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Stability analysis of occipitocervical fixation by occiput-C2 pedicular screws construct. A human cadaveric study

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Abstract

Objective: The present study aims to evaluate the stability provided by occipitocervical (OC) fixation using occipital plate and C2 pedicular screws. **Methods:** The study included 6 formalin preserved whole human cadaveric specimens. Occipito-cervical fixation was performed using occipital plate and C2 pedicle screws connected by rods. Specimens were manually loaded by the maximum possible flexion, extension and axial rotation. Assessment of stability of fixation was done after 100, 500, 1000, 2000 and 3000 cycles. In the first 3 specimens (group 1), repetitive loading was planned to be initially applied in flexion and extension. If there was no failure of the construct at 3000 cycles, loading has to be continued in axial rotation. In the second 3 specimens (group 2), repetitive loading was planned to be applied initially in axial rotation up to 3000 cycles. If there was no failure of the construct, loading has to be continued in flexion and extension. **Results:** group 1 showed no implants failure apparently or radiologically after 3000 loading cycles. However, failure occurred at different sites when axial rotation loading was applied at 500, 700 and 900 cycles respectively by axial rotation loading cycles. On the other hand, when axial rotation was initially applied to group 2, failure occurred at 1050, 1000 and 800 respectively cycles before applying flexion and extension loading. **Conclusions:** Our study revealed that occiput-C2 pedicle screw construct, without supplementary C1 lateral mass provided stability in flexion and extension loading. However, repeated axial rotation loading causes failure of construct.

Keywords

Cadaveric, Biomechanics, Occipitoatlantoaxial fixation, Occipital screw, C2 pedicle screw.

Authors' role

Tarek Elfiky: Dissection and instrumentations of the specimens and writing the manuscript, Waleed Sabbah Ayman: Stability testing and writing the manuscript. Ayman Ahmed Kkanfour: preparation of the specimens, critical revisions and dissection and exposure, Hesham Elsaghir: study design and critical revisions

Introduction

The occipitocervical (OC) region is the most mobile part of the cervical spine, with 50% of flexion and axial rotation occurring at the atlantooccipital and atlanto-

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axial joints. The OC junction is stabilized only by capsuloligamentous and muscular structures. As a result, its stability is vulnerable to a multitude of disorders to include infection, trauma, tumor, inflammatory, and other degenerative conditions.[1,2]

Historically, stabilization of this junction dates back to 1927 when Foerster used a fibular strut graft construct.[3] Since then, other nonrigid methods of stabilization have been used, including wire fixation, pin fixation, hook constructs, and others with onlay bone graft and halo immobilization.[4] However, these techniques have been shown to be biomechanically inferior to procedures that offer segmental fixation.[5,6] Surgical fixation has advanced during the past decades, and occipital plate-rod-screw instrumentations are currently the most widely used method. These techniques use C2 pedicle screws with and without C1 lateral mass screws that are then incorporated into occipital plate fixation with occipital screws.[7-9] Special considerations are necessary for surgery because of the unique neurologic, musculoskeletal, and vascular anatomy of the spine, and the need to restrict all planes of motion.[10] Proper stabilization system in this unique transitional area must be able to resist loads in the different axis of motion (flexion, extension, lateral flexion, rotation, distraction and axial loading), until solid fusion is obtained.[11] Several biomechanical and finite element studies have compared the stability of various occipitoatlantoaxial stabilization techniques.[10,12-15] However, to date there are no consensus about the standard occiput to C2 fixation and the necessity of routine incorporation of C1 lateral mass screws into (OC) instrumentation constructs.[16,17]

The present study aims to evaluate the stability provided by OC fixation using occipital plate and C2 pedicular screws.

Material and methods

The study included 6 formalin preserved whole human cadaveric specimens obtained from the dissecting room of the Anatomy Department at our institute. Occipitocervical fixation using occipital plate and C2 pedicle screws connected by rods was performed in all specimens. The cadavers included 6 males, with different ages. However, the exact age of the cadaveric specimens was not available from the records. This study protocol was approved by the institutional review board and ethics committee.

