EREDETI KÖZLEMÉNY

ORIGINAL ARTICLE

Is it possible to evaluate upper and lower cervical interdependency on supine magnetic resonance imaging?

Hamza KARABAG[1], Ahmet Celal IPLIKÇIOĞLU[2]

[1]Harran University, Medical Faculty, Department of Neurosurgery, Şanlıurfa, Turkey
[2]BHT Clinic Istanbul TEMA Hospital, Department of Neurosurgery, İstanbul, Turkey

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Felső és alsó cervicalis interdependencia értékelése fekvő testhelyzetben készült MR-képalkotáson
Karabag H, MD; Iplikçioğlu AC, MD

Correspondent:
Dr. Hamza KARABAG,
Harran University, Medical Faculty, Department of Neurosurgery, Şanlıurfa, Turkey.
Telephone: +905056843818,
e-mail address:
hamzakarabag@yahoo.com
https://www.orcid.org/0000-0001-0091-5571-1326

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Background and purpose – There is a significant correlation between the upper and lower cervical alignments associated with a compensatory mechanism to maintain horizontal gaze. Evaluating this correlation before cervical fusion operations is essential, particularly in the upper cervical region, to prevent the occurrence of postoperative malalignment. This study was designed to investigate whether evaluating the interdependency between the upper and lower cervical alignments on neutral supine magnetic resonance imaging (MRI) or supine MRI with neck extension is possible.
Methods – This study included 36 male and 30 female volunteers without symptoms aged between 16 and 60 years. Cervical radiographic images and supine cervical spinal MRI scans were obtained twice on the neutral supine position and on the supine position with pillows placed at 5 cm high under the shoulder. Cervical lordosis (CL) (C2–7 Cobb angle), C0–2 Cobb angle, C2–7 sagittal vertical axis (C2–7SVA), T1 slope (T1S), and T1 slope minus CL (T1S-CL (C2S)) were measured from the imaging sets from each patient, including X-ray images and two MRI scans, and the main values were obtained. The mean values of the measurements from the radiographic images were compared with those obtained from MRI scans using Student's *t*-test. The agreement between the parameters (C0–2 Cobb angle, CL Cobb angle, and T1S-CL) obtained from the radiographic images and MRI scans was evaluated using Pearson correlation analysis.

Háttér és cél – Jelentős összefüggés van a felső és alsó cervicalis gerincszakasz kiegyenesedése között, ami a horizontális tekintet fenntartására irányuló kompenzációs mechanizmushoz kapcsolódik. E korreláció értékelése a nyaki fúziós műtétek előtt alapvető fontosságú a posztoperatív rendellenességek előfordulásának megelőzése érdekében, különösen a felső cervicalis régióban. E tanulmány célja annak vizsgálata volt, hogy a felső és alsó cervicalis tájolás közötti összefüggés értékelése lehetséges-e neutrális, fekvő mágnesesrezonancia-képalkotás (MRI) vagy nyaknyújtással kombinált fekvő MR-vizsgálat során.
Módszerek – A vizsgálatban tünetmentes önkéntesek vettek részt (36 férfi és 30 nő, 16 és 60 év közötti életkor). Nyaki röntgenfelvételeket és fekvő nyaki gerinc-MR-vizsgálatokat végeztünk kétszer neutrális fekvő helyzetben és fekvő helyzetben, a váll alá helyezett 5 cm magas párnákkal. A nyaki lordosist (CL) (C2–7 Cobb-szög), a C0–2 Cobb-szöget, a C2–7 sagittalis vertikális tengelyt (C2–7SVA), a T1 meredekség (T1S) és a T1 meredekség mínusz CL-értéket [T1S–CL (C2S)] megmértük mindegyik betegről készült képalkotó sorozaton, beleértve a röntgenfelvételeket és a két MR-vizsgálatot, így kaptuk meg a fő értékeket. A röntgenfelvételekből származó mérések átlagértékeit Student's t-próbával hasonlítottuk össze az MR-vizsgálatokból kapott értékekkel. A röntgenfelvételekből és az MR-vizsgálatokból kapott paraméterek (C0–2 Cobb-szög, CL Cobb-szög és T1S–CL) közötti egyezést Pearson-féle korrelációs elemzéssel értékeltük.

