Korean J Neurotrauma. 2020 Oct;16(2):226-234
https://doi.org/10.13004/kjnt.2020.16.e18
pISSN 2234-8999·eISSN 2288-2243

KJNT

Clinical Article

Can Supine Magnetic Resonance Imaging Be an Alternative to Standing Lateral Radiographs for Evaluating Cervical Sagittal Alignment?

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Received: Mar 23, 2020
Revised: May 8, 2020
Accepted: May 13, 2020

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Conflict of Interest
The authors have no financial conflicts of interest.

ABSTRACT

Objective: Recently, many studies have reported that cervical alignment is related to clinical outcomes. However, poor visibility of anatomical structures during X-ray (XR) imaging limits accurate measurements. In supine magnetic resonance (MR) imaging, the boundary of the anatomical structure is clear, but the correlation to XR images taken in a standing position is problematic. In this study, we evaluated the agreement of sagittal alignment parameters between MR and XR measurements.
Methods: We retrospectively reviewed 268 patients. Cervical sagittal parameters were measured using XR and MR images, and their relationships were evaluated using Pearson's correlation, paired *t*-tests, and 2-way random, single score intraclass correlation coefficient (ICCs) (2,1). Using simple linear regression analysis, MR results were converted to the expected value (MR-E). The subsequent comparison of MR-Es with XRs was used to examine whether MR-Es could replace XRs when the measurement difference was less than 2 mm or 2°.
Results: The correlation between the MR and XR measurements was high, but ICCs showed low reliability. All parameters were significantly different between XR and MR measurements in paired *t*-tests. Converting the MR values eliminated the *t*-test differences between MR-Es and XRs, but did not affect correlations and ICCs. The replacement ratio included the Cobb angle: 20.3%, T1: 27.1%, the sagittal vertical axis: 17.6%, C1–2: 29.7%, and C2: 16.0%.
Conclusion: These results indicate that supine MR measurements could not replace upright XR measurements.

Keywords: Spine; Cervical vertebrae; Supine position; Radiography; Magnetic resonance imaging

INTRODUCTION

The sagittal balance of the spine can maintain the balance of the body and a horizontal gaze with minimal energy consumption.[19] Loss of balance results in increased muscle forces, higher consumption of energy, and the development of clinical symptoms. Recently, cervical sagittal alignment has focused not only on cervical deformities, but also on simple anterior cervical discectomy and fusion and laminoplasty.[17]

Cervical sagittal balance begins at the T1 slope (T1s), which is determined by pelvic and thoracolumbar alignment; therefore, the T1s is critical. However, since some bony structures, such as the shoulders, the upper edges of the sternum, thoracic vertebrae (T1), or even C7 endplates, are unclear on X-ray (XR) images, measurements can be inaccurate.[15,27)]

Compared to standing lateral radiographs, supine advanced imaging such as computed tomography or magnetic resonance (MR), can clearly show specific anatomical landmarks and allow for accurate measurements.[20)] However, because MR imaging is performed in a supine position, the possibility of substituting one measurement for the other is questionable. Liu et al.,[20)] suggested that MR results could be a comparable alternative to XR results by using a simple linear regression equation which would convert MR measurements to XR results that would correlate accurately. However, the statistical analyses were insufficient to evaluate all alternatives.

In this study, we aimed to analyze differences and correlations between cervical sagittal parameters using XR and MR images in patients with cervical spondylosis and to determine whether MR measurements could accurately replace XR measurements.

MATERIALS AND METHODS

Ethics statement

The study protocol was approved by the Institutional Review Board (IRB) of affiliated hospital, which waived the requirement for informed consent due to the retrospective nature of this study (IRB number: 05-2019-158).

Patient enrollment

We retrospectively reviewed 373 patients diagnosed with cervical spondylosis who underwent both cervical XR and MR examinations during the same period in our hospital from 2008 to 2017. To control for age-related cervical curvature deviations, only patients 60–69 years of age were included. The exclusion criteria were as follows: 1) trauma (n=7), 2) congenital cervical deformities (n=8), 3) infectious diseases (n=8), 4) tumors (n=12), 5) previous cervical surgeries (n=17), 6) C7 upper endplate not visible due to short necks (n=15), and 7) McGregor's slope <−5 (n=15) or >15 (n=23). A total of 268 patients were ultimately included.

