

Flexion Dysfunction of Atlanto-occipital Joint as a Risk Factor for Cervical Spondylosis

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Research article

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Abstract

BACKGROUND:

There exist varied craniocervical flexion angles from the teenagers to the elderly. To our best knowledge, there is no prior study to examine the role of range of motion (ROM) of the atlanto-occipital joint in the pathogenesis of cervical spondylosis (CS). The purpose of this study was to investigate the association between atlanto-occipital radiographic alignment in flexion and CS.

METHODS:

232 CS patients, including 45 patients who accepted surgical treatment, were retrospectively reviewed. The angle between McGregor's line and C1 line (O-C1 angle) was evaluated on images taken in flexion (F-OC) and neutral positions (N-OC) independently. The relationship between the FOC (FOC=F-OC-N-OC) and Neck Disability Index (NDI) was examined, and the involvement of the FOC in the onset of CS was analyzed. Receiver operating characteristic (ROC) curve analysis was performed to determine the optimal cut-off for detecting an increased risk of CS.

RESULTS:

The FOC showed a significant correlation with NDI ($P < 0.05$). The mean FOC was significantly lower in the CS groups than in the control group ($P < 0.001$). Logistic regression analysis showed involvement of the FOC in the onset of CS, and the threshold value according to receiver operating characteristic curve analysis was 4.2 degree, with the odds ratio of 8.2 (95% CI: 6.4–10.0; $P < 0.001$).

CONCLUSION:

Stiff atlanto-occipital joint, represented by low FOC, is an independent risk factor in the incidence of CS compared with healthy individuals. This parameter can help spine surgeons to identify these people to implement appropriate preventive and management steps.

Introduction

Cervical spondylosis (CS) is not considered a rare condition, with a reported prevalence of 5–21% [1–3]. Degenerative changes of the cervical spine are seen radiographically in over half of the population aged 55 years or higher [2]. Rates of surgery for this condition increased by 90% in the US population from 1990 to 2000 [2]. With an increasingly sedentary population, especially with reliance on mobile devices, the current prevalence rate can be higher [3]. The pathogenesis of CS has been convincingly related to primary disc degeneration, disc space reduction, and subsequent pathological processes such as osteophyte formation and ligament flavum hypertrophy that eventually lead to spinal and neural canal stenosis and related neurological symptoms and deficits [1, 2]. Unfortunately, currently CS is quite

common among young people, and even teenagers who are generally expected to be remote from degenerative processes with age [3]. In this context, this question arises: what on earth push them to suffer the pathological changes early?

Previous studies revealed that the abnormal atlantoaxial joint accelerates spinal degeneration as the disorder of the muscular-ligament balance system and mechanical stress conduction [4–7]. The atlantoaxial joint allows for flexion and extension of 15 degrees and 30 degrees of axial rotation [7]. In contrast, the atlanto-occipital joint accommodates 25 degrees of flexion and extension and 5 degrees of axial rotation [7]. Extensive studies have indicated the importance of deep cervical flexors (DCFs), the longus capitis and colli, in support of the cervical lordosis and motion segments, and a close relationship between their impairments and neck pain [9–14]. There exists an inferior ability to increase craniocervical flexion in individuals with neck pain, which results from the worse performance of DCFs [10, 12, 13]. It is based on the anatomical ground that the main action of DCFs is craniocervical flexion [14]. Thus, the craniocervical flexion test [10], has been developed to assess the capacity of DCFs.

However, relevant researches merely focused on neck pain and evaluated the range of motion (ROM) of craniocervical flexion by a digital camera and custom-designed analytical software, which has a limited accuracy of the real ROM. To our best knowledge, there is no prior study to examine the role of atlanto-occipital joint in the pathogenesis of CS. The ROM of craniocervical flexion captured our interest in whether it associates with CS, prompted both by the clinical observations which showed regular impairment of DCFs in patients with neck pain and by the functional anatomical research that confirmed electromyographically their importance in support of the cervical lordosis and motion segments. Besides, the craniocervical flexion angles vary within a relatively wide range from the teenagers to the elderly from our clinical observations. Therefore, this study aimed to investigate the association between atlanto-occipital radiographic alignment in flexion and CS.

Methods

1. Study Population

CS patients were recruited from our hospital, and the age-/gender-/body mass index (BMI)-matched healthy controls were selected from the subjects in health examinations of the same hospital between January 2015 and May 2019.

A senior orthopedist performed the diagnosis of CS following the International Classification of Diseases 9th Revision (ICD-9). CS patients were considered the case group while they had received medical care at least three times during outpatient visits and/or one-time hospitalization for principal/secondary diagnosis of CS. Base on whether surgical treatments, they were subdivided into non-operation group and operation group. Operation group: patients with severe cervical spondylotic radiculopathy (CSR)/cervical spondylotic myelopathy (CSM), not improved by conservative treatments over a 12-weeks observation; Non-operation group: the CS-related symptoms can be improved by conservative treatments over a 12-

weeks observation. Those having congenital or acquired postural deformities such as kyphosis and scoliosis; spinal diseases such as tumors, fractures and inflammatory; headache resulting in daily activity limits; or history of any neck surgery were excluded. By contrast, subjects with no signs and symptoms of CS and no evidence of radiographic abnormalities were the control group.