Results – Pearson correlation analysis revealed significant correlations between the C0–2 and C2–7 Cobb angles in standing X-ray and neutral MRI values (*r* = −0.425 and -0.397, respectively). In plain radiography and MR studies, the T1 slope was correlated with the C2–7 angle (*r* = 0.4824, 0.734, and 0.702, respectively). The C2 slope values were also significantly correlated with the C0–2 Cobb angle in standing X-ray and neutral MRI images (*r* = 0.5595 and 0.5719, respectively). There were significant correlations between the C2 slope and C2–7 Cobb angles in all modalities (*r* = −0.5645, −0.7917, and −0.8526).
Conclusion – Negative correlations between the upper and lower cervical alignments are also present in supine MRI studies, consequently in the supine position, with statistical significance. The C2 slope is an important cervical spine parameter that is significantly correlated with both the C0–2 and CL Cobb angles. The C2 slope can be used to evaluate the interdependency of the upper and lower cervical alignments.

Keywords: supine, magnetic resonance imaging, standing, interdependency of the upper and lower spine

Eredmények – A Pearson-féle korrelációs elemzés szignifikáns korrelációt mutatott az álló röntgenfelvételeken és a neutrális MR-vizsgálaton mért értékek – a C0–2 és C2–7 Cobb-szögek – között (r = –0,425, –0,397, illetve –0,397). A sima röntgen- és MR-vizsgálatokban a T1 meredekség korrelált a C2–7 szöggel (r = 0,4824; 0,734, illetve 0,702). Szintén szignifikánsan korreláltak az álló röntgen- és neutrális MR-felvételeken a C2 meredekség értékei a C0–2 Cobb-szöggel (r = 0,5595 és 0,5719). A C2 meredekség és a C2–7 Cobb-szögek között minden modalitásban szignifikáns korreláció volt (r = –0,5645; –0,7917 és –0,8526).
Következtetés – A felső és az alsó cervicalis gerinckiegyenesedés közötti statisztikailag szignifikáns negatív korrelációk a fekvő MR-vizsgálatban, következésképpen a háton fekvő helyzetben is jelen vannak. A C2 meredekség fontos cervicalis gerincparaméter, ami szignifikánsan korrelál mind a C0–2-, mind a CL Cobb-szöggel. A C2 meredekség használható a felső és az alsó nyaki gerincszakasz kiegyenesedése közötti interdependencia értékelésére.

Kulcsszavak: hanyatt fekvő testhelyzet, mágneses rezonanciás képalkotás, álló testhelyzet, felső és alsó gerincszakaszok interdependenciája

The cervical spine is the most mobile part of the spine, and its main functions include bearing the weight of the head and maintaining a horizontal gaze with head and neck movements[1, 2]. The cervical spine is divided into two sections: upper (C0–2) and lower (C2–7).

There is a significant negative correlation between the upper and lower cervical alignments associated with a compensatory mechanism for maintaining horizontal gaze[3–6]. Therefore, evaluating this correlation before cervical fusion operations is essential, particularly in the upper cervical region, to prevent the occurrence of postoperative misalignment[7–9].

Classically, this evaluation is performed by measuring the cervical angles or parameters on standing plain radiography. However, some authors considered that supine magnetic resonance imaging (MRI) is a good alternative to standing X-ray for measuring cervical sagittal parameters, although there is a significant difference in most equivalent parameters obtained from the two modalities[10–14]. In contrast, most cervical fusion operations are performed with the patients in the supine or prone position, without axial loading. We have recently shown that Cervical lordosis (CL) in the standing position could be simulated in the supine position by extending the neck and placing a 5-cm-high pillow under the patient's shoulder[15]. Therefore, this study was designed to investigate to determine whether neutral supine MRI and supine MRI with neck extension could be used to evaluate the interdependency between the upper and lower cervical alignments using the Cobb angle method. The Cobb angle method is the most widely used measurement technique for assessing spinal deformities and the physiological curves of the spine in the sagittal or coronal plane. The Cobb angle is the angle between the upper or lower endplate of two chosen vertebrae. The importance of the C2 and T1 slopes, with two cervical markers in the supine position, was also evaluated.

