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ORIGINAL STUDY

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Simulating upright cervical lordosis in the supine position

Hamza Karabag, Ahmet Celal Iplikcioglu

From the Department of Neurosurgery, Harran Üniversity, Şanlıurfa, Turkey

Cervical alignment or lordosis evolution is still attained by direct radiography in standing position because an ideal cervical curvature is essential to maintain a horizontal gaze with minimal energy consumption. However, upright cervical lordosis changes in supine position. Anterior fusion surgery and more sophisticated radiological examinations, such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI), are performed in lying position. Therefore, if upright cervical alignment can be simulated in the supine position, true (upright) cervical lordosis can be demonstrated on CT and MRI and also a more proper anterior cervical fusion can be performed in operation with better surgical outcomes. Forty-nine (49) adult patients underwent radiological examinations, including upright cervical radiography and three session of supine MRI in different positions. MRI was performed in (1) conventional neutral supine position, (2) supine position with a 5-cm-high pillow, and (3) supine position with a 10-cm-high pillow under the shoulders. MRI results were analyzed. Wilcoxon, Kolmogorov-Smirnov, and Spearman correlation tests were used to analyze MRI the validity in compared with those of cervical radiography. Cervical lordosis (C2-C7 Cobb angle) of the radiography group was similar to that of supine MRI group using a 5-cm-high pillow, and they have a strong correlation. The T-1 slope from radiography group was similar to and correlated with that of supine MRI groups with both pillows. Cranial tilt measurements of radiography group were different but correlated with the MRI group using a 5-cm-high pillow. Simulating upright cervical lordosis in the supine position is possible by adding a 5-cm-high pillow under the shoulders of the patients. This simulation reduces the need for direct radiography. Anterior cervical fusion surgery performed in this position can provide better surgical results.

Keywords: Cervical lordosis; MRI; Lateral cervical radiography; T-1 slope; Cranial tilt; Cervical alignment parameters.

INTRODUCTION

An ideal cervical curvature is needed to maintain a horizontal gaze with minimal energy consumption; therefore, cervical alignment evaluation is still performed according to the direct radiography in the standing position *(1,2)*. However, it has the following two major disadvantages: (1) potential risk of radiation exposure *(3,4,5)* and (2) unclear appearances of some anatomical landmarks, such as the T1 vertebral body and upper edge of sternum, as a result of the superposition of the shoulders *(6,7,8)*. A few authors have reported that measurements of

■ Hamza Karabag[1],
■ Ahmet Celal Iplikcioglu[2].
[1]*Department of Neurosurgery, Harran* Üniversity, Şanlıurfa, *Turkey.*
[2]*Department of Neurosurgery, BHT Clinic Istanbul TEMA Hospital, İstanbul, Turkey.*
Correspondence : Hamza Karabag, Department of Neurosurgery, Harran Üniversity, Şanlıurfa, Turkey. Phone: +90 5056843818, Fax: 0(414) 313 3614.
Email : hamzakarabag@yahoo.com

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cervical alignment parameters obtained on supine MRI and CT showed that cervical lordosis (C2-C7 Cobb angle) is lesser on the supine position than on the upright position *(2,6,7,9,10)*. Other cervical alignment parameters were also different, although some of them were correlated.

However, anterior cervical fusion surgery is performed in the supine position and reconstruction of lordosis should be performed with correct alignment and balance, which refers to that of the upright position. Therefore, if upright cervical alignment can be simulated in the supine position, then a more appropriate anterior cervical fusion to restore the correct cervical alignment can be performed with better surgical outcomes *(10)*. Evaluation of the true (upright) cervical alignment can be also possible with more sophisticated radiological examination (MRI) in the lying position. Considering that cervical lordosis (CL) is lesser in the supine position, neck extension is necessary to simulate upright CL. The simplest way to enhance neck extension is the placement of a pillow under the shoulder of the patients.

Therefore, in this study, pillows placed at different heights were used and analyzed for their suitability in the simulation of upright cervical lordosis in supine position.

MATERIALS AND METHODS

This cross-sectional study was conducted at the Department of Neurosurgery. The study protocol, which was in accordance with the ethical principles for human investigations as outlined by the second version of the Declaration of Helsinki, was reviewed and approved by the local ethics committee. A written informed consent was obtained from all patients.