Every procedure performed in this study involving human subjects was following the ethical standards of the institutional review board of the hospital. All subjects were included after informed and written consent.

Radiographic evaluation

The O-C1 (atlanto-occipital) angle was measured on the lateral view (Fig. 1). This radiographic parameter was measured based on McGregor's line [7] as the occipital baseline, the C1 line defined as the line between the centers of the anterior and posterior arch of the atlas. The O-C1 angle was defined as the angle between McGregor's line and the C1 line. The O-C1 angles were evaluated on images taken in flexion (F-OC) and neutral positions (N-OC). Specifically, the neutral position was defined as that the subject was looking forward to the upright state with the extended knee and hip. When taking a flexion view, the subject was required to the flexed cervical spine as much as possible. The flexion function of the O-C1 (FOC) was defined as F-OC minus N-OC (Fig. 2).

3. Clinical evaluation

Clinical outcome was evaluated by the Neck Disability Index (NDI) at first visit [8]. The NDI, a self-reported questionnaire with ten items, quantifies neck-related disability on a score from 0 (no disability) to 50 (maximum disability) [8], which involves ten items on daily activities such as the ability to dress, lift heavy objects, read, work and sleep. The higher score represents a more severe disability.

Statistical analysis

The ordinal variables were described as proportions and quartiles. The Chi-square test for dichotomous variables was carried out to compare cases and controls. And the Mann–Whitney, the Student's t-test, or the Variance test was done for continuous variables. One-way analysis of variance and a post-hoc Tukey test were performed to compare FOC levels between the control and two case groups. To evaluate the reliability of techniques used to measure the O-C1 angles, two authors assessed the intra- and inter-observer variabilities. Each author measured a parameter twice, and then interobserver, and intraobserver reliability was evaluated by calculating the intraclass correlation coefficient (ICC). The internal consistency of the measurements was characterized as excellent ($ICC \geq 0.9$), good ($0.7 \leq ICC < 0.9$) and acceptable ($0.6 \leq ICC < 0.7$) [15]. The Pearson correlation coefficient was calculated to find a correlation between FOC and NDI. Receiver operator curve (ROC) analysis by calculating the area under the curve and risk analysis model by logistic regression was performed to estimate the odds ratio (OR) and the 95% confidence interval (CI) to determine FOC's predictive role in CS. The statistical significance and power

analysis were set at p -value ≤ 0.05 and 0.8 . All analyses were performed using SPSS version 20.0 (SPSS; Chicago, IL, USA).

Results

1. Subject characteristics

A total of 464 subjects was included in the study. Thereinto, the operation group and non-operation group had 45 and 187 patients, respectively, while 232 subjects were included in the control group. The characteristics of the subjects are listed in Table 1. There were no significant differences in gender, BMI between groups ($p > 0.05$). However, the case groups, especially the operation group, tended to be older and have a higher NDI score and longer medical history. In the case groups, there were more patients with CSM ($p < 0.05$) (Table 1).

Table 1
Subject characteristics

Characteristics	Operation Case group (n = 45)	Non-operation Case group (n = 187)	Control group (n = 232)	p-value
Male (n, %)	26 (57.8%)	116 (62.0%)	140 (60.0%)	0.8558
Age (years) (Mean \pm SD)	55.8 \pm 11.2	41.6 \pm 13.8	23.5 \pm 5.5	< 0.001*
BMI (kg/m ²) (Mean \pm SD)	22.5 \pm 4.2	23.2 \pm 3.8	23.5 \pm 4.5	0.3249
NDI	12.2 \pm 4.5	6.2 \pm 2.1	3.2 \pm 1.2	< 0.001*
Type of CS (n, %)				
CSR	34 (75.6%)	175 (93.6%)	-	< 0.001*
CSM	11 (24.4%)	12 (6.4%)	-	< 0.001*
Medical history of CS (years) (Mean \pm SD)	10.5 \pm 9.5	6.8 \pm 11.2	-	< 0.001*
BMI Body Mass Index, NDI Neck Disability Index, CSR Cervical Spondylotic Radiculopathy, CSM Cervical Spondylotic Myelopathy.				
* Significant ($p < 0.05$).				

2. The difference of Flexion Function of O-C1 (FOC) among groups

The mean FOC in the control group was 7.2 degrees compared with 1.4 degrees and 3.6 degrees in the operation group and non-operation group (Table 2). One-way analysis of variance showed statistically

significant differences in FOC between the control and case groups ($P < 0.001$). A post-hoc Tukey test showed a higher FOC in the control group compared with the case groups ($P < 0.001$). Besides, it was lower in the operation group compared with that in the non-operation group ($p < 0.001$). N-OC and F-OC were not statistically significantly different among the three groups ($p = 0.1373$ and $p = 0.0839$, respectively).