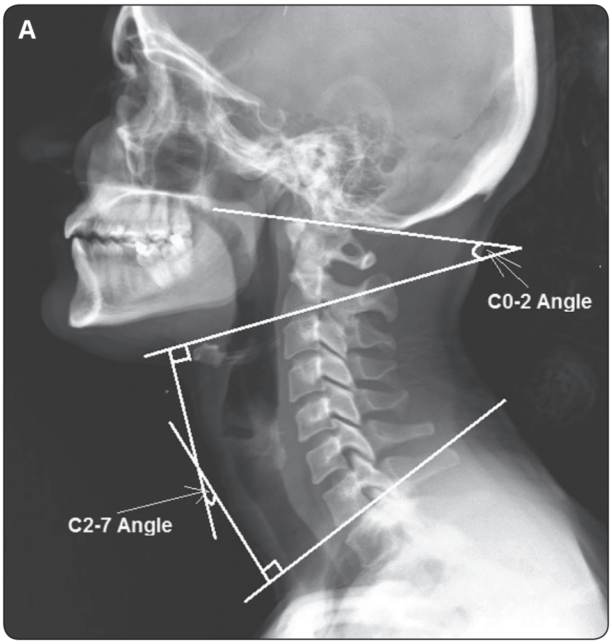

Figure 1.A *C2–7 Cobb angle and C0–2 Cobb angle*

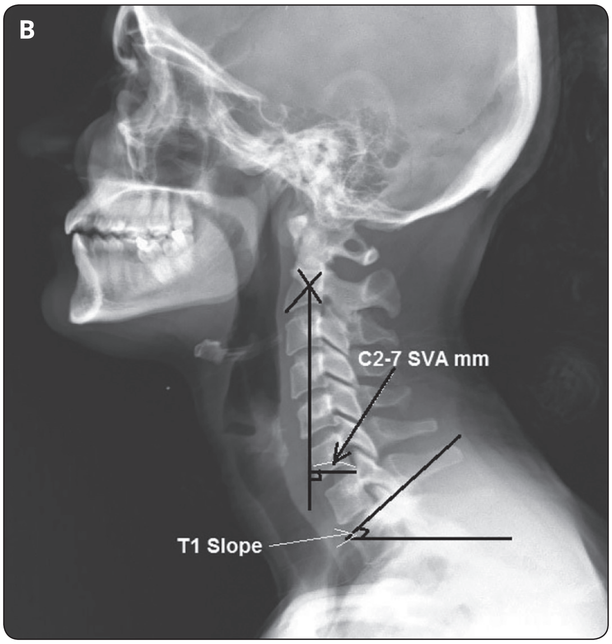

Figure 1.B *C2–7 sagittal vertical axis and T1 slope*

Materials and methods

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

This study included 36 male and 30 female volunteers without symptoms aged between 16 and 60 years (the average age of the subjects was 36.3 ± 11.2 years). Subjects who were overweight and had a history of spinal surgery, infection, trauma, and medical diseases that may affect the spine, such as rheumatoid arthritis and neurovascular diseases, were excluded. After plain cervical radiography was performed, subjects with cervical deformity and spondylosis were also excluded.

