

# MRI kinematic analysis of T1 sagittal motion between cervical flexion and extension positions in 145 patients

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## Abstract

**Purpose** Although the T1 vertebra is considered as an important factor of cervical balance, little is known about its motion between flexion and extension. The purpose of present study was to analyze the T1 sagittal motion using kinematic magnetic resonance imaging (kMRI), and to identify factors that relate to T1 sagittal motion.

**Methods** We retrospectively analyzed 145 kMR images taken in weight-bearing neutral, flexion and extension positions. Cervical balance parameters were evaluated in each position. The degree of T1 sagittal motion was defined as [(T1 slope at extension) – (T1 slope at flexion)]. All patients were divided into three groups: Positive group (T1 followed the head motion, T1 sagittal motion > 5°), Stable group (5° ≥, ≥ – 5°) and Negative group (T1 moved in the opposite direction from the head motion, > – 5°). The groups were compared and multivariate logistic regression analysis was calculated.

**Results** There were 57 (40%) patients in the positive, 56 (39%) in the stable and 32 (22%) in the negative group. The positive group had the largest C2–7 sagittal vertical axis in flexion ( $p < 0.001$ ) and the shortest in the extension ( $p = 0.023$ ). Similar trends were seen in cranial tilt and cervical tilt. The value of T1 height < 27 mm was a significant

independent factor for the negative group ( $p = 0.008$ , adjusted odds ratio = 5.958).

**Conclusion** Based on T1 sagittal motion, 40% of the patients were classified in positive group (the T1 vertebra followed the head motion in flexion and extension), and 20% were classified in the negative group (the T1 vertebra moved in the opposite direction from the head motion). T1 height < 27 mm was a potential predictor of negative group.

**Keywords** Kinematic magnetic resonance imaging · T1 slope · T1 sagittal motion · Cervical sagittal balance · T1 height

## Introduction

Cervical sagittal balance is one of the most critical components which affects health-related quality of life (HRQOL) and surgical outcomes [1, 2]. Although there are many factors that can influence the cervical balance [3], T1 vertebral body is considered as one of the key players [4, 5]. Orientation of T1 vertebral body has an effect on the amount of lordosis required to maintain the sagittal balance of cervical spine and upright horizontal gaze. Several studies have verified the relationship between the surgical outcomes or HRQOL and T1 slope, a landmark of spinal sagittal balance [6–9]. However, little is known about the change in T1 sagittal motion and T1-related parameters between flexion and extension, essential information needed to understand the influence of posture on T1 slope. One of the reasons for the lack of knowledge is the difficulty to identify the T1 vertebral body. Upright X-ray films are often used to analyze T1-related parameters; however, the T1 vertebral body is not clearly seen on the upright cervical X-ray due to the shoulder and thoracic trunk interference. Studies have shown that the

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sternum and T1 vertebral body parameters could be estimated in 11% of the X-ray scans [10] and that the reproducibility of the T1-related parameters was extremely low [11]. Computer tomography (CT) has also been used to evaluate the T1-related parameters [12]; however, those images do not represent physiologic alignment, as they are obtained in the supine position. Use of kinematic magnetic resonance imaging (kMRI) could potentially overcome those limitation, as it allows for scans to be taken in various weight-bearing positions, including neutral, flexion, and extension positions [13–15]. The purpose of the present study was to analyze the T1 sagittal motion using kMRI, and to identify factors that relate to T1 sagittal motion.

## Materials and methods

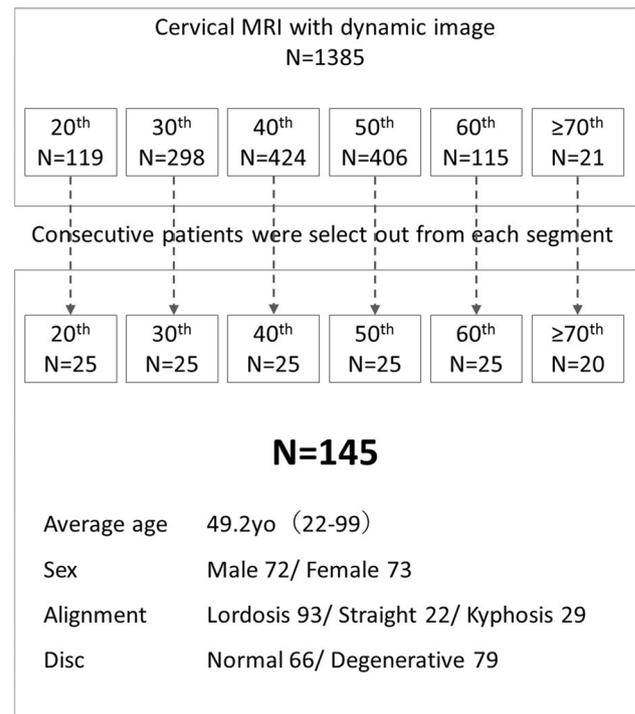
### Selection of patients

Our database was compliant with all regulations associated with the Health Insurance Portability and Accountability Act (HIPAA). The institutional review board at our institution approved the study protocol with a full waiver of HIPAA Authorization and Informed Consent due to the retrospective nature of our study.

