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Analysis of Correlation Between Age and Cervical Facet Joint Degeneration and Modic Changes in Patients with Cervical Spondylotic Myelopathy

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Background: Because facet joints move with the disc, changes in vertebral bodies occur simultaneously with progression of degeneration of cervical facet joints. This study investigated age-related differences in cervical facet joint abnormalities and multi-dimensional characteristics of MCs in patients with cervical spondylotic myelopathy.

Material/Methods: Forty-five patients underwent both magnetic resonance imaging (MRI) and computed tomography (CT) of the cervical spine. Axial and sagittal parameter changes from C3 to C7, including facet orientation (FO) and facet tropism (FT), and Modic changes (MCs), were evaluated and documented preoperatively, and we also measured the heights and diameters of MCs and performed correlation analysis and established linear regression models.

Results: The axial facet orientation increased slightly from C3 66.5 (11.4) to C7 89.9 (19). The sagittal facet orientation and facet tropism increased between C3–C4 and C6–C7, but it decreased between C4 to C6. The MCs volume decreased from C3 to C4 and increased from C4 to C7. There was a gradual decrease of FO and FT from C3 to C5 and a gradual increase of these 2 angles from C5 to C7 in all age groups. The lowest values of FO and FT were detected at C5, while the highest values of FO and FT were detected at C7.

Conclusions: Age was negatively correlated with the axial, sagittal, and coronal cervical facet orientation, especially at C4/5 level. The FT with respect to the axial and sagittal plane from C5 to C6 increased with age.

MeSH Keywords: **Cervical Atlas • Cervical Length Measurement • Neck Dissection**

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Background

Degenerative cervical spine changes are common on radiographs in both symptomatic and asymptomatic adults [1]. Cervical facet joints, which are the sole contact between vertebrae, work in pairs to drive cervical morphology by affecting stability and mobility. The cervical facet joints constrain the shear movement of the vertebra while aiding in torsional stiffness [2]. FO and FT are significant structural factors expediting the degenerative changes in facet joints and adjacent intervertebral discs [3].

Modic changes (MCs) refer to the endplate signal intensity changes and bone marrow regions on magnetic resonance imaging (MRI) [4]. Several studies have reported the pathobiology, prevalence, risk factors, and pain are associated with MCs in the cervical spine, focusing on identifying the risk factors of MCs [5].

Cervical facet joints are three-dimensional structures, but few studies have assessed facet orientation in the axial plane and coronal plane using CT and MRI [6,7], and whereas whether FO in three-dimensional analysis varies with the passage of time. The aim of this study was to elucidate the association between MCs and cervical FO in the axial and sagittal planes in different age groups and to compare cervical FO with the changes in MCs dimensions.

Accumulating studies have investigated the relationship between the severity of CSM and vertebral disc degeneration [8,9], but the mechanism underlying the facet joint and vertebral body dimension – MCs degeneration-mediated cervical spondylotic myelopathy – is unclear. Within the spine, FO and MCs are 2 significant factors affecting cervical alignment [10]. The FO and MCs have been reported to change during the progression of cervical degeneration [11–13]. Park et al. [14] found no association between cervical facet joint degeneration and the presence of MCs at the corresponding level. Hayashi et al. [15] reported that less angular motion and disc degeneration were significantly more likely to be detected in cervical vertebra with MCs, indicating that MCs are associated with loss of mobility.

Given that the endplate-discs move simultaneously with facet joints, we hypothesized that there is an association between MCs detected on MRI images and facet joint degeneration seen on CT scans. Therefore, the present study assessed changes in cervical facet orientation in the axial and sagittal planes according to age and cervical alignment, and compared it with the changes in MCs dimensions.

Material and Methods

Study population

Our retrospective study was approved by the Institutional Ethics Committee of the Affiliated People's Hospital of Jiangsu University. Patients who underwent neck MRI or lateral radiograph were enrolled for investigation. We retrospectively reviewed the records of 45 patients (39 males and 6 females) with cervical spondylotic myelopathy between December 2013 and March 2018 in our hospital.