Cervical radiographs and images in two sessions of MRI of the cervical spine were obtained from all subjects. Supine MRI scans of the cervical spine were performed twice on the neutral supine position and on the supine position with 5-cm-high pillows placed under the shoulder. Direct radiographic images were acquired from a distance of 72 inches by focusing on the C4 vertebrae. MRI was performed using a 1.5 T unit (Magnetom Symphony, A Tim System; Siemens, Erlangen, Germany) and quadrature transmit/receive heat coil. Midline T2-weighted images (repetition time, 4.120 ms; echo time, 100 ms) were used for the measurements. A standard head stabilizer was used for the neutral MRI examination. Pillows measuring 5 cm in height were placed separately under the patients' shoulders.

CL, C0–2 Cobb angle, C2–7 sagittal vertical axis (SVA), and T1S were measured thrice at different time points from the imaging sets of each patient, including X-ray images and two MRI scans, by H.K. and A.C.I., and the main values were obtained. These values were obtained according to the following parameters: 1., CL: The Cobb angle between the lines of the C2 and C7 lower endplates; 2., C0–2 Cobb angle: The Cobb angle between the lines of McGregor (the line between the posterior edge of the hard palate and the most caudal point of the occipital bone) and C2 lower endplate **(Figure 1.A)**; 3., C2–7 SVA: The distance between the vertical lines from the center of C2 and the posterior upper edge of C7 **(Figure 1.B)**; 4., T1S: The angle between the line of the T1 upper endplate and the horizontal line; 5., T1S-CL (C2 slope): The T1S angle minus the CL angle. This value was calculated by subtracting the CL Cobb angle from T1S.

T1S-CL is an approximation of the C2 slope (in this article, T1S-CL and C2S were used interchangeably).

Both authors measured all cervical spinal alignment parameters thrice at different time points. The mean measurement values from the radiographic images were compared with those obtained from the MRI scans using Student's *t*-test. The agreement between the parameters (i.e., C0–2 Cobb angle, CL Cobb angle, and C2S) obtained from the radiographic images and MRI scans was evaluated using Pearson correlation analysis. Statistical Package for the Social Sciences, version 22.0, was used to analyze the results, and *p*-values of less than 0.05 were used to indicate statistical significance.

Table 1. *Mean values and standart deviation of cervical sagittal parameters their comparisons and correlattions*

		p	r	
C2–7 Angle				
X-Ray	15.6 ± 9.2			
Neutral MR	4.6 ± 10.1	0.021	0.752	S
Extension MR	16.3 ± 11.4	0.425	0.718	S
C0–2 Angle				
X-Ray	23.3 ± 7.1			
Neutral MR	15.2 ± 7.7	0.029	0.0502	NS
Extension MR	14.2 ± 7	0.024	–0.0239	NS
SVA (mm)				
X-Ray	14.2 ± 6.1			
Neutral MR	5.4 ± 9	0.019	0.535	S
Extension MR	-0.3 ± 6.1	0.009	0.493	S
T1 Slope				
X-Ray	20.9 ± 8.7			
Neutral MR	15.3 ± 11.5	0.035	0.910	S
Extension MR	19.2 ± 10.5.1	0.240	0.788	S
T1S–C2–7 Angle (C2 Slope)				
X-Ray	5.3 ± 8.1			
Neutral MR	10.7 ± 12	0.041	0.390	S
Extension MR	2.9 ± 9.8	0.120	0.0695	NS

p: Student t test, r: Pearson correlation analysis, S: significant, NS: non-significant

Results

Table 1 shows the average values of the cervical sagittal parameters, statistical differences, and correlations between the values from the standing X-ray images and those from the MRI scans (neutral and extended). The average CL Cobb angle was 15.6° ± 9.2°, 4.6° ± 10.1°, and 16.3° ± 11.4° in the standing X-ray, neutral MRI, and extension MRI scans, respectively. The average C0–2 Cobb angle was 23.3° ± 7.1°, 15.2° ± 7.7°, and 14.2° ± 7° in the standing X-ray, neutral MRI, and extension MRI scans, respectively **(Figure 2)**.

The average CL Cobb angle, T1S, and C2S values from the standing X-ray and extension MRI scans were similar to their equivalents. All other parameters from MR studies were different from those of the standing X-ray images.