A total of 26 male and 23 female patients were involved in this study. All patients with neck pain and numbness in the arm with or without motor weakness were admitted to the hospital. Patients

Figure 1a

Figure 1b

Figure 1c

Figure 1. — Positions of patients in magnetic resonance imaging. (a) Neutral supine position, (b) Supine position with 5 cm-height pillow (low), (c) Supine position with 10-cm-height pillow (high).

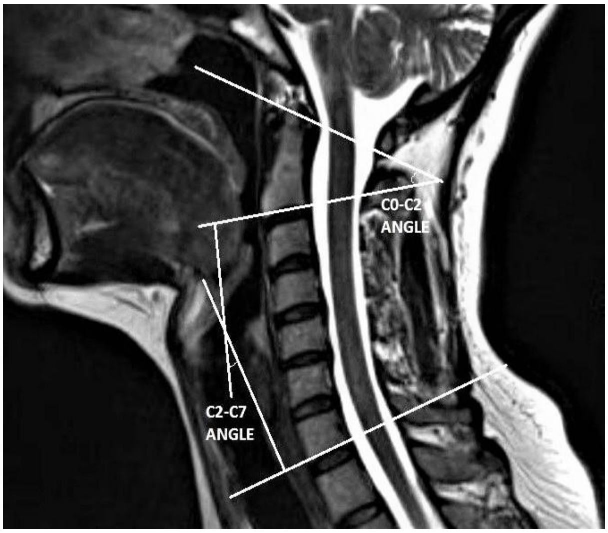
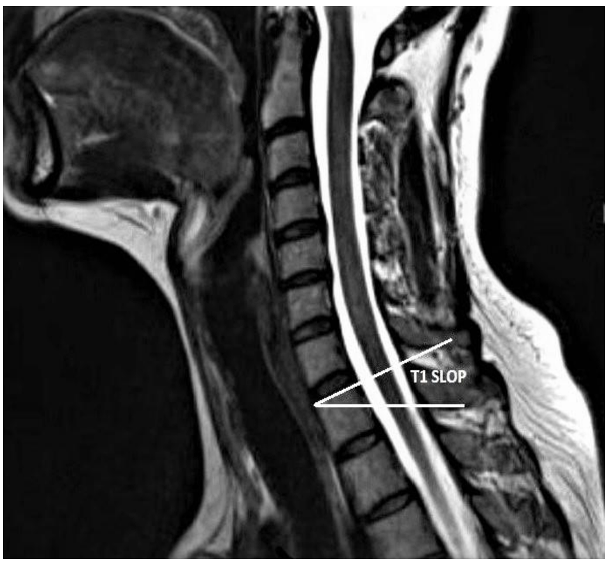


Figure 2a

Figure 2b



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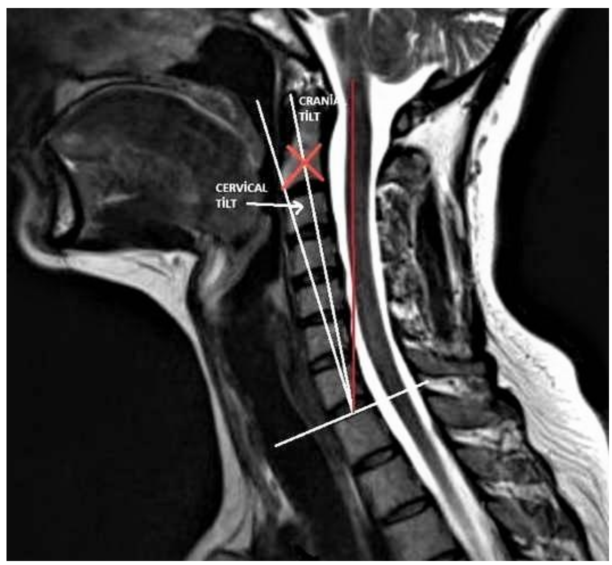

Figure 2d

Figure 2. — Measurements of cervical alignment parameters.
(a) C0-C2 and, C2-C7 Cobb angles, (b) C2-C7 sagittal vertical axis, (c) T1 slope, (d) Cranial tilt and cervical tilt.

who were overweight, had thoracic kyphosis, had spondylosis, and had cervical kyphosis on upright cervical plain radiography and the patients who were too short or long were excluded. In the supine position, overextension with a high position of the cervicothoracic junction was initiated in patients who were overweight and in patients with dorsal kyphosis. The neck of patients with spondylosis could be rigid or "S" shaped. The Cobb angle of patients with cervical kyphosis is negative, and neck flexion can be essential to simulate an upright cervical alignment. In these patients probably a thicker or thinner pillow is needed to simulate upright lordosis. To eliminate the effect of body size and shape, we used a relatively homogeneous group.

