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ORIGINAL ARTICLE

Influence of cervical spine position on the radiographic parameters of the thoracic inlet alignment

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Abstract

Purpose Cervical sagittal balance is a complex phenomenon, influenced by many factors, which cannot be described by cervical lordosis alone. Attention has been focused on the relationship between T1 slope, thoracic inlet angle, and cervical sagittal balance. However, the effect of cervical position on these parameters has not been evaluated yet. The aim of this study was to assess the influence of cervical flexion and extension on radiographic thoracic inlet parameters.

Methods 60 patients with one level radiculopathy symptoms underwent radiological examination. Mean age was 53 (40–72) years; there were 24 males and 34 females. Lateral standing X-rays of cervical spine were taken on the same day in neutral position, full flexion and full extension. Patients with previous cervical operations or congenital malformations were excluded. Thoracic inlet angle (TIA), neck tilt (NT) and thoracic (T1) slope were measured. Agreement between measurements was assessed and quantified by intra-class correlation coefficient (ICC) and median error for a single measurement (SEM). The ICC value greater than 0.75 reflected sufficient agreement.

Results The mean values of the parameters were: (1) for the *neutral position*: TIA $71.7° \pm 9.5°$; T1 slope $26.7° \pm 6.3°$; and NT $44.9° \pm 7.2°$, (2) In *extension*: TIA $71.8° \pm 9.4°$; T1 slope $24.9° \pm 7.6°$; and NT $46.9° \pm 7.2°$ and (3) In *flexion* $78.3° \pm 10.3°$; T1 slope $33.6° \pm 7.8°$; and NT $44.7° \pm 7.4°$. An excellent agreement was revealed for all NT measurements (ICC 0.76) and for TIA measured in flexion and neutral position (ICC 0.79). There was insufficient overall and in-pairs agreement for T1 slope measurements.

Conclusions Neck tilt measurements were not influenced by position of the cervical spine. T1 slope was significantly influenced by flexion and extension of the neck. This puts the concept that TIA is a morphologic parameter into question. This information should be taken into consideration when analyzing lateral radiographs of the cervical spine for clinical decision-making.

Keywords TIA · T1 slope · Thoracic inlet · Cervical spine · Radiological parameters

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Introduction

The main task of the cervical spine is to maintain the position of the head over the body, and allow for horizontal gaze [1]. Disorders of the cervical spine may interfere with sagittal alignment and induce a compensatory mechanism resulting in higher energy expenditure, increased muscular forces, fatigue and pain [2]; therefore, restoration of individual sagittal balance, is crucial, to achieve long-term therapeutic success [3]. To reproducibly evaluate cervical sagittal alignment in clinical practice, reliable descriptive parameters are needed.

Cervical sagittal alignment is influenced by many factors and cannot be accurately described solely by cervical lordosis. Initially, the concept of T1 slope was introduced [3], to describe the relationship between the T1 vertebra and cervical lordosis. Cervical lordosis is reported to be dependent on the anatomy of the cervico-thoracic junction, which typically involves the C-7 and T-1 vertebrae [1]. Correlation of T1 slope with sagittal vertical axis measured from the C2 dens indicates that the amount of sagittal T1 tilt can be used as a good predictor of overall sagittal balance [3]. More recently, thoracic inlet angle (TIA) was described as a relationship between T1 vertebrae and the sternum [4, 5]. Lee at al. described TIA as the equivalent of pelvic incidence (PI) for the cervical spine [4, 5]. The authors suggested that thoracic inlet is an immobile structure consisting of sternum, 1st ribs and T1 vertebra [4–6]. Therefore, TIA can be assumed to be a constant, morphologic parameter, and independent of patient position or movement [4, 5]. Until now, the main morphologic parameter described in spine was PI, contrary to other parameter such as sacral slope, lumbar lordosis, thoracic kyphosis, which are positional parameters [4, 7]. Based on the morphologic parameters, operative treatment could be planed to restore proper spine alignment, as it was described with PI [7]. Morphologic parameters should not change with spinal position. However, the effect of cervical spine position on radiographic thoracic inlet parameters has not been evaluated.

The aim of this study was to assess the influence of cervical spine position, namely flexion and extension on radiographic thoracic inlet parameters.

Materials and methods

After having obtained an Institutional Review Board approval, a retrospective analysis of radiographs of 60 patients was performed. There were 24 males and 36 females in the mean age of 53 years (range: 40–72 years). Patients with prior cervical surgery or congenital malformations were excluded from the study. Lateral standing radiographs of the cervical spine of each patient were taken in a comfortable position, with the upper extremities positioned naturally at the side of the body in: (1) neutral position with horizontal gaze, (2) in full forward neck flexion and (3) full extension of the neck. The sternum, entire cervical spine, T1 vertebra and base of the skull were clearly visible on each of the radiographs.