Except for the C0–2 Cobb angles and C2S from the extension MRI scans, all parameters from MR studies were correlated with their standing X-ray equivalents. Pearson correlation analysis showed significant correlations between the C0–2 and C2–7 Cobb angles in the standing X-ray and neutral MRI values ($r = -0.425$ and 0.397, respectively), although no significant correlation was found between the C0–2 and CL Cobb angles in the extension MRI scans **(Table 2)**. T1S was correlated with the CL Cobb angle in plain radiography and MRI studies ($r = 0.4824$, 0.734, and 0.702, respectively) **(Table 3)**. C2S values were also significantly correlated with the C0–2 Cobb angle in the standing X-ray and neutral MRI scans ($r = 0.5595$ and 0.5719, respectively) **(Table 4)**. There were significant correlations between C2S and the CL Cobb angle in all modalities ($r = -0.5645$, -0.7917, and -0.8526). The correlations between C2S and the CL Cobb angle were greater in MRI studies than those in standing X-ray.

Discussion

Standing X-ray used for measuring cervical sagittal parameters has two major disadvantages. The first is the radiation effect, and the second is the unclear visibility of anatomical landmarks, such as the T1 vertebral body and the upper edge of the sternum because of the superposition of the shoulders[10]. Therefore, some authors have used MRI to measure cervical alignment parameters. However, such studies are few and usually focused on CL and the following parameters: thoracic inlet angle

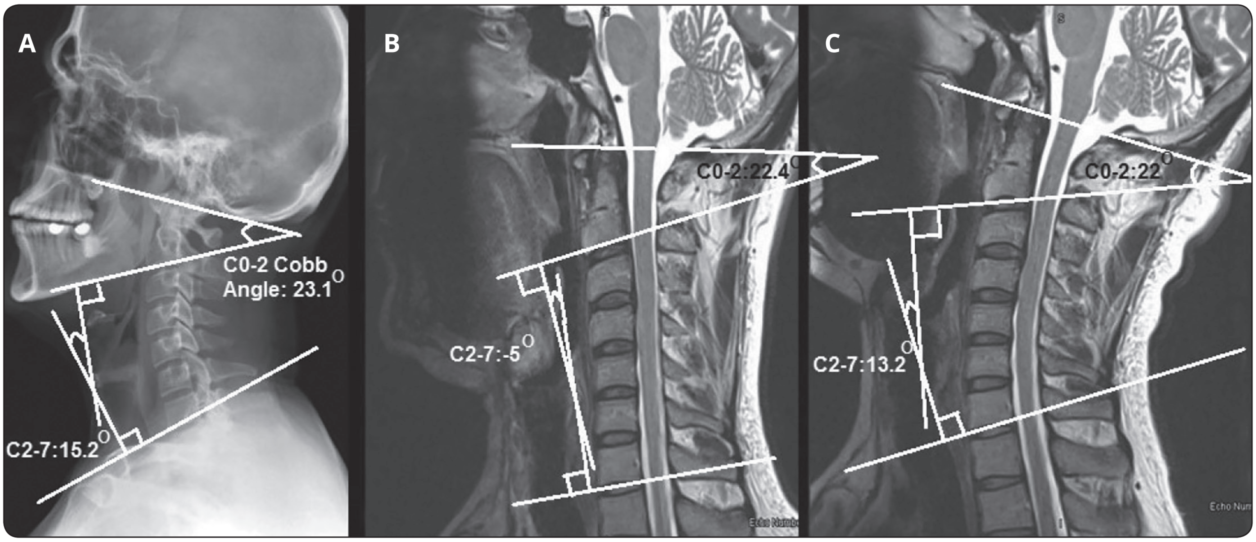

Figure 2. *X-ray* **(A)***, Neutral MRI* **(B)** *and extending MRI* **(C)**

Table 2. *Correlation analysis of C0–2 and C2–7 Cobb angles measured on different modalities*

