RESEARCH ARTICLE

Cervical Anatomical Landmarks Indicate the Amount of Vertebra Resection during ACAF Surgery: A Semi-Quantitative Anatomical Parameter Study on Imaging Data

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Objective: With the innovation and development of cervical spine surgical procedures, there is currently a lack of new and reliable data on cervical anatomical landmarks. The purpose of this study is to measure the CT data of the cervical vertebrae of healthy volunteers, so as to make up for the missing part of the measured value of cervical vertebra bone markers, and provide data support for the safety and accuracy of anterior controllable antedisplacement and fusion (ACAF) surgery.

Methods: From January 2019 to January 2020, the cervical computed tomography (CT) scan image data of volunteers in Changhai Hospital and Zhabei Hospital were randomly selected. The radiological parameters included three parameters were measured in the upper lamina plane. a: the distance from the anterior edge of the vertebral body to the anterior edge of the bilateral uncinate joint; c1: the sagittal diameter of the vertebral body; and d: the distance between the anterior edge of the uncinate joint. Three parameters were measured in the pedicle plane. b: the vertical distance from the anterior edge of the vertebral body to the junction line between the two lateral processes; c2: the sagittal diameter of the vertebral body; e: the transverse diameter of the vertebral body; and f: the sagittal diameter of the vertebral canal. The correlation ratios were calculated: a/c1, b/c2, a/f, b/f, d/e. The data between the two groups were compared by independent sample t-test.

Results: Finally, 51 patients were included in this study, 18 males and 33 females, with an average age of 47.9 years (21–72 years). The maximum values of seven parameters measured were all at C7. The minimum b value was at C5, and the minimum f value was at C4. The minimum values of the other five parameters were all at C3, and there was an increasing relationship from C3 to C7 ($P < 0.05$). There was significant difference between male and female with regard to c1, c2, e and d values ($P < 0.05$). No significant differences were observed between men and women regard to the ratio of related parameters (a/c1, b/c2, a/f, b/f, d/e).

Conclusions: Anatomical consideration of this area is useful to estimate amount of vertebral body resection when performing the bony cut made in ACAF surgery; however, pre-operative examinations with appropriate radiographic analysis are also recommended.

Key words: Anterior controllable antedisplacement and fusion; Computed tomography; Knuckle joint; Transverse process

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Introduction

Multi-segmental cervical spondylosis and ossification of the posterior longitudinal ligament (OPLL) are the serious types of cervical spinal diseases, which are important causes of sensory and motor dysfunction.[1] The traditional treatment methods included anterior and posterior (laminectomy and laminoplasty).[2,3] However, as the compression involves a large range and severe degree, they usually led to poor postoperative efficacy and were usually accompanied by C5 radiculopathy, cerebrospinal fluid leakage, implant related complications and so on.[4] Antedisplacement and fusion (ACAF), a new surgical technique, is an effective way to treat multi-segmental cervical spondylosis and OPLL. Through this technique, the cervical spinal cord could get more direct, safe and effective decompression. Compared with traditional cervical surgery, ACAF has a better postoperative effect and a lower incidence of complications.[5–7]

The key procedure of ACAF was removing part of the vertebrae to provide enough space for lifting the related vertebrae forward and achieve direct decompression of spinal cord.[5] It has been reported that the completion of the lifting procedure was closely related to the postoperative effect of ACAF.[6] However, in the actual surgical procedure, we were unable to measure the accurate thickness of vertebrae. In the circumstances, it was inevitable that if more thickness of vertebrae was removed, the stability of the vertebrae would be affected. On the other hand, less thickness of vertebrae was removed, the space for lifting the related vertebrae was not insufficient and compression in the front of the spinal cord would still exist, which might lead to poor postoperative effect.[6] Hence, how to judge the thickness of vertebrae accurately during the operation becomes the key problem of ACAF.

