IMAST 2017

Thomas Whitecloud Basic Science Award Nominee

Paper #11

June 13th, 11:05 – 12:30

Moderators: Dr. Kenneth Cheung, Dr. Justin S Smith

"Changes in cervical facets orientation during child growth"

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Abstract

Introduction

During growth, the orientation of articular facets of the cervical spine increases progressively. The inclination of the cervical joints reinforces cervical spine stability, acting as a mechanical brake. To date, changes in facets orientation have never been clearly proved. Due to the mainly cartilaginous composition of the vertebrae in young children, the assessment of vertebral landmarks is challenging and can be misleading. The aim of this study was to demonstrate the increase of cervical facets orientation during growth based on an MRI study.

Methods

Based on the sagittal slices of cervical MRI of 90 children aged from 4 months to 18 years old, the facets orientation at each cervical vertebra was measured. This angle was defined as the angle between the superior facet and a perpendicular line to the posterior wall of the vertebral body.

Results

For each level from C3 to C7, there was a positive correlation between the facets orientation and age (R=0.497, IC95% [0.41; 0.57], $p<0.001$). The orientation angles were higher for C3 and C6 compared to other levels (43.5° and 47.8°, respectively). On the other hand, the orientation angle of C5 was lower.

Conclusion

This study confirms the correlation between age and increase of the cervical facets orientation. Differences were visible according to the vertebral level. At each end of the cervical spine, the higher values correspond to smaller mobility areas. The lower orientation at C5 corresponds to the maximum range of cervical flexion-extension. This particularity persists at adult age and can explain the frequency of trauma and degenerative diseases at this level.

Introduction

Cervical spine motion is complex and requires a compromise between stability and mobility. Optimal cervical stability allows protection of the spinal cord and is necessary in order to maintain horizontal gaze. On the other hand, cervical spine movements requires a high mobility of articular and ligamentous structures, under the action of strong muscles. Among articular structures, facet joints are the only bony contact existing between vertebras. So far, the exact biomechanical role of cervical facets remains unclear, even if it has been pointed out to be crucial [1,2].

During growth, the stability of the spine is reinforced by changes in several anatomical structures[3,4]. In addition to changes in overall dimensions, a change in sagittal orientation of the facet joints has been observed. Several authors report more shallow and horizontal facet joints in young children, becoming more and more vertical with growth [3–6]. This anatomical specificity is probably responsible for a more flexible cervical spine and can explain the increased frequency of spinal cord trauma in young children[5,6].

Initially, the changes in facet joint orientation were reported by Ogden from his observation of anatomical specimens [4]. This observation has been confirmed by Kasai *et al.* based on radiographic data, in addition to other changes such as vertebral body growth[3]. However, the radiographic measurements in children can be misleading because of the mainly cartilaginous nature of the vertebras at this age. In this particular condition, the use of magnetic resonance imaging (MRI) is useful and allows a better visualization of the cartilaginous structures.

Our main hypothesis was that there were significant changes in facet joints orientation with growth. Our second hypothesis was that changes were different according to the vertebral level and gender.

The aim of our study was, therefore, to evaluate changes in the sagittal orientation of cervical facet joints in a cohort of asymptomatic subjects, based on MRI images.

Methods

Study design

We conducted a single-center retrospective study after approval by the local ethics committee. We included subjects aged from 0 to 18 years old with MRI pictures of the cervical spine available on the picture archiving and communication system of our institution (Centricity Enterprise Web v3.0, GE Healthcare, Illinois, USA). Every child included in the study underwent MRI for the investigation of neurological disorders that was interpreted as normal by a senior radiologist. Children suffering from spine or cranio-cervical junction diseases were excluded from the study. Images were acquired using a 1.5 Tesla MRI. Measurements were performed on T1 flash 2D sagittal reconstructions.

