The Feasibility of Anterior Occipital Condyle Screw for the Reconstruction of Craniovertebral Junction: A Digital Anatomical and Cadaveric Study of a Novel Technique

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Research article

Keywords: Anterior occipital condyle screw, Craniovertebral reconstruction, Optimal trajectory, Cadaveric study

DOI: https://doi.org/10.21203/rs.3.rs-113707/v1

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Abstract

Background: Anterior occipital condyle screw (AOCS) could be a feasible technique apply to the reconstruction of craniovertebral junction. This study was to analyze the feasibility of AOCS.

Method: The craniovertebral junction computed tomography (CT) scans of 40 adults were enrolled and imported into Mimics software. Then the three-dimensional reconstruction digital model of craniovertebral junction were established to determine entry point, insertion angle and screw’s trajectory. After AOCS inserted into ten human cadaver spine specimens, CT scans were performed to verify the location between screws and important structures.

Result: The optimal entry point is located caudally and medial to the ventral of occipital condyle. The optimal trajectory is in inclination angle ($5.9°±3.4°$) in the sagittal plane and diverge angle ($26.7°±6.0°$) in the axial plane with the screw length around $21.6±1.2$ mm. There were no screws invaded into hypoglossal canal and vertebral artery in all specimens.

Conclusion: AOCS fixation is a feasible novel technique for anterior craniovertebral junction reconstruction, and it could be an effective alternative operation for anterior reconstruction with titanium mesh cage.

Background

The craniovertebral junction (CVJ) which connect the spinal and skull base is a pivotal structure, because they are complex combinations of osseous and ligamentous which not only supports a large degree of motion, but also allows biomechanical stability[1]. However, there are some disorders that lead to death and disability in CVJ, such as rheumatoid, tuberculosis, deformity, trauma, infection, congenital malformation and tumor, those diseases will result to cranial nerve dysfunction, limbs paralysis, myelopathy even death[2].

Upper cervical reconstruction should be performed when CVJ is rendered unstable or spinal cord compression by those dangerous diseases. Usually, the treatments of them are total en bloc spondylectomy using a combined approach[3] and reconstruction using clival plate with titanium mesh cage[4]. Although those two methods can guarantee immediate immobility and achieve satisfactory bone fusion, lots of complications were reported including new neurologic deficit, implant failure, cerebrospinal fluid leakage and cervical nerve root injury[5, 6]. And, clival plate with titanium mesh cage may be invade into skull without long learning time and abundant exercises[7]. Moreover, the optimal internal fixation should permit stronger support and could be safely insertion the instrumentation into the upper cervical spine, even could achieve enough support using single anterior approach without supplement fixation.

Nowadays, the occipital condyle comes to be a hot point among spine surgeons, and regard occipital condyle as a feasible anchor point in the craniovertebral junction reconstruction. As for anatomy, Zhou et
al reported a CT-based method for morphometric analysis of 27 fresh-frozen human cadaveric, and they concluded that the occipital condyle can safely contain a 3.5 mm diameter screw[8]. On the other hand, Tong et al reported that they have used occipital condyle-C1 complex screw to 8 patients with basilar invagination, and the screw haven’t misplaced or poorly positioned in the CT-scan and no neurovascular complications were detected during follow-up[9]. In this study, we proposed an anterior occipital condyle screw (AOCS) fixation for craniovertebral junction reconstruction and the anatomical feasibility was evaluated using a commercially 3D reconstruction software package and human cadaver specimens.

Methods

40 volunteer’s craniovertebral junction 3D models were generated based on CT data and measured the parameters of virtue screws inserted in the models. Then design a plate for anterior occipital condyle screw fixation and verify the feasibility and accuracy of the plate by specimen simulation. The flow of this study shown as follow (Fig. 1). All patients provided the printed informed consent to participate in our study, and ethical approval and written consents from ethics committee of our hospital were waived because the retrospective design of this study.