Anatomic markers can provide a clear mark during the surgery, which can effectively reduce the difficulty and time of surgery.[8] Different from the traditional operation, the spatial position information of the knuckle joint and the front of the transverse process were essential for ACAF surgery.[9] As far as we know, the above key anatomic information has not been reported. Our purposes are: (i) to look for specific anatomic markers, so as to accurately measure the amount of vertebra resection during operation; (ii) to measure the CT data of cervical vertebral bone markers in healthy volunteers, to explore the position relationship of bone markers change from C3 to C7; and (iii) To explore ratio method and its application in research.

Objectives and Methods

Subjects

The study protocol was reviewed and approved by the corresponding author's Changzheng Hospital Ethics Committee (2017SL040) before starting this study. Data were collected from patients, who were referred to the radiology department of Changhai Hospital and Zhabei Hospital between January 2019, and January 2020. Images were evaluated retrospectively. Demographic information regarding the patients (age, sex) was assessed from their medical files.

The inclusion criteria were: (i) volunteers with complete imaging data (thin-layer CT scan of cervical vertebrae); and (ii) the general condition of volunteers was good, and there was no serious medical disease.

The exclusion criteria were: (i) volunteers with history of previous neurosurgical diseases, history of cervical surgery, etc.; (ii) volunteers with unclear C3-C7 vertebral body on the X-ray image of cervical vertebra; (3iii) volunteers with structural changes such as vertebral body instability, vertebral body fracture, space occupying lesions, infection, inflammatory reaction, and vertebral body dislocation; (iv) volunteers with history of cervical surgery; and (5) volunteers with incomplete information.

A total of 88 volunteers were selected, excluding structural changes such as vertebral instability, vertebral fracture, space occupying lesions, infection or inflammatory response, and those whose imaging data could not meet the requirements of this study. Finally, 51 patients were included in this study, 18 males and 33 females, with an average age of 47.9 years (21–72 years).

Research Parameters

Considering the maneuverability and the stability of the reference markers, the uncinate joint and the front edge of the transverse process were used as the bone markers in this study. The following data were measured in C3-C7 cervical spine (Fig. 1).

Three parameters were measured in the upper lamina plane. a: the distance from the anterior edge of the vertebral body to the anterior edge of the bilateral uncinate joint; c1: the sagittal diameter of the vertebral body; and d: the distance between the anterior edge of the uncinate joint.

Three parameters were measured in the pedicle plane. b: the vertical distance from the anterior edge of the vertebral body to the junction line between the two lateral processes; c2: the sagittal diameter of the vertebral body; e: the transverse diameter of the vertebral body; f: the sagittal diameter of the vertebral canal. The correlation ratios were calculated: a/c1, b/c2, a/f, b/f, d/e.