Cervical radiographs and images in three sessions of cervical spinal MRI of all patients were obtained (Figure 1). Cervical spinal MRI scans were taken three times in the neutral position, in supine position with pillows placed at 5, and supine position with pillows placed at 10 cm high under the shoulders. In a pilot study with several patients, pillows with a height <5 cm did not show a significant difference in the findings; as a result, pillows with 5- and 10-cm heights were preferred. In addition, pillows were filled with sand to maintain incompressibility. However, patient's weight could induce a decrease in height up to 1 cm. Direct radiographs were taken from a distance of 72 inches by focusing on the C4 vertebrae. MRI was carried out by using 1.5 T unit (Magnetom Symphony, A Tim System; Siemens, Erlangen, Germany), and quadrature transmit/receive heat coil: Midline T-2 weighted (repetition time, 4120 msn; echo time, 100 ms) images were used for the measurements. A standard head stabilizer was used for the neutral MRI examination. Pillows with a height of 5 cm and 10 cm were placed separately under the shoulders of the patients.

Measurements of CL (C2-7 Cobb angle), C0-2 Cobb angle, C2-7 sagittal vertical axis (SVA), T-1 slope, cranial tilt, and cervical tilt from the imaging sets of each patient, including those from X-ray images and three MRI scans, were performed by the authors (H.K. and A.C.I.) three times in different times and the main values were obtained (Figure 2). These values were obtained according to the following parameters:

1. CL: The Cobb angle between the lines of the C2 lower end plate and C7 lower end plate.
2. C0-2 Cobb angle: The Cobb angle between the lines of the foramen magnum and C2 lower end plate.
3. C2-7 SVA: The distance between the vertical lines from the center of C2 and posterior upper edge of C7 vertebrae.
4. T1S: The Cobb angle between the line of the T-1 upper endplate and the horizontal line.
5. Cervical tilt: The angle between the line from the center of the T-1 upper end plate to the C2 vertebral body and the line perpendicular to the T-1 upper end plate.
6. Cranial tilt: The angle between the line from the center of the T-1 upper end plate to the C2 vertebral body and the vertical line from the center of T-1 upper end plate.

The thoracic inlet angle (TIA) and neck tilt were also measured, but in more than half of the patients, these measurements could not be carried out because of the invisibility of the upper sternum; therefore, TIA and neck tilt parameters were excluded.

All cervical spinal alignment parameters were measured by both authors twice at different times. Mean values of measurements from MRI were compared with those obtained from radiography using Wilcoxon test. Kolmogorov-Smirnov test and Spearman's correlation analysis were used to