Radiological parameters

We measured the following cervical sagittal parameters using XR and MR images with the various measurement methods being defined in **TABLE 1**: C2 slope (C2s), C7 upper slope (C7Us), C7 lower slope (C7Ls), T1s, C1–2 Cobb angle (CA) (C1–2), C2–7 CA, and C2–7 sagittal

TABLE 1. Measuring methods for radiological parameters

Parameter	Definition
C2s	The angle between the horizontal line and inferior endplate of C2
T1s	The angle between the upper endplate of T1 and the horizontal line
C7Us	The angle between the upper endplate of C7 and the horizontal line
C7Ls	The angle between the lower endplate of C7 and the horizontal line
C1–2 CA	The angle subtended by a line drawn parallel to the inferior aspect of C1 and the line below C2
C2–7 CA	The angle subtended by a line drawn parallel to the posterior border of C2 and a line drawn parallel to the posterior border of C7
SVA	The horizontal distance between a plumb line dropped from C2 to the posterosuperior corner of C7

C2s: C2 slope, T1s: T1 slope, C7Us: C7 upper slope, C7Ls: C7 lower slope, CA: Cobb angle, SVA: sagittal vertical axis.

https://doi.org/10.13004/kjnt.2020.16.e18

vertical axis (SVA). Due to the differences in C7Us, C7Ls, and T1s using XR images, visibility was evaluated as clear, unclear, or invisible.[27] A standing lateral XR image was obtained in a neutral position, with patients looking forward in an upright state with their knees and hips extended. Supine MR images were obtained in a comfortable supine position and only the basic pedestal provided by the manufacturer was used without any additional fixtures. All parameters were measured twice at different time points by one spinal surgeon. The mean value was used when comparing data from the 2 modalities.

Statistical analysis

All statistical analyses were performed using SPSS 21 (SPSS Inc., Chicago, IL, USA). Statistical analysis was performed in 4 steps to evaluate the agreement between XR and MR data. We used Koo and Li's method of interpretation of a 2-way random, single score intraclass correlation coefficient (ICC) (2,1); poor: <0.50, moderate: 0.5–0.75, good: 0.75–0.90, and excellent: >0.9.[14]

Step 1: determine the reliability between repeated measurements by a single rater: ICC (absolute agreement); ICC (XR measurement 1, measurement 2); and ICC (MR measurement 1, measurement 2).

Step 2: determine the relationship between MR and XR: Pearson's correlations (MR, XR); paired t-tests (MR, XR); and ICCs (MR, XR). Using regression analysis between MR and XR measurements, MR data were converted to expected MR data (MR-E) (**FIGURE 1**).

Step 3: determine the relationship between MR-E and XR: Pearson's correlations (MR-E, XR); paired t-tests (MR-E, XR); and ICCs (MR-E, XR).

Step 4: calculate the replacement ratio: In this step, we calculated the difference between MR-E and XR measurements and determined that MR-Es could replace XRs when the measurement differences were <2 mm or 2°. In generally, below 2 mm or 2° were assumed as a tolerance range of measurement error, so we set as a replacement range.[4] When the difference of XR and MR-E measurements were included within this replacement range, we categorized it is as a replaceable, and the ratio of replaceable was calculated (replacement ratio).

RESULTS

The visibility of C7Us, C7Ls, and T1s were as follows: C7Us (clear: 95.5%, unclear: 4.5%, invisible: 0%); C7Ls (clear: 73.5%, unclear: 25.7%, invisible: 0.7%); and T1s (clear: 29.1%, unclear: 47.4%, invisible: 23.5%). Invisible cases were excluded from the analyses.

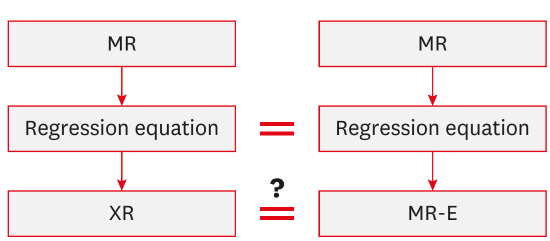

FIGURE 1. Schematic diagram of statistical analyses.
XR: X-ray, MR: magnetic resonance, MR-E: magnetic resonance-expected value.