We retrospectively reviewed the age distribution of our kMRI database including 1385 cervical patients who received kMRI for neck pain or radiculopathy with or without neurological deficits between November 2010 and February 2016. Patients were divided into six groups according to their age: 20 years of age ( $n = 119$ ), 30 years of age ( $n = 298$ ), 40 years of age ( $n = 424$ ), 50 years of age ( $n = 406$ ), 60 years of age ( $n = 115$ ) and  $> 70$  years of age ( $n = 21$ ). Before selecting the patients, one-way analysis of variance (ANOVA) was used to calculate power analysis for three groups; 108 patients (power 0.80,  $\alpha = 0.05$ ,  $f = 0.30$ ) were needed for the analysis [16]. Therefore, from each age group, we picked consecutive patients from randomly selected time point to eliminate the deviation of age. As a result, 155 patients were included in this study. The average age was 49.2 years (22–99 years), with 72 males and 73 females (Fig. 1).

### Kinematic magnetic resonance imaging (kMRI)

MRI of the spine was performed using a 0.6-T MRI machine (Upright Multi-Position, Fonar Corp., New York, NY, USA). Two horizontal orientated, opposing magnetic doughnuts placed 18 in. apart were used, allowing scanning of the patient sitting in an upright, axially loaded position. The image protocol included T1- (TR 671 ms, TE 17 ms, thickness 4.0 mm, field of view 30 cm, matrix  $256 \times 224$ , number of excitations 2) and T2- (TR 3000 ms, TE 140 ms, thickness



**Fig. 1** Patients selection. 1385 cervical kMRI were divided into six groups according to generations. To eliminate the deviation of age, we selected out the consecutive patients from each generational group. Finally, 145 kMRI images were enrolled in this study

4.0 mm, field of view 30 cm, matrix  $256 \times 224$ , number of excitations 2) weighted sagittal fast spin-echo images that were obtained using a flexible surface coil with the patient seated in upright weight-bearing neutral ( $0^\circ$ ), flexion ( $40^\circ$ ) and extension ( $-20^\circ$ ) positions. Observers reviewed the images using the eRAD PACS system software (version 7.2.38.0, South Carolina, USA).

### Cervical disc degeneration

Disc degeneration was classified into five grades using T2-weighted sagittal MR images according to the grading system proposed by Pfirrmann et al. [13, 17]. Grade I indicated normal, whereas Grade V indicated the most advanced disc degeneration. Intra- and inter-observer reliability for this grading system was previously reported: 0.982 and 0.962, respectively [18]. We recorded the grades of all six levels from C2–3 to C7–T1 for each patient and divided patients into two groups: mild disc degeneration (grade I, II and III) and severe degeneration (grade IV and V).

### Cervical spine parameters

All cervical parameters were evaluated using T2-weighted MR sagittal image. Cervical alignment was categorized into

one of the four groups, lordosis, kyphosis, straight, and sigmoid, using a system proposed by Chiba et al. [19, 20]. The C2–C7 Cobb angle was defined as the angle between the tangent lines of the lower endplates of C2 and higher endplates of C7 vertebral body (Fig. 2). Cervical range of motion was calculated as follows: [(C2–7 Cobb angle at extension position) – (C2–7 Cobb angle at flexion position)]. C2–7 sagittal vertical axis (SVA) was defined as the horizontal distance between the center of C2 and the center of the C7 vertebral body. The center of vertebral body was determined as the point of intersection of crossing diagonals within body on the central sagittal kMRI image [3]. Orientation parameters including cervical tilt and cranial tilt were measured [4]. Cervical tilt was defined as the angle formed between a perpendicular line off the center of T1 upper end plate and another line extending from the center of T1 upper end plate to the center of C2. The cranial tilt was defined as the angle formed between the line from the center of T1 upper end plate through the C2 center and a vertical line off the center of the T1 upper end plate. Positive value of cervical tilt or cranial tilt indicated that the line extending from the center of T1 upper end plate to the center of C2 is anterior to the perpendicular line off the center of T1 upper end plate.