All of the radiographs were saved as bmp images and analyzed in Surgimap Spine software (Nemaris Inc, New York, NY, USA).

Agreement between TIA, NT and S1 slope measured on the radiographs acquired with various position of the neck

Three following parameters were measured on each of the radiographs by one researcher (orthopedic spine surgeon with 6 years of experience):

- Thoracic inlet angle (TIA) - defined as an angle formed by a line perpendicular to the superior endplate of T1 and a line connecting the centre of the T1 upper end plate and the upper end of the sternum [4].
- Neck tilt (NT) - defined as an angle formed by the reference vertical line drawn in the upper end of the sternum and a line connecting the centre of the T1 upper end plate and the upper end of the sternum [4].
- T1 slope - defined as an angle formed between the reference horizontal line and the T1 upper end plate [4] (Fig. 1).

Mean values and standard deviations for each parameter were calculated.

Three different positions (flexion, neutral, and extension) of cervical spine radiographs were considered as three methods of measuring the same parameters.

The agreement between the values of the particular parameter measured on three radiographs with different neck position was assessed and quantified by intra-class correlation coefficient (ICC) and median error for a single measurement (SEM).

Intra-observer reproducibility and inter-observer reliability of TIA, NT and S1 slope measurements in flexion, neutral, and extension positions

To assess intra-observer reproducibility and inter-observer reliability of TIA, NT, and T1 slope, all the measurements were tested and the agreement was quantified by using ICC and SEM.

Two independent researchers (orthopeadic spine surgeon with 6 years of experience and orthopedic resident interested in spine with 3 years of experience) performed two series of measurements of TIA, NT and S1 slope on the radiographs acquired in the neutral position, full flexion, and full extension of the neck. Time span between these two series of measurements was 4 weeks. The order of radiographs analyzed in each of 2 series was different and random.

The ICC value of less than 0.40 indicated poor agreement, 0.40–0.75 indicated fair to good agreement, and values greater than 0.75 reflected excellent agreement [8]. The data were analyzed using the JMP 10.0.2 (SAS Institute Inc, Cary, NC, USA) statistical software.

Fig. 1 Lateral radiographs in extension, neutral position and flexion with a draft of the parameters measured
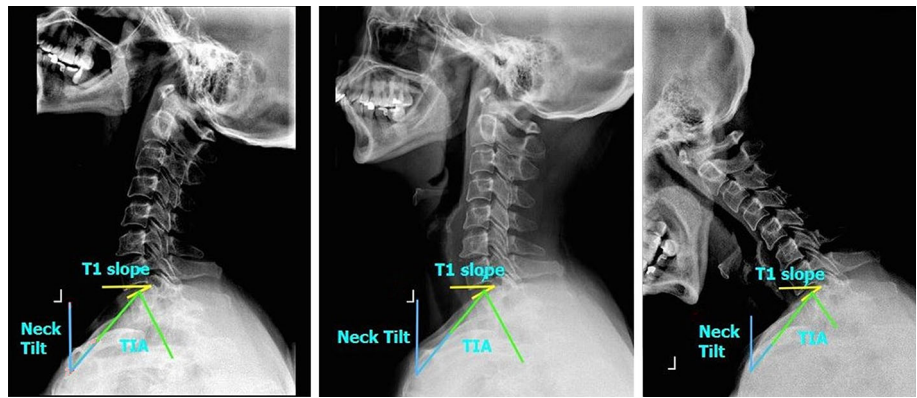
Results

Agreement between TIA, NT and S1 slope measured on the radiographs acquired with various position of the neck

The mean values of the parameters were: (1) for the *neutral position*: TIA 71.7° ± 9.5°; T1 slope 26.7° ± 6.3°; and NT 44.9° ± 7.2°, (2) In *extension*: TIA 71.8° ± 9.4°; T1 slope 24.9° ± 7.6°; and NT 46.9° ± 7.2° and (3) In *flexion* 78.3° ± 10.3°; T1 slope 33.6° ± 7.8°; and NT 44.7° ± 7.4° (Table 1).

The differences between the values of the parameters measured in neutral position, flexion, and extension are presented in Table 1.

An excellent agreement was revealed for all NT measurements and for TIA measured in flexion and neutral position with negligible values of SEM (Table 2). There was insufficient overall and in-pairs agreement for T1 slope measurements (Table 2).