	X-Ray		Neutral-MR		Extension-MR	
C0–2/C2–7	–0.425	S	–0.3933	S	–0.3250	NS

S: significant, NS: non-significant

influenced by positions, such as flexion and extension, because of the motionless bony circle, including the first ribs, upper sternum, and T1 body. The effect of the flexion and extension positions on cervical parameters are well known and reverse[17–19]. All parameters, except for TIA and NT, change significantly according to positions. However, changes in the supine position are more complex. In the supine position, the flexion effect occurs on C0–2 and CL, whereas the extension effect is present on C2–7 SVA and T1S. The mean CL, C0–2 Cobb angle, C2–7 SVA, and T1S values from MRI are significantly lower than those from upright radiography. The mean T1S-CL (C2S) value is greater on MRI be-

(TIA), T1S, and neck tilt (NT), which could be better measured using MRI[16]. Despite some conflicts, it is generally accepted that there is a significant difference in the parameters obtained from X-ray from those obtained from MRI, except for T1A and NT[16]. The differences are due to the absence of the axial loading effect of the head. T1A is a relatively constant parameter not

Table 3. *Correlation between T1 slope and upper and lower cervical angles*

	X-Ray		Neutral-MR		Extension-MR	
T1S/C0–2	r: –0.1015	NS	r: –0.541	S	r: –0.217	NS
T1S/C2–7	r: 0.4804	S	r: +0.734	S	r: 0.702	S
T1S/C2–7 SVA	r: 0.4827	S	r: –0.0985	NS	r: –0.2267	NS

S: significant, NS: non-significant

Table 4. *Correlation between C2-slope and upper and lower cervical angles*

	X-Ray		Neutral-MR		Extension-MR	
C2 Slope /C0–2	0.5595	S	0.5719	S	0.1465	NS
C2 Slope /C2–7	–0.5645	S	–0.7917	S	–0.8526	S
C2 Slope /C2–7 SVA	0.7473	S	0.2728	NS	0.1309	NS

S: significant, NS: non-significant

cause a decrease in CL is more than that in T1S. Furthermore, statistically significant correlations were observed between the same parameters from standing X-ray and neutral MRI, except for the C0–2 Cobb angle. The C0–2 Cobb angle was measured in only one study comparing X-ray and MRI measurements of cervical sagittal parameters. *Oshina* et al. found a significant correlation between the C0–2 values obtained from standing X-ray and those obtained from supine MRI, which is in contrast to our findings[11]. In extension MRI, we attempted to neutralize the flexion effect of the supine position on CL. The mean CL, T1S, and T1S-CL values obtained from standing X-ray and extension MRI were similar. However, the mean CL, C2–7 SVA, and T1S values obtained from X-ray and extension MRI were correlated significantly. The importance of MRI examination in the supine position with neck extension and flexion is also well-known[20, 21]. The so-called dynamic supine MRI was introduced in the 1980s. It is preferred particularly 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 preferred the maximum cervical extension or flexion[21]. However, dynamic MRI has rarely been used to simulate upright cervical alignment in the supine position[15].

The correlation between the C0–2 and CL Cobb angles is a simple evidence for the interdependency between the upper and lower cervical alignments. However, this correlation was reported as weak and lower in men and patients with symptoms[3–6]. According to Oshina et al., the C0–2 Cobb angle is correlated with the CL Cobb angle measured on X-ray, but not on MRI[11].

In this study, correlations between the C0–2 and CL Cobb angles were $r = -0.425$, -0.393, and -0.3250 in the standing X-ray, supine neutral MRI, and extension MRI scans, respectively. The correlations were stronger in X-ray and neutral MRI scans than in extension MRI.

