant.

3. Results

Around 48 males and 72 females were included in the study, and the average age of the patients was 51.84 ± 12.49 years (range 15–77 years). Of these, 19 patients had chronic neck and shoulder pain, 37 patients had cervical spondylotic radiculopathy, and 64 patients had cervical spondylotic myelopathy.

3.1. Cervical and thoracic inlet parameters

On MRI, mean TIA (TIAM) was 72.82° ± 9.76° (range, 47.30°–100.10°); mean T1S (T1SM) was 21.75° ± 6.53° (range, 5.80°–42.40°); mean NT (NTM) was 51.06° ± 9.83° (range, 5.90°–75.20°); mean C2-C7 angle (C2–7M) was 4.34° ± 12.45° (range, 24.90°–44.30°); and mean C2–7 SVA (C2–7 SVAM) was 6.03 mm ± 9.23 mm (range, 18.57–36.62 mm).

On x-ray, mean TIA (TIAX) was 72.11° ± 9.23° (range, 54.40°–98.30°); mean T1S (T1SX) was 24.30° ± 7.02° (range, 7.70°–42.40°); mean NT (NTX) was 47.80° ± 8.50°(range, 30.80°–75.20°); mean C2-C7 angle (C2–7X) was 7.92° ± 12.01° (range, −18.00°–35.40°); and mean C2–7 SVA (C2–7 SVAX) was 10.53 mm ± 12.60 mm (−19.94–50.76 mm). All parameters showed a normal distribution (Fig. 2, Table 1).

3.2. Comparisons and correlations

By the paired *t* test, there were significant differences in mean T1SX and T1SM (T1SM-T1SX) (−2.55 ± 6.14°), mean NTX and NTM (NTM-NTX) (3.26 ± 6.01°), mean C2–7X and C2–7M (C2–7M-C2–7X) −-3.57 ± 10.00°), and mean C2–7 SVAX and C2–7 SVAM (C2–7 SVAM-C2–7 SVAX) (−4.50 ± 1.26 mm) (all $P \leq .001$). The difference in mean TIAX and TIAM (TIAM-TIAX) (0.72 ± 5.82°) was not significant ($P > .05$) (Table 1).

There were positive correlations between TIAM and TIAX ($r = 0.807$), T1SM and T1SX ($r = 0.581$), NTM and NTX ($r = 0.759$), C2–7 M and C2–7X ($r = 0.666$), C2–7 SVAM and C2–7 SVAX ($r = 0.226$), T1SM and C2–7 M ($r = 0.722$), and T1SX and C2–7X ($r = 0.607$). There were negative correlations between C2–7 M and C2–7 SVAM ($r = -0.553$) and C2–7X and C2–7 SVAX ($r = -0.242$). There was a negative correlation between T1SM and C2–7 SVAM ($r = -0.361$), but a positive correlation between T1SX and C2–7 SVAX ($r = 0.271$) (Table 2).

3.3. Linear regression

Linear regression models were significant: TIAX = 0.763 × TIAM +16.574; T1SX = 0.636 × T1SM + 10.460; NTX = 0.687 × NTM + 12.733; C2–7X = 0.643 × C2–7 M + 5.125; C2–7 SVAX = 0.309 × C2–7 SVAM + 8.663 (Fig. 3).