Measurement method of MCs diameter and MCs volume

All patients underwent MRI examination in supine position with the head immobilized. A senior radiologist and a spine surgeon performed measurements on the picture archiving and communication system (PACS) at our institution. Sagittal images of the cervical spine (from C3 to C7) were acquired for assessments. Using a method validated by Wang et al. [16], dimensions of MCs were characterized by the area, transverse diameter, anteroposterior (AP) diameter, height of Modic changes region (MCs Height), and vertebral body diameter (MCs Diameter) measured on T2-weighted images. The anteroposterior diameter of MCs was calculated as the ratio of anteroposterior MCs diameter to the anteroposterior vertebral diameter.

The MCs heights were evaluated as the ratio of MCs height to the vertebral body height. Assuming that the MCs were cylinders, the MCs volume (MCs Vol) were evaluated with the formula:

$$MCs\ Vol = \pi * MC \frac{Diameter^2}{4} * MCs\ Height$$

Measurement method of facet orientation in axial (A) and sagittal (B) views

In axial view (A), axial FO was defined as the angle between the line drawn though the margins of the facet joint and midline of the vertebra. The sagittal FO (B) was measured using the method described by Pesenti et al. [17]. The sagittal FO was defined as the angle between the line perpendicular to the posterior vertebral wall and the superior facet. The superior facet was selected for its superiority in straighter facet joint. Vertical orientation was considered to be parallel to the posterior wall, and horizontal orientation was considered to be perpendicular to the posterior wall (Figure 1A–1C).

Statistical analysis

We performed statistical analyses with SPSS (version 21 IBM). All data are expressed as the mean (standard deviation). Two independent observers measured radiographic parameters

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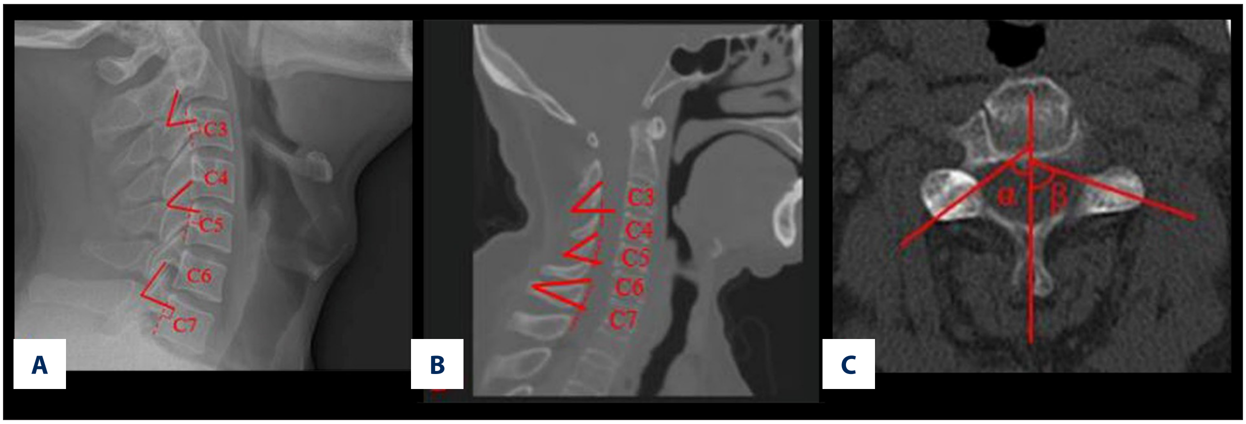

Figure 1. Schematic representation of facet orientation in sagittal (**A, B**) and axial (**C**) views.

independently. Statistical relationships between radiographic parameters and age were identified with the Pearson method. We performed stratification by age groups of 10 years. A repeated mixed-measure method was performed to analyze differences in cervical level with the facet orientation. Analysis of variance (ANOVA) was used to compare differences between age groups. P-values below 0.05 was considered statistically significant.

Results

Study population

After application of inclusion criteria, 39 males and 6 females were enrolled.

Facet orientation and MCs dimension & cervical level

The mean axial FO in each cervical level was 66.5 (11.4), 83.9 (11.7), 86.3 (18.1), 91.6 (16), and 89.9 (19). The mean sagittal FO in each cervical level was 48.9 (5.6), 49.5 (6.1), 46.2 (5.6), 50.4 (5. 3), and 57.8 (5.3). The mean MCs volume in each cervical level was 378.2 (337.5), 338.4 (269.6), 526.6 (519.1), 529.9 (368.5), and 583.9 (351.5) (Table 1, Figure 2).