Measuring Methods

The images of the volunteers were scanned by E Discovery 600 16-detector CT machine (Siemens Healthineers, Erlangen, Germany), with the 1 mm thickness and continuous non-septal scanning. After the scanning, the image contrast and gray level were preliminarily adjusted in the CT medical image workstation to obtain the bone window CT image that meets the requirements, and then exported to the mobile hard disk in the appropriate data format for measurement by the RadiAnt DICOM Viewer 2020.2 (64bit). During the measurement, each group of parameters was measured by two of the authors three times, and then the average value was taken.
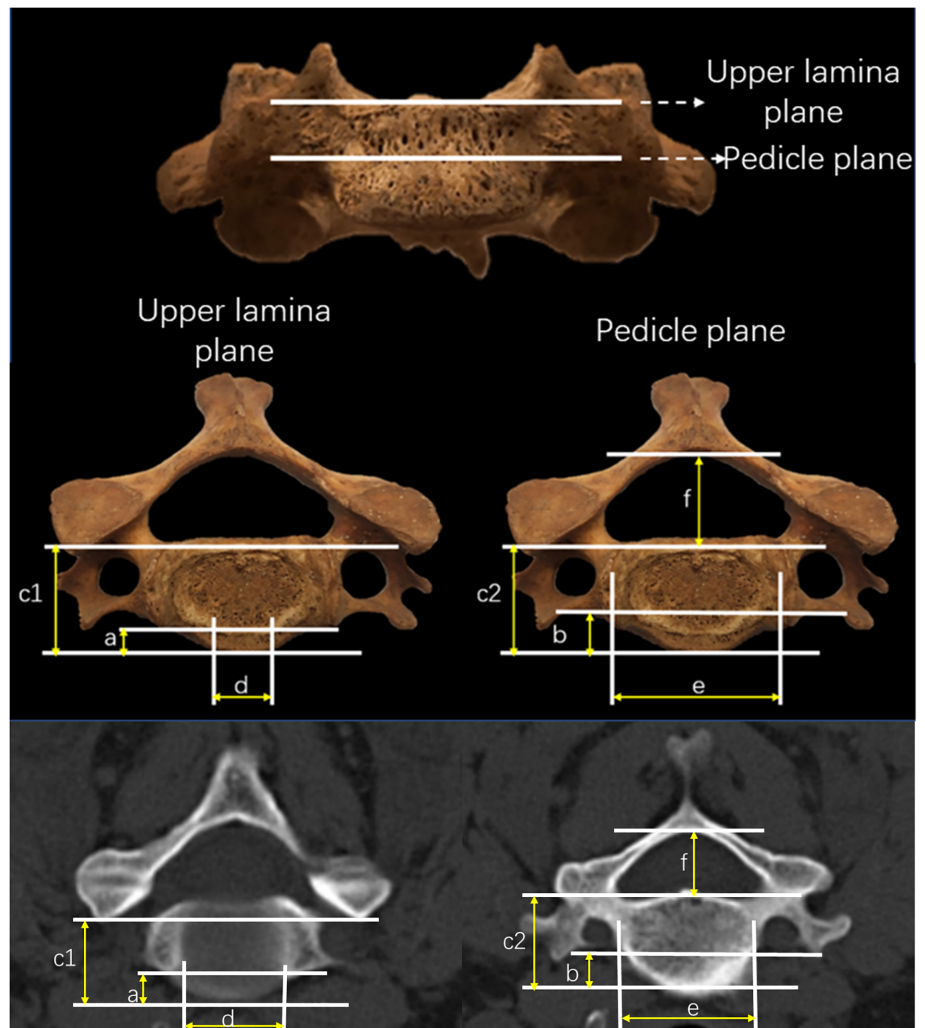
Fig. 1 Example of measurement parameters of cervical vertebra. (a) the distance from the anterior edge of the vertebral body to the anterior edge of the bilateral uncinate joint; (b) the vertical distance from the anterior edge of the vertebral body to the junction line between the two lateral processes; (c1) the sagittal diameter of the vertebral body; (c2) the sagittal diameter of the vertebral body; (d) the distance between the anterior edge of the uncinate joint; (e) the transverse diameter of the vertebral body; (f) the sagittal diameter of the vertebral canal

Statistical Methods

The measurement results were analyzed by SPSS statistical software (Version 19.0; IBM Corp., Armonk, NY, USA). The measurement data were all expressed by mean ± standard deviation. An intraclass correlation coefficient (ICC, two-way random effects model) was calculated to quantify the inter-observer reliability. An ICC value between 0.60 and 0.80 was considered good reliability, and values higher than 0.80 were considered excellent reliability. The data between the two groups were compared by independent sample t-test. Values <0.05 ($P < 0.05$) were considered statistically significant.

Results

Characteristics of Cervical Vertebrae Markers

According to CT images, the distance between uncinate joint and transverse process was moderate (1.4 ± 0.4 mm) and the position was stable. The anterior edge of the vertebral body, the knuckle joint and the transverse process were arranged from front to back (see Table 1). Hyperplasia of transverse process and / or articular process was observed in some volunteers, the incidence was 15.6%.