Measurement method

For each vertebra from C3 to C6, the orientation of facet joints was measured. Because of its low availability on cerebral MRIs, the C7 facet joint was not assessed. The orientation angle (OA) was defined as the angle between the superior facet joint and a perpendicular line to the posterior wall of vertebral body (**Figure 1**). Measurements were performed on the 2 sagittal slices passing (1) through the center of the facet joint and (2) through the center of the vertebral body.

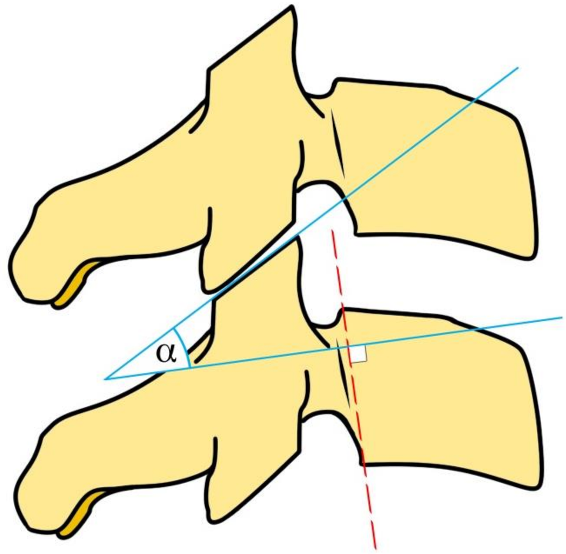

Figure 1 *- Measurement method for the orientation angle: angle between the superior facet joint and a perpendicular line to the posterior wall of vertebral body.*

Statistical analysis

Data were described as means, standard deviations and range. Before performing the statistical comparison, normality was tested using a Kolmogorov Smirnov test. If data was normally distributed, comparisons of means were performed using Student T-tests. If not, Kruskall-Wallis tests were used. ANOVA were used for multiple comparisons. Correlations were obtained using a Pearson correlation test. A first comparison was performed to analyze the correlation between age and orientation angle at each vertebral level. Then, stratifications by age (groups of 3 years) and gender were performed. The pattern of change was analyzed by performing linear regressions. A p-value under 0.05 was considered to be statistically significant.

Results

Ninety children were included in this retrospective study. There were 45 boys and 45 girls. The mean age was 8.8 years old (±5.2, from 4 months to 18 years old).

Orientation angle according to the cervical level

The mean values of the OA for each level are presented in **Table 1**. The lowest values were observed for C5 whereas the greatest ones were observed for C3 and C6. Statistical comparison of orientation angle at each level is summarized in **Table 2**.

Level	**Orientation angle**	***Min-Max***	***SD***	**Correlation coefficient**	***p***
C3	43.5°	*19-71*	*10.7*	0.661	*<0.001*
C4	40.8°	*11-73*	*11.3*	0.514	*<0.001*
C5	39.3°	*14-68*	*10.9*	0.512	*<0.001*
C6	42.2°	*21-65*	*11.5*	0.527	*<0.001*

Table 1 – *Mean values of the orientation angle of the facet joints, at each cervical level.*

	C3	**C4**	**C5**	**C6**
C3	-	-	-	-
C4	0,12	-	-	-
C5	**0,01**	0,38	-	-
C6	0,44	0,49	0,13	-

Table 2 – *Statistical comparison of orientation angle at each cervical level.*

Results from the correlation analysis are presented in **Table 1**. Significant correlations were found between age and the orientation angle for each vertebral level, meaning that a progressive increase of the orientation angle existed with growth.

Stratification by age

Stratification by age was performed. Patients were grouped by increments of 3 years and 6 groups were formed (0-3, 3-6, 6-9, 9-12, 12-15 and 15-18) (**Table 3 and Figure 2**). At each level, the mean values of the orientation angle increased across age groups (*all p<0.01*).