The development of subaxial kyphosis or decreased lordosis and swan neck deformity following atlantoaxial or occipitocervical fusion is well-known[7–9, 22–24]. *Toyama* et al. reported that 33% of patients had malalignment of the subaxial cervical spine after atlantoaxial arthrodesis[23]. *Matsunaga* reported that the rate of subaxial cervical malalignment following occipitoaxial fusion was 13%[22]. These findings suggest a relationship between the upper and lower cervical alignments associated with a compensatory mechanism. *Nojiri* et al. found a weak negative correlation between C0–2 and CL alignments and concluded that if the C0–2 Cobb angle increases, the alignment of the lower cervical spine becomes kyphotic and vice versa[3]. Later, *Guo* et al. also reported negative correlations between the C0–2 and CL Cobb angles and between the C1–2 and CL Cobb angles[4]. The former correlation was stronger. In both studies, the subjects were asymptomatic. In 2015, *Nuñez-Perreria* et al. revealed significant correlations between the CL and C0–2 Cobb angles and the CL and C1–2 Cobb angles in asymptomatic, symptomatic, and surgically treated patients[6]. Upper cervical angles were also correlated with the C7 slope.

According to Nuñez-Perreria et al., total lordosis (C0–7 Cobb angle) is approximately 30°, and 40% of total lordosis is provided by C0–2 lordosis[6]. In this study, total lordosis were 39° and 20° in standing X-ray and neutral supine MRI, respectively. Upper CL consists of 60% and 79% of total lordosis on standing X-ray and neutral supine MRI, respectively. However, similar results from standing X-ray and MR studies have been reported[11, 16].

T1S is a marker for predicting the lower cervical alignment, thoracal kyphosis, and overall sagittal balance[25–27]. T1S is strongly correlated with the CL Cobb angle and C2-7 SVA. Some authors prefer using the C7 slope instead of T1S because the shoulders can obscure the T1 upper endplate on standing cervical radiography[6]. In MRI studies, the T1 slope can be measured easily. Nuñez-Perreria also found a significant correlation between the C7 slope and C0–2 Cobb angle[6]. It is generally accepted that there was no correlation between the T1 slope and C0–2 Cobb angle, although it was present in the neutral MRI group in this study.

C2 S (T1S-CL Cobb angle) is a relatively new parameter linking the occipitocervical and cervicothoracic spines[28–30]. It is a mathematical approximation of T1S minus the CL angle, inspired from PI-LL[31]. It is significantly correlated with cervical alignment, the neck disability index, and patient-reported health-related quality of life scores[32]. It is also a modifier of cervical deformity[29]. In this study, the mean C2S value from MRI scans was greater than that from standing X-ray, as in a previous study. C2S was also significantly correlated with the C0–2 and CL Cobb angles in the X-ray and neutral MRI groups. To predict the upper and lower cervical alignments, we believe that C2S is more important than T1S.

In this study, we investigated the interdependency between the upper and lower cervical alignments in subjects without symptoms. However, the cervical curvature is influenced by thoracic and thoracolumbar malalignments.

In patients with thoracic hypokyphosis, CL decreases, whereas, in patients with hyperkyphosis, cervical hyperlordosis occurs to maintain horizontal gaze[29]. Similar effects of thoracolumbar malalignment on CL were reported in adult patients with spinal deformity and adolescent patients with idiopathic scoliosis. If changes in CL are sufficient to maintain horizontal gaze in these patients, the C0–2 Cobb angle remains constant at approximately

30°. C0–2 Cobb angle values of >30° indicate that the upper cervical spine alignment was recruited[33–34].

However, this study has some limitations. First, the number of subjects was small. Another important limitation is the lack of basic knowledge about the C0–2 and C2S values from MRI studies. According to *Staub* et al., C2S should be 16.5° ± 2°; however, no MRI study on the normative values of C2S was conducted[32].

Conclusion

A statistically significant negative correlation between the upper and lower cervical alignments is also present in MRI studies in the supine position. Supine MRI and intraoperative X-ray with the patient in the supine position are valuable for assessing this relationship. Our findings may be useful for surgical planning and research designing. C2S is an important cervical spine parameter that is significantly correlated with both the C0–2 and CL Cobb angles. C2S can be used to evaluate the interdependency between the upper and lower cervical alignments.

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