Table 2
Comparison of Flexion Function of O-C1 (FOC) among groups

Variable(degree)	Operation Case group (n = 45)	Non-operation Case group (n = 187)	Control group (n = 232)	p-value
FOC Mean \pm SD	1.4 \pm 1.2	3.6 \pm 1.9	7.2 \pm 2.0	< 0.001*
N-OC Mean \pm SD	11.0 \pm 4.2	10.0 \pm 4.0	10.2 \pm 4.6	0.1373
F-OC Mean \pm SD	12.4 \pm 4.0	13.6 \pm 4.2	17.4 \pm 4.5	0.0839
FOC Flexion Function of O-C1, F-OC O-C1 angles in flexion, N-OC neutral positions. * Significant ($p < 0.05$).				

3. A predictive model of FOC as a radiological marker for CS

Using FOC as a radiological predictive model to predict CS, the area under the curve (AUC) was 0.86 (95% CI: 0.78–0.92, $p < 0.001$) (Fig. 3). FOC had a sensitivity, specificity, Youden index, and cut-off value of 87%, 90%, 0.77, and 4.2 degrees, respectively.

4. Risk analysis model for FOC in CS

Risk analysis was based on the cut-off value calculated by ROC, for those higher than 4.2 degrees classified as having a better FOC. In the univariable risk analysis model, conditional logistic regression showed that the FOC level was an independent factor with an important role in the risk of CS. The odds rose to 8.2 times (OR = 8.2; 95% CI: 6.4–10.0; $P < 0.001$) when FOC reached the level under the 4.2 degree.

5. Distribution of low-level FOC in different age groups.

The percentage of individuals with a FOC level less than 4.2 degrees slightly increased with the increasing age in the cohort of the non-CS population. However, the percentage of their counterparts in the cohort of the CS population experienced an obvious decrease with the increasing age from 79.7–60.0% (Fig. 4).

6. Correlation between FOC levels and NDI

A correlation test was performed using a partial correlation test only for CS patients by controlling the variables of age, gender, BMI to determine the correlation between FOC levels and NDI. There existed a significant negative correlation between FOC levels and NDI ($r = -0.451$; $p = 0.016$) (Fig. 5).

7. The reliability analysis of ROC measurements

The results for FOC showed good interobserver reliability (ICC = 0.865) and excellent intraobserver reliability (ICC = 0.911).

8. Case presentation

A 33-year-old female teacher had had intermittent pain in the neck and shoulder and numbness in the medial side of the right upper limb for one year. On admission, she had experienced the aggravated pain for two months in addition to the paralysis of her right upper extremity. The X-ray showed a stiff atlanto-occipital joint (FOC = 2.5 degrees) (Figure 6A), and CT examination showed sclerosis of the vertebral body edge and facet joint (Fig. 6B). The MRI T2-weighted sagittal imaging revealed dural sac compression from C3 to C7 with a C5–6 herniated disc and spinal cord anterior indentation at the level of C5–6 with a high signal change. MRI T2-weighted axial imaging at the level of C5–6 showing right side C6 nerve root compression in addition to the spinal cord compression (Fig. 6C). She accepted the plate and screw internal fixation with an anterior discectomy.

Discussion

Previous studies indicated that pathophysiological changes, such as disc degeneration and disc protrusion, were surprisingly common findings in young adults with neck pain [16, 17]. The course and outcome of CS are highly varied, especially in young patients [16]. A minority of them have to accept surgical treatments due to severe pain and neurologic symptoms, while others do not. Several studies investigated that the risk factors about anatomical variables of the cervical vertebrae, such as anteroposterior vertebral body diameter, mid-sagittal vertebral canal diameter, and canal-body ratio [17, 18]. However, these anatomical variations just statically reveal their effects.

CS gradually occurs over time accompanied by dynamic activities that are complex anatomically and biomechanically. Cheng Huang reported that in a population of 10,930 dentists and 73,718 controls, younger dentists had a higher risk of developing cervical herniated intervertebral disc [17]. Sustained contraction of the cervical muscles to keep forward-head postures that involve holding the neck and head in an unbalanced and unnatural forward position to gain better visibility is universally unavoidable in daily dental operations [19]. The painless, insidious nature of repetitive minor trauma caused by such a prolonged static posture (PSP) may lead to the degeneration of spinal discs [17, 19, 20]. These suggested that there existed a significant role of the head's movement in a pathophysiologic change of the cervical spine. This effect is produced through the craniovertebral junction (CVJ), including atlanto-occipital joint and its surrounding ligaments and muscles. DNFs are the only cervical muscles that lie closely in front of the cervical spine and has attachments confined to the vertebrae [20]. DNFs, function as cervical

segmental flexors that provide physical support to the cervical column and dynamically stabilize the neck, are considered necessary for the cervical spine [9–11, 20]. A compromised function is a feature of neck pain disorders, including whiplash-induced, idiopathic, work-related neck pain [10–13]. Retraining DCFs has been shown to decrease neck pain and improve the ability to maintain an upright posture of the cervical spine [12–14].

