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Original Article

Advancements in occipitocervical fusion: Biomechanical insights, surgical techniques, and clinical outcomes

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ABSTRACT

Background: Occipitocervical fusion (OCF) has been performed for over 70 years to address craniocervical instability caused by trauma, tumors, or congenital anomalies. Despite technological advances, challenges persist due to the unique anatomy, high mobility, and complex pathological processes at the occipitocervical junction. This study aimed to evaluate clinical, radiographic, and surgical outcomes of OCF in patients with craniocervical instability.

Methods: A 2-year cohort study was conducted at Dr. Saad Alwitry's Neurosciences Hospital (April 2021–March 2023) involving 45 patients aged 17–53 (mean age 35.6). Inclusion criteria required radiologically confirmed instability, psychological fitness, and a normal coagulation profile. Patients with advanced rheumatoid arthritis or prior posterior fossa surgery were excluded. OCF procedures were performed using modern rigid instrumentation, including plates and rods, and outcomes were monitored using radiographic fusion assessments and clinical evaluations.

Results: All patients achieved solid fusion (100%) within a mean of 7.06 months (range 5–9 months). Myelopathy and neurological deficits were present in all patients preoperatively, while neck pain affected 73.3%. Postoperatively, 73.3% of patients showed improvement in myelopathic symptoms, and all patients reported resolution of neck pain. Complications included one transient neurological deterioration, one wound infection, and one cerebrospinal fluid leak, all managed successfully. No operative mortalities or vascular injuries occurred.

Conclusion: Rigid occipitocervical fixation stabilizes the craniocervical junction, achieving high fusion rates and symptom resolution with minimal complications. Thorough preoperative planning, precise surgical technique, and an understanding of craniocervical anatomy are crucial for optimal outcomes.

Keywords: Craniocervical instability, Neurological deficit, Occipitocervical fusion, Rigid fixation, Spinal surgery

INTRODUCTION

OCF has essentially guaranteed the management of craniocervical instability for the better part of the past 70 years. Despite decades of surgical evolution, the search for an ideal universally applicable technique has remained elusive, partly driven by the anatomic complexity and unique biomechanical demand of the occipitocervical junction.[15] This junction offers unprecedented mobility between the occiput and the first two cervical vertebrae; therefore, stabilization efforts at this level raise expectations to a very high level and are demanding. Other pathological

conditions that further complicate the surgical intervention include basilar invagination and atlantoaxial dislocation.[13]

For such, the development of biomechanically sound constructs is necessary to resist axial hypermobility and rotational forces at this level. Modern techniques, including screw and rod systems, have proven superior results compared to earlier methods of non-rigid fixation.[2] These offer immediate stability, facilitate deformity correction, and allow earlier mobilization without the extensive use of external orthoses.[12]

While contemplating the anatomy, physiology, and pathological presentations of the occipitocervical region, constructs tailored in various distinctive motion planes have to be considered, such as in flexion extension, apart from lateral bending and axial rotation. Finite element analyses have strongly pointed out the need to have biomechanically verified instrumentation for optimal surgical performance.[9]

This study presents the clinical, radiographic, and surgical results of occipitocervical fusion (OCF) in 15 patients with craniocervical instabilities and correlates the same with the results available in the literature.

MATERIALS AND METHODS

It was a cohort study conducted for 2 years, starting from April 2021 and ending on March 2023, at Dr. Saad Alwitry's Neurosciences Hospital. Fifteen patients, aged 17–53 years with craniocervical instability, underwent OCF. All the patients had clinical manifestations that included myelopathy, neurological deficits, and resistant neck pain to conservative treatment.

The inclusion and exclusion criteria were central to the process of selecting patients for the study. Patients in this series were middle-aged with radiologically confirmed instability of the craniocervical junction. Informed consent was obtained from all patients. In cases of associated conditions such as Down syndrome, permission was obtained from their parents. All had to be psychologically fit. Moreover, patients had to be ambulant with objectively established neurological deficits and with a normal coagulation profile, considering that they probably would remain bedridden during the 1st days after the operation.

The exclusion criteria included, but were not limited to, patients in the pediatric age group, history of any cerebrovascular events ever, or any form of paralysis with power zero grade, such as hemiplegia or paraplegia. Patients with post-radiotherapy skin infections, severe rheumatoid arthritis resistant to medical treatment, or previous surgery in the posterior fossa were excluded from the study. Such a meticulous selection ensures that the patient cohort is very well demarcated, enhancing the reliability of the results.