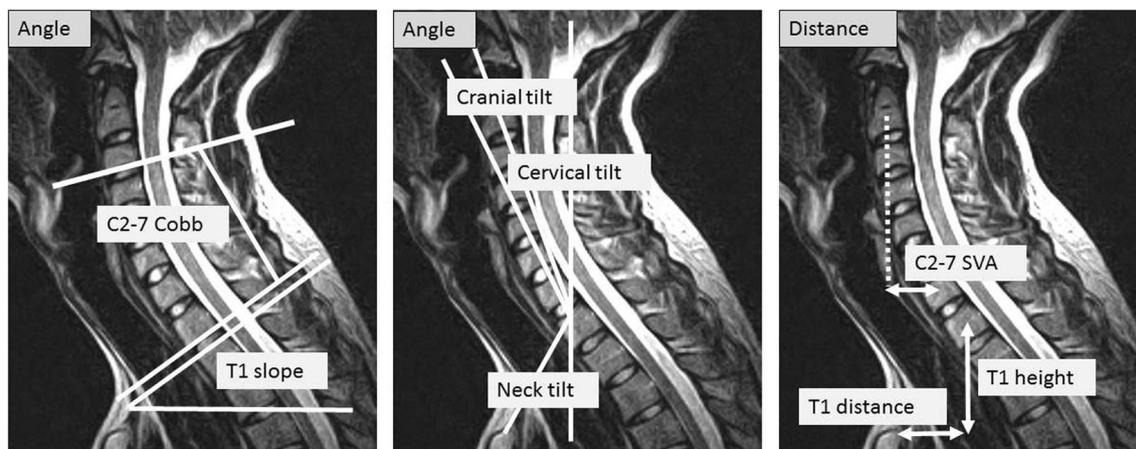
### Thoracic index (TI) parameters

T1 slope was measured as the angle between a horizontal line and the T1 upper end plate [3] (Fig. 2). Neck tilt (NT) was defined as the angle formed by a vertical line passing

through the upper border of sternum and a second line drawn from the sternum tip through the center of T1 upper end plate [4]. Furthermore, we added the new parameters, T1 distance and T1 height, to evaluate the location of T1 and sternum. T1 distance and height were defined as the horizontal and vertical distances between the center of T1 and the top of the sternum, respectively. These five cervical spine parameters and four thoracic index parameters were evaluated in neutral, flexion and extension positions.

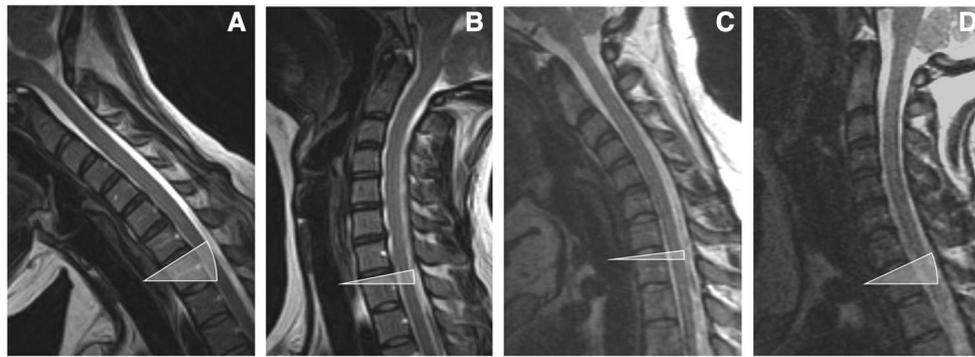
### T1 sagittal motion

T1 sagittal motion was defined as a difference between flexion and extension; [(T1 slope at extension position) – (T1 slope at flexion position)]. We divided all subjects into three groups according to the T1 sagittal motion: positive group, stable group and negative group. Positive group included patients with T1 sagittal motion of  $> + 5^\circ$ , meaning that the T1 vertebra followed the head motion in F-E movement (Fig. 3a and b). The negative group included patients who had T1 sagittal motion  $< - 5^\circ$ , the T1 moved opposite from the head motion (Fig. 3c and d). Stable group was defined with T1 sagittal motion between  $+ 5^\circ$  and  $- 5^\circ$ . Cutoff value ( $5^\circ$ ) was defined based on the measurement error of T1 slope among three observers (KT, PP and KS; senior spine surgeons), representing an average differences between the maximum and minimum value of three observers using 25 sample kMR images.



**Fig. 2** Schematic drawing of the parameters. C2–C7 angle: the angle formed by tangents of the C2 and C7 lower end plates. T1 slope: the angle formed by a horizontal line and the upper end plate of T1. Neck tilt: the angle between a vertical line off the sternum tip and a second line drawn from the sternum tip through the center of the T1 upper end plate (T1 UEP). Cervical tilt: the angle between the perpendicular line off the center of the T1 UEP and another line drawn from the C2 center through the center of the T1 UEP. Cranial tilt: the angle

formed by the plumb line off the center of the T1 UEP and the line connecting the center of C2 with the center of T1 UEP. SVA C2–C7: the distance between the plumb line through the C2 center and the plumb line of the posterior of C7 upper end plate. SVA sagittal vertical axis. T1 height the minimum distances between the center of T1 vertebral body and horizontal line passes the top of sternum. T1 distances the minimum distances between the top of sternum and vertical line passes the center of T1 vertebral body