Intra-observer reproducibility and inter-observer reliability of TIA, NT and S1 slope measurements

There was excellent intra-observer reproducibility and inter-observer reliability for all of the measured parameters measured. The lowest values of the intra-rater ICC was 0.86 for NT measured in extension of the neck and the lowest inter-rater ICC was 0.76 for T1 slope in extension (Table 3).

Discussion

In this study, we demonstrated that neck tilt measurements were not influenced by position of the cervical spine. The results also showed that T1 slope was significantly influenced by flexion and extension of the neck. There are many radiological parameters describing cervical spine alignment based on global or segmental cervical spine lordosis [1, 9–11], horizontal distances between plumb lines [1, 3–

Table 1 Mean values, standard deviations and differences between parameters measured in neutral, flexion and extension

	Neutral Mean ± SD (°)	Extension Mean ± SD (°)	Flexion Mean ± SD (°)	Neutral vs extension Mean difference, ° (%)	Neutral vs flexion Mean difference, ° (%)	Extension vs flexion Mean difference, ° (%)
TIA	71.7° ± 9.5°	71.8° ± 9.4°	78.3° ± 10.3°	0.1° (0.1 %)	6.5° (9.0 %)	6.5° (9.0 %)
T1 slope	26.7° ± 6.3°	24.9° ± 7.6°	33.6° ± 7.8°	1.8° (6.7 %)	6.9° (25.8 %)	7.7° (32.5 %)
NT	44.9° ± 7.2°	46.9° ± 7.2°	44.7° ± 7.4°	2.0° (4.5 %)	0.1° (0.2 %)	2.2° (4.9 %)

TIA thoracic inlet angle, *NT* neck tilt, *SD* standard deviation

Table 2 Inter-class correlation coefficient and standard/median error for comparison between neutral, flexion and extension measurements

|	TIA		T1 slope		NT	
	ICC	SEM	ICC	SEM	ICC	SEM
Overall agreement between 3 positions	0.69	4.1	0.42	4.2	**0.76**	2.6
Neutral vs extension	**0.79**	3.2	0.73	2.8	**0.79**	2.5
Neutral vs flexion	0.67	4.5	0.40	4.4	**0.76**	2.5
Extension vs flexion	0.62	4.5	0.22	5.6	**0.76**	2.8

Bold values are indicate excellent agreement (ICC>0.75)

ICC inter-class correlation coefficient, *SEM* standard/median error, *TIA* thoracic inlet angle, *NT* neck tilt

Table 3 Intra-rater and inter-rater ICC for all measurements

	Intra-rater ICC	SEM	Inter-rater ICC	SEM
Extension NT	0.95	1.21	0.94	1.24
Extension TIA	0.90	2.17	0.87	2.31
Extension T1 slope	0.86	2.08	0.83	1.97
Neutral NT	0.96	0.97	0.94	1.09
Neutral TIA	0.96	1.28	0.88	2.45
Neutral T1 slope	0.92	1.34	0.76	2.14
Flexion NT	0.97	1.00	0.94	1.26
Flexion TIA	0.94	1.91	0.87	2.31
Flexion T1 slope	0.90	1.81	0.83	1.97

ICC inter-class correlation coefficient, *SEM* standard/median error, *TIA* thoracic inlet angle, *NT* neck tilt
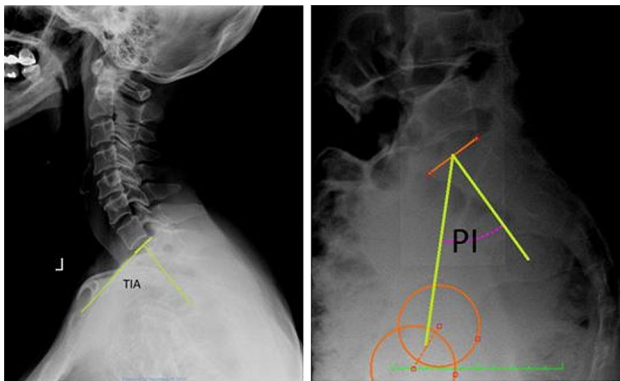
Fig. 2 Comparison of thoracic inlet angle to pelvic incidence

5, 11], or angular relationships between anatomic structures [1, 4, 5, 11]. Each has its unique advantages and limitations. In this study, we have focused strictly on the thoracic inlet parameters.