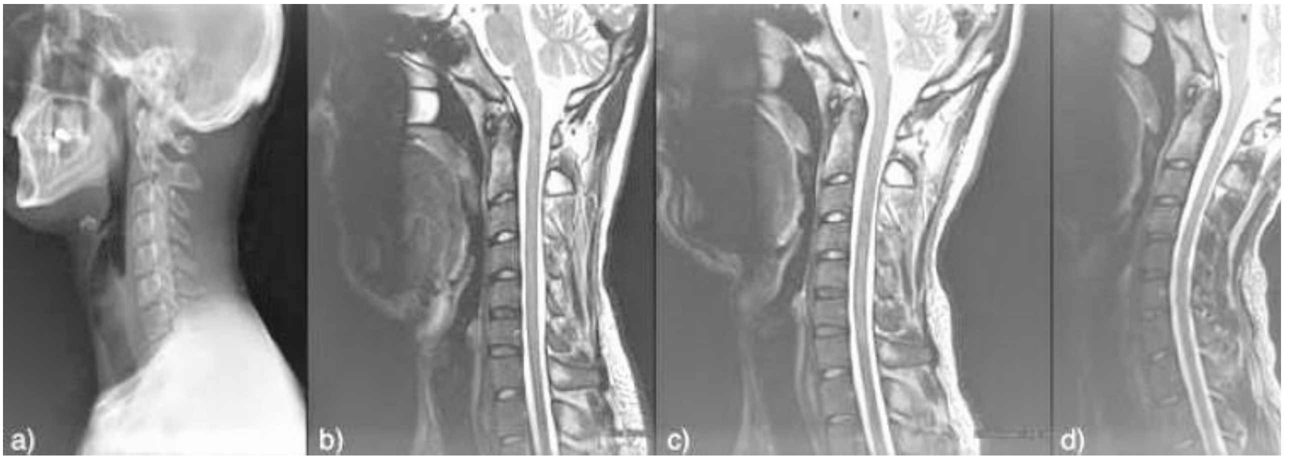

Figure 3. — Lateral radiographs and T2 mid-sagittal images of the cervical spine. (a) Standing radigraphy, (b) Conventional supine magnetic resonance imaging (MRI), (c) Supine MRI with a 5-cm-high pillow under the shoulders of the patient, (d) Supine MRI with 10 cm high pillow.

Table-1. — Statistical Analises of cervical parameters obtained from radiography and different MRI groups

	Min-Max	Mean+SD	P*	r	p‡
C2-7 Cobb Angle					
X-Ray	14.0 - 37.0	20.4 ± 8.3			
Neutral MRI	-11.5 - 40.0	5.6 ± 17.4	*0.017*[w]	0.778	*0.023*[s]
5 cm. pillow MRI	-2.0 - 49.0	19.5 ± 12.4	0.401[w]	0.707	*0.049*[s]
10 cm. pillow MRI	9.5 - 38.0	25.9 ± 10.4	*0.041*[w]	0.136	0.771[s]
CO-2 Cobb Angle					
X-Ray	28.0 - 43.5	33.3 ± 6.2			
Neutral MRI	8.0 - 28.5	18.9 ± 7.3	*0.012*[w]	0.195	0.643[s]
5 cm. pillow MRI	9.0 - 30.0	18.2 ± 7.1	*0.012*[w]	-0.025	0.954[s]
10 cm. pillow MRI	18.0 - 30.0	22.7 ± 3.9	*0.027*[w]	-0.171	0.745[s]
SVA mm					
X-Ray	-7.0 - 26.0	12.2 ± 7.1			
Neutral MRI	-6.6 - 15.5	5.7 ± 8.2	*0.038*	0.586	0.127[s]
5 cm. pillow MRI	-7.5 - 4.4	-0.2 ± 4.1	*0.025*[w]	0.467	0.243[s]
10 cm. pillow MRI	-21.0 - 0.0	-7.5 ± 8.0	*0.043*[w]	0.198	0.670[s]
T1 Slope					
X-Ray	13.5 - 42.0	26 ± 8.5			
Neutral MRI	4.0 - 38.5	16.3 ± 12.5	*0.012*	0.922	*0.001*[s]
5 cm. pillow MRI	8.0 - 35.5	17.8 ± 10.2	0.093[w]	0.793	*0.033*[s]
10 cm.pillow MRI	6.5 - 40.0	21.0 ± 12.0	0.398[w]	0.775	*0.041*[s]
Cervival Tilt					
X-Ray	9.0 - 32.0	19.1 ± 8.1			
Neutral MRI	1.0 - 35.0	13.2 ±	0.207[w]	0.539	0.168[s]
5 cm. pillow MRI	12.5 - 36.0	18.9 ± 8.5	0.735[w]	0.541	0.210[s]
10 cm.pillow MRI	20.0 - 33.0	26.0 ± 4.9	0.075[w]	0.064	0.892[s]
Cranial Tilt					
X-Ray	-8.0 - 10.0	3.9 ± 7.0			
Neutral MRI	-4.0 - 4.0	1.1 ± 2.6	0.233[w]	0.424	0.295[s]
5 cm. pillow MRI	-8.5 - 0.0	-4.1 ± 2.9	*0.043*[w]	0.786	*0.036*[s]
10 cm. pillow MRI	-14.0 - 0.0	-7.9 ± 4.5	*0.027*[w]	0.393	0.383[s]

[w] Wilcoxon test (p*) /[s] Spearman correlation (p‡/r)

evaluate the agreement between radiography and MRI scans. SPSS 22.0 was used to analyze the results. P < 0.05 was considered significant.