**Fig. 3** Representative images of T1SM. **a, b** Positive group (38 year old female): the T1 slope was 44° in flexion position and 18° in extension position. T1 sagittal motion was 26°. **c, d** Negative group

(56 years old male): the T1 slope was 8° in flexion position and 41° in extension position. T1 sagittal motion was – 33°

**Statistical analysis**

The inter- and intra-observer reliabilities of T1 slope were assessed using intraclass correlation coefficients (ICCs). Three observers measured T1 slope with 30 T2 weighted images twice. ICCs were calculated between and within them. Chi square tests for categorical variables, and one-way ANOVA for continuous variables, were used to identify differences among the positive, stable, and negative groups. To verify which factors determine the T1 sagittal motion, negative and positive group parameters in neutral position were compared using Tukey test and residual analysis, as univariate analysis. The result of residual analysis was described as  $p < 0.05$  when the all variables of two groups were  $|r| > 1.96$ , according to the Haberman’s method [21]. Variables with a significance of  $p < 0.05$ , per univariate analysis, were included in the multivariate logistic regression model which was adjusted for disc degeneration and cervical alignment. The negative group was set as a dependent variable. Additionally, continuous variables were converted into three categorical variables according to their average and standard deviation (SD); Average + 1.0SD >, between Average ± 1.0SD, > Average – 1.0SD. Finally, parameters in flexion and extension position were compared between three groups using one-way ANOVA and between each combination using Tukey

test. All analyses were performed using SPSS computer software (version 23; SPSS, Chicago, IL, USA).  $p < 0.05$  was considered as statistically significant.

**Results**

The overall intra-observer reliability of T1 slope was 0.977 (95% CI 0.961–0.986) and the inter-observer reliability between three spine surgeons was 0.973 (95% CI 0.918–0.990) during the first assessment and 0.982 (95% CI 0.962–0.992) during the second measurement. Among 145 patients, 93 patients (64.1%) had cervical lordosis, 29 patients (20.0%) showed kyphosis, 22 patients (15.2%) showed straight and 1 patient (0.7%) showed sigmoid in neutral position. The mean value of T1 slope was  $29.3° ± 9.1°$  in neutral,  $30.3° ± 10.6°$  in flexion and  $27.4 ± 9.1$  in extension, and T1 sagittal motion was  $-0.2° ± 10.2°$  (range from  $-24.8°$  to  $23.8°$ , Table 1). The difference between E–F ( $\Delta E-F$ ) for C2–7 Cobb angle, indicating the range of cervical motion, was  $37.7° ± 18.2°$ . Also, the cranial tilt, cervical tilt and  $\Delta E-F$  for C2–7 SVA were  $-25.4° ± 16.3°$ ,  $-23.9° ± 14.7°$  and  $-33.8 ± 19.2$  mm, respectively, suggesting the forward movement of head in flexion position.

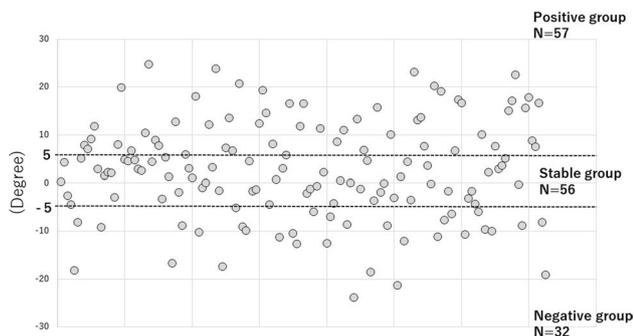
**Table 1** Average of all parameters at three positions

	Cobb C2–7 (°)	SVA C2–7 (mm)	T1 slope (°)	Neck tilt (°)	Cranial tilt (°)	Cervical tilt (°)	T1 height (mm)	T1 distance (mm)
Neutral	13.3 ± 16.2	17.3 ± 11.0	29.3 ± 9.1	45.5 ± 10.8	14.5 ± 7.7	20.9 ± 7.9	37.4 ± 10.3	48.4 ± 9.8
Flexion	- 13.5 ± 14.6	40.8 ± 15.6	30.0 ± 10.6	47.2 ± 10.8	31.6 ± 11.9	37.4 ± 12.1		
Extension	24.2 ± 15.7	6.9 ± 12.3	27.4 ± 9.1	47.0 ± 10.8	6.3 ± 11.4	13.6 ± 8.5		
$\Delta E-F$	37.7 ± 18.2	- 33.8 ± 19.2	-2.6 ± 10.2	-0.2 ± 7.9	- 25.4 ± 16.3	- 23.9 ± 14.7		

$\Delta E-F$  differences between flexion and extension

## Analysis of T1 sagittal motion

The scatter diagram showed the diversity of T1 sagittal motion, although the mean value was nearly zero (Fig. 4). Regarding the T1 sagittal motion positive group had 57 cases, stable group 56 and negative group had 32 cases. The comparison between three groups showed no statistical significance in sex ( $p = 0.196$ ), average age ( $p = 0.091$ ), cervical ROM ( $p = 0.570$ ), rate and extent of cervical disc degeneration ( $p = 0.082, 0.071$ , respectively)