Specimen preparation

All specimens were dissected, instrumented and tested in prone position. A midline vertical incision was done at the occipitocervical region. Dissection was done with preservation of the facet joints and osteoligamentous structures. (Nondestructive stability testing).

Methods of fixation

1. Occipital fixation was performed with an occipital plate using 2 bicortical screws (4.5 ×12mm). The occipital plate has 4 rigidly locked holes for midline screws placement and arms that extend laterally, which contain bilateral slots for rods attachment.

2. Cervical fixation was performed with bilateral C2 pedicular screws which were 3.5 mm in diameter.

3. Adequacy of screws placement was assessed in all specimens before testing using portable x-ray machine.

4. The rods were inserted in the slots of the screws that are placed on the lateral wing of the plate and the slots of the pedicle screws in C2, and final tightening of the nuts was performed.

The dissection and fixation were carried out by a senior consultant spine surgeon.

Methods of Appling forces

1. The specimens were manually loaded by the maximum possible flexion, extension and axial rotation, with the head lying free at the edge of the table.

2. Assessment of stability of fixation was done after 100, 500, 1000, 2000 and 3000 cycles, and any construct failure was documented.

3. In the first 3 specimens (group 1), repetitive loading was planned to be initially applied in flexion and extension. If there was no failure of the construct at 3000 cycles, loading has to be continued in axial rotation.

4. In the second 3 specimens (group 2), repetitive loading was planned to be initially applied in axial rotation up to 3000 cycles. If there was no failure of the construct, loading has to be continued in flexion and extension. (Fig. 1)

The manual loading was applied by a spine fellow.

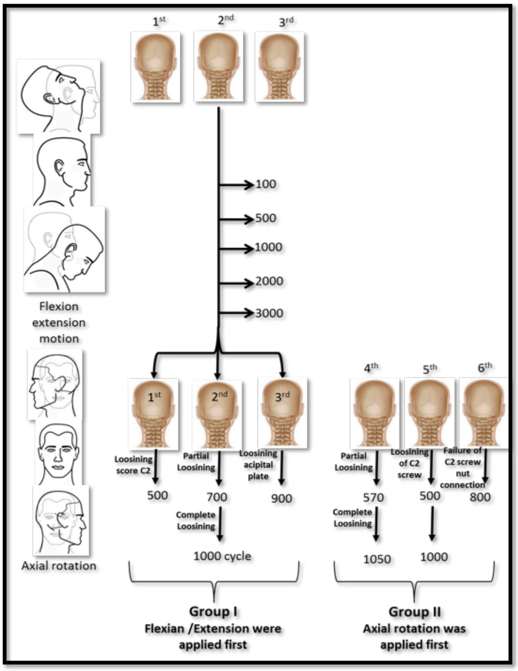


Figure 1. Flow chart summarizing the methods of applying loading and the results.

Methods of Radiological evaluation

Lateral radiographs of cervical spine were done in neutral, flexion, and extension after instrumentation to all specimens and after 100, 500, 1000, 2000 and 3000 loading cycles, and any construct failure was documented.

Method of statistical analysis

After data collection, the results were tabulated and analyzed. Descriptive statistics were used for parameters which did not need statistical analysis. SPSS software (v 9.4) software was used for the analysis.

Results

The maximum possible flexion, extension and axial rotation were performed in all specimens, with some difficulty, because of their stiffness as a result of formalin preservation. The first 3 specimens (group 1) showed no implants failure apparently or radiologically after 3000 loading cycles. However, failure occurred at different sites when axial rotation loading was applied at 500, 700 and 900 cycles respectively.

On the other hand, when axial rotation loading was initially applied to the second 3 specimens (group 2), failure occurred at 570, 500 and 800 cycles respectively before applying flexion extension loads (Fig. 1, Table 1,2).

Sites of failure

As shown in table 2, loosening of C2 screw occurred in 4 specimens, while occipital plate loosening occurred in one specimen and loosening of screw nut connection in one specimen.

Case illustrations are shown in figures 2, 3 and 4.