Analysis of Internal Correlation Coefficient (ICC) of C3-C7 Cervical Vertebra Bone Markers

The ICC value of a was 0.643 (range 0.543–0.721), indicating good inter-observer reliability. The ICC value of b was 0.698 (range 0.614–0.764), indicating good inter-observer reliability.

TABLE 1 Analysis of internal correlation coefficient (ICC) of C3–C7 cervical vertebra bone markers

	Intra class correlation	95% confidence interval
a	0.643	0.543–0.721
b	0.698	0.614–0.764
c1	0.883	0.851–0.909
c2	0.832	0.785–0.869
d	0.879	0.845–0.906
e	0.901	0.873–0.922
f	0.931	0.911–0.946

The ICC value of c1 was 0.883 (range 0.851–0.909), indicating excellent inter-observer reliability. The ICC value of c2 was 0.832 (range 0.785–0.869), indicating excellent inter-observer reliability. The ICC value of d was 0.879 (range 0.845–0.906), indicating excellent inter-observer reliability. The ICC value of e was 0.901 (range 0.873–0.922), indicating excellent inter-observer reliability. The ICC value of f was 0.931 (range 0.911–0.946), indicating excellent inter-observer reliability. (Table 1).

Measurement Results of C3-C7 Cervical Vertebra Markers

The maximum values of seven parameters measured were all at C7. The minimum b value was at C5, and the minimum f value was at C4. The minimum values of the other five parameters were all at C3, and there was an increasing relationship from C3 to C7 ($p < 0.05$). There was significant difference between male and female with regard to c1, c2, e and d values ($P < 0.05$). No significant differences were observed between men and women regard to the ratio of related parameters (a/c1, b/c2, a/f, b/f, d/e). (Table 2, Fig. 2).

Discussion

In this article, we found two specific bone markers, the junction of uncinate vertebra joint and transverse process vertebral body, which can be ideal markers in ACAF surgery. The values of a and b were measured for the first time in the world, and their change trends were described. c1, c2, and e were measured and compared with other study data. Finally, it is found that the ratio method may have surprising significance in this study.

Specific Anatomic Markers of Lifting Technology in ACAF

The study of morphology and anatomy of cervical spine is of great significance to the development of cervical spinal surgery.[10] Accurate anatomical positioning can effectively reduce the difficulty of operation and reduce the operation time.[11] Previous studies on cervical vertebra related anatomy focused on the three-dimensional structure of the uncinate joint, the size of the intervertebral foramen and the transverse diameter and angle of the pedicle, but ignored the anatomical information between the anterior edge of the vertebral body and the uncinate joint, as well as the junction of the transverse process and the vertebral body.[9] As far as we know, this is the first detailed description of the anatomical information, which is related to the special needs of different surgical methods. Usually, the thickness of the compression mass from the front of the cervical spinal cord was measured preoperatively to determine the thickness of vertebrae removed during operation. Only judging by operation experience was inaccurate. In order to accurately estimate the thickness of the extracted vertebral body, we need to find the related anatomical markers. In addition, the junction of uncinate vertebra joint and transverse process vertebral body is easy to identify and stable in the procedure of ACAF, which is an ideal marker.

The Measurement and Significance of a, b, c1, c2 and e

a and b, as important parameters in ACAF, have not been reported in the previous literature. In our study, it was found that a and b of different cervical segments were very different. The values of a gradually increased from C3-C7 (4.34–6.91 mm) and reached the maximum value at C7. On the other side, the values of b had a different trend (C7 > C6 > C3 > C4 > C5). The minimum value of b was 6.8 mm at C5 and the maximum was 8.79 mm at C7. The big difference existed between the maximum and the minimum value of a and b (>2 mm). It should be noted that the surgical segment should be accurately judged in the procedure of ACAF, because the thickness of the resection vertebral body suggested by the same anatomical