The force initiated from the head is transferred to the lower segments by atlanto-occipital joint. Therefore, stiff atlanto-occipital joint, represented by low FOC, makes increased mechanical stress downward. This may aggravate degeneration or herniation of the spinal discs [17, 21]. The presented case (Fig. 6), which should have been generally supposed to be remote from visible degenerative changes in cervical segments, has a limited FOC and this helps further support our present assumption. Previous studies reported that a restricted ROM at the C2-C7 angle in flexion after cervical laminoplasty induced the compensatory increase in the ROM in O-C2 flexion [21, 22]. Therefore, we believe that the middle-lower cervical segments and the upper one must interact with each other, as there exists a natural biomechanical balance.

Our results showed that the gap for the percentage of low FOC in 3 different age groups between cases and controls tended to be narrowed as the age increased (Fig. 4). Biological elements such as degenerated discs and ligaments gradually appear, reveal themselves, and ultimately developed into CS [4]. However, these are unusually seen for the young. Hence, the larger gap in -30 years old group may help indicate the negative role of low FOC in the development of CS.

There existed a significant negative correlation between FOC and NDI ($r = -0.451$; $p = 0.016$) (Fig. 5). Mousavi reported that a 10-min static flexion could lead to changes in the neck proprioception and feed-forward control on account of mechanical and neuromuscular changes in the viscoelastic cervical spine structures and these changes in sensory-motor control could be a risk factor for neck pain and injury [23]. Besides, PSPs are much more taxing than moving forces [24]. Suffering from PSPs, the subsequent consequences of neck muscular tissues include muscle fatigue, protective muscle contraction, muscle imbalance, and finally spinal disc degeneration or herniation [24]. In the light of the transferring role of CVJ, the stiff atlanto-occipital joint could make the middle-lower cervical segments experience more PSPs. In this way, therefore, FOC levels were negatively correlated with NDI.

This is the first study to demonstrate that the lower flexion function of atlanto-occipital joint could be a risk for accelerated degeneration of CS. The implication of this study lies in that individuals with low FOC can be screened by a cheap, easily accessible X-ray. These people should receive more education and care about musculoskeletal health related to the prevention of CS as early as possible. Currently, a need for flexion and even hyperflexion of the cervical segments have to increase, as many people use technological devices for recreation or/and work, especially smartphones for hours during the day. In 2014, the proportion of adolescents who used the smartphone was more than 60% in Shanghai, China, and this figure still keeps rising [25]. Therefore, considering the adverse health effects of the increasing

prevalence of smartphones on young adults, the present risk analysis of FOC about such an exposure, could be a promising new parameter in predicting CS, which is of great significance to spine surgeons.

The present study had a few limitations. First, the primary limitation is its retrospective case-control design, which was less eloquent to deduce causality from the results. Second, this is a retrospective study based on X-ray instead of CT, which reflect the real FOC in a more accurate way. Although X-ray is not the best choice to depict FOC, we identified the bone cortex as best as we could and meanwhile our results revealed that X-ray was also practical to detect individuals with low FOC. Last, there was inconsistency regarding the atlanto-occipital angles in flexion and neutral positions between our results and the Dohzono's [21]. Dohzono reported that the atlanto-occipital angle decreased when neck flexed from the mean of 12.4 degrees in the neutral position to 8.6 degrees in flexion. However, our result showed the opposite situation where the angle increased (Table 2). These limitations open the door for the future study.

Conclusion

Stiff atlanto-occipital joint, represented by low FOC, is an independent risk factor in the incidence of CS compared with healthy individuals. This study showed that FOC less than 4.2 degrees could experience an 8.2-fold increase in the odd of CS. This parameter can help spine surgeons to identify these people to implement appropriate preventive and management steps.

Abbreviations

ROM	Range of motion
CS	Cervical spondylosis
O-C1 angle	The angle between McGregor's line and C1 line
F-OC	O-C1 angle in flexion
N-OC	O-C1 angle in neutral positions
FOC	F-OC–N-OC
NDI	Neck Disability Index
ROC	Receiver operating characteristic
DCF _s	Deep cervical flexors
ICD-9	International Classification of Diseases 9th Revision
CSR	Cervical spondylotic radiculopathy
CSM	Cervical spondylotic myelopathy
ICC	Intraclass correlation coefficient
CI	Confidence interval
AUC	area under the curve
BMI	Body mass index

Declarations

Ethics approval and consent to participate

The study was approved by the ethics committee of the China-Japan Friendship Hospital

Consent for publication

Not applicable

Competing interests

The authors declare that they have no further competing interests.

Funding

No funding was obtained for this study.

Authors' contributions

TM and GL participated in concept development, data generation, quality control of the data, data analysis and interpretation, and writing of the manuscript. YP and GL were responsible for the data analysis and participated in the interpretation and presentation of the data. TM and GL provided input into the data interpretation. TM and YP were involved in the concept development, quality control of the data, and data analysis and interpretation of the manuscript. All authors have read and approved the final version of the submitted manuscript.

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Availability of data and materials

Data can be made available upon request to the corresponding author.