Significance of T1 vertebra as a basis of the cervical spine, represented by T1 slope was postulated [3, 12]. Knott et al. described relevance of the T1 slope as the best correlating parameter with SVA, measured from the tip of the C2 dens, and suggested that based on this parameter, an overall sagittal balance can be established [3]. In many studies, correlation of the T1 slope with the cervical lordosis and SVA was described [1, 3–5, 12, 13]. Despite of clinical importance, T1 slope is a positional parameter and in spine disorders, the T1 vertebra configuration may be altered by disease or by compensatory response of the body. Therefore, use of T1 slope in preoperative planning has limits.

In clinical practice, reliable parameters show the highest utility and value, when they provide information about local or global spine alignment; that is why in cervical spine, a parameter similar to PI is needed. Lee et al. introduce the TIA and based on their findings suggested that

it resembles PI. Based on their results, TIA appears to be a valuable radiological parameter (Fig. 2).

We believe that TIA can be useful in clinical practice, especially, since a significant correlation between TIA, T1 slope and NT was described [4, 5, 12]. However, correlation between TIA and cervical lordosis is not clear. Lee et al. reported significant correlation between TIA and C2–C7 cervical lordosis [4, 5]. While, according to Jun et al., TIA correlates with T1 slope and with NT, but not with the C2–C7 lordosis measured on radiographs [12]. TIA was revealed to be comparable on lateral neutral radiographs with CT scans, whereas T1 slope and cervical lordosis were impaired by supine position [12]. TIA measured on CT scans in supine position is reported to correlate with T1 slope, NT and, with cervical lordosis [12, 13]. Further clinical studies on implications of thoracic inlet parameters are needed.

According to this study T1 slope seems to be sensitive to the flexion/extension position of the neck, however, more for flexion than for extension. T1 slope is a radiological parameter describing T1 vertebrae configuration in space. Changes in T1 slope are a reflection of the global spine alignment as well as T1 vertebra motion in relation to horizontal plane.

The segmental movements of the T1 vertebra in sagittal plane in relation to T2 vertebrae measured on the CT scans between flexion and extension of the thoracic spine segment were described to be $3.9° \pm 2.8°$ [14]. The described increase of T1 slope in flexion was $3.4° \pm 4.1°$ what was significantly higher than decrease in extension [14], what matches our results.

The T1 segmental movement associated with cervical forward bending was described to be around 4° [15]. It could be explained by firm connection between subsequent segments by disc, joints, ligaments and muscles, and C7 segment motion must provoke motion in T1 segment [15].

T1 segment movement in sagittal plane appears to be greater in flexion than in extension. This could be the reason, why TIA on CT scans obtained in the supine position, were comparable to those obtained on radiographs in standing neutral position in a study by Jun et al. [12]. It should be emphasized, that imaging obtained in the supine position can lead to inaccurate measurements.

Based on the results of this study, uncertainty could arise. Is TIA a truly morphologic parameter, as was described earlier, or rather could be impaired by the position of the cervical spine while acquiring the radiograph?

In our opinion, to call TIA a morphologic parameter seems to be an oversimplification of the structural anatomical relationships. That being said, in the neutral standing and supine position, TIA measurements both positions reliably reflect proximal spine alignment.

NT appeared to be the most stable parameter among those evaluated. NT reflects the position of thoracic inlet in relationship to vertical line and does not depend directly on T1 tilt (slope). In our opinion, it may be interpreted as fact that flexion and extension motions were performed mostly in the cervical spine and the position of the thorax was not impaired.

The results of this study satisfied the formula: TIA = T1 slope + NT. When comparing our results with previously published studies, the mean values of TIA and NT on lateral radiographs taken in neutral position were similar to those presented by Lee et al. We did note a difference in, the T1 slope (1.0°), which most likely is of little clinical significance [5].

All of the parameters measured revealed excellent inter-rater and intra-rater correlation, which was comparable to data presented by Lee et al. [4].

Proposed interpretation in this study, considering three cervical spine positions on radiographs as three different measuring methods of the same parameters in the same individuals, allows us to use ICC to assess consistency of measurements. We presume that ICC provides precise and reliable analysis of evaluation methods [16–18].

One limitation of this study could be the fact that the evaluated group consisted of patients with a one level cervical radiculopathy. However, this condition could potentially limit the amount of cervical spine motion and its influence on the thoracic inlet parameters should be more limited.

Conclusions

Neck tilt measurements were not influenced by the position of the cervical spine. T1 slope was significantly influenced by flexion and extension of the neck. Although accurate measurements can be obtained with the cervical spine in neutral position, TIA should not be viewed as a morphologic parameter. This information should be taken into consideration when analyzing lateral radiographs of the cervical spine for clinical decision-making.

Conflict of interest None.

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