**Fig. 4** Scatter diagram of T1 sagittal motion. The scatter diagram showed the diversity of T1 sagittal motion, although the mean value was nearly zero

and all parameters in neutral position except for T1 height ( $p = 0.033$ , Table 2). Univariate analysis between the positive and the negative group showed significant differences only in T1 height ( $p = 0.029$ ) in neutral position. The average value and SD of T1 height were 37.4 and 10.3 mm; therefore, the T1 height was converted into three categorical groups for multivariate analysis;  $> 47, 47-27$  and  $27 \text{ mm} >$ . Multivariate logistic regression analysis adjusted for cervical disc degeneration and cervical alignment showed that the  $27 \text{ mm} >$  T1 height was an independent factor (ref  $47-27 \text{ mm}$ ,  $p = 0.008$ , adjusted odds ratio 5.598) relating to the negative group (Table 3).

## Analysis of flexion and extension position

There was no significant change in the C2–7 Cobb angle between three groups in flexion and extension ( $p = 0.225, 0.650$ , respectively, Table 4). However, C2–7 SVA showed that positive group had the largest distances in flexion position ( $p < 0.001$ ) and the shortest in the extension position ( $p = 0.023$ ). Similar trends were also seen in cranial tilt and cervical tilt.

**Table 2** Demographics of three groups

	Positive group	Stable group	Negative group	$p$ value <sup>#§</sup> (three groups)	$p$ value <sup>†‡</sup> (P vs N)
Number (%)	57 (39.3)	56 (38.6)	32 (22.1)		
Age	50.3 (28–87)	45.4 (22–74)	53.5 (22–99)	0.091	0.673
Sex (male/female)	23/34	31/25	18/14	0.196	$> 0.05$
C2–7ROM	$39.1 \pm 20.2$	$38.0 \pm 19.3$	$34.9 \pm 11.7$	0.570	0.543
Disc degeneration					
Mean grade	$3.7 \pm 0.9$	$3.4 \pm 0.9$	$3.8 \pm 0.8$	0.082	0.791
Number of DD	34 (59.6)	24 (42.9)	21 (65.6)	0.071	$> 0.05$
Parameters in neutral position					
Kyphosis	13 (22.8)	9 (16.1)	7 (21.8)	0.640	$> 0.05$
C2–7 Cobb	$12.8 \pm 17.4$	$14.8 \pm 15.7$	$11.4 \pm 15.0$	0.619	0.914
C2–7 SVA	$18.7 \pm 12.0$	$17.2 \pm 9.3$	$15.0 \pm 11.7$	0.304	0.272
Neck tilt	$44.8 \pm 8.9$	$44.9 \pm 11.7$	$47.9 \pm 12.1$	0.356	0.383
Cervical tilt	$32.2 \pm 8.5$	$20.6 \pm 6.9$	$18.8 \pm 8.1$	0.140	0.121
Cranial tilt	$15.8 \pm 8.5$	$14.2 \pm 6.6$	$12.8 \pm 7.7$	0.177	0.167
T1 slope	$30.2 \pm 8.4$	$30.2 \pm 8.1$	$25.9 \pm 11.3$	0.058	0.082
T1 height	$39.0 \pm 10.1$	$38.0 \pm 9.3$	$33.3 \pm 11.7$	0.033*	0.029*
T1 distance	$49.3 \pm 10.0$	$47.1 \pm 9.8$	$48.9 \pm 9.4$	0.799	0.984

\*  $P > 0.05$

# Chi square test

§ One-way ANOVA

† Tukey test

‡ Residual analysis

**Table 3** Multivariate logistic regression analysis

	OR	<i>p</i> value	95% CI
Disc degeneration			
Grade I, II, III	1.00		
Grade IV, V	0.991	0.994	0.369–2.681
Cervical alignment			
Lordosis or straight	1.00		
Kyphosis	0.751	0.634	0.230–2.681
T1 height			
27–47 mm	1.00		
> 47 mm	0.580	0.516	0.112–3.007
27 mm >	5.598	0.008	1.595–22.265

Dependent variables: negative group

### Discussion

This is the first study to demonstrate the difference in T1 sagittal motion between the flexion and extension position. Furthermore, we found that T1 height was the independent variables relating to T1 sagittal motion groups, but not cervical disc degeneration and cervical alignment.

In this study, the positive group, included almost 40% of the patients, had motion of T1 vertebra aligned with the head motion in F–E. On the other hand, in the negative group including 20% of the patients, T1 vertebra motion had opposite direction to the head motion. In the positive group, C2–7 SVA, cervical tilt and cranial tilt were the largest in the extension, and the smallest in flexion. In particular, the head position in the positive group was the most forward

in flexion and the most backward in extension compared to the other groups. At the same time, patients in the negative group kept their head position stable during flexion–extension as compared to patients in the positive group. This suggests that patients in the positive group do their cervical flexion–extension with head swinging, while patients in the negative group do flexion–extension without head swinging.

