Journal of Clinical Neuroscience 44 (2017) 335–339

Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.elsevier.com/locate/jocn

Tools and techniques

Changes in the axial orientation of the zygapophyseal joint in the subaxial cervical spine from childhood to middle-age, and the biomechanical implications of these changes

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ARTICLE INFO

Article history:
Received 24 May 2017
Accepted 23 June 2017

Keywords:
Cervical spine
Facet orientation
Spinal maturation
Spinal degeneration

ABSTRACT

The objective of this study was to investigate the effect of age on facet orientation (FO) of the cervical spine during development, maturation, and degeneration. Computed tomography (CT) data of the cervical spine of 131 subjects without pathology of the cervical spine were analyzed. Subjects were categorized as: pediatric (n = 36, 8–16 years old), young adult (n = 33, 18–24 years old), and middle-age (n = 62, 40–59 years old). Serial CT scans were reconstructed by image processing. The FO in the axial plane was measured bilaterally at each vertebral level from C3/4 to C6/7. Differences in FO were analyzed between the 3 groups. The degree of external rotation of FO significantly decreased at C3/4 and C4/5 with increasing in age, and maximum external rotation was observed at C5/6. The external rotation at C6/7 increased from pediatric to young adulthood, but decreased from young adults to middle-aged adults. The dominant external rotation was seen in C4/5 and C5/6 in the pediatric age group, C5/6 and C6/7 in young adults, and C4/5 and C5/6 in middle-aged adults. These results lead us to conclude that FO in the axial plane exhibits significant differences with age. The degree of external rotation with respect to FO at each vertebral level is comparable to changes in cervical spinal dynamics with age. Hence, FO in the axial plane is a biomechanical parameter that can be used to assess changes in the cervical spinal during maturation and degeneration.

1. Introduction

The subaxial cervical spine is a highly mobile region allowing complex motions, and the most common site of spinal degeneration or injury [1]. In addition to the intervertebral disk, the zygapophyseal (facet) joints are important structures that influence proper spine motion and spine stabilization. The articular surface of the facet joint in the subaxial cervical spine is geometrically planar, and the facet orientation (FO) influences the dynamics of the spine by guiding or limiting intervertebral motion [2,3]. Studies of the FO of the subaxial cervical spine in asymptomatic adults show that the FO in the axial plane exhibits various degrees of external rotation [4]. Although the external rotation varies in individuals, the degree of external rotation of the facet joint is higher at the C4/5 and C5/6 levels, and lower at the C3/4 and C6/7 levels [5]. The clinical importance of the FO is its relevance with respect to intervertebral flexion-extension range of motion (ROM), which may be related to axial rotation or lateral bending [6]. From a geometrical perspective, increased external rotation of the FO in the axial plane provides greater ROM for axial rotation. In the case of everted joints, FO in the coronal plane provides increased ROM for lateral bending because of its correlation with FO in the axial plane [5].

Greater ROM of the subaxial cervical spine, however, is associated with disk herniation and degeneration. The maximum average ROM is in C4/5 or C5/6 [7,8], and age independently inversely influences cervical ROM [9,10]. The FO in the axial plane exhibits significantly less external rotation with aging, which also results in decreased ROM [5,11,12].

In cases of cervical spine injury in children, there is a general trend of downward migration of the injury site [13]. As children age, flexibility and loading of the cervical spine undergo notable transformation, and the head- and neck-trunk ratios in children of different ages may be a major factor influencing the injury level [14]. Therefore, it can be reasonably hypothesized that ROM and FO transformation are influenced by both developmental and remodeling effects. Thus, detailed analysis of the FO in young and older pediatric to middle-aged persons, groups that represents

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http://dx.doi.org/10.1016/j.jocn.2017.06.072
0967-5868/

Table 1
Patient characteristics.

	8–17 years (pediatric) (n = 36)		18–24 years (young adult) (n = 33)		40–59 years (middle-age) (n = 62)		*p*
Age, years	14.4 ± 2.9	15 (8, 17)	20.9 ± 2.1	21 (18, 24)	48.8 ± 5.8	47.5 (40, 58)	**<0.001**
Body mass index, kg/m^2	21.6 ± 5.7	19.4 (11.8, 33.5)	22.5 ± 3.9	21.7 (17.6, 32.8)	23.3 ± 4.3	23.6 (14.5, 32.2)	0.394
Male, number (%)	26 (72.2)		19 (57.6)		52 (83.9)		**0.020**
Facet orientation (°)							
C3/4	3.8 ± 9.7	3.8 (−14.7, 24.7)	4.1 ± 9.9	3.9 (−13.1, 22.9)	−3.2 ± 10.3	−3.7 (−24.7, 19.0)	**<0.001**
C4/5	11.7 ± 7.1	12.6 (−6.9, 22.1)	7.1 ± 10.7	7.9 (−18.7, 32.3)	3.8 ± 8.9	4.4 (−14.2, 21.4)	**<0.001**
C5/6	11.2 ± 10.6	13.0 (−17.5, 37.1)	9.5 ± 9.3	9.7 (−9.7, 27.2)	8.3 ± 12.2	11.4 (−17.3, 36.1)	0.450
C6/7	2.5 ± 10.7	4.6 (−26.4, 19.6)	1.1 ± 10.0	3.2 (−21.2, 21.8)	−0.2 ± 11.1	−0.9 (−23.6, 20.3)	0.471

Data are presented as mean ± standard deviation and range (minimum, maximum).
1. Age $p < 0.001$ indicated specific grouped according to age.
2. Male $p = 0.020$ indicated no male/female predominance among groups.
3. C3/4 C4/5 $p < 0.001$ indicated FO in the subaxial cervical spine significantly different in pediatric, young adult, and middle-age individuals.

the period of spinal development, maturation, and degeneration, will prove valuable. However, normal ranges are uncertain, and normal values have to be determined by age group because of age-dependent degeneration.