Parameter	sex	C3	C4	C5	C6	C7
a/c1**	M	0.26 ± 0.05	0.27 ± 0.05	0.27 ± 0.04	0.28 ± 0.04	0.35 ± 0.05
	F	0.27 ± 0.04	0.27 ± 0.03	0.27 ± 0.05	0.29 ± 0.06	0.38 ± 0.06
b/c2**	M	0.45 ± 0.05	0.42 ± 0.04	0.39 ± 0.05	0.38 ± 0.04	0.47 ± 0.08
	F	0.44 ± 0.05	0.4 ± 0.04	0.39 ± 0.05	0.39 ± 0.05	0.49 ± 0.06
a/f**	M	0.33 ± 0.07	0.39 ± 0.1	0.39 ± 0.07	0.41 ± 0.07	0.48 ± 0.08
	F	0.33 ± 0.07	0.38 ± 0.07	0.37 ± 0.08	0.4 ± 0.1	0.52 ± 0.09
b/f**	M	0.56 ± 0.09	0.6 ± 0.12	0.54 ± 0.12	0.54 ± 0.08	0.61 ± 0.1
	F	0.53 ± 0.09	0.55 ± 0.11	0.51 ± 0.09	0.51 ± 0.09	0.66 ± 0.1
d/e**	M	0.66 ± 0.05	0.72 ± 0.04	0.73 ± 0.06	0.77 ± 0.06	0.77 ± 0.04
	F	0.7 ± 0.05*	0.75 ± 0.04*	0.75 ± 0.04	0.76 ± 0.05	0.78 ± 0.07