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TABLE 2. Reliability between repeated measurements by a single rater

Parameter	ICC (XR1, XR2)		ICC (MR1, MR2)	
C2s	0.961	Excellent	0.904	Excellent
T1s	0.823	Good	0.911	Excellent
C1–2	0.903	Excellent	0.833	Good
CA	0.960	Excellent	0.954	Excellent
SVA	0.993	Excellent	0.953	Excellent

CA: Cobb angle, SVA: sagittal vertical axis, ICC: intraclass correlation coefficient, XR: X-ray, XR1: 1st time measurement XR data by single rater, XR2: 2nd time measurement XR data by single rater, MR: magnetic resonance, MR1: 1st time measurement MR data by single rater, MR2: 2nd time measurement MR data by single rater, C2s: C2 slope, T1s: T1 slope.

Reliability between repeated measurements by a single rater

A single rater performed repeated measures for cervical parameters using both XR and MR images. The results of ICC (2,1) of an absolute agreement using a single measure are summarized in **TABLE 2**. The results showed that nearly all parameters were in excellent agreement except T1s in XRs (good) and C1–2s in MRs (good).

Relationship between MR and XR images

The results of paired *t*-tests between XR and MR images showed that all parameters showed statistically significant differences between the 2 modalities, but C7Us was not statistically different from MR T1s (**TABLE 3**). Pearson's correlation analyses between XR and MR measurements were performed and all parameters showed significant correlations (**TABLE 4**). However, **TABLE 5** shows that ICC (XR, MR) was poor for C2s and SVA and moderate for T1s, C1–2, and CA. We also calculated the regression equation used to convert MR to XR by simple linear regression analysis: XR=(a*MR)+b (**TABLE 4**). Using these regression equations, we converted MR data into MR-E: MR-E=(a*MR)+b.

Relationship between MR-E and XR

Compared with MR data, MR-E data showed a similar mean value with XR data for all parameters (**TABLE 3**). The regression line between MR-E and XR also showed higher

TABLE 3. Difference between cervical parameters according to modality

Parameter	XR	MR	*p*-value (XR vs. MR)	MR-E	*p*-value (XR vs. MR-E)
C2s	9.82±8.29	14.41±7.44	<0.001	9.82±4.00	0.998
C7Us	20.49±7.20	20.91±7.00	0.254	20.48±4.61	0.979
C7Ls	22.03±7.57	20.95±6.98	0.004	22.02±4.95	0.992
T1s	24.04±7.14	20.68±6.99	<0.001	24.04±4.67	0.999
C1–2	27.51±6.26	26.26±6.58	<0.001	27.50±3.86	0.964
CA	11.84±10.15	5.19±10.86	<0.001	11.84±6.62	0.998
SVA	19.57±10.55	16.84±6.34	<0.001	19.58±4.51	0.986

CA: Cobb angle, SVA: sagittal vertical axis, ICC: intraclass correlation coefficient, XR: X-ray, MR: magnetic resonance, C2s: C2 slope, T1s: T1 slope, C7Us: C7 upper slope, C7Ls: C7 lower slope, MR-E: magnetic resonance-expected value.

TABLE 4. Correlation analysis between XR and MR

Parameter		XR vs. MR		Regression equation (XR=(a*MR)+b)	XR vs. MR-E	
		r	*p*-value		r	*p*-value
C2s		0.482	<0.001	=0.537*MR+2.08	0.482	<0.001
C7Us	T1s	0.640	<0.001	=0.658*MR+6.72	0.640	<0.001
C7Ls		0.654	<0.001	=0.709*MR+7.17	0.654	<0.001
T1s		0.654	<0.001	=0.668*MR+10.23	0.654	<0.001
C1–2		0.618	<0.001	=0.587*MR+12.08	0.618	<0.001
CA		0.652	<0.001	=0.610*MR+8.67	0.652	<0.001
SVA		0.427	<0.001	=0.711*MR+7.60	0.427	<0.001