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Figures

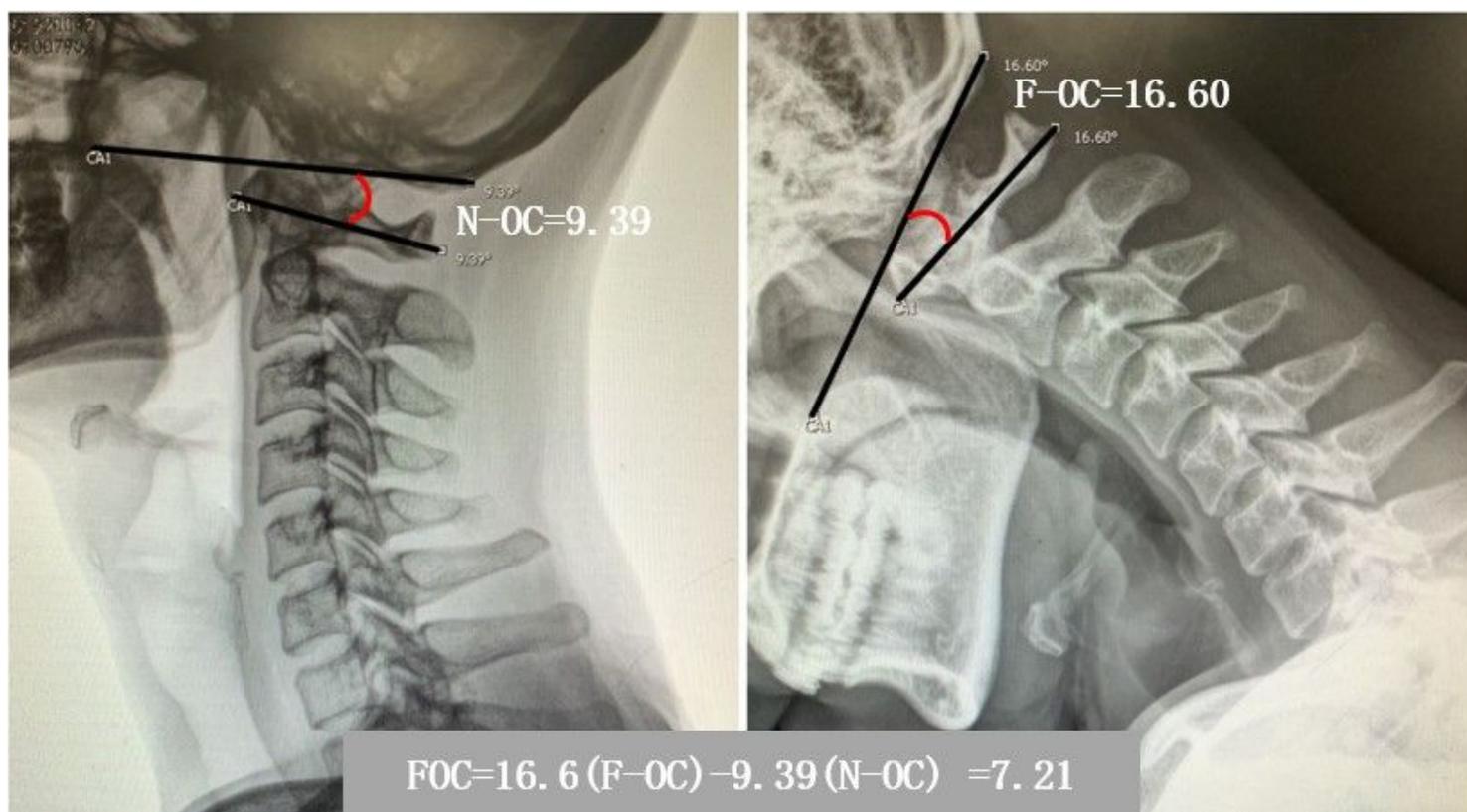


Figure 1

Representation of the radiographic measurement of O-C1 angle in neutral position (left) and flexion (Right) on the lateral view. The O-C1 angle was measured between the McGregor's line and the line passing through the center of the C1 anterior arch and the center of the C1 posterior arch.