Cervical level	**Age groups**						***p-value****
	0-3 (n=14) Mean *(SD)*	**3-6** (n=16) Mean *(SD)*	**6-9** (n=17) Mean *(SD)*	**9-12** (n=14) Mean *(SD)*	**12-15** (n=15) Mean *(SD)*	**15-18** (n=14) Mean *(SD)*	
C3	34.7° *(7.3)*	37.7° *(9.3)*	40° *(8.6)*	44.9° *(4.9)*	51.4° *(10.9)*	53.3° *(4.5)*	*<0.001*
C4	31.3° *(8.7)*	34.5° *(11)*	43.1° *(13.1)*	41.9° *(8.7)*	47.6° *(3.8)*	48° *(4.4)*	*<0.001*
C5	30.3° *(8.9)*	32.9° *(8.1)*	39.4° *(13.1)*	44.4° *(8.3)*	47° *(7)*	46.6° *(7.1)*	*<0.001*
C6	34.1° *(9.5)*	37.1° *(8.1)*	42.1° *(13.9)*	46.2° *(6.9)*	52.6° *(7.3)*	53.2° *(6.5)*	*<0.001*

Table 3 *– Mean values of the orientation angle at each cervical level for different age groups. *Results of the statistical comparison at each level across age groups (ANOVA).*

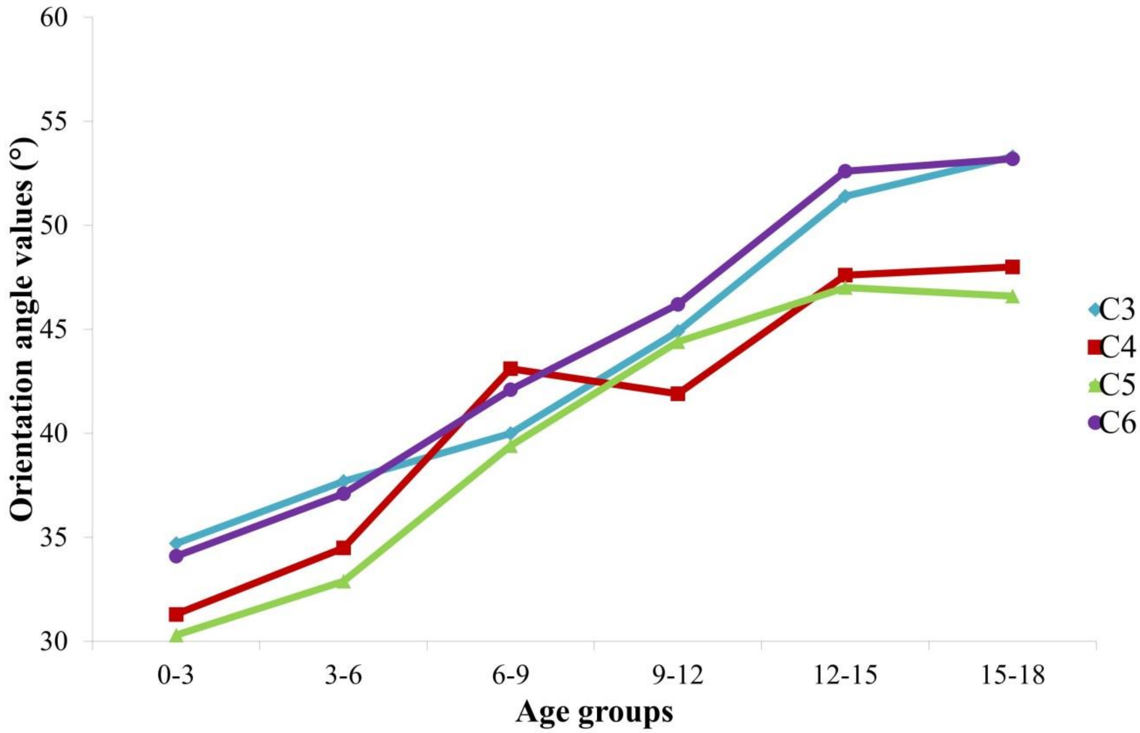

***Figure 2** – Orientation angle at each cervical level according to age groups.*

Stratification by gender

Comparisons of the mean values regarding gender are presented in **Figure 3**. Overall, the mean values of the orientation angle were generally greater in boys but without statistical significance, except between 6 and 12 years old at C3 level.