TABLE 2 Ratio of related parameters of C3-C7 cervical vertebra markers

a: the distance from the anterior edge of the vertebral body to the anterior edge of the bilateral uncinate joint; b: the vertical distance from the anterior edge of the vertebral body to the junction line between the two lateral processes; c1: the sagittal diameter of the vertebral body; c2: the sagittal diameter of the vertebral body; d: the distance between the anterior edge of the uncinate joint; e: the transverse diameter of the vertebral body; f: the sagittal diameter of the vertebral canal. The data represents the mean ± SD.; *There was significant difference between them ($p < 0.05$).; **There was significant difference in one-way ANOVA ($p < 0.05$)
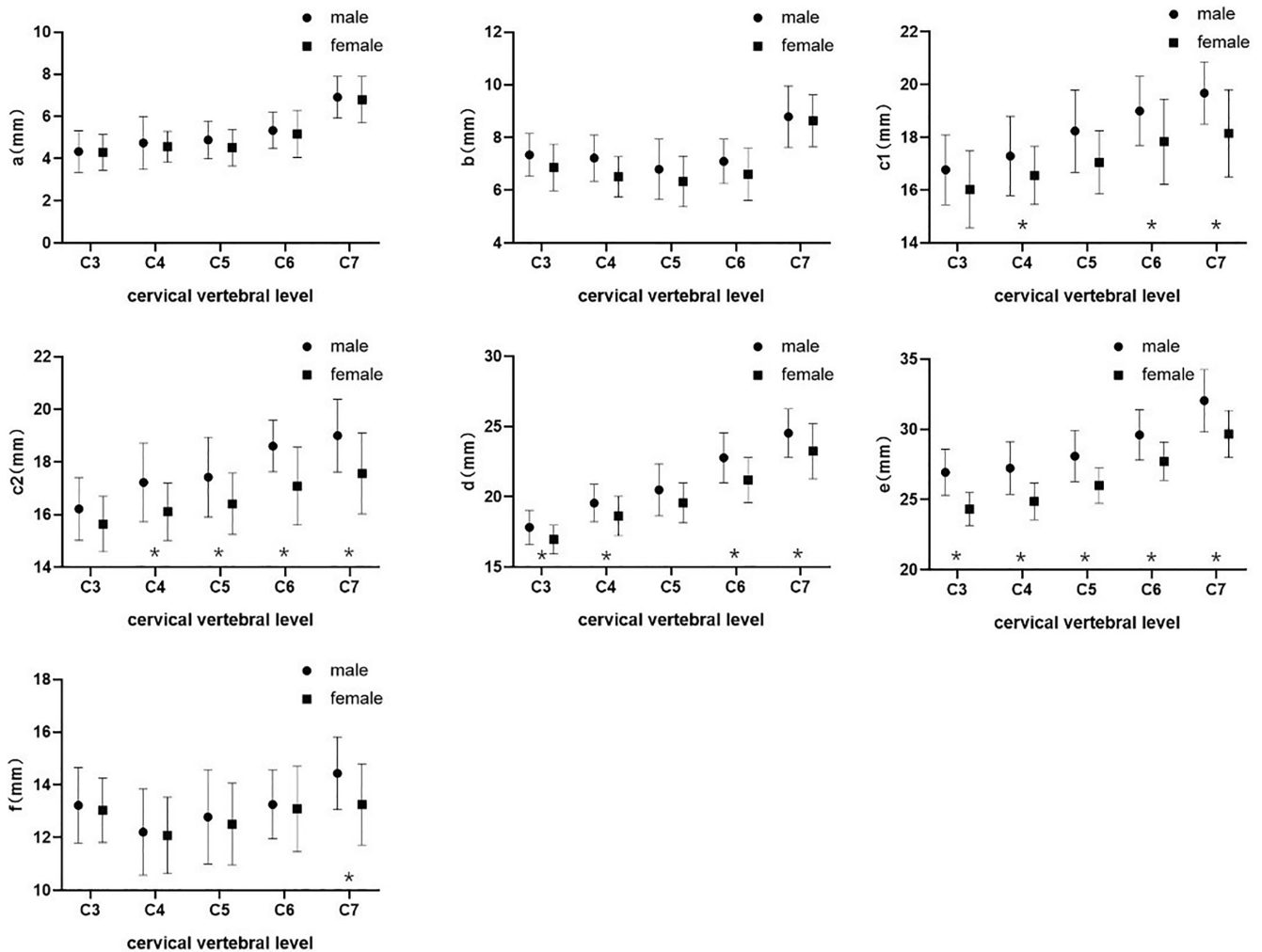
Fig. 2 Measurement results of C3–C7 cervical vertebra markers. (a) The distance from the anterior edge of the vertebral body to the anterior edge of the bilateral uncinate joint; (b) The vertical distance from the anterior edge of the vertebral body to the junction line between the two lateral processes; (c1) The sagittal diameter of the vertebral body; (c2) the sagittal diameter of the vertebral body; (d) the distance between the anterior edge of the uncinate joint; (e) the transverse diameter of the vertebral body; f: the sagittal diameter of the vertebral canal. The data represents the mean $\pm$ SD. *There was significant difference between them ($P < 0.05$).

markers at different segments was not the same. The corresponding thickness of the vertebral body was resected according to the thickness of the compression in front of the spinal cord at different cervical levels, to achieve the minimum trauma and best postoperative effect. At the same time, because the maximum value of b was 8.79 mm, the anatomical mark will not be enough for resecting more thickness (>8.79 mm). Therefore, it was recommended to use the o-arm scanning machine as a supplement in the operation to help determine the thickness of the resected vertebral body.

There were some differences in the measurement results of c1 and e in different studies. Kwon *et al.*[12] performed CT scan on the cervical vertebrae of 100 volunteers (including 50 males and 50 females). The average value of e was 24.6 $\pm$ 2.4 mm for males, 23.0 $\pm$ 2.4 mm for females.