Regarding the factors relating to T1 sagittal motion, our result demonstrated that T1 height was the only independent factor regardless to age, sex, cervical disc degeneration and cervical alignment in neutral position. The patients with T1 height < 27 mm had 5.6 times higher incidence to be placed in the negative group than the patients with T1 height between 27 and 47 mm. The T1 height and head position are just one of the factors in determining T1 sagittal motion, along with other factors such as global spinal balance or thoracic flexibility which were not possible to be evaluated in the current study.

T1 sagittal motion has several clinical implications in cervical sagittal balance. Firstly, it helps to understand the impact of posture on T1-related parameters such as T1 slope. A number of papers analyzed cervical balance using T1 slope in neutral position [22–24]; however, in patients with a severe spine pathology obtaining a neutral position might be difficult. Our results demonstrated that flexion does not always increase the T1 slope, thus highlighting the need to better understand the change of T1 motion with position. In addition, there could be a potential relationship between T1 sagittal motion and progression of cervical deformity after surgery. Oe et al. reported that large T1 slope was a risk factor of correction loss in patients with adult spine deformity

**Table 4** Parameters at dynamic position

	Positive group	Stable group	Negative group	<i>p</i> value of ANOVA	<i>p</i> value of Tukey test		
					P vs S	P vs N	S vs N
Flexion position							
C2–7 Cobb	–16.1 ± 14.6	–12.2 ± 13.9	–11.2 ± 16.0	0.225			
C2–7 SVA	50.3 ± 11.8	38.2 ± 13.7	28.1 ± 13.8	0.001 >	**	***	
Neck tilt	43.5 ± 8.1	46.9 ± 11.7	54.2 ± 10.2	0.001 >		***	**
Cervical tilt	45.9 ± 8.6	35.1 ± 9.6	26.3 ± 10.5	0.001 >	***	***	***
Cranial tilt	40.2 ± 8.6	29.1 ± 9.7	20.9 ± 9.9	0.001 >	***	***	***
T1 slope	35.6 ± 8.1	30.7 ± 8.7	18.9 ± 8.8	0.001 >	***	***	***
Extension position							
C2–7 Cobb	23.1 ± 16.6	25.8 ± 16.7	23.2 ± 12.2	0.650			
C2–7 SVA	3.5 ± 13.1	8.4 ± 11.7	10.1 ± 10.6	0.023		*	
Neck tilt	48.7 ± 8.9	45.5 ± 12.1	46.5 ± 11.5	0.295			
Cervical tilt	10.5 ± 8.5	10.5 ± 8.3	16.5 ± 7.4	0.001	*	**	
Cranial tilt	4.1 ± 9.1	6.6 ± 14.7	9.6 ± 7.2	0.094			
T1 slope	23.0 ± 8.6	30.3 ± 8.5	30.2 ± 8.0	0.001 >	***	**	

Blank: *p* > 0.05, \* *p* < 0.05, \*\* *p* < 0.01, \*\*\**p* < 0.001

*P* group positive group, *S* group stable group, *M* group negative group

[8]. Kim et al. reported that the decrease in cervical lordosis after laminoplasty was correlated with pre-operative T1 slope [9]. We assume that not only the T1 slope but also the T1 sagittal motion can be related to postoperative deformity.

This current study has several limitations. First, results of the current study are derived using kMRI modality. Further study using standard radiography (X-ray film, CT or MRI) would be needed to validate the relationships between various factors and T1 sagittal motion. Second, this study included symptomatic patients with neck pain or radiculopathy with or without neurological deficits. Although those symptoms might have influenced the outcomes, eliminating the deviation of age during patient selection should have minimized this bias. Furthermore, we did not evaluate the whole spine balance. Finally, the lack of patient's medical records made it difficult to verify the relationship between T1 sagittal motion and symptoms, and to determine the normal and abnormal range. To overcome these limitations, further studies verifying the factors which determine the T1 sagittal motion, or evaluating the relationship between T1 sagittal motion, symptoms and deformity, would be important. However, this study was conducted using clear MR images with a sufficient number for analysis, and showed high ICCs confirming high reproducibility. Therefore, in spite of these limitations, we believe that these findings can provide guidance in understanding the cervical balance.

## Conclusions

Among 145 patients, 32 (22.1%) were in the negative group with T1 sagittal motion having an opposite direction to the head motion. Age, sex, cervical alignment, cervical disc degeneration, range of motion and T1 slope in neutral position were not significantly different between the groups. T1 height was the only significant independent factor related to the T1 sagittal motion; patients with T1 height < 27 mm had 5.6 times higher chance to be in the negative group than patients with T1 height between 27 and 47 mm.