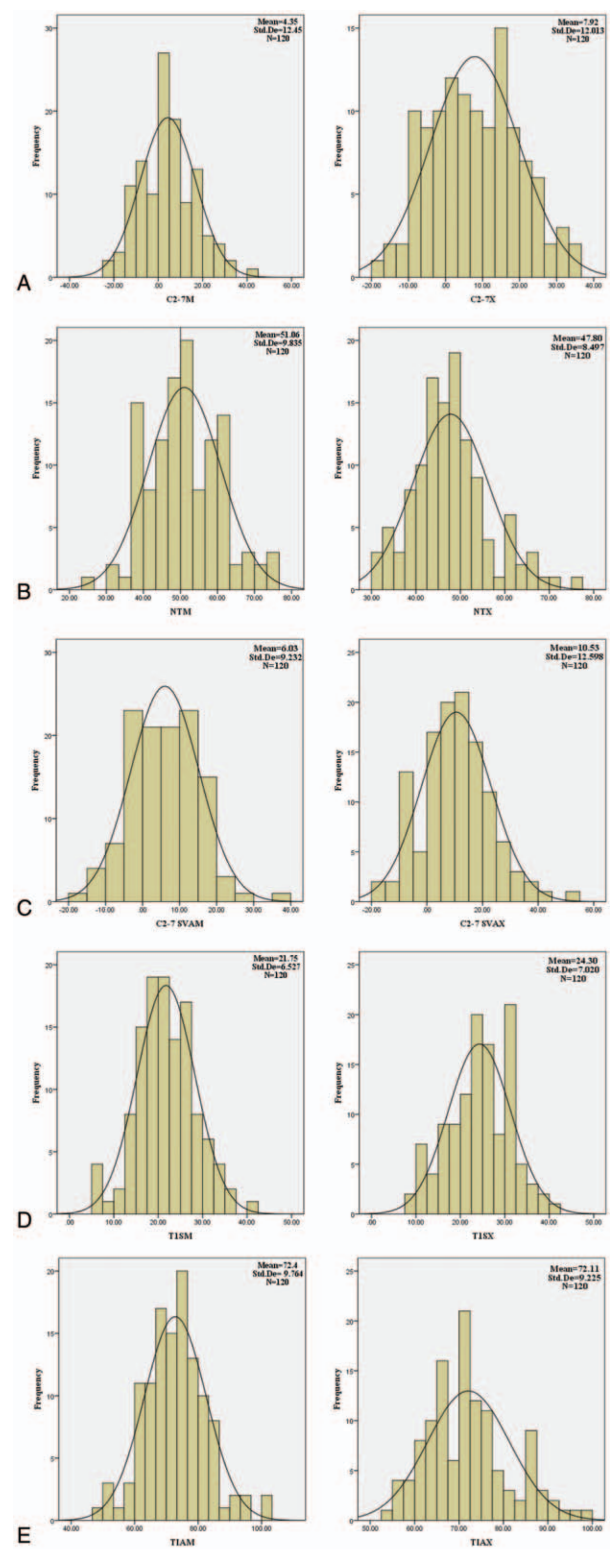

Figure 2. Distribution of the parameters: (A) C2-7 angle; (B) neck tilt (NT); (C) C2-7 sagittal vertical axis (SVA); (D) T1 slope; (E) thoracic inlet angle (TIA). SVA = sagittal vertical axis, TIA = thoracic inlet angle, NT = neck tilt.

4. Discussion

The current study investigated the relationship between cervical and thoracic sagittal alignment parameters measured by MRI and x-ray in a symptomatic population. On x-ray, the mean TIA was 72.11° ± 9.23°, T1S was 24.30° ± 7.02°, NT was 47.80° ± 8.50°, and mean cervical lordosis was 7.92° ± 12.01°. In contrast, Lee et al[8] investigated cervical sagittal parameters in 77 asymptomatic adult volunteers (aged 21–50 years), and reported a mean

Table 1

Mean, SD, paired *t* test of the cervical and thoracic inlet parameters.

	MRI value	Radiographical value	Paired difference of mean	
	(Mean ± SD)	(Mean ± SD)	(MRI Values − Radiographical Values)	*P*
TIA	72.82 ± 9.76°	72.11 ± 9.23°	0.72 ± 5.82°	.187
T1S	21.75 ± 6.53°	24.30 ± 7.02°	−2.55 ± 6.14°	<.0001
NT	51.06 ± 9.83°	47.80 ± 8.50°	3.26 ± 6.01°	<.0001
C2–7 angle	4.34 ± 12.45°	7.91 ± 12.01°	−3.57 ± 10.00°	<.0001
C2–7 SVA	6.02 ± 9.23 mm	10.53 ± 12.60 mm	−4.50 ± 1.26 mm	.001

TIA = thoracic inlet angle, T1S = T1 slope, NT = neck tilt.
$P < .05$.

TIA of 69.5° ± 8.6°, a mean T1S of 5.7° ± 6.4°, a mean NT of 43.7° ± 6.1°, and mean cervical lordosis of −9.9° ± 12.5°. Iyer et al[25] prospectively analyzed 120 adult volunteers with no back or neck symptoms and found a mean TIA of 79.8 ± 13.3°, a mean NT of 51 ± 9.3°, a mean T1S of 26.1 ± 9°, and a mean cervical lordosis of −12.2 ± 13.6°. The discrepancy between our results and previous findings may be because our patients were symptomatic, or due to age group and ethnic differences between studies. A review of the literature revealed that normative values for cervical and thoracic sagittal alignment parameters have not been defined in individuals with cervical spondylosis. The current retrospective analysis of 120 adults may, therefore, enable assessment of the differences in cervical and thoracic sagittal alignment parameters between symptomatic and asymptomatic populations.