RESULTS

Of the patients, 26 were men and 23 were women. The mean age was 34.8 (range, 22-52) years. The diagnoses were cervical disc disease in 21 and cervical muscle spasm in 28 patients. However, surgical indications were present only in 3 patients. The mean standard deviation and range of the C2-7 Cobb angle, C0-2 Cobb angle, C2-7 SVA, T-1 slope, cervical tilt, and cranial tilt parameters are shown on Table 1.

The C2-7 Cobb angle of the radiography group was different significantly only from that of the neutral MRI group, whereas it showed correlation with neutral MRI and 5 cm extension group (Figure 3). This finding confirmed that upright lordosis (C2-7 Cobb angle) can be simulated in the supine position by adding a pillow of 5 cm height under the shoulders of the patients. To evaluate the effect of MRI diagnosis (cervical disc, cervical muscle spasm) on results, patients were divided into two groups: cervical disc herniation and muscle spasm. Cervical lordosis results that were obtained from upright x-ray and supine MRI with 5 cm. height pillows were similar and correlated in both groups.

The T-1 slope from the radiography group was different from that of the neutral MRI group, whereas it was similar to the 5- and 10-cm extension groups. It also correlated with all MRI T-1 slope groups.

Cranial tilt measurements of the radiography group were only correlated with the 5-cm extension group, although a significant difference was found between them. Other parameters obtained from the radiography group did not show any similarities or significant correlations with the MRI groups.

DISCUSSION

This study showed that it is possible to simulate upright CL (C2-7 Cobb angle) in the supine position by adding a pillow of 5 cm height under the shoulders of the patients. Only the T-1 slope and cranial tilt parameters are correlated in this simulation.

We recently developed a formula to estimate upright CL, using MRI data obtained in the supine position *(2)*. Simulating upright spinal alignment during surgery and sophisticated radiological examinations, such as CT and MRI, are more valuable; however, studies on these features are limited *(11,12)*. Kimura et al. used an axial loading device to simulate upright cervical alignment in the lying position *(11)*. They also found that a body weight of 8.4% corresponding to the weight of the head and neck caused cervical alignment in the supine position, simulating that of upright position *(11)*.

Hansen et al. investigated the effect of adding a lumbar pillow during supine MRI and found equal changes in the lumbar spine with standing MRI *(12)*.

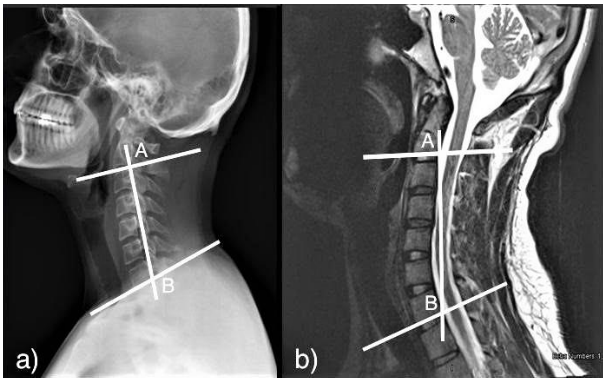

Figure 4. — Lateral standing radiographs. (a) Supine magnetic resonance imaging with 5-cm-high pillow. (b) Eight cervical arcs that are very close.

However, these studies were performed to assess the narrow spinal canal. To our knowledge, our study is the second study on the simulation of upright CL in the supine position. Our technique does not require a mechanical device, which is its main advantage compared to the method of Kimura et al. In our study, the force created in extension is in the reverse direction to the axial force; hence, the cervical arc in extension may be longer than the vertebral arc in axial loading. Nonetheless, the difference of AB longs was less than several millimeters (data not shown) (Figure 4).

The effect of extension in the supine position is well-known and used in surgeries and radiological examinations. Most of the spinal surgeons perform the anterior cervical operations on patients with extended neck to provide a wider and more vertical disc space, especially in lower cervical levels.