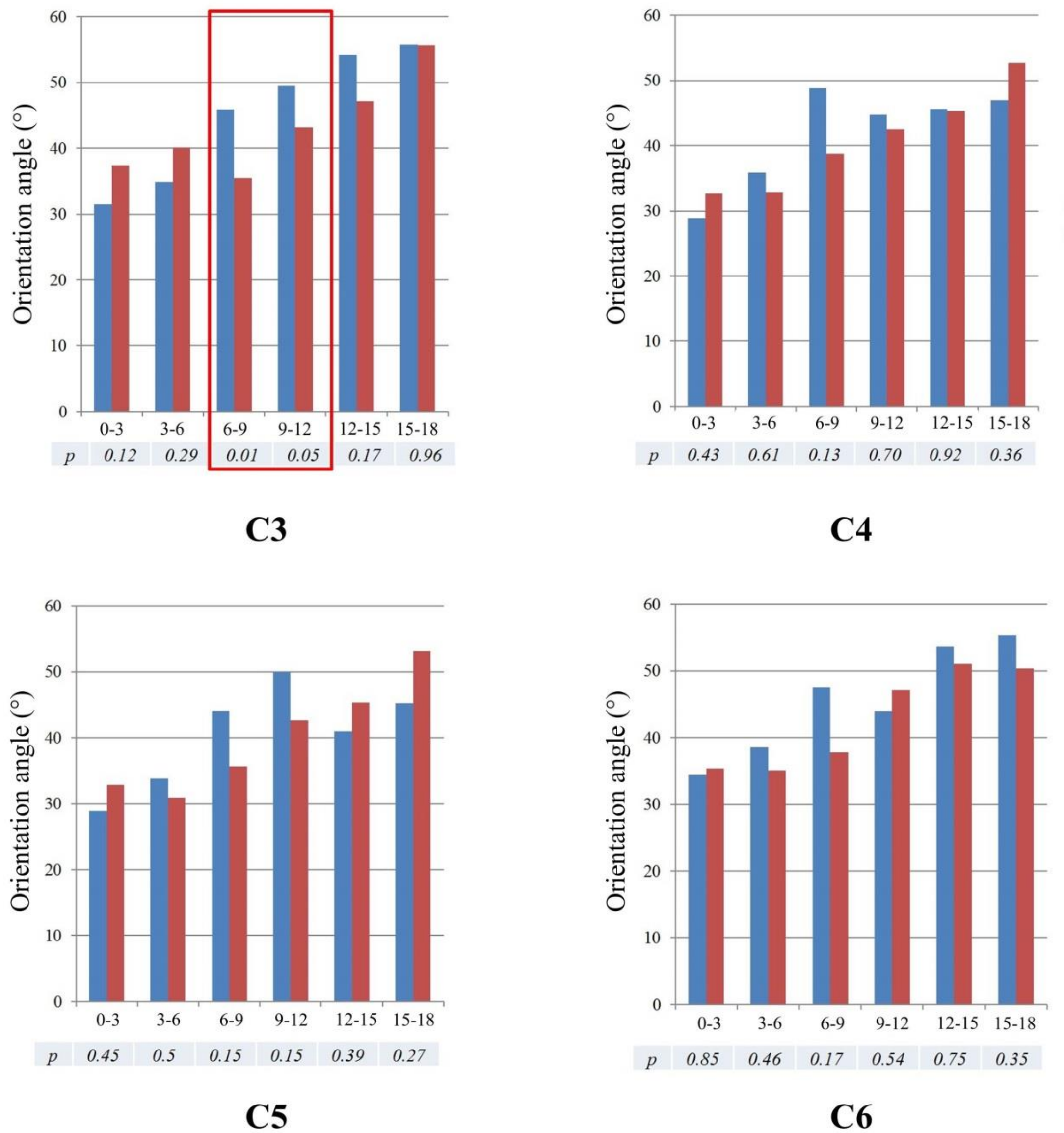

Figure 3 *– Comparisons of the mean values of the orientation angle at each level and for each age group, with respect to gender.*