All patients received extended imaging, including lateral standing radiographs, to assess cervical alignment and further imaging studies, such as computed tomography (CT) and magnetic resonance imaging, to delineate structural anomalies, neural compression, and the severity of instability. Careful positioning during the preoperative phase was undertaken with concern for safety and optimization of surgical outcomes. Initial positioning was supine with no traction in a neutral position for baseline motor evoked potentials/somatosensory evoked potentials (MEP/SSEPs) for intraoperative monitoring. Patients were then repositioned prone, with either a fixed head holder or tongs positioned to assure neutral alignment of the cervical spine. Anesthesia induction included fiber-optic intubation to minimize cervical motion; the craniocervical area was shaved, antiseptically prepared, and draped in a sterile manner.

The surgical technique emphasized meticulous dissection and hardware placement. A midline incision was performed to expose the occipital squama and cervical spine. Subperiosteal dissection in this fashion avoided unnecessary exposure of uninvolved levels, preserving the posterior tension band critical for stability. Pilot holes were drilled in the occipital squama for screw placement, tailored to the patient's bone density as assessed preoperatively through CT. Screws and rods were chosen appropriately to provide rigidity and anatomical compatibility, while distraction was selectively applied in cases of cranial settling or basilar invagination. Intraoperative rod bending allowed for proper alignment so that anatomy and function of the craniocervical junction could be appropriately restored; after fixation, autologous bone grafts were placed according to the defect to span the occipital squama and cervical spine, providing a scaffold on which to achieve fusion. The postoperative management involved the use of a rigid cervical brace to support recovery and to ensure stability of the operated segment during the period of fusion [Figures 1 and 2]. Regular follow-ups regarding clinical assessment, as well as radiographic images, were needed to monitor the progress of healing and the state of alignment. Intraoperative techniques are complemented by postoperative care to minimize complications and aid in optimal recovery.

This approach underlined the importance of precise anatomical knowledge, scrupulous preoperative planning, and intraoperative performance with caution in successfully overcoming the specific challenges of instability of the occipitocervical junction. Descriptive statistics – mean, range, and standard deviation (SD) – were calculated for all data. Continuous variables were reported as mean and standard deviation. We used the Chi-square test to analyze the relationship between postoperative complications and patient sex and between postoperative complications and intraoperative monitoring. Moreover, the *P*-value was calculated to determine the significance of the observed correlation. Data analysis was done using the Statistical Package for the Social Sciences version 25.

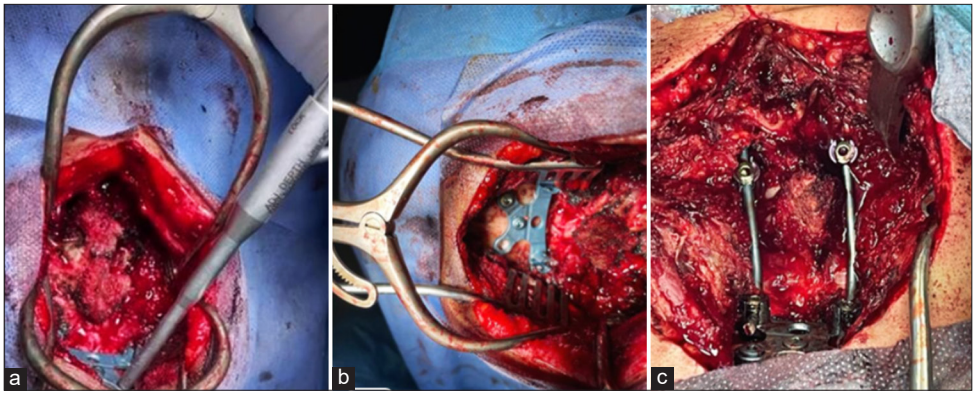

Figure 1: (a) This photo shows a fixed T plate device by a screw in the occipital, (b) a T plate device fixed in the midline occipital bone, and (c) occipital cervical fixation o-C2.

Figure 2: Position of the patient (prone position fixed by Sugita) and landmark from occipital nuchal line to C5.

RESULTS

The study included 45 patients, with a mean age of 35.6 years (range 17–53 years). Age distribution revealed that 13% of patients were under 20 years, 47% were between 20 and 40 years, and 40% were older than 40 years. Among the participants, 30 (66.7%) were male and 15 (33.3%) were female. The most common clinical symptoms included neck pain in 33 patients (73.3%), while all 45 patients (100%) presented with myelopathy and neurological deficits [Table 1].

The primary etiologies of craniocervical instability were trauma in 21 cases (46.7%), tumors in 15 cases (33.3%), basilar invagination in 6 cases (13.3%), post-radiotherapy in 2 cases (4.4%), and congenital aplasia in 1 case (2.2%). Fusion outcomes demonstrated a mean fusion time of 7.06 months (range 5–9 months). Six patients achieved fusion at 5 months, 18 at 6 months, 3 at 7 months, 9 at 8 months, and 9 at 9 months. Radiographic follow-up confirmed solid fusion in all patients (100%) with no evidence of instability at adjacent levels.