Facet orientation and MCs dimension and age

There was a gradual decrease in facet orientation and facet tropism between C3 and C5 and a gradual increase of these 2 angles from C5 to C7. The lowest values of facet orientation and facet tropism were detected at C5, while the highest values of facet orientation and facet tropism were detected at C7. However, no significantly difference between the 5 age groups was found ($p>0.05$). Further, MCs volume decreased significantly with age (Table 2, Figure 3).

Discussion

To the best our knowledge, this is the first investigation to assess the relationship between MCs and axial and sagittal facet orientation based on age and sex using MRI data. Unlike the method described by Ogden et al., we measured anatomic FO independent of head position or cervical lordosis by taking the posterior wall as a reference based on Pesenti's method [17]. Moreover, the present study verifies that age and sex are associated with differences between subaxial cervical levels. In addition, we found that dimensions of MCs are associated with the severity of cervical facet joint degeneration.

The association between FO being and MCs dimensions was another finding of this study. The cervical facet joints were observed to become more vertical as the dimensions of the MCs increased. This result could be explained by the fact that high pressure at both the vertebral bodies and facet joints can increase the MCs dimensions. The MCs dimensions was significantly associated with facet joint degeneration, suggesting that MCs are risk factors for facet joint degeneration. This result was in accordance with the conclusion of a previous study, linking macroscopic and microscopic grades of disc degeneration with the size of cadaveric endplate defects [18]. Cervical facet joints, located between adjacent neural arches, are the only osseous contact bearing nontrivial loads when the neck undergoes flexion-extension and torsion [19]. Postural position changes can cause stress concentration [20]. Our results show that Modic changes lead to non-homogeneous stress concentration and a majority of of the stress pass through the neural arch, affecting the cervical facet joints. Larger dimensions of the Modic changes region are associated with stronger connection.

As facet joints are three-dimensional structures, our findings confirm that FO was associated with age in the axial and sagittal plane. Being independent of head position or cervical curvature, the posterior wall was taken as a reference for FO in our study. Different from previous measurement methods,

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Table 1. Correlation analysis of cervical parameter and age stratified by cervical level.

	C3	C4	C5	C6	C7
Axial facet orientation					
Mean and SD (deg)	66.5 (11.4)	83.9 (11.7)	86.3 (18.1)	91.6 (16)	89.9 (19)
Range (deg)	44.3~93.9	53.7~108.7	48.5~123.2	81.3~126.7	61.2~120.9
Correlation with age	0.251	–0.051	0.063	0.19	0.21
P value	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05
Sagittal facet orientation					
Mean and SD (deg)	48.9 (5.6)	49.5 (6.1)	46.2 (5.6)	50.4 (5. 3)	57.8 (5.3)
Range (deg)	36.9~55.2	36.9~63.7	36.6~58.6	37.5~59.9	48~70.6
Correlation with age	–0.101	–0.203	–0.105	0.03	–0.084
P value	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05
MCs volume					
Mean and SD (mm³)	378.2 (337.5)	338.4 (269.6)	526.6 (519.1)	529.9 (368.5)	583.9 (351.5)
Range (mm³)	23.1~927.5	46.5~787.9	92.2~1909.8	146.2~1109.9	195.2~1376.8
Correlation with age	–0.065	–0.392	–0.21	–0.753	–0.295
P value	P>0.05	P<0.008*	P>0.05	P>0.05	P=0.049*

SD – standard deviation; deg – degree; MCs – Modic changes.

