Original Article

Surgical, clinical, and radiological outcomes of occipitocervical fusion using the plate–screw–rod system with allograft in craniocervical instability

ABSTRACT

Objective: We evaluated surgical, clinical, and radiological outcomes of posterior occipitocervical fusion (OCF) using plate–rod–screw construct supplemented with allograft in cases of occipitocervical instability.

Study Design: This was a retrospective analysis of prospective collected data.

Methods: Data of 52 patients who underwent posterior OCF using plate–screw–rod construct supplemented with allograft at a single institute from 2009 to 2014 were analyzed. Demographics, clinical parameters (Visual Analog Score [VAS], ODI, and mJOA score), functional status (McCormick scale), radiological parameters – mean atlantodens interval, posterior occipitocervical angle, occipitocervical 2 angle, and surgical parameters (operative time, blood loss, hospital stay, and fusion) with complications were evaluated.

Results: The mean age of the patients was 54.56 ± 16.21 years with male: female was 28:24. The mean operative time was 142.2 min (90–185 min) and mean blood loss was 250.8 ml. The mean duration of hospital stay was 6.7 days and mean follow-up period was 65.17 ± 5.39 months. There was significant improvement in clinical parameters (modified JOA score, VAS, and Oswestry Disability Index values) postoperatively. Forty patients showed recovery in neurological status at least in Grade 1 in McCormick scale with no neurological deterioration in any patient. Furthermore, radiological parameters at cervicomedullary junction got into acceptable range. Implant-related complications noted in 1 patient and 1 patient had vertebral artery injury. We had dural tear in 3 patients and infection in 2 patients. Fusion was achieved in 46 cases with mean time for fusion was 11.039 months.

Conclusion: Patients with occipitocervical instability can successfully undergo posterior OCF using plate–screw–rod construct supplemented with allograft with high fusion rate, good clinical and functional outcomes, and low complication rate.

Keywords: Craniocervical instability, myelopathy, occipitocervical fusion

INTRODUCTION

Patients with craniovertebral anomaly and occcipitocervical instability usually have three-dimensional malformation of the junction with anterior translation of the atlas on the axis, vertical subluxation of the odontoid process, and flexion deformity caused by anterior subluxation or dislocation of the occipitoatlantal complex on the axis.[1-3] This results in mechanical symptoms and neurological symptoms ranging from mild neck stiffness with pain to radicular symptoms, frank myelopathy, respiratory distress, and paralysis with or without involvement of lower cranial nerves.[4,5] Therefore, occipitocervical stabilization and fusion are commonly recommended in these patients[1,6] and is an effective method to treat neck pain, myelopathy, and to provide biomechanical stability due to various pathologies.[7-12]

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Mihir Upadhyaya, Sanyam Jain, Neilakuo Kire, Zahir Merchant, Vishal Kundnani, Ankit Patel
Bombay Hospital and Research Centre, Mumbai, Maharashtra, India

Address for correspondence: Dr. Sanyam Jain,
Bombay Hospital and Research Centre, 128, 1st Floor, MRC Building, Marine Lines, Mumbai - 400 020, Maharashtra, India.
E-mail: jainsanyam933@gmail.com

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Conservative methods such as prolonged immobilization using halo-vest or Minerva jacket is rarely indicated nowadays.[13]

Various modalities of treatment using rigid fixation constructs have been developed from simpler methods such as onlay graft with or without wiring to more rigid fixation techniques using screws with plate or rods in conjunction with sublaminar wiring augmented with bone grafting.[14] However, occipitocervical fixation using plate–screw–rod construct system has gained popularity nowadays and is commonly performed.

Our study aims to assess the clinicoradiological efficacy with functional and neurological outcomes of posterior occipitocervical fixation using plate–screw–rod construct system supplemented with allograft in cases of occipitocervical instability.

METHODS

Retrospective analysis of prospectively collected data of 57 patients who underwent occipitocervical fusion (OCF) using plate–screw–rod construct supplemented with allograft at a single institute by senior spine surgeon from 2009 to 2014 was done by an independent observer. Five patients were lost in follow-up; therefore, 52 patients formed the study cohort. Institutional review board approval was obtained before conducting the study.

Inclusion criterion

- Patients operated with OCF for any pathology with
    - Occipitocervical instability with/without basilar invagination (O-C1).
    - Irreducible/reducible C1–C2 instablity.
- Only posterior surgery
- Minimum 5 years follow-up.