The C-7 SVA, defined as the horizontal offset from the posterosuperior corner of S1 to the vertebral body of C7, is a common parameter for evaluating spinal sagittal balance. The C7 plumb line predicts the position of the cervical–thoracic junction relative to the sacrum; however, it may not accurately assess the position of the occiput relative to the rest of the spine because of variation in the tilt of the cervical vertebral bodies.[26] Knott et al[27] used the center of the odontoid process (dens) as an alternate landmark, as this assumes the patient's head position is at the level of C1. In our study, we defined the C2–7 SVA as the sagittal horizontal offset between a vertical line through the peak of the odontoid process and a vertical line through the center of the vertebral body of C7. These two landmarks contain the cranial and caudal end vertebrae of the cervical spine, and should, therefore, directly represent cervical shape.

In our symptomatic population, on x-ray, mean C2–7 SVA was 10.53 mm ± 12.60 mm (−19.94–50.76 mm), representing a tendency of positive sagittal imbalance. The C2–7 SVA value indicates the amount of anterior translation of the head relative to the thorax. The presence of a large C2-C7 sagittal vertebral axis value suggests neck pain and trapezial spasm, as the trapezius is recruited in an attempt to correct deformity.[28] Our cohort experienced neck and shoulder pain, radiculopathy symptoms, and/or myelopathy symptoms. Individuals with chronic neck and shoulder pain gradually develop anterior neck tilting because of a poor life style, including long periods of time spent using the computer and telephone in fixed positions. In these circumstances, the trapezius and rhomboids contract to maintain muscle tone. As a result, the trapezius and rhomboids fatigue and spasm, resulting in clinical symptoms exhibited in these individuals. Affected individuals will assume a forced posture (cervical spine flexion[29]) in order to relieve symptoms, and will gradually develop or worsen anterior head and neck tilting.

Lee et al[30] found significant correlations between the TIA and the craniocervical parameters. The authors reported that a small TIA creates a small T1S and a small cervical lordosis angle to maintain physiological neck tilting. In contrast, Park et al[31] found that the C2–7 angle increased with age, whereas the T1S decreased with age, suggesting that the spine pitches forward into a positive sagittal imbalance with age in order to maintain horizontal gaze. The authors proposed that this was a compensatory mechanism; as the head pitches forward, the neck becomes more lordotic to maintain a forward gaze, and T1, at the base of the neck, becomes more horizontal to allow for this lordosis.

Furthermore, Park et al[31] reported that females became less kyphotic in the thoracic spine with age; however, males maintained their thoracic kyphotic angle. There is general agreement that cervical lordosis positively correlated with

Table 2

Pearson correlation coefficient and *P* value.

	TIAM	T1SM	NTM	C2–7M	SVAM	TIAX	T1SX	NTX	C2–7X	SVAX
Age	0.352†	-0.030	0.368†	0.246†	−0.033	0.308†	0.033	0.306†	0.221†	0.034
TIAM		0.309†	0.782†	0.258†	0.043	.807†	0.212*	0.700†	0.165*	0.116
T1SM			−0.349†	0.722†	−0.361†	0.301†	0.591†	−0.168	0.491†	0.021
NTM				−.225†	0.275†	0.591†	−0.181	0.795†	−0.163	0.098
C2–7M					−0.553†	0.344†	0.561†	−0.097	0.666†	0.004
SVAM						−0.081	−0.315	0.178*	−0.298	0.226†
TIAX							0.486†	0.682†	0.282†	0.200*
T1SX								−0.306	0.607†	0.271†
NTX									−0.209	−0.002
C2–7X										−0.242

NTM = neck tilt on MRI, TIAM = thoracic inlet angle on MRI, TIAX = thoracic inlet angle on x-ray, T1SM = T1 slope on MRI, T1SX = T1 slope on x-ray, NTX = neck tilt on x-ray.
* Correlation is significant at the 0.05 level.
† Correlation is significant at the 0.01 level.