Digital measurement of AOCS in volunteer’s 3D models

Patients performed CT scan (Philips Medical Systems, Eindhoven, the Netherlands) of the craniovertebral juncture from July 2017 to November 2018 were enrolled in this study. Exclusion criteria are shows as follow: (1) patients less than 25 years of age or old than 65 years of age, (2) Surgical history of craniovertebral junction, (3) abnormalities including Klippel-Feil syndrome, atlas assimilation and basilar invagination. (4) Patients with trauma, tumor, rheumatic arthritis. Finally, a total of 40 suitable patients met those criteria after our analysis whose average age are 35.4 ± 7.6 (22 males, 18 females). Then all patients’ CT scan sets were converted as DICOM 3.0 format, and imported all data into commercially 3D reconstruction software package Mimics 19.0 (Materialise, Leuven, Belgium). Generate 3D reconstruction model of skull base, occipital and atlas (Fig. 2).

After generated the 3D model, we inserted the anterior occipital condyle screw in those models, and the optimal trajectory should have the longest screw length of bicortical purchase and no invade to hypoglossal canal or vertebral artery. The insertion point at the medial and caudal on the anterior occipital condyle, then one screw was inserted at this insertion point and the screw direction is point to transfigure site of occipital condyle and skull base (Fig. 3). Then import the 3D model and screws into 3-matic (Materialise, Leuven, Belgium), and building up horizontal plane (P1) and vertical plane (P2) of foramen magnum and the long axis of screws by Analyze Tool. The angle between screw and P1, P2 is inclination angle, and divergent angle respectively (Fig. 4).

Cadaver specimen verification of AOCS

We designed a plate depend on the parameters of anterior occipital condyle screw and craniovertebral junction (Fig. 5). Ten human cadaver specimens were collected from our hospital. The age and cause of
death were unknown. The specimens were confirmed by CT scans as normal craniovertebral junction to exclude the existence of any deformities, trauma, tuberculosis, tumors, and rheumatoid arthritis.

**Measure parameters of AOCS in 3D model of specimens**

Firstly, generate the 3D model of 10 specimens in Mimics 19.0 based on CT scans, and we placed plate model to the anterior of occipital and atlas. Secondly, screws were inserted from plate to occipital according the plate model. Finally, import 3D models into 3-matic 19.0 and measure inclination angle, divergent angle and screw length of AOCS.

**Measure parameters of AOCS in specimens**

After exposure of anterior occipital condyle and atlas, we firstly put up plate to the craniovertebral junction and inserted screws assisted by plate created by 3D print. Secondly, those specimens performed CT scan to clarify whether there was any hypoglossal canal or vertebral artery injury. Finally, measure inclination angle, divergent angle and screw length of AOCS and compare the parameters of anterior occipital condyle screw between 3D models and cadaver specimens (Fig. 6).

**Statistical analysis**

All results were presented as Mean ± Standard deviation. The left and right occipital condyle's inclination angle, diverge angle and screw length of volunteer's 3D models were analyzed using compared T-test in SPSS version 21.0 (Chicago, IL). And the comparison of occipital condyle's inclination angle, diverge angle and screw length between specimen's model and specimens were conducted by compared T-test. P < 0.05 was set as statistically significant in this study.

**Result**

**The parameters of AOCS measured in Volunteer’s 3D models**

All 3D models can insert screw with hypoglossal canal or vertebral artery injury, and the parameters of anterior occipital condyle screw were shown in Table 1. There was no significant difference between left and right site in the parameters of anterior occipital condyle screw (P > 0.05). The totally inclination angle was 5.9° ± 3.4° (0.6° ~ 11.9°) and diverge angle was 26.7° ± 6.0° (17.1° ~ 37.7°), the screw length in all model is 21.6 ± 1.2 mm (19.1 ~ 25.0 mm) in the meanwhile.
Table 1. The parameters of anterior occipital condyle screw on the volunteer's 3D model

| Parameter            | Mean±SD  | Range     | P-value |
|----------------------|----------|-----------|---------|
| Inclination angle,°  |          |           |         |
| left                 | 6.1±3.5  | 0.6~11.9  | 0.21    |
| right                | 5.8±3.2  | 0.9~11.1  |         |
| total                | 5.9±3.4  | 0.6~11.9  |         |
| Diverge angle,°      |          |           |         |
| left                 | 26.7±6.1 | 17.2~37.7 | 0.48    |
| right                | 26.9±5.9 | 17.1~37.6 |         |
| Total                | 26.7±6.0 | 17.1~37.7 |         |
| Screw length,°       |          |           |         |
| left                 | 21.5±1.2 | 19.4~24.0 | 0.2     |
| right                | 21.7±1.3 | 19.1~25.0 |         |
| Total                | 21.6±1.2 | 19.1~25.0 |         |