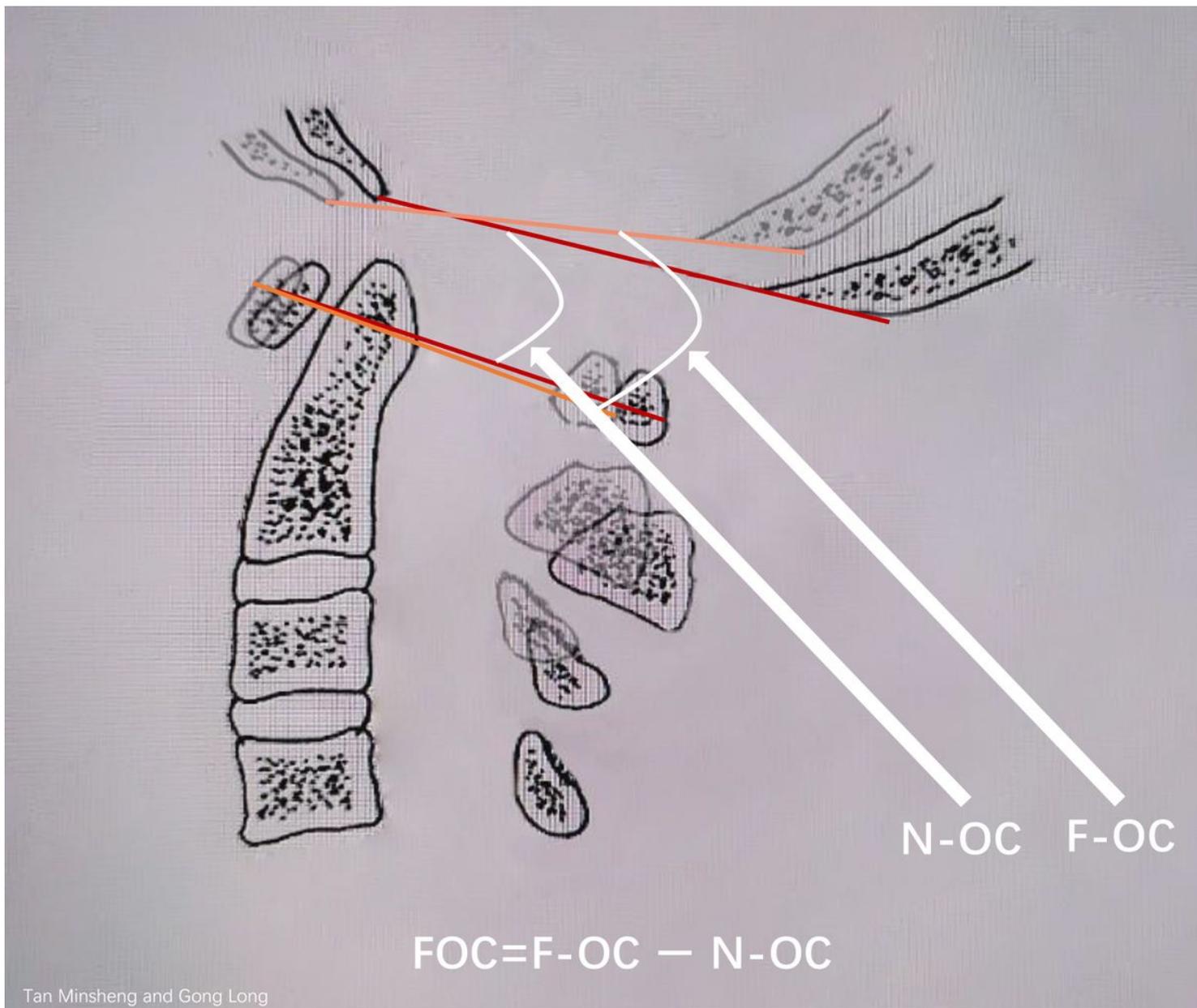


Figure 2

The sketch of the flexion function of O-C1 (FOC) defined as O-C1 angle in flexion (F-OC) minus O-C1 angle in neutral position (N-OC).