Functional outcomes based on the Frankel grading system showed that 12 patients (26.7%) improved from Grade C to D, 23 patients (51.1%) remained at Grade D postoperatively, 7 patients (15.6%) stayed at Grade C, and 3 patients (6.7%) retained normal function at Grade E. Perioperative complications included four cases of transient neurological deterioration, which resolved within 6 months, three wound infections managed successfully with antibiotics, and five cerebrospinal fluid (CSF) leaks treated conservatively with diuretics. There were no vascular injuries or operative mortalities.

The association between intraoperative monitoring and postoperative complications was analyzed and found to be statistically insignificant ($P = 0.295$). Among the 30 patients with intraoperative monitoring, 22 (73.3%) experienced no complications, compared to 10 of 14 patients (71.4%) without monitoring. Similarly, the analysis of patient sex and postoperative complications showed no significant association ($P = 0.973$). Of the 30 male patients, 22 (73.3%) had no complications, while among the 15 female patients, 11 (73.3%) had no complications. Anti-thrombotic therapy was administered to 24 patients (53.3%), whereas 21 patients (46.7%) did not receive it [Tables 2 and 3].

These findings suggest that neither intraoperative monitoring nor patient sex significantly influenced the occurrence of postoperative complications in this study population. The results also demonstrated favorable functional and radiographic outcomes, with solid fusion achieved in all patients and significant improvement in myelopathic symptoms and neck pain.

DISCUSSION

Over the last many decades, there has been a significant evolution in the understanding of OCF, especially with advancements in surgical techniques, better biomechanical understanding, and improvement in instrumentation. The

Table 1: Demographic and clinical details of the patients.

Frequencies			
Frequencies of SEX			
SEX	**Counts**	**% of Total**	**Cumulative %**
M	30	66.7 %	66.7 %
F	15	33.3 %	100.0 %
Frequencies of neck pain			
Neck pain	**Counts**	**% of Total**	**Cumulative %**
+	33	73.3 %	73.3 %
-	12	26.7 %	100.0 %
Frequencies of myelopathy			
Myelopathy	**Counts**	**% of Total**	**Cumulative %**
+	45	100.0 %	100.0 %
Frequencies of neurological deficits			
Neurological deficits	**Counts**	**% of Total**	**Cumulative %**
+	45	100.0 %	100.0 %
Frequencies of etiology			
Etiology	**Counts**	**% of Total**	**Cumulative %**
Tumor	15	33.3 %	33.3 %
Post radiotherapy	2	4.4 %	37.8 %
Trauma	21	46.7 %	84.4 %
Basilar invagination	6	13.3 %	97.8 %
Congenital aplasia	1	2.2 %	100.0 %
Frequencies of Frankel grading scale pre-operative/post-operative			
Frankel grading scale pre-operative/post-operative	**Counts**	**% of Total**	**Cumulative %**
C-D	12	26.7 %	26.7 %
D-D	23	51.1 %	77.8 %
C-C	7	15.6 %	93.3 %
E-E	3	6.7 %	100.0 %
Frequencies of Anti-thrombotic			
Anti-thrombotic	**Counts**	**% of Total**	**Cumulative %**
+	24	53.3 %	53.3 %
-	21	46.7 %	100.0 %
Frequencies of intraoperative monitoring			
Intraoperative monitoring	**Counts**	**% of Total**	**Cumulative %**
+	30	68.2 %	68.2 %
-	14	31.8 %	100.0 %

+: yes, -: No, M: Male, F: Female

occipitocervical junction, however, being anatomically and biomechanically peculiar, remains one of the most daunting regions to stabilize.

The occipitocervical junction is characterized by remarkable mobility, allowing a broad range of motions (ROMs) but also leaving it vulnerable to instability. Studies using finite element models have emphasized the need to understand the biomechanical interaction at this level. Liu *et al.* (2016)[7] demonstrated the critical biomechanical role that C1 lateral mass screws play in enhancing stability during occipitoatlantoaxial fixation. Likewise, Zhang and Bai (2007)[16] also expressed that "physiologically correct" load modeling must be instituted to produce good fixation constructs. Such findings emphasize a continuing need to tailor the fixation technique for the biomechanical requirements of the region.

Table 2: Test of association between postoperative complications and intraoperative monitoring.

Test of association between post-operative complications and intraoperative monitoring						
Intraoperative monitoring	**Post-operative Complication**				**Total**	***P*-value***
	No complications	**Wound infection**	**Neurological deficit**	**CSF leak**		
+	22	1	4	3	30	0.295
-	10	2	0	2	14	
Total	32	3	4	5	44	

*Chi-square test. +: yes, -: No, CSF: Cerebrospinal fluid

Table 3: Test of association between postoperative complications and patient sex.