Thus, the purpose of this study was to establish normal values of zygapophyseal FO in the subaxial cervical spine in 3 age groups representing development, maturation, and degeneration, which may assist in the understanding, diagnosis, and treatment of cervical spine-related diseases.

2. Materials and methods

The study was approved by Institutional Review Board of Chang Gung Memorial Hospital, and because of the retrospective nature the requirement of informed consent was waived.

The records of patients 8–59 years of age who received head and neck computed tomography (CT) from July 2006 to June 2010 were retrospectively reviewed for possible inclusion. Patients were categorized into 3 age groups: 8–17 years (pediatric); 18–24 years (young adult); and 40–59 years (middle-age), reflecting development, maturation, and degeneration of the cervical spine. Patients were included if the received head and neck CT that included the cervical spine, and the indication for the examination was not cervical spine pathology. Patients were excluded if they had a history of pathology or surgery of the cervical spine, or there was radiographic evidence of spinal disease, fusion of vertebrae, or deformity. Patients in the middle-age group with degenerative changes due to aging were included; however, those with a marked decrease in the intervertebral disk height of any level from C3/4 to C6/7 were excluded so that only cases with even cervical spine degeneration across all vertebrae would be included. Patients >60 years old were also excluded because of the high rate of cervical spine degeneration.

Images of the cervical spinal region were extracted from the initial serial CT images, and were processed using Image J version 1.42 (National Institutes of Health; http://rsb.info.nih.gov/ij/). The images were reconstructed in the axial plane through the intervertebral disk to show the FO at each level. If the FO was unidentifiable for any reason, the patient was excluded. The FO on the axial plane was defined as positive degree values for external rotation, and negative degree values for internal rotation. The FO was measured bilaterally from C3/4 to C6/7, and the mean value of both sides at each level of each age group was calculated and used for analysis.

2.1. Statistical analysis

Data were expressed as mean ± standard deviation, except for sex that was presented as frequency (percentage). Chi-square test for sex, and the Kruskal-Wallis test for other continuous parameters with skewed distributions were used to compare data. When a significant different was revealed by the Kruskal-Wallis test, Mann-Whitney *U* test was carried out for multiple comparisons. FO values were presented as mean ± standard deviation with 95% confidence intervals (CIs) to examine group differences. Values of $p < 0.05$ were considered statistically significant, and the significance was adjusted to 0.017 (0.015/3) when post-hoc tests were necessary. All statistical analysis s were 2-sided, and performed using PASW statistical software (IBM Corp., Armonk, NY).

3. Results

A total of 131 patients were included: 27.5% (n = 36) were between 8 and 17 years old (pediatric; 26 males, 10 females), 25.2% (n = 33) were between 18 and 24 years (young adult; 19 males, 14 females), and 47.3% (n = 62) were between 40 and 59 years (middle-age; 52 males, 10 females). Patient data are summarized in Table 1. FO values at C5/6 and C6/7 were similar between the 3 groups, but the middle-aged group had smaller C3/4 FO values than the other 2 groups (−3.7° vs. 3.8° pediatric and 3.7 in young adult, $p \leq 0.004$), and smaller C4/5 FO values than the pediatric group (4.4° vs. 12.6°, $p < 0.001$) (Fig. 1). Mainly the FO showed external rotation; internal rotation rate of FO was 54.4% at C3/4, 22.5% at C4/5, 47.8% at C5/6, and 27.6% at C6/7.

In pediatric patients, the mean C3/4 FO was 3.8 ± 9.7° (range, −14.7 to 24.7°; median, 3.8°); more than half of patients a FO > 3.8°. The mean C4/5 FO was 11.7 ± 7.1° (range, −6.9 to 22.1°; median, 12.6°). The mean C5/6 FO was 11.2 ± 10.6° (range, −17.5 to 37.1°; median, 13.0°). The mean C6/7 FO was 2.5 ± 10.7° (range, −26.4 to 19.6°; median, 4.6°); half of patients had a value >4.6°.

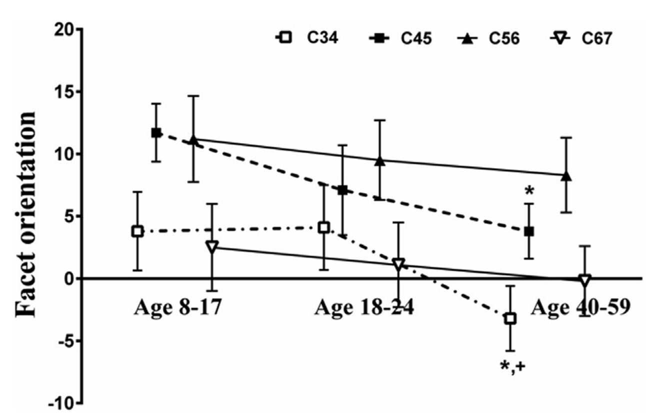

Fig. 1. FO in the axial plane measured from C3/4 to C6/7 in 3 age groups. Data were shown as mean and 95% confidence interval. Asterisk indicates significantly different from the pediatric group (age 8–17 years), $p < 0.017$. Cross denotes significantly different from the young adult group (age 18–24 years), $p < 0.017$.