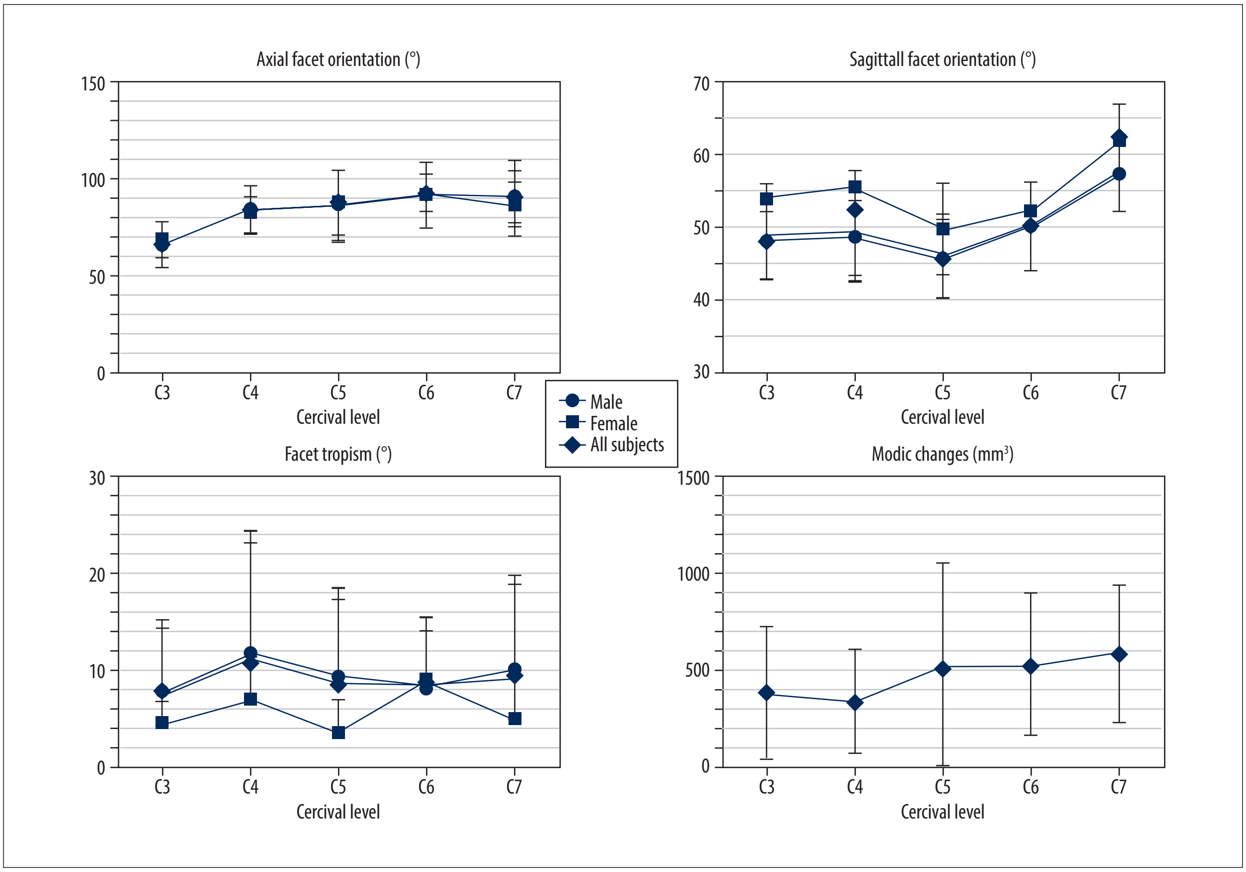

Figure 2. Cervical parameters based on cervical level.

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Table 2. Axial facet orientation, sagittal facet orientation, and MCs dimensions stratified by age group.

	No. of patients	C3	C4	C5	C6	C7
Axial facet orientation (deg)						
30 to 40 yr	3	61.1 (5.7)	93.0 (11.5)	83.6 (19.5)	95.9 (7.4)	85.0 (9.7)
40 to 50 yr	14	62.2 (10.7)	82.5 (14.1)	85.8 (22.9)	85.6 (13.0)	86.9 (10.5)
50 to 60 yr	11	66.7 (7.9)	83.8 (12.3)	79.3 (13.0)	89.8 (15.0)	87.2 (12.9)
60 to 70 yr	12	72.5 (12.1)	83.9 (7.8)	90.5 (13.9)	96.4 (17.3)	95.6 (13.9)
70 to 80 yr	5	62.1 (18.5)	78.6 (22.1)	81.0 (24.8)	85.7 (25.5)	83.9 (24.3)
Sagittal facet orientation (deg)						
30 to 40 yr	3	52.1 (2.2)	51.1 (4.0)	46.8 (5.5)	52.7 (7.5)	59.7 (4.3)
40 to 50 yr	14	48.4 (5.0)	51.3 (7.1)	47.6 (7.8)	50.5 (4.3)	59.4 (5.8)
50 to 60 yr	11	48.9 (5.8)	49.0 (4.7)	45.2 (6.7)	48.9 (3.9)	55.4 (4.4)
60 to 70 yr	12	48.7 (6.5)	46.9 (5.9)	45.8 (5.8)	49.6 (5.8)	57.4 (5.7)
70 to 80 yr	5	48.7 (5.8)	50.7 (5.3)	45.2 (2.7)	53.9 (5.8)	65.3 (2.4)
MCs volume (mm3)						
30 to 40 yr	3	299.1 (/)	0 (/)	1909.8 (/)	708.3 (401.6)	1376.8 (/)
40 to 50 yr	14	244.1 (301.6)	360.9 (291.9)	258.3 (134.7)	212.2 (/)	487.4 (/)
50 to 60 yr	11	405.3 (372.3)	271 (170.7)	415.1 (177.7)	566.4 (381.8)	351.8 (147.4)
60 to 70 yr	12	778.5 (/)	0 (/)	205.5 (/)	0 (/)	0 (/)
70 to 80 yr	5	0 (/)	0 (/)	604 (/)	381 (/)	0 (/)