CA: Cobb angle, SVA: sagittal vertical axis, XR: X-ray, MR: magnetic resonance, C2s: C2 slope, T1s: T1 slope, C7Us: C7 upper slope, C7Ls: C7 lower slope, MR-E: magnetic resonance-expected value.

https://doi.org/10.13004/kjnt.2020.16.e18

TABLE 5. The agreement between cervical parameters according to modality

Parameter		ICC (XR, MR)	ICC (XR, MR-E)
C2s		0.648	0.548
C7Us	T1s	0.780	0.735
C7Ls		0.789	0.749
T1s		0.790	0.749
C1–2		0.763	0.712
CA		0.788	0.748
SVA		0.547	0.471

CA: Cobb angle, SVA: sagittal vertical axis, ICC: intraclass correlation coefficient, XR: X-ray, MR: magnetic resonance, C2s: C2 slope, T1s: T1 slope, C7Us: C7 upper slope, C7Ls: C7 lower slope, MR-E: magnetic resonance-expected value.

similarity to the XR line than the regression line between MRs and XRs (**FIGURE 2**). However, this conversion did not affect Pearson's correlation (MR-E, XR) (**TABLE 4**) and ICC (MR-E, XR) results from ICC (MR, XR) (**TABLE 5**).

Replacement ratio

The replacement ratio was: CA, 20.3%; C7Us, 26.5%; C7Ls, 29.9%; T1s, 27.1%; SVA, 17.6%; C1–2, 29.7%; and C2s, 16.0% (**FIGURE 2**).