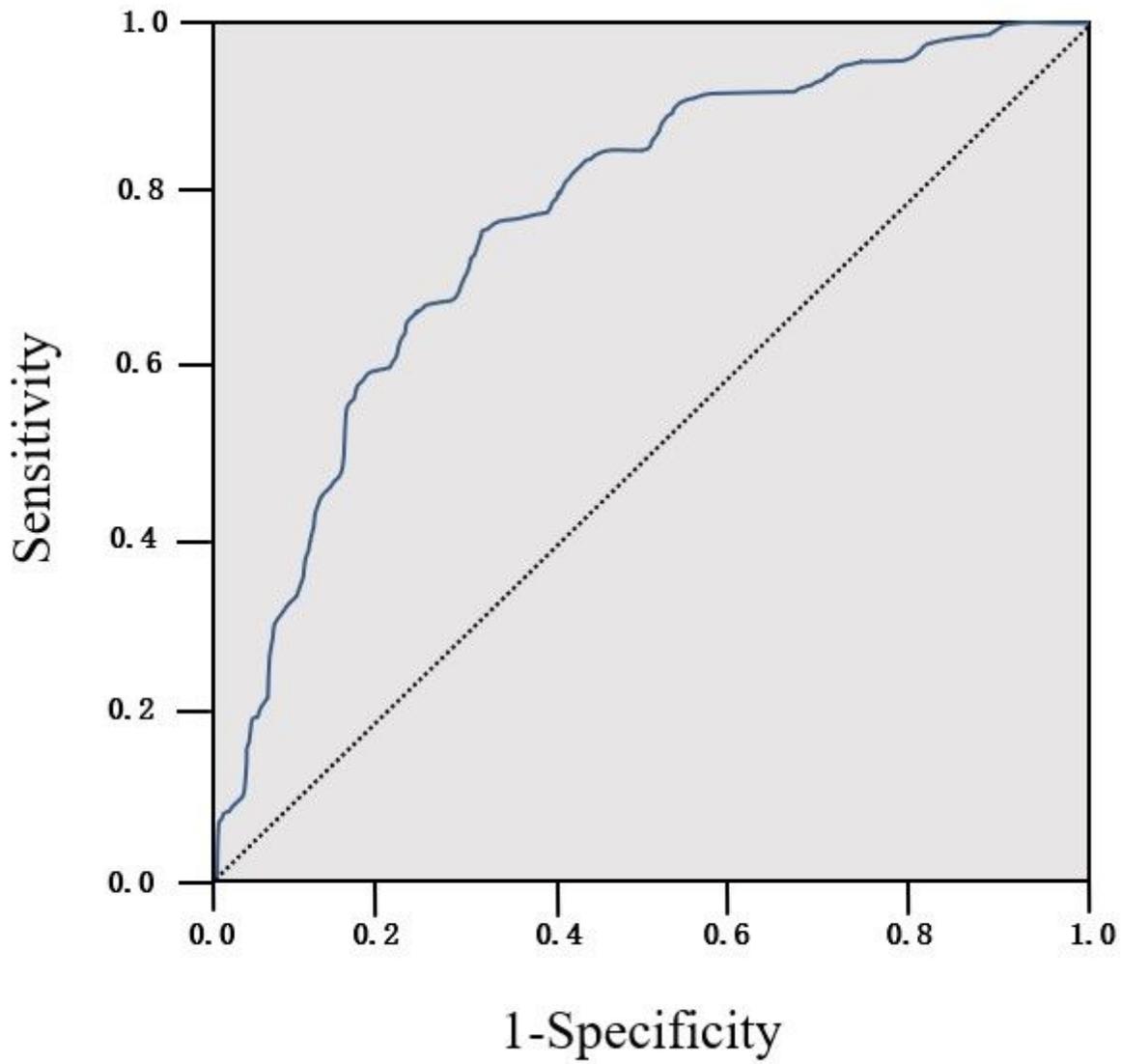


Figure 3

Receiver operating curve (ROC) of FOC.

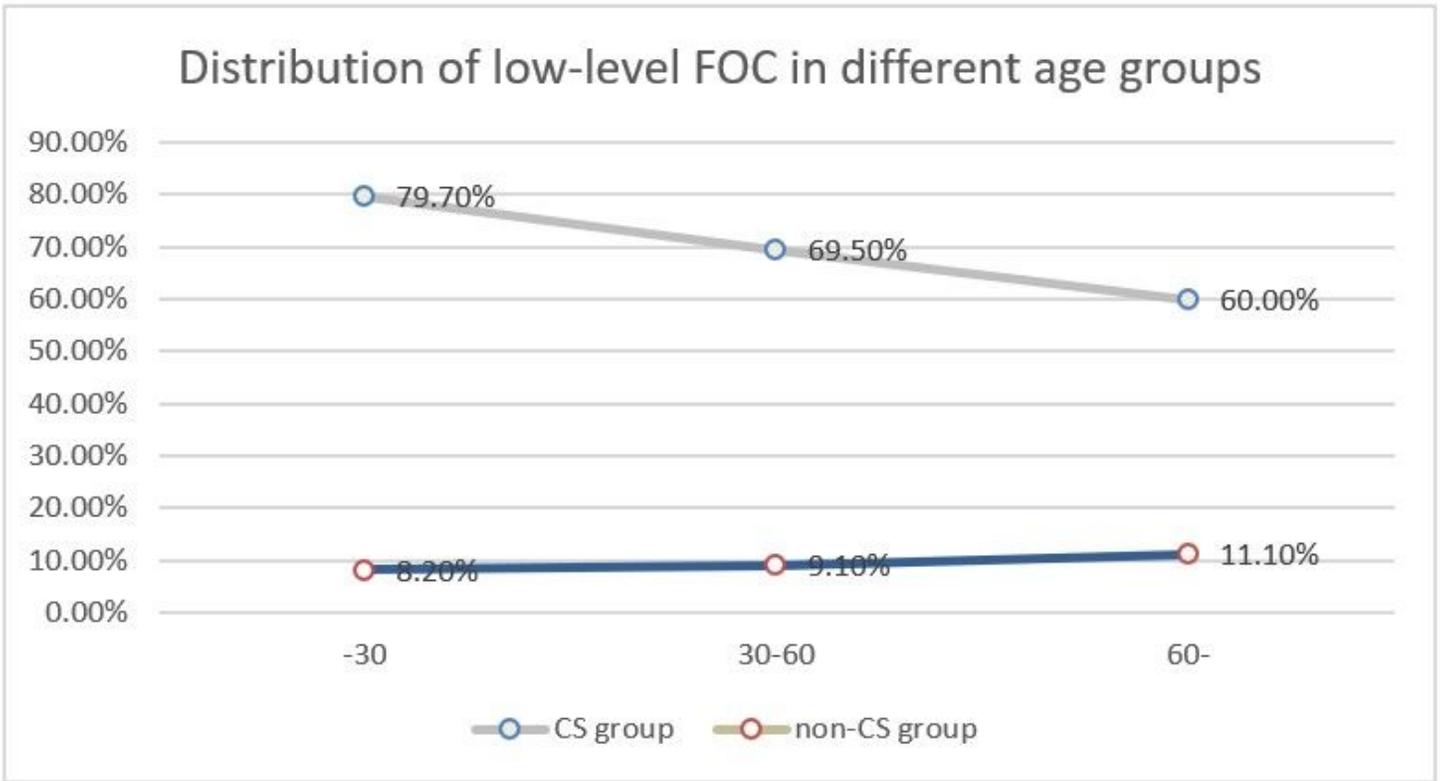


Figure 4

Distribution of low FOC in different age groups.