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## Compliance with ethical standards

**Conflict of interest** There are no conflicts of interest for the current study.

**Disclosures outside of submitted work** ZB-Xenco Medical (consultancy), AO Spine (consultancy, past); PCH-Consulting: DePuy Synthes, Medtronic, NuVasive, Zimmer Biomet; JCW—Royalties: Aesculap, Biomet, Amedica, Seaspine, Synthes; Stock Ownership: Fziomed; Private Investments: Promethean Spine, Paradigm spine, Benevenue, NexGen, Vertiflex, electrocore, surgitech, expanding ortho-

paedics, osprey, bone biologics, curative biosciences, pearlriver; Board of Directors: North American Spine Society (Second Vice President), North American Spine Foundation (non-financial), Cervical Spine Research Society (Travel expenses), AO Spine/AO Foundation (honorariums for board position); Fellowship Support: AO Foundation (spine fellowship funding paid to institution).

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## References

1. Tang JA, Scheer JK, Smith JS, Deviren V, Bess S, Hart RA, Lafage V, Shaffrey CI, Schwab F, Ames CP, ISSG (2012) The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. *Neurosurgery* 71:662–669. [10.1227/NEU.0b013e31826100e9](https://doi.org/10.1227/NEU.0b013e31826100e9) (**discussion 669**)
2. Sakai K, Yoshii T, Hirai T, Arai Y, Torigoe I, Tomori M, Sato H, Okawa A (2016) Cervical sagittal imbalance is a predictor of kyphotic deformity after laminoplasty in cervical spondylotic myelopathy patients without preoperative kyphotic alignment. *Spine (Phila Pa 1976)* 41:299–305. [10.1097/BRS.0000000000001206](https://doi.org/10.1097/BRS.0000000000001206)
3. Ames CP, Blondel B, Scheer JK, Schwab FJ, Le Huec JC, Masicotte EM, Patel AA, Traynelis VC, Kim HJ, Shaffrey CI, Smith JS, Lafage V (2013) Cervical radiographical alignment: comprehensive assessment techniques and potential importance in cervical myelopathy. *Spine (Phila Pa 1976)* 38:S149–S160. [10.1097/BRS.0b013e3182a7f449](https://doi.org/10.1097/BRS.0b013e3182a7f449)
4. Weng C, Wang J, Tuchman A, Wang J, Fu C, Hsieh PC, Buser Z, Wang JC (2016) Influence of T1 slope on the cervical sagittal balance in degenerative cervical spine: an analysis using kinematic MRI. *Spine (Phila Pa 1976)* 41:185–190. [10.1097/BRS.0000000000001353](https://doi.org/10.1097/BRS.0000000000001353)
5. Knott PT, Mardjetko SM, Tschy F (2010) The use of the T1 sagittal angle in predicting overall sagittal balance of the spine. *Spine J* 10:994–998. [10.1016/j.spinee.2010.08.031](https://doi.org/10.1016/j.spinee.2010.08.031)
6. Cho JH, Ha JK, Kim DG, Song KY, Kim YT, Hwang CJ, Lee CS, Lee DH (2014) Does preoperative T1 slope affect radiological and functional outcomes after cervical laminoplasty? *Spine (Phila Pa 1976)* 39:E1575–E1581. [10.1097/BRS.0000000000000614](https://doi.org/10.1097/BRS.0000000000000614)
7. Kim TH, Lee SY, Kim YC, Park MS, Kim SW (2013) T1 slope as a predictor of kyphotic alignment change after laminoplasty in patients with cervical myelopathy. *Spine (Phila Pa 1976)* 38:E992–E997. [10.1097/BRS.0b013e3182972e1b](https://doi.org/10.1097/BRS.0b013e3182972e1b)
8. Oe S, Yamato Y, Togawa D, Kurosu K, Mihara Y, Banno T, Yasuda T, Kobayashi S, Hasegawa T, Matsuyama Y (2016) Preoperative T1 slope more than 40 degrees as a risk factor of correction loss in patients with adult spinal deformity. *Spine (Phila Pa 1976)* 41:E1168–E1176. [10.1097/BRS.0000000000001578](https://doi.org/10.1097/BRS.0000000000001578)
9. Kim B, Yoon do H, Ha Y, Yi S, Shin DA, Lee CK, Lee N, Kim KN (2016) Relationship between T1 slope and loss of lordosis after laminoplasty in patients with cervical ossification of the posterior longitudinal ligament. *Spine J* 16:219–225. [10.1016/j.spinee.2015.10.042](https://doi.org/10.1016/j.spinee.2015.10.042)
10. Park JH, Cho CB, Song JH, Kim SW, Ha Y, Oh JK (2013) T1 slope and cervical sagittal alignment on cervical CT radiographs of asymptomatic persons. *J Korean Neurosurg Soc* 53:356–359. [10.3340/jkns.2013.53.6.356](https://doi.org/10.3340/jkns.2013.53.6.356)
11. Singhatanadgige W, Kang DG, Luksanapruksa P, Peters C, Riew KD (2016) Correlation and reliability of cervical sagittal alignment parameters between lateral cervical radiograph and lateral