Kinetics of change

Regarding the pattern of change, C3 and C6 had a linear progression across growth and were approximated using a linear regression (R^2=0.437 and 0.278, respectively). C4 and C5 had a quick progression pattern until 10 years old. After this point, the orientation angle continued to increase but in a slower fashion (**Figure 4**) (approximated using a degree 4 equation, R^2=0.264 and 0.262, respectively).

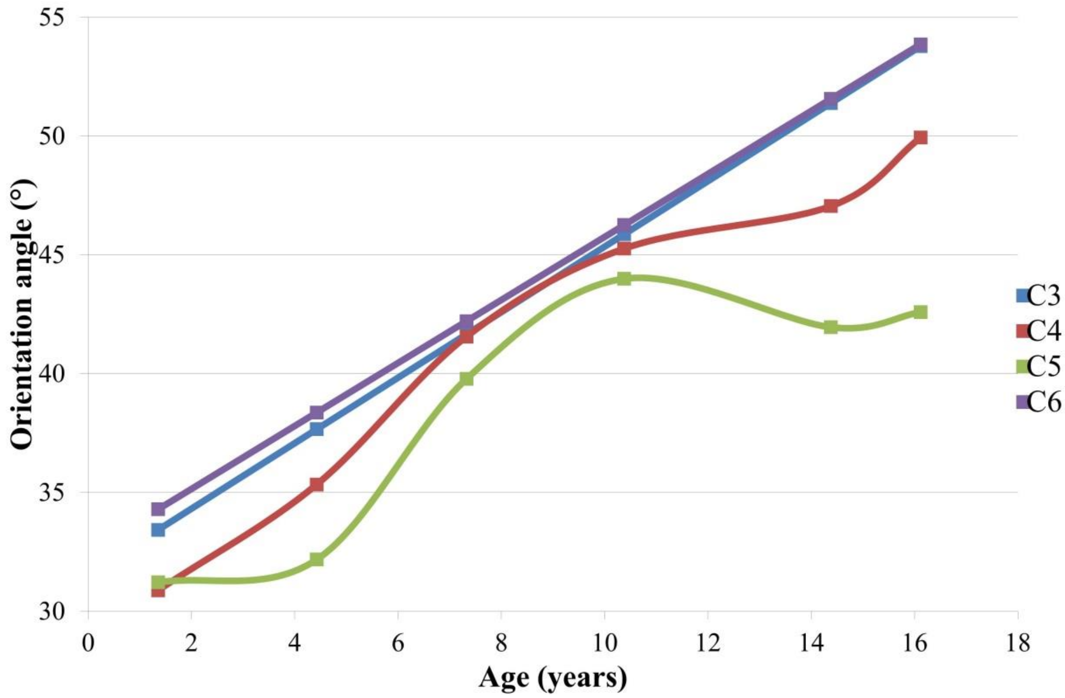

***Figure 4** – Progression pattern for each level. C3 and C6 had a linear progression, whereas C4 and C5 had a quick progression pattern until 10 years old.*

Discussion

The progressive changes in facet joints orientation with age is commonly admitted among spine physicians. To the best of our knowledge, there is no published data that objectively reports the changes in facets orientation during growth based on MRI images. Our series is the first to analyze this parameter throughout growth. The measurements were performed on a homogeneous population, in terms of age and gender. There was similar number of boys and girls in regard to age. Furthermore, age of the youngest patients, included in the study, was very low (4 months), reflecting precisely the facet orientation angle for each vertebra at birth.