Table 1. Distribution of cadaveric occipitocervical stability regarding axial rotation loading.

Number of cycle	Number of success	Percent
100	6	100
500	5	83.3
1000	3	50
2000	0	0
3000	0	0
Total	6	100

Table 2. Distribution of the cadaveric occipitocervical stability after rotation loading and the sites of failure.

Case No.	No. of cycle till Partial failure	No. of cycle till complete failure	Site of failure
1	-	500	Loosening of C2 screw
2	700	1000	Loosening of C2 screw
3	-	900	Loosening occipital plate
4	570	1050	Loosening of C2 screw
5	500	1000	Loosening of C2 screw
6	-	800	Failure of C2 screw nut connection

A

B

Figure 2. The first specimen from group 1. Flexion and extension loading were applied first till 3000 cycles, and fixation remain stable. After that, axial rotation was applied till 500 cycles when loosening of C2 screw occurred.

Discussion

This study was to evaluate the stability of OC fixation using occipital plate and C2 pedicle screws in 6 human cadavers under flexion, extension and axial rotation loading. Our results showed that axial rotation and not flexion and extension loading affect the stability of the contract.

Clinical studies have demonstrated that the occipital plate combined with pedicle screws provided a high fusion rate and maintained alignment in the OC region, in both elderly and pediatric patients.[18,19] Hankinson et al have reported a 100% occipitoatlantoaxial fusion rate in pediatric patients.[19] Furthermore, Oda et al showed,

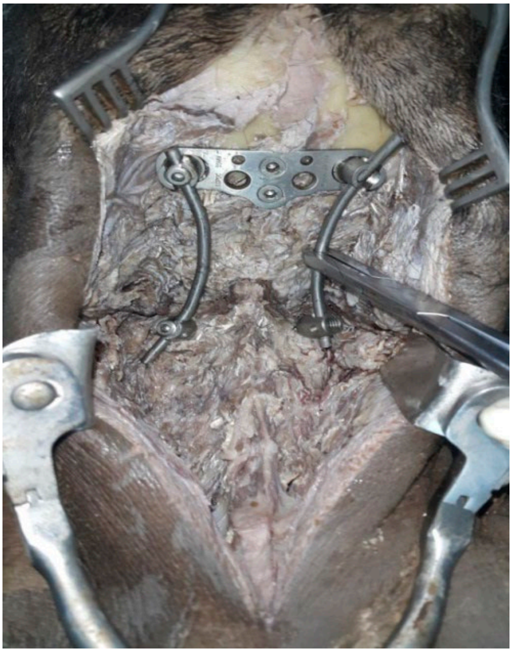
A B

Figure 3. The third specimen from group 1. Flexion and extension loading were applied first till 3000 cycles and fixation remained stable. After that, axial rotation was applied till 900 cycles when occipital screw loosening occurred.

in their cadaveric models, that the combination of occipital screws and C2 pedicle screws provided the highest stability among other constructs.[5]

Several techniques of C2 fixation have been evaluated. In addition to being a challenging screw insertion technique, the transarticular screw has the greatest risk of injuring the vertebral artery during placement. The C2 pars screw has the same high risk of vertebral artery injury without the biomechanical strength of C2 pedicle screws. The pedicle screw technique may have a slightly less risk of vertebral artery injury. The C2 laminar screw technique theoretically has the least risk of vertebral artery injury. However, difficulty in rod contouring can also present a challenge. Moreover, the presence of laminae is a prerequisite for using the crossing C2 laminar screws. [20]

A debate of inclusion of lateral mass C1 to the construct existed. In their biomechanical study, Wolfla et al showed that the placement of C1 lateral mass screws did not increase occipitocervical construct stability when compared with construct without of C1 lateral mass screws. The authors, however, used C2 pars screws, but not pedicle screws.[16] On the other hand, in their nonlinear finite element model, Liu et al revealed that the addition of supplemental C1 lateral mass screws to occiput-C2 fixation not only enhances greater stability, especially during axial rotation, but also has the advantage of distributing the stress evenly and reduces the risk of construct