SD – standard deviation; deg – degree; MCs – Modic changes.

FO in sagittal plane was independent of variation of cervical lordosis and was an anatomic parameter [21]. To the best of our knowledge, this is the first study to investigate the pattern of change in patients of various ages within the entire subaxial cervical spine.

Previous studies have showed that axial cervical facet joints are more sagittally orientated [22]. However, there remains a need for further exploration of sagittal facet orientation. Rong et al. [23] reported that cervical FO was associated with spinal movements, but they did not assess the relationship between age, sex, and cervical facet orientation. Independent of age, we revealed that the subaxial cervical facet at each level showed the most vertical orientation. It is generally accepted that the rotation movements are dominated by the axial cervical spine, whereas the flexion-extension is dominated by the subaxial spine [24]. The shallowness of C3 facet joints determines mobility between 2 vertebral bodies, and vertical facets restrain the translation of the axial spine over C3. C7, which is the transition between the cervical spine and thoracic spine, was the vertebra with the most vertical facets, as in the thoracic spine.

Axial, sagittal, and coronal orientation of the subaxial cervical spine was reported to change from level to level [24]. The present study shows that the variation of facet orientation is associated with MCs dimensions at different cervical levels. Higher mobility of C3 and C7 is associated with greater stress on the articular surface and vertebral body, showing higher pressure on vertebral bodies and facet joints. This suggests that, with regard to the FO, FT predisposes to the progression of MCs dimensions, especially C3 and C7.

Prior work has demonstrated the value of cervical facet orientation in different cervical level [25] and reported the relationship between FO, facet joint degeneration, and MCs [26]. Zehra [18], for example, reported that facet joint abnormalities are associated with larger endplate defect dimensions. Rong et al. [23] assessed the association between cervical FO and spinal movements, but no previous study has assessed the association with patient age.

As a person ages, the facet joints have thinner articular cartilage and increased laxity of the capsular ligaments and eroded