The maximum value of e was 17 mm for males and 14 mm for females. The average value of c1 was 17–18 mm for males with the minimum value 13 mmand 15–16 mm for women with 10 mm for the minimum. The difference between males and females was statistically significant. Zhu *et al.*[13] performed three-dimensional CT scan on 136 Chinese adult cervical vertebrae, including 68 males (22–57 years old) and 68 females (19–71 years old). It was found that C1 and e gradually increased from C3-C7, and males were larger than females, but the measurement values were smaller than the previous study. The trend of our results was the same as that of the above two studies, but the results were slightly larger. At the same time, there showed no statistical significance of gender impact. We speculated that it might be due to the influence of different age distribution and the region of the

selected population. c_1 and c_2 were both sagittal diameter of the vertebral body, but they belonged to different anatomical planes. In previous studies, the commonly measured plane is the same as c_1, while the value of c_2 has the same significance in ACAF surgery. The results showed that c_1 was slightly larger than c_2, but there was no significant difference between them. Moreover, c_1 and c_2 increased from C3–C7, which was the same as the previous studies.[12,13]

Ratio Method and its Application in Research

In multilevel cervical spondylotic myelopathy and OPLL, there were usually ossification, intervertebral disc or osteophyte invading the spinal canal, resulting in spinal canal stenosis and spinal cord compression injury. Tatarek et al.[14] proved that the shape of spinal canal varies greatly among different genders and people, so it was difficult to use a fixed cervical canal value to determine the diagnosis of cervical canal stenosis. At present, the Torg–Pavlov ratio is widely accepted as a practical and objective index to judge cervical spinal stenosis, that is, the ratio of sagittal diameter of cervical spinal canal and its corresponding vertebral body. Pavlov et al.'s study showed that there was a difference in sagittal diameter of the spinal canal between the sexes, but there was no difference in the Torg–Pavlov ratio.[15] To a certain extent, the application of the ratio could exclude the differences of measurement results caused by factors such as gender and people.[16] Tan et al. invented a novel radiographic ratio method evaluating the risk of cervical spondylotic myelopathy, which indicates that the ratio method is more reliable compared to direct numerical comparison methods.[17] In our study, there were significant differences between men and women in c_1, c_2, d, e, f, but the difference was not significant when the ratio was used (a/c_1, b/c_2, a/f, b/f, d/e). The results suggested that the ratio could be used to locate anatomical markers. In other words, the ratio method may be more convenient and accurate in practical application, because it excludes the influence of gender and other factors on the results. In the practice of ACAF surgery, the cervical canal rate was calculated according to different segments preoperative, and the thickness of the resected vertebral body was determined according to the results of a/f and b/f of the corresponding segments to achieve accurate resection.

Limitations

There is some limitations in this study: (i) the small sample size and single center approach which could theoretically bias the results. Therefore, randomized controlled trials with larger sample sizes and multicenter research are needed to further investigate; (ii) for patients with cervical hyperplasia or deformation, this judgment standard is not applicable. It is necessary to pay attention to whether the patient has

cervical deformity before the operation; (iii) there are physiological differences among individuals, so patients should be combined with their own conditions for reference in this study; (iv) there may be differences in image quality, images reading and measurement between cases; and (v) only a retrospective study of imaging data was conducted, and the clinical effect test was not completed.

Conclusion

With this study, we have provided detailed data on the anatomy of the spatial position information of the knuckle joint and the front of the transverse process, and determined that they are important anatomical structures for the surgical approach of ACAF. Seven parameters related to ACAF were also measured, including two parameters (a and b) measured for the first time. In addition, we have an exciting finding: the ratio method can exclude the influence of gender factors in ACAF related parameters. Knowledge about morphometry may contribute to avoiding various complications and achieve higher success rates in cervical spine surgeries. Also, to a certain extent, understanding the anatomic structures and application of the ratio method will help anatomy study.

Ethics Approval and Consent to Participate

The procedure related to human subjects was approved by the Ethics Committee of the Changzheng Hospital.

Conflict of Interest

We declare that all authors have no conflict of interest.

Author Contributions

Qingyang Pang, Shiyong Ling and Bin Zhang have contributed equally to this work. Jingchuan Sun conceptualized and designed this study. Qingyang Pang and Shiyong Ling measured image data. Qingyang Pang and Bin Zhang wrote the first draft of the manuscript. Zhu Jian directed the revision of the article. All authors contributed to the article and approved the submitted version.

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