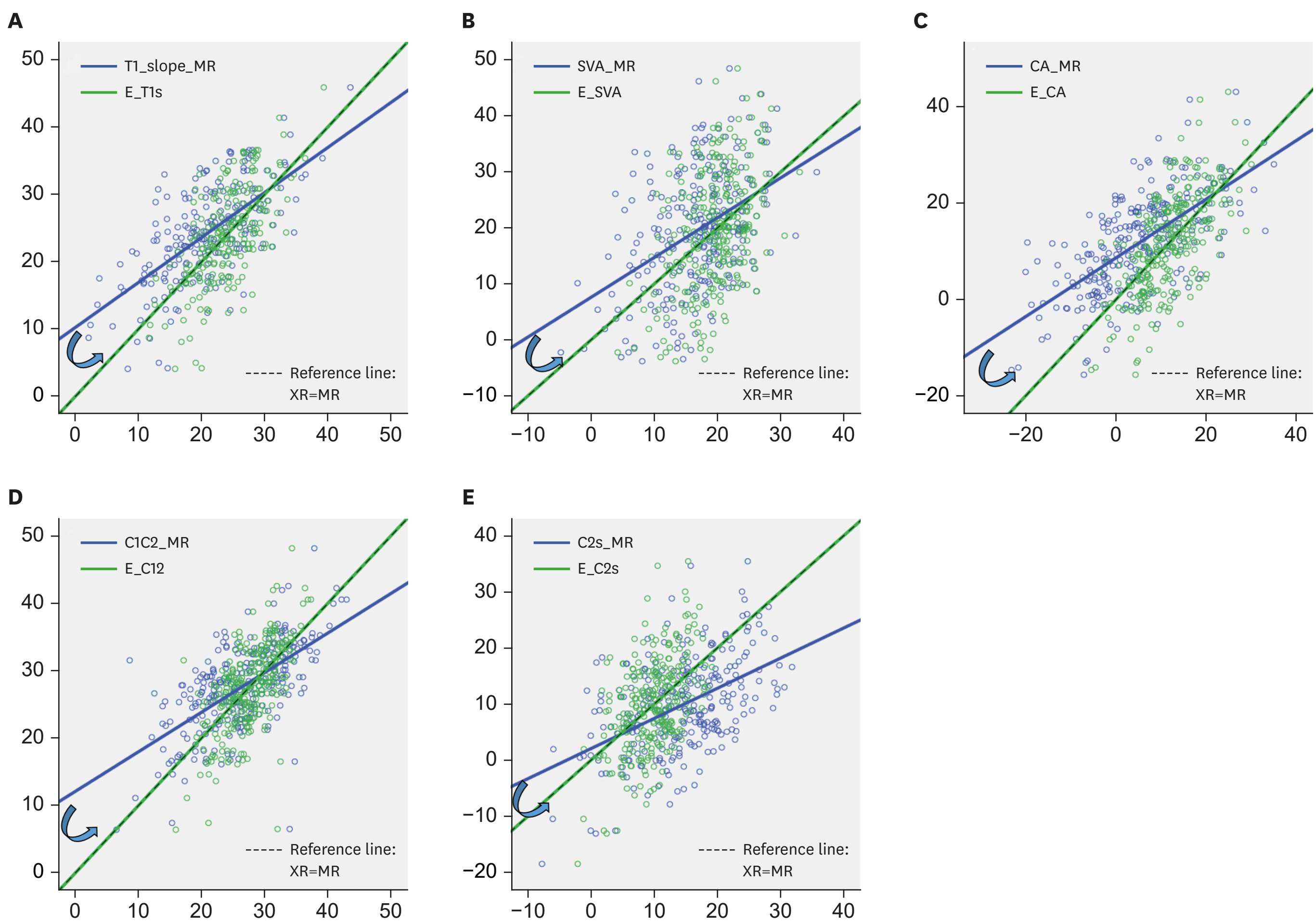

FIGURE 2. Linear regression analysis of the effect of converting MR to MR-E. The dotted line indicates MR value equal to XR value, blue line indicates regression line between MR and XR, green line indicates regression line between MR-E and XR. (A) T1s, (B) CA, (C) SVA, (D) C1–2, (E) C2s.
XR: X-ray, MR: magnetic resonance, MR-E: magnetic resonance-expected value, CA: Cobb angle, C2s: C2 slope, SVA: sagittal vertical axis, T1s: T1 slope.

https://doi.org/10.13004/kjnt.2020.16.e18

DISCUSSION

Previous studies have reported the link between cervical sagittal malalignment and disability and an unfavorable health related quality-of-life (HRQOL).[5-7] Malalignment was related to increased energy expenditure and painful compensatory alignment changes to maintain a horizontal gaze and upright posture.[2,3,12,21] Common parameters used to define sagittal alignment include the SVA, C2–7 CA, T1s, and T1s minus CA (T1s−CA).

SVA is an important parameter for evaluating sagittal imbalance in cervical deformities.[1] In addition, SVA is the most studied parameter for its relevance to HRQOL.[6,7,9,18,25] T1s−CA is another parameter used to evaluate sagittal imbalance in cervical deformities,[1] and Hyun et al.,[8] reported that this parameter was related with the Neck Disability Index (NDI). However T1s−CA also includes T1s measurements, and has a limitation of poor accuracy. However T1s−CA could be arithmetically replaced with C2s.

The importance of T1s has recently been emphasized in cervical sagittal balance. T1s strongly correlated with SVA,[13] CA,[28] thoracic kyphosis, and the thoracic inlet angle.[16] In addition, a high T1s was related to degenerative cervical spondylolisthesis.[10] Clinically, there have been reports regarding the relationship between T1s and EQ-5D[22] or NDI.[9] Furthermore, T1s is also important as a predictor of radiological outcome after surgery. A high T1s was related to postoperative kyphotic changes after laminoplasty[11] and loss of correction in adult spinal deformity surgery.[23] Despite the importance of T1s, it has poor measurement accuracy due to anatomical interference[20] and the reproducibility of the measurement is also low.[24,26] Previous studies reported only 11% had a clear boundary in XR images.

In light of these issues, some have suggested replacing the T1s measurement. Tamai et al.,[27] suggested that the T1s can be replaced with C7s using sitting kinematic MR images.[27] However, if there is segmental kyphosis at C7/T1, C7s cannot be substituted for T1s. Liu et al.,[20] suggest that the correlation between MR and XR measurements is very high and that replacement is possible by predicting MR (MR-E) through a regression equation.[20] However, this analysis was insufficient to evaluate the possibility of replacement.