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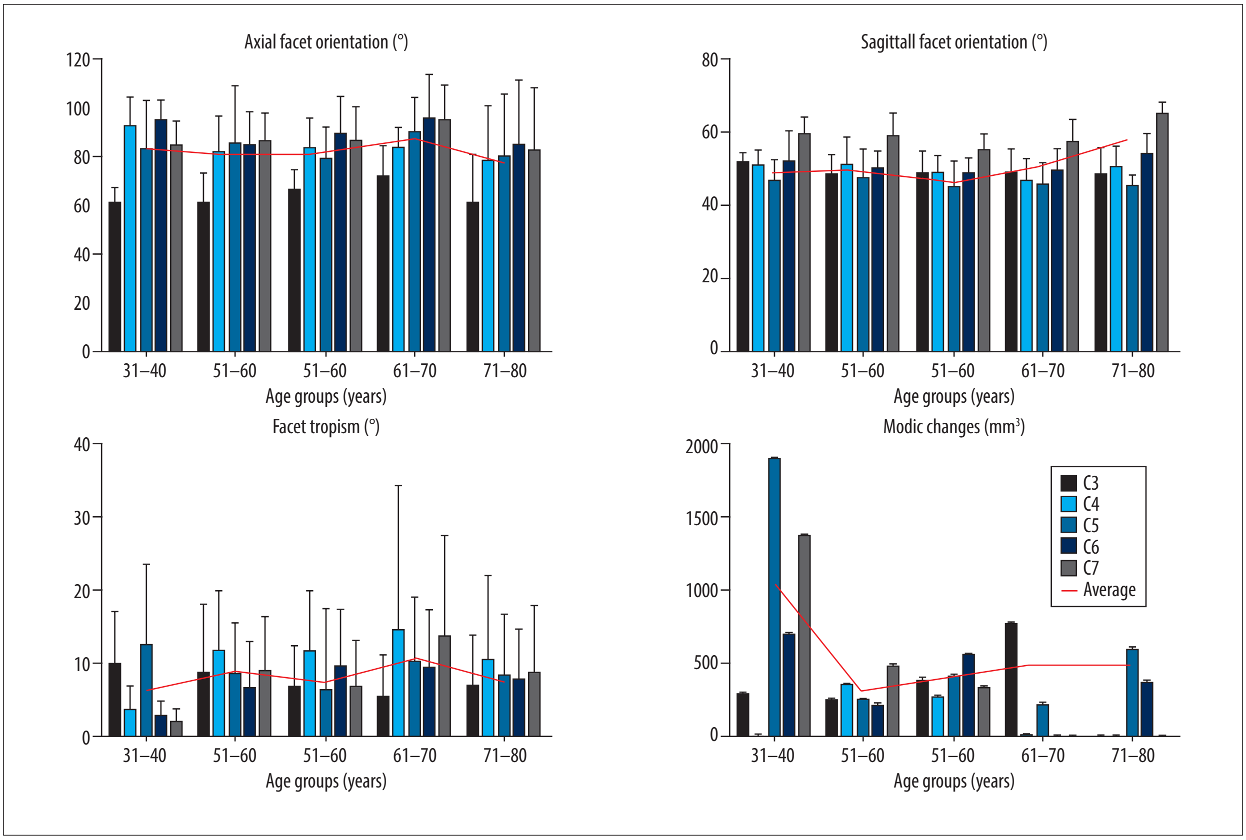

Figure 3. Mean value of FO in the axial and sagittal plane, vertebral body (VB) diameter, and MCs volume after stratification by age groups.

subchondral bone [27]. The radiographic changes are characterized by narrowed joint space, progression of osteophytes, and sclerosis of the subchondral bone [28]. It was reported that abnormal motion or loading pattern can lead to initiation or acceleration of the progression of facet degeneration [29]. The present study demonstrated that vertebral contact force is greater in individuals with facet tropism, especially flexion-extension movement. The increased loading on the vertebra-endplate contact can cause micro-injury to the cervical facet joints [30]. The cumulative effect of micro-injury can initiate or accelerate the cervical degenerative process. These results suggest that larger MCs are a predisposing factor for facet degeneration, but this requires verification by further clinical observations.

The moderate association between age and FO shows that other factors can change facet morphology. Several hypotheses have been formulated to explain changes in FO. Yeh et al. [31] demonstrated that variation of sagittal spinopelvic parameters was correlated with patient age. Arshad et al. [32] found that the age-dependent reduction in lumbar lordosis and the range of motion was non-monotonic and differed between men and women. Jaumard et al. [2] demonstrated that pressure on cervical facet joints increases with extension. Cervical extension causes increased pressure on facets and can change facet orientation. We suggest that loss of lumbar lordosis is responsible for the changed pattern of cervical facet orientation and that postural changes rather than aging influence cervical FO.

Our study has several limitations. First, our estimation of the MCs volume was imprecise, as our aim was only to assess the association between MCs dimensions and cervical facet orientation. Second, the CT and MRI images were not controlled by standard protocols for assessing retrospective bias. Third, the heads of patients were not in absolutely neutral positions, and this may have reduced the precision of our results.

Conclusions

This study is the first to investigate changes in FO and FT according to MRI data and using a measurement method that is not influenced by cervical curvature or head position. Our results showed that cervical facets became more vertical as a function of age. At each end of the cervical spine, C5 is associated with increased mobility and flexion-extension range of motion with the most horizontal facets. C3 and C7 may increase stability in the sagittal plane with more vertical facets.

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Conflicts of interest

None.

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