- whole-body EOS stereoradiograph. *Global Spine J* 6:548–554. [10.1055/s-0035-1569462](https://doi.org/10.1055/s-0035-1569462)
12. Jun HS, Chang IB, Song JH, Kim TH, Park MS, Kim SW, Oh JK (2014) Is it possible to evaluate the parameters of cervical sagittal alignment on cervical computed tomographic scans? *Spine (Phila Pa 1976)* 39:E630–E636. [10.1097/BRS.0000000000000281](https://doi.org/10.1097/BRS.0000000000000281)
  13. Suzuki A, Daubs MD, Inoue H, Hayashi T, Aghdasi B, Montgomery SR, Ruangchainikom M, Hu X, Lee CJ, Wang CJ, Wang BJ, Nakamura H (2013) Prevalence and motion characteristics of degenerative cervical spondylolisthesis in the symptomatic adult. *Spine (Phila Pa 1976)* 38:E1115–E1120. [10.1097/BRS.0b013e31829b1487](https://doi.org/10.1097/BRS.0b013e31829b1487)
  14. Hayashi T, Daubs MD, Suzuki A, Scott TP, Phan KH, Ruangchainikom M, Takahashi S, Shiba K, Wang JC (2015) Motion characteristics and related factors of Modic changes in the lumbar spine. *J Neurosurg Spine* 22:511–517. [10.3171/2014.10.SPINE14496](https://doi.org/10.3171/2014.10.SPINE14496)
  15. Phan KH, Daubs MD, Kupperman AI, Scott TP, Wang JC (2015) Kinematic analysis of diseased and adjacent segments in degenerative lumbar spondylolisthesis. *Spine J* 15:230–237. [10.1016/j.spinee.2014.08.453](https://doi.org/10.1016/j.spinee.2014.08.453)
  16. Cohen J (1962) The statistical power of abnormal-social psychological research: a review. *J Abnorm Soc Psychol* 65:145–153
  17. Pfirrmann CW, Metzdorf A, Zanetti M, Hodler J, Boos N (2001) Magnetic resonance classification of lumbar intervertebral disc degeneration. *Spine (Phila Pa 1976)* 26:1873–1878
  18. Tan Y, Aghdasi BG, Montgomery SR, Inoue H, Lu C, Wang JC (2012) Kinetic magnetic resonance imaging analysis of lumbar segmental mobility in patients without significant spondylosis. *Eur Spine J* 21:2673–2679. [10.1007/s00586-012-2387-8](https://doi.org/10.1007/s00586-012-2387-8)
  19. Chiba K, Ogawa Y, Ishii K, Takaishi H, Nakamura M, Maruiwa H, Matsumoto M, Toyama Y (2006) Long-term results of expansive open-door laminoplasty for cervical myelopathy—average 14-year follow-up study. *Spine (Phila Pa 1976)* 31:2998–3005. [10.1097/01.brs.0000250307.78987.6b](https://doi.org/10.1097/01.brs.0000250307.78987.6b)
  20. Tamai K, Suzuki A, Terai H, Toyoda H, Hoshino M, Nakamura H (2016) Laminar closure after expansive open-door laminoplasty: fixation methods and cervical alignments impact on the laminar closure and surgical outcomes. *Spine J* 16:1062–1069. [10.1016/j.spinee.2016.04.018](https://doi.org/10.1016/j.spinee.2016.04.018)
  21. Haberman SJ (1973) The analysis of residuals in cross-classified tables. *Biometrics* 29:205–220
  22. Janusz P, Tyrakowski M, Glowka P, Offoha R, Siemionow K (2015) Influence of cervical spine position on the radiographic parameters of the thoracic inlet alignment. *Eur Spine J* 24:2880–2884. [10.1007/s00586-015-4023-x](https://doi.org/10.1007/s00586-015-4023-x)
  23. Oe S, Togawa D, Nakai K, Yamada T, Arima H, Banno T, Yasuda T, Kobayasi S, Yamato Y, Hasegawa T, Yoshida G, Matsuyama Y (2015) The influence of age and sex on cervical spinal alignment among volunteers aged over 50. *Spine (Phila Pa 1976)* 40:1487–1494. [10.1097/BRS.0000000000001071](https://doi.org/10.1097/BRS.0000000000001071)
  24. Lee SH, Son ES, Seo EM, Suk KS, Kim KT (2015) Factors determining cervical spine sagittal balance in asymptomatic adults: correlation with spinopelvic balance and thoracic inlet alignment. *Spine J* 15:705–712. [10.1016/j.spinee.2013.06.059](https://doi.org/10.1016/j.spinee.2013.06.059)