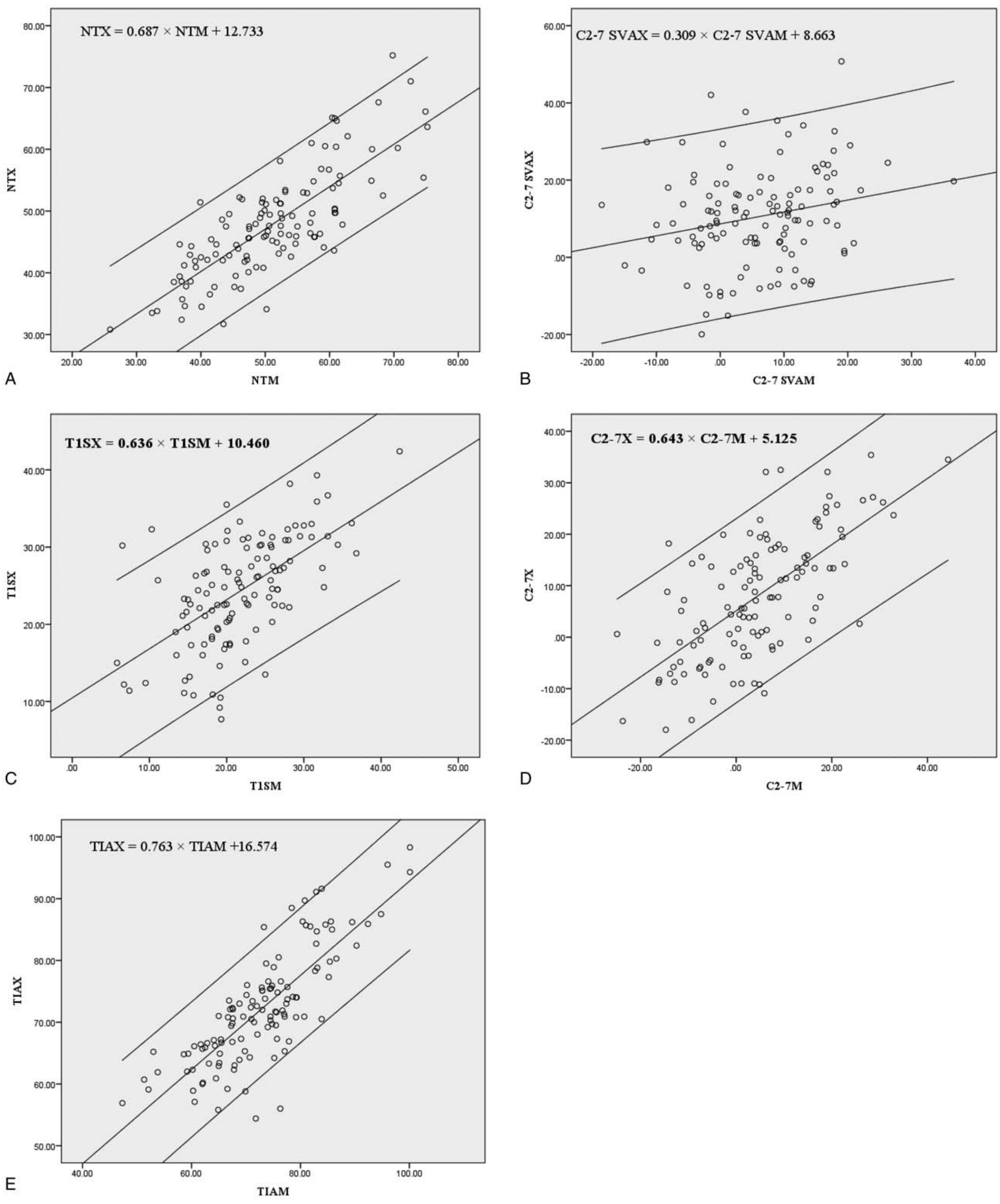

Figure 3. Linear regression analysis of the parameters showing significant relationships: (A) Neck tilt (NT); (B) C2-7 sagittal vertical axis (SVA); (C) T1 slope (T1S); (D) C2-7 angle; (E) Thoracic inlet angle (TIA). SVA=sagittal vertical axis, TIA=thoracic inlet angle.

thoracic kyphosis[32], but Boyle et al[33] found that cervical lordosis progressively flattened and thoracic spinal curvature significantly increased with age. These differences showed complicated relationship between cervical region and global spine in sagittal alignment with age, what is more, a further research on global alignment in patients with cervical spondylosis is beneficial for identifying the correlation between the development of cervical spondylosis and the changing cervical sagittal alignment.

In accordance with Lee et al,[30] we found significant correlation between the T1S and the C2–7 angle on MRI and x-ray (rm = 0.722, rx = 0.607). We hypothesize that in response to spinal sagittal imbalance, the compensatory mechanisms that are recruited to counteract sagittal malalignment show diversity across the different stages of cervical natural history and in various physiopathologies. The compensatory mechanisms in younger populations with few degenerative changes in the spine may follow those proposed by Lee et al. Spinal degenerative and age-related changes, including a decrease in the height of the vertebrae and discs, osteoarthritis of the facet joint, ossification of the anterior and posterior longitudinal ligament, ligamentum flavum, and ligamentum nuchae, and an increase in the anteroposterior diameter of the thorax, may result in compensatory mechanisms that are not in accordance with Lee's principles. A further study is needed to verify this assumption in order to profoundly understand the characteristic of cervical spondylosis in different populations.