In the current study, we found that MR measurements had the advantage of relatively clear anatomical boundaries with measurement reliability being higher than XR measurements. However, MR is measured in a supine position, which reduces the CA, the T1s, and the SVA when compared to a standing position (**TABLE 3**). Converting to MR-E had the effect of creating a regression line more similar to the reference line (**FIGURE 2**), with the mean of MR-E being similar to the mean XR value (**TABLE 3**). However, this conversion did not reduce the deviation between XR and MR measurements in each patient. As shown in **FIGURE 2**, the regression line between MR-E and XR is more similar to the reference line (XR=MR) than the regression line between MR and XR. However, when compared to the deviation between MR and XR, the deviation between MR-E and XR was not significantly changed (**FIGURE 3**). When we applied the 2 mm deviation line, we found that most of the data had a deviation > than 2 mm. Only 20–30% of the variables were within 2 mm or 2°. In addition, ICC (MR-E, XR) showed the same or slightly reduced results compared to ICC (MR, XR).

This study confirmed that supine MR measurements cannot replace upright XR measurements; however, there were some limitations in our study. First, we targeted a population cohort in their 60s, and there was selection bias for patients who underwent

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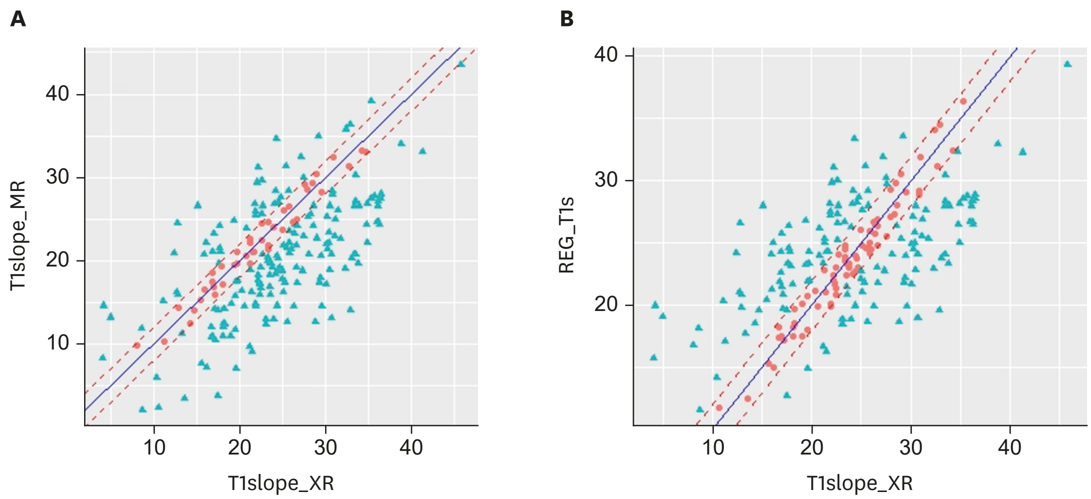

FIGURE 3. Replacement ratio for T1s. (A) Blue line indicates regression line between MR and XR, and the red dotted line indicates MR value equal to XR±2°. (B) Blue line indicates regression line between MR-E and XR, and the red dotted line indicates MR-E value equal to XR±2°.
MR: magnetic resonance, MR-E: magnetic resonance-expected value, T1s: T1 slope, XR: X-ray.

imaging tests because of cervical spine related symptoms not healthy volunteers. Secondly, we only identified factors that were not consistent between supine and upright positions. However, literature reviews have confirmed that there are no radiographic factors or methods that can be used to allow for the interchange of supine and upright positions. In the future, new technologies such as EOS-technology (EOS imaging, Paris, France) and kinematic MR images might be able to overcome these limitations.

CONCLUSION

Our results show that MR and XR measurements are highly correlated, but agreement between the 2 modalities was very low. Conversion to MR-E to reduce differences in paired *t*-tests did not affect the correlation and reliability tests. We also found that the replacement rates were low. These results indicate that supine MR measurements could not replace upright XR measurements.

ACKNOWLEDGMENTS

We would like to thank Editage (www.editage.co.kr) for English language editing.
This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2018R1C1B5045855).

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