The importance of MRI examination in the supine position with combined neck extension and flexion is also well-known *(13)*. The so-called dynamic supine MRI was introduced in 1980s. It is preferred in cases of spondylotic myelopathy because the cervical canal is narrowed by 10%-23% on extension. In some studies, specific neck angles were recommended, or purpose-built devices were used in dynamic MRI. Others researchers pre-ferred maximum cervical extension or flexion *(14)*. However, dynamic MRI has not been used previously to simulate upright cervical alignment in the supine position.

Whether the cervical alignment parameters are valid in simulating position is still unclear. Several studies comparing the various cervical alignment parameters obtained by radiography in the standing position and those by CT and MRI in the supine position *(6,7,9,10)*. Although some conflicts were present, results from these studies could be summarized as follows:

- Anatomical landmarks are more detectible in MRI than in radiography.
- Although significant differences are present in some parameters, such as CL, C2-7 SVA, and T-1 slope obtained from different imaging modalities because of the position of the patients (supine vs. standing), some of these parameters can be correlated statistically.
- TIA is a relatively constant cervical alignment parameter not influenced by the posture because of the relatively motionless bony circle, including the first ribs, upper sternum, and T-1 body.

Only a few studies have investigated the influence of flexion and extension on cervical alignment parameters. Janusz et al. compared the lateral standing radiographs in neutral position, full flexion, and full extension. They found that the T-1 slope was decreased by extension, but the neck tilt was not influenced by extension *(15)*.

Other similar studies have performed imaging in the upright position using kinematic MRI *(16)*. However, the effects of extension on cervical alignment parameters in the supine position have not been reported. These studies have used one variable (standing-supine or flexion-extension); while our study used two variables (standing-supine and neutral-extension), which yield more complicated results.

Although our study focused on the CL (C2-7 Cobb angle), other parameters need to be considered, including C2-7 distance (C2-7 SVA), T-1 slope, TIA, and neck tilt, used in the evaluation of cervical alignment. Recent studies have also shown that these cervical parameters were highly correlated with the clinical parameters of pain, motor and sensory functions, as well as quality of life *(17,18,19,20,21)*. They are also essential for surgical planning and predicting prognosis *(20,21,22,23)*.

C2-7 SVA is a strong parameter that correlated with the neck visual analog scale and neck disability index, especially following posterior and anterior cervical fusion *(17,24)*. Lee at al. found a difference and poor correlation in CVA measurements between radiography and MRI *(24)*. According to Tang et al., the threshold value of C2-7 SVA was 40 mm, but usually much lesser in patients without symptoms *(17)*. This parameter is must commonly affected by other factors *(9)*. It increases in flexion and decreases in extension. Our results are similar to those of Lee et al. and Tamai et al. *(9,16)*.

The T-1 slope is a landmark of cervical sagittal balance, as well as of overall spinal sagittal balance. The T-1 slope is influenced by aging, and CL increases as T1 slope becomes higher *(8,10)*. In most previous studies, T-1 slope is also higher on radiographs than on MRI scans but showed correlation *(6,9,10)*. Janusz et al. also reported that T-1 slope was significantly influenced by flexion and extension *(15)*. We also found that T-1 slope decreases in the supine position, but increases in the supine extension, showing significant correlation. Therefore, T-1 slope was a strong and essential parameter in our study.

Cranial tilt is a novel cervical alignment parameter that correlates with both T-1 slope and C2-7 SVA; however, it is rarely used in cervical alignment studies *(25,26)*.

Our study clearly showed that simulating upright cervical alignment (CL) in the supine position by standardized extension is possible. T-1 slope and cranial tilt measurements are also valuable in this position. However, our study has some limitations. First, the number of the patients is small and most of them showed mild symptoms. Patients with kyphotic neck and spondylotic myelopathy were excluded. Second, the most important limitation was the unavailability of TIA and neck tilt parameters owing to the invisibility of the upper sternum. Some studies have reported this problem; Park et al. found that TIA alignment could be measured in only 11% of the patients by radiography *(8)*. Liu et al. also reported the measurement rate of 14% *(7)*. In our study, we could not detect the upper sternum on MRI because of the oblique position of cervical column in the frame.

CONCLUSION

It is possible to simulate upright CL in supine position by adding a 5-cm-high pillow under the shoulders of the patients. Only T-1 slope and cranial tilt parameters were correlated and valuable in this simulation. One of the advantages of this simulation is the reduced need for direct radiography. Additionally, anterior cervical fusion surgery performed in this position can provide better surgical results.

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