Table 2. The comparison of screw parameters between specimen's Model and Specimen

| Parameters                 | Model    | Specimen | P-value |
|----------------------------|----------|----------|---------|
| inclination angle(°)       | 5.8±0.5  | 5.7±0.5  | 0.42    |
| diverge angle(°)           | 26.7±5.4 | 26.3±5.1 | 0.25    |
| Screw length(mm)           | 21.6±0.7 | 21.7±1.0 | 0.75    |

The parameters measure in specimen’s models and specimens

Before inserted anterior occipital condyle screws in those ten cadaveric specimens, we performed CT data and imported it into Mimics 19.0 for 3D model generation. Then inserted anterior occipital condyle screws in specimen's 3D models and measured the parameters including inclination angle, divergent angle and screw length. Then, anterior occipital condyle screws were inserted assisted by plate, and measured screw's parameters later. The parameters of models and specimens were shown in Table 2. There was no significant difference in inclination angle between specimen's model (5.8° ± 0.5°) and specimen (5.7° ±
0.5°) (P = 0.42). Similarly, there were no statically significant in diverge angle and screw length between specimen's model and specimens (26.7° ± 5.4°, 21.6mm ± 0.7 mm VS 21.7° ± 1.0°, 20.3mm ± 6.0 mm. P > 0.05).

**Discussion**

In recent years, there is a towering up tendency in the incidence rate of tumor, tuberculosis, and trauma in craniovertebral junction, many scholars have reported the dangerousness and challenge of these diseases\[10, 11\]. And en bloc resection is a popular operation method for upper cervical reconstruction, which has been reported achieved desired clinical efficacy\[6, 12, 13\]. Similarly, clival screw and plate fixation was also reported as a feasible technique for craniovertebral reconstruction in anatomy\[14\]. However, both two surgical method have some disadvantages. On the one hand, there were some complications and risks of aforementioned methods including (1) the inner structure of clivus was the epencephalon and foramen magnum which contains medulla oblongata and it maybe injury when inserted the clival screw. Invade into cranial cavity is a fatal risk, (2) Duding the posterior approach exposure, the vertebral, venous sinus and plexus around the upper cervical spine which maybe cause bleeding once injured\[15\]. On the other hand, many important anatomical structures such as vertebral artery, C2 nerve root and posterior cervical muscle will be damaged during exposure in posterior approach which may result neck pain\[16, 17\]. And posterior pedicle screws maybe infeasible in some patients with anatomic variation such as narrow C2 isthmus and absence of bone structure\[18, 19\].

As a consequence, our group was intended to design an alternative operation method, which can prevent from aforementioned difficult and complications. Bosco et al reported a morphometric evaluation and anatomical parameters of occipital condyle, and shows that the average occipital condyle length, width, anterior height and posterior height is 18.8 ± 2.3 mm, 10.3 ± 1.5 mm, 13.2 ± 2.2 mm and 8.5 ± 1.6 mm, respectively. Moreover, the occipital condyle can safely contain a screw without hypoglossal canal invaded\[20\]. Similarly, our group have reported the same outcome in a CTA based study\[21\]. As for cadaveric specimen evaluation, Yu et al reported that a total of 40 4-mm posterior occipital condyle screws successfully inserted into twenty (40 occipital condyles) cadaveric specimens. And no screw invaded into hypoglossal canal verified by postoperative CT scan\[22\]. According to those study, occipital condyle could be a feasible bone structure for craniovertebral junction reconstruction in anterior approach. However, this novel surgical method shows feasible but vital surrounding structures need take into account. The cephalad and medially of occipital condyle is hypoglossal canal which contains hypoglossal nerve, and foramen magnum\[23\]. So, in the sagittal plane, if the anterior occipital condyle screw placed with a large inclination angle, it may invade hypoglossal canal and damage hypoglossal nerve, on the contrary, if the screw inserted too caudally or medially, it may violate vertebral artery or foramen magnum which may injury to spinal cord and medulla oblongata\[24, 25\].