Test of association between post-operative complications and patient sex						
SEX	**Post-operative Complication**				**Total**	***P*-value***
	No complications	**Wound infection**	**Neurological deficit**	**CSF leak**		
M	22	2	3	3	30	0.973
F	11	1	1	2	15	
Total	33	3	4	5	45	

*Chi-square test. CSF: Cerebrospinal fluid

The transition from wire and cable systems to rigid screw-rod constructs has been nothing short of revolutionary. Modern screw-rod systems offer not only enhanced stability but also limit the necessity of postoperative external orthoses.[3] The biomechanical superiority of these constructs has been corroborated by such studies as that by Nassos *et al.* (2009),[10] in which improved segmental stabilization using screw-based techniques was demonstrated.

Further, the pursuit of minimally invasive techniques has opened up new perspectives in the treatment of complex cases, among which is anterior occipitocervical fixation with anatomically shaped titanium plates. Ji *et al.* (2019)[5] outlined the possibilities anterior approaches offer for the treatment of congenital and iatrogenic instabilities; however, precise screw placement remains a significant challenge.

Clinical outcomes regarding OCF surgery have been promising, with many reports of high fusion rates and significant neurological improvements. Martinez-del-Campo *et al.* (2016)[8] reported that >91% of patients who preoperatively had neurological deficits improved postoperatively. Wang *et al.* (2019)[13] emphasized the biomechanical rationale for the treatment of basilar invagination complicated by poor outcomes if the condition is left untreated.

Yet, complications are still a challenge. Complications described in the literature include vertebral artery injury, pseudoarthrosis, and instrumentation failure. Bhatia *et al.* (2013)[1] said that stress risers in curved rod systems may promote rod fractures, and further design considerations should be made to prevent these. This agreed with the previous biomechanical studies conducted by Puttlitz *et al.* (2000),[11] who emphasized that the distribution of stresses within fixation constructs should not be ignored.

Recent trends in its usage appear to be on the rise, with improved diagnostic capabilities, particularly in pathologies like Ehlers–Danlos Syndrome. Dysphagia is one of the major complications, which, in many cases, is associated with misalignment of fixation, and strategies such as optimal alignment and selective fusion have been recommended to mitigate this risk. The decrease in rheumatoid arthritis OCF reflects improvement in medical management. Advances in rigid instrumentation and minimally invasive techniques continue to improve the outcome, but the long-term biomechanical consequences need further elucidation.[4] Wang *et al.*,[14], in 2020, showed that O-arm navigation in OCF elevates the accuracy of surgery, with specific reference to those cases with challenging cervical pedicle fixation. They had an accuracy rate of 94.1% about screw placement and did not record any neurovascular injuries within their series. This approach ensures a significant decrease in complication rates while guaranteeing improved biomechanical stability and clinical outcomes that are effective to a great extent in complex craniocervical pathologies.

Lee *et al.* (2024)[6] compared outcomes of atlantoaxial fusion (AAF) and OCF, revealing significant differences in postoperative neck ROM. OCF produced a greater reduction in ROM (−20.1°) compared to AAF (−6.4°), which affected functional activities such as lifting. Although OCF has simpler techniques and reduced neurovascular risks, AAF is more suitable for younger patients or those who need better postoperative mobility.

Advanced imaging integrated intraoperative navigation brought great improvement in surgical precision. Further

biomechanical studies could be done, as per the suggestion by Meng *et al.* (2010),[9] to optimize the strategy of surgery and refine the treatment approach. Future long-term results should be undertaken to investigate modern constructions' durability.

In short, the evolution of occipitocervical fixation techniques reflects a synthesis of biomechanical insights, technological advancements, and clinical experience. While current approaches have substantially improved outcomes, ongoing innovation, and research are necessary to address persistent challenges and further improve patient care. The incorporation of biomechanical principles and individualized treatment planning remains central to the success of OCF procedures.

CONCLUSION

Occipitocervical fixation is still one of the very essential yet formidable procedures for the management of craniocervical instabilities due to various congenital abnormalities, tumor conditions, rheumatoid arthritis, and trauma. Complication avoidance and overall successful management depend on precise knowledge about the anatomy around the occipitocervical junction, apt imaging, and judicious selection of patients. Further improvements in instrumentation and advancement of imaging have reduced most of these risks and offered accuracy in this regard. Technical complications may not be absolutely avoidable. New approaches, such as no decompression of the posterior fossa atlantoaxial fixation and anterior realignment with stabilization, further give a new dimension to various management techniques. The fundamental approach to early prevention of neurological deterioration involves diagnosis and early intervention. Therefore, innovating techniques and rigid planning form the basis of low morbidity and effective stabilization.

Ethical approval: The Institutional Review Board approval is not required as it is an observational study. This study adhered to established clinical and surgical practices within the institution and did not introduce any experimental procedures or deviations from standard care. All patients were treated following routine clinical guidelines for occipitocervical fusion, which are recognized and accepted by the institution.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent.

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