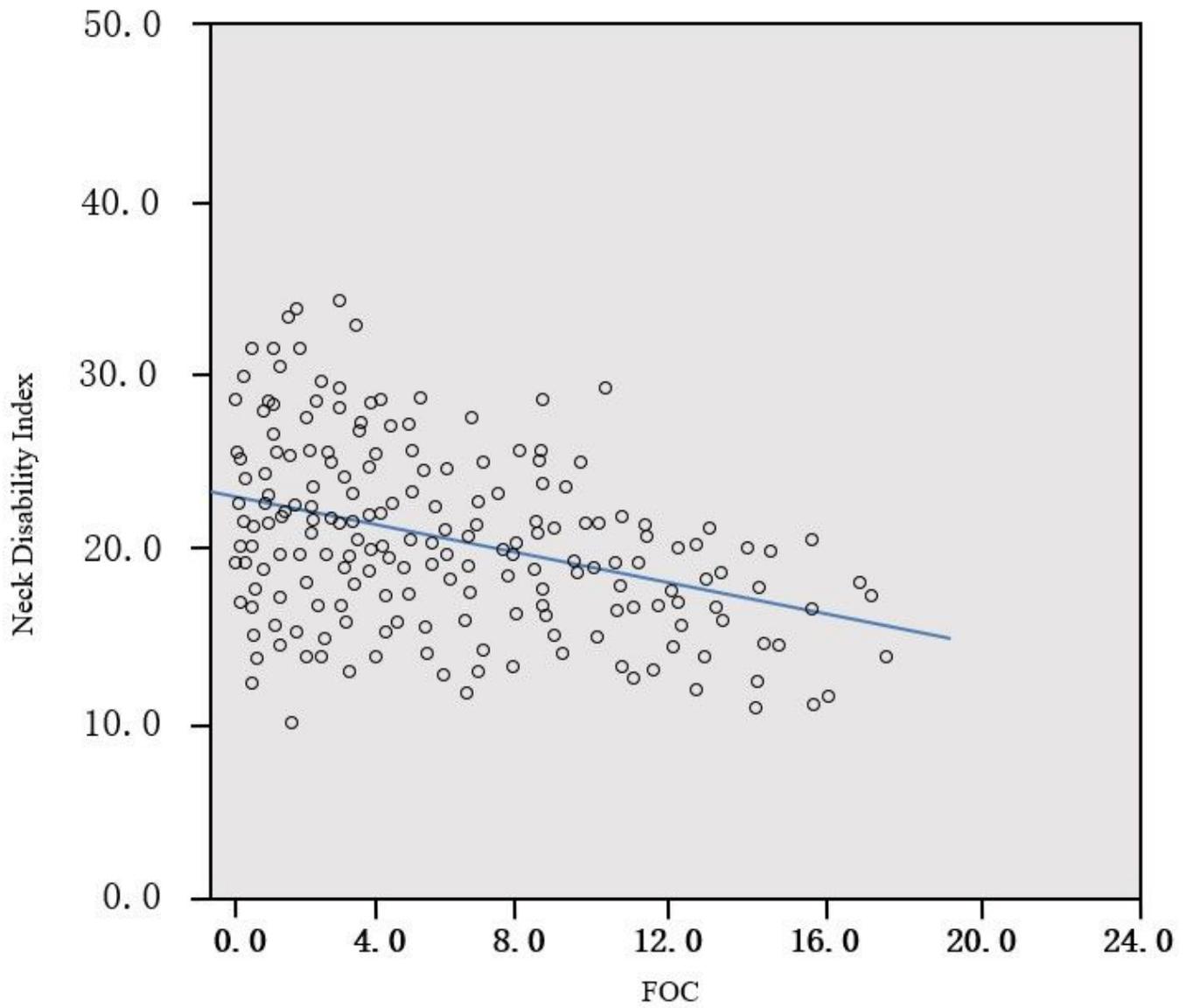


Figure 5

Correlations between the FOC and NDI ($Y = 22.343 - 0.451X$, $R^2 = 0.203$, $P = 0.016$).



Figure 6

A 29-year-old female with a stiff atlanto-occipital joint. (A). Straightening of the physiologic lordosis and degeneration of cervical segments, and decreased FOC in the atlanto-occipital joint. (B). Computed tomography reveals sclerosis of the vertebral body edge and facet joint (red arrow). (C). The MRI T2-weighted sagittal imaging revealed dural sac compression from C3 to C7 with a C5–6 herniated disc, and spinal cord anterior indentation at the level of C5–6 (red arrow) with a high signal change. MRI T2-weighted axial imaging at the level of C5–6 showing right side C6 nerve root compression (nerve root sleeve disappearance, red arrow) in addition to the spinal cord compression.