The measurement method reported by Ogden was highly reproducible [4]. The author described the measurement of the facet joints orientation as the angle between the superior facet and the horizontal plane. These measurements were performed on anatomical specimens. In clinical practice, this method of measurement is not appropriate because of changes in cervical sagittal curvature. The influence of age on cervical lordosis is not perfectly known and shows great variability [3,7]. By choosing the horizontal plane as a reference, the orientation angle becomes a positional parameter. This could, therefore, be misleading when analyzing the results. Furthermore, the head-to-body ratio is greater in young children and can influence cervical curvature, especially in supine position. For these reasons, it is difficult to keep the horizontal plane as a reference for the measurement of facet joints orientation in clinical practice.

The previously reported values of the orientation for cervical levels ranged from 30 to 70° between C2 and C4 and from 55 to 70° between C5 and C7 [3,4]. Our results are consistent with the literature as we established the same correlation between age and facet joints orientation. The maximum values that we reported for each vertebra were similar to those observed by Ogden [4]. On the other hand, the minimum values that we observed were lower than those reported by the same author. This difference can be explained by the fact that authors measured the orientation angle based on radiographs. In a young child, the most of the vertebra is cartilaginous, so, the measurements from X-rays probably over-estimated the orientation of the facets.

The orientation of the facet joints is probably not the only anatomical structure participating in the stability of the cervical spine. However, in children, the relative weakness of nuchal muscles makes this structure crucial in order to maintain stability [6,8,9]. The analysis of different cervical levels revealed interesting findings. First of all, C5 showed the lowest values of the orientation angle, meaning that it was the level for which the facet joints were the most horizontal. This observation was made from very early childhood until the end of growth. In the same setting, a biomechanical study by Kumaresan *et al.* has shown that more horizontal facet joints allow to increase the flexion-extension range of motion [8]. These results are also in line with the study of Stemper *et al.*, which reported the changes in C4-C5 and C5-C6 joints due to its function [10]. Even though, the maximum flexion-extension range of motion is observed at C2-C3 level in a younger child, C5 is considered as the fulcrum of flexion-extension from childhood to adulthood[11,12]. The maximum translation of C4 over C5 is possible due to the low value of the orientation angle at C5. These findings are interesting as they can also explain the frequency of trauma and degenerative disease at this level in adulthood [10,13–15].

The second remarkable vertebral level was C3. From early age to the end of the growth, the facet joints of C3 were the most inclined ones. In young child, the high weight ratio between head and body, combined with the immaturity of muscles are responsible for hypermobility of C2-C3 intervertebral disc. It explains the aspect of C2-C3 pseudo-subluxation, frequently observed on the lateral X-rays of the cervical spine in young children[16]. This physiologic aspect reflects a postural hypermobility, imposed by high head-to-body ratio in younger children. The high orientation angle of C3 throughout the growth can, therefore, be the answer to a necessity for a zygapophyseal stability, in order to compensate for the immaturity of other stability systems. This instability also explains the high frequency of upper cervical spine traumas in early age [6,11,12].

When looking at the kinetics of change throughout growth, we observed two different patterns. C3 and C6 had a linear pattern of change. On another hand, C4 and C5 had a fast pattern of change from 4 to 10 years old. These results are in line with those of Kasai *et al.* [3], except that in our study, we were able to show different patterns among the cervical levels. The particular pattern of growth of C4 and C5 could be explained by their function. Indeed, these vertebras are located at the fulcrum of flexion-extension. During growth, it has been shown that the neurological control of mature gait is established at 4 years old and stable gait is acquired around 7 years old. Moreover, we have found in a previous report that the body leans more forward during gait as children are getting older [17]. Therefore, the cervical spine needs to be in extension in order to maintain a horizontal gaze during gait, explaining the rapid changes at C4 and C5 around this age. These results suggest that the changes in facet joints orientation are more under the influence of function, rather than puberty, as it has been widely demonstrated for other parts of the cervical vertebras[18,19]. We can suppose that puberty and growth spurt are responsible for increase in vertebral dimensions, while function is responsible for changes in vertebral shape. Further studies focusing on the correlation of results of the present study with gait analysis data, could confirm this hypothesis and ,therefore, be of major interest for understanding of the cervical spine growth.

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