In this study, we enrolled 40 healthy volunteers’ craniovertebral junction CT data and generated 3D models using Mimics 19.0 software successfully. This digital anatomy and cadaveric study of craniovertebral junction confirmed the anatomical feasibility of anterior occipital condyle screw and plate
fixation and primarily verified the entry point and optimal trajectory of AOCS. According to our result, the optimal trajectory for AOCS is inserted with an inclination angle of 5.9° ± 3.4° on sagittal plane and diverge angle is 26.7° ± 6.0° on axial plane, and the average screw length is 21.6 ± 1.2 mm. Researchers reported that screw length longer than 18 mm can have enough pull-out strength[26]. As for simulation in cadaveric specimens, then all anterior occipital condyle screws were inserted assisted with plate successfully without hypoglossal canal injury or cortex broken. All specimens were performed CT scan and generated 3D models using Mimics 19.0 software, after that parameters of anterior occipital condyle screw were measured and compared in specimen's models and specimens. There was no significant difference in inclination angle, diverge angle and screw length between two group (P > 0.05). This shown that the anterior occipital condyle screw can be safely placed assisted with plate, and using plate can enhance the accuracy and decrease the risk of vital surrounding anatomical structure damage.

We should pay attention to the hypoglossal canal during anterior occipital condyle screw fixation, because hypoglossal canal which contains hypoglossal nerve and venous plexus passes from intracranial to the anteromedial upper part of occipital condyle, its location determined the safe area of screw placement. Usually, the hypoglossal canal located in the anterior medial of occipital but some patients’ hypoglossal canal located posterior medial of occipital condyle. As a result, we should analyze the CT scan every single patient and justify the inclination angle when hypoglossal canal located in the posterior medial of occipital condyle[27]. Therefore, correct preoperative diagnosis and radiological outcome analysis should be taken before perform anterior occipital condyle screw fixation.

The primary indication of anterior occipital condyle screw fixation shown as follow: (1) Anterior craniovertebral junction reconstruction; (2) upper cervical spine abnormal such as C2 isthmus narrow; (3) occipital condyle fracture; (4) patients suffer from failure of posterior upper cervical spine fixation who can't perform a second operation. However, patients with occipital condyle or vertebral artery deformity should be considerate as the contraindication.

**Limitation**

This study has some limitations, first, the simple size of the volunteers was not ideal, but this is a study which aimed to propose a new technique and testify the feasibility. Second, as a result of limited source of specimens, only ten cadaveric specimens were simulated anterior occipital screw fixation. Although all specimens were placed anterior occipital condyle screws safely, this technique still needs a lot of researches for further testify. Finally, anterior occipital condyle screw plate fixation is feasible but whether it can achieve immediate stability and abundant support strength still needs biomechanical study and further clinical study.

**Conclusion**

In conclusion, anterior occipital condyle screw plate fixation for craniovertebral junction reconstruction maybe a feasibility and safety surgical technique, and it could regard as a salvage technique eventually,
and insert anterior occipital condyle screw assisted with plate can improve the accuracy and avoid risks.

**Abbreviations**

AOCS
Anterior occipital condyle screw; CVJ:The craniovertebral junction; 3D:Three dimensional.

**Declarations**

**Ethics approval and Consent for participate**

All patients have signed a printed informed consent form to participate in our study, and ethical approval and written consents from ethics committee of our hospital were waived because the retrospective design of this study. In this study, there is no any identifying personal or clinical details along with any identifying images to be published.

**Consent to publish**

Not applicable.

**Availability of data and materials**

All data are available from the corresponding author on reasonable request.

**Competing interests**

The authors declare no conflicts of interest in association with the present study.

**Author details**

**Funding**

The role of funding which named National Nature Foundation of China (81572217) is in the design of the interpretation of data and in writing the manuscript, and Natural Science Foundation of Zhejiang Province (LY18H060002) is in the design of this study.

**Author’s contributions**

The contribution of each author to this paper was list below: XDL (Data collection, Writing original manuscript); MHJ (Methodology); WY (Software measure, statistical analysis); GKF and MWH (prepared the figures, revised the manuscript). All authors read and approved the final manuscript.

**Acknowledgements**

Not applicable.
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