On x-ray, we found a weak positive correlation between the T1S and C2–7 SVA ($r=0.271$). Knott et al[27] showed that a T1S >25° was associated with at least 10 cm of positive sagittal imbalance in patients who presented to an orthopedic spine surgeon for evaluation of back pain, leg pain, or progressive deformity, and those with a negative sagittal imbalance had low T1S values, usually below 13°. However, Park et al[17] concluded that Cobb's angle positively correlated with the T1S, but negatively correlated with the C2–7 SVA in asymptomatic individuals. They proposed a compensatory mechanism whereby the T1S increases, the head's center of gravity moves forward, and the high T1S results in a low C2–7 SVA by keeping the C2 plumb line close to the C7 plumb line.

In our cohort, the cervical spine was in a forced position (neck tilting), and had a relatively low capacity for compensation as the individuals examined had suffered from cervical spondylosis for a prolonged duration of time. When the head or trunk moves anteriorly, the C2–7 SVA may not be able to maintain the horizontal providing further explanation for the weak relationship between the T1S and C2–7 SVA in our patients. In addition, a chain of compensatory mechanisms may be triggered to sustain the upright position and a horizontal gaze, including reduction of thoracic kyphosis, retrolisthesis, hyperextension, pelvis backtilt, knee flessum[34] and finally recruitment of the occiput (increase Cobb's C0–2 angle).[35] On MRI, our data found a negative correlation between the T1S and C2–7 SVA (rm = -0.361). This may be due to changing the posture from the upright to the supine position eliminates the effect of the head; therefore, the cervical spine is able to compensate for sagittal malalignment.

On MRI and x-ray, mean T1SM was smaller than mean T1SX, mean NTM was larger than mean NTX, mean C2–7M was smaller than mean C2–7X, and mean C2–7 SVAM was smaller than mean C2–7 SVAX. This may be due to the differences in the effect of gravity on the spine in the erect and the supine position.[36] Thoracic kyphosis decreased in the supine position, and the T1S became more horizontal. Correspondingly, the C2–7 angle decreased in a continuous and compensatory manner.

No significant correlation was found between TIAM and TIAX ($P=.187$). Anatomically, the thoracic inlet is a fixed circular bony structure that consists of the T1 vertebral body, the first ribs, and the upper sternum.[37] Some researchers have suggested that the thoracic inlet is a oligodynamic bony structure. Janusz et al[38] found that the TIA was significantly different in flexion and extension of the neck, and was influenced by the anteroposterior diameter of the thorax (COPD), and age-related spinal degenerative changes, such as loss of disc height or loss of vertebrae height.

We noticed key differences between cervical and thoracic sagittal alignment parameters on MRI and x-ray; however, they were smaller than one standard deviation, and there was no difference in the TIA (Table 1). These findings suggest that MRI could be used instead of x-ray to more precisely evaluate cervical and thoracic inlet sagittal alignment when x-ray in the cranial–cervical thoracic regions cannot show anatomical sites clearly due to overlapping soft and bony tissues.

Spinal sagittal balance is restored by anterior cervical fusion, which is carried out in the supine position. If the cervical and thoracic sagittal alignment parameters are not carefully evaluated, or there was insufficient correction of cervical kyphosis, cervical iatrogenic imbalance or instability may occur, resulting in poor clinical outcomes. The current study showed that cervical and thoracic inlet sagittal parameters obtained from an x-ray in the upright position could be estimated from equivalent parameters obtained from an MRI in the supine position, and vice versa. Knowing the variation in cervical sagittal parameters on MRI and x-ray ensures that the fusion angle is enough to maintain cervical sagittal balance during surgery and provide optimal cervical sagittal balance in the upright position, even when operating in a supine position.

This study was associated with several limitations. First, there was an uneven age and sex distribution across the study cohort. Second, the sample size was relatively small. Third, subgroup analyses were not performed due to the small sample size, and a healthy control group was not included. Finally, global sagittal balance was not considered. Additional prospective studies with a larger sample size are warranted to confirm the results of this study.

5. Conclusion

On the basis of our results, MRI may be an alternative way to evaluate thoracic inlet and sagittal alignment parameters in patients with cervical spondylosis when x-ray in the cranial–cervical thoracic regions cannot show anatomical sites clearly due to overlapping soft and bony tissues. On x-ray, we found a significant positive correlation between the T1S and C2–7 angle, a weak negative correlation between the C2–7 angle and C2–7 SVA, and a weak positive correlation between the T1S and C2–7 SVA. These findings may be caused by the relatively low capacity for compensation in the cervical region of patients with cervical spondylosis.

Author contributions

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