A B

Figure 4. The Second specimen from group 2. Axial rotation loading was applied first till 1050 cycles, when loosening of C2 screw occurred.

failure due to occipital screw pullout and rod fracture.[17] We agree with them that this method may be a reasonable option in some selected cases in severe rheumatoid arthritis, the chronic smoker, tuberculosis, osteopenia, or osteoporosis in elderly patients, where the bone mineral density is of poor quality and screw purchase is weaker, and it may promote a high OC fusion rate. Their study design was, however, only a computational simulation with all its limitations. It should be noted, however, that the placement of C1 lateral mass screws is technically demanding and susceptible to possible complications such as vertebral artery injury, blood loss, and longer overall operative time.[19]

Our results showed the occiput-C2 construct can tolerate flexion extension loading more than rotational loading. Liu et al study results indicated that the addition of supplemental C1 lateral mass to the construct may offer similar stability in flexion but greater stability in extension, lateral bending, and axial rotation in comparison to the occiput-C2 fixation.[17]

Our data indicated that most of the construct failure occurs at C2 (loosening of C2 screws occurred in 4 specimens, loosening of C2 screw nut connection in one specimen, while occipital plate loosening occurred in only one specimen). However, several studies have shown that OC instrumentation failure most commonly occurs at the occipital screw and superior part of the rod.[17,21] Bhatia et al reported 4% patients undergoing fixation had rod fracture in the stress region of rod curvature or occipital screw pullout.[21] They explain this observation by the low holding capacity of the occipital screw because of its short purchase length, compared to C2 pedicle screw. Moreover, the occipital screw and superior part of the rod bear main part of stress.[17] We were unable to explain this difference. However, our occipital screws were applied bicortically. Obtaining purchase of the ventral cortex would provide the screw with increased strength of fixation and pullout strength. However, the concept of bicortical occipital screws may be taken cautiously during surgery for adjacent structures concerns.

Since our results indicated that occiput-C2 construct can tolerate flexion extension loading and not axial rotation, we would recommend immobilization, at least at the early postoperative period, in a way that allow flexion and extension, but restricts axial rotation.

The results of our study should be kept within the context of its limitations. The limitations of our study are that it is a cadaveric, in vitro design, which may not truly reflect clinical application, the relatively small numbers of specimens, the lack of lateral pending loading testing, and the lack of destructive tests.

In addition, the experiment has been done using formalin preserved cadavers, which are not the standard cadavers used for biomechanical studies. Formalin hardens the tissues including joint capsules and ligaments leading to loss of pliability of the joints and the elastic properties of the ligaments. Hence the actual stability to the joint, offered by the capsuloligamentous structures might not be accurately assessed by the experiment. If the study had been performed using fresh frozen cadavers (not available in our department) which are brought to room temperature during the study, that would replicate the living tissues, the results would reflect the actual stability of the C0-C2-C2 joint complex.

Furthermore, the OC junction complex has been subjected to manual loading by the same person for all 6 specimens. Even if it was done by the same person, the amount of force applied by manual loading may not going to be consistent in each cycle and may vary to a significant extent between cadavers.

However, the cadaveric biomechanical data could be useful to adequately test and validate the biomechanical principles for further understanding of occiput- C2 pedicle screw constructs. In addition to the biomechanical stability, there are several factors that could determine the choice of the OC construct, including the patient's clinical situation, the structural regional anatomy, especially the vertebral artery, the size of the C2 pedicle, the presence or absence of a C2 lamina and surgeon preference. We believe that the choice of the OC instrumentation should depend on the clinical situation, including the previously mentioned factors, and not only on the biomechanical considerations.

Conclusion

Our study revealed that occiput-C2 pedicle screw construct, without supplementary C1 lateral mass provided stability in flexion and extension loading. However, repeated axial rotation loading causes failure of construct. Therefore, we could suggest immediate postoperative restriction of axial rotation while flexion extension motion could be allowed.

Conflict of interest

None of the authors have any conflict of interest. None declared.

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