Exclusion criterion

- Anterior surgery
- Revision surgery
- Sublaminar wiring
- Follow-up <5 years.

Surgical technique

Patient was positioned prone with neutral cervical position using a horseshoe-type or a Mayfield head holder, and the shoulders were pulled caudal by a heavy bandage for intraoperative lateral radiographic imaging of the lower cervical spine. Intraoperative traction was given in all patients. An incision was kept in the midline, from just proximal to the external occipital protuberance to the midlevel of the subaxial cervical spine. The length of the incision depends on the cervical vertebrae intended to be fused. Dissection was carried down through the ligamentum nuchae to the occiput proximally, and the spinous processes distally. An intraoperative lateral radiograph on fluoroscopic image was then used to confirm the cervical level. Care must be taken to avoid aggressive dissection too far laterally on the posterior arch of C1.

We preferred to use an occipital plate that can accommodate both midline and lateral screw with 10–12 mm screws near the external occipital protuberance and 6–8 mm screws lateral or inferior to the external occipital protuberance placed inferior to the superior nuchal line.

C2 pedicle screw was inserted, by palpating with a Penfield 4 laterally along the superior surface of the C2 lamina to its junction with the medial isthmus of C2. The entry point is 4–5 mm above inferior articular facet, 4–5 lateral to valley and the trajectory is 15°–20° medially. The C2 pedicle screw was inserted using a high-speed drill under fluoroscopic guidance.

In some cases, C2 isthmic screw was inserted due to the high-riding vertebral artery (VA) visible on magnetic resonance imaging (MRI) or C1–C2 transarticular screw was inserted to achieve maximum stability in some cases of rhematoid arthritis (RA).

For C3–C6 lateral mass screw insertion, the entry point is made in the center point of inferiomedial quadrant of rectangular lateral mass, with help of high-speed burr and the direction of the screw was determined by the lower spinous process under fluoroscopic guidance. Long-segment fixation with C3–C6 lateral mass was needed in some cases of ankylosis spondylitis, RA patients, and in those cases in which cervical stenotic myelopathic changes were there on MRI imaging at lower cervical segments.

The plate portion of the rod was slightly bent to fit the occipital contour and was fixed by self-tapping screws onto the occiput and then fixed with cervical screws after reduction and maintaining it. Reduction was achieved with traction and manipulation (distraction and extension) with posterior soft-tissue release. If not reduced, it was fixed *in situ*. Then, posterior decompression was done in cases which were having signs snd symptoms of significant compression with correlating MRI imaging. All patients received morcellized allograft placed over the prepared graft bed around the rod screw construct on exposed lamina and lateral masses at all fusion levels which were processed in the bone bank present in our institution.

Demographic data (age, sex, and level), clinical parameters (neck pain score – Visual Analog Score [VAS], functional score – Oswestry Disability Index [ODI] and modified JOA [mJOA] score), and functional status (Modified McCormick scale) were evaluated and recorded preoperatively and postoperatively.

Radiological parameters, atlantodens interval, posterior occipitocervical angle, occipitocervical 2 angle, were evaluated preoperatively and postoperatively.

Surgical parameters – operative time, intraoperative blood loss, hospital stay and intraoperative complications (VA injury, dural tear), and postoperative complications (infection, implant loosening/pull out screw, neurological worsening) were noted. Fusion was assessed on computed tomography scan according to the Bridwell's crieteria.

Postoperative soft cervical collar was advised for 4 weeks, and out-of-bed mobilization was recommended as the general condition of the patient permited postoperatively. Regular follow-up was done at 2 weeks, 3 months, 6 months, 12 months, and then yearly. Neck physiotherapy was advised at 2 weeks follow-up after removal of sutures.

- Case 1. Syndromic AAD Irreducible AAD + BI Klippel Feil Anomaly + [Figure 1a-d]
- Case 2. Tubercular OC instability - Eroded C1–C2 lateral masses [Figures 2a-c]
- Case 3. Craniocervical instability (atlantoaxial dislocation) treated with long-segment OC fusion [Figures 3a-e].

The statistical analysis was carried out using paired Student's "*t*-test" and Mann–Whitney test with $P < 0.05$ was considered as statistically significant. Statistical analysis was done using SPSS software 20.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

The mean age of the patients was 54.56 ± 16.21 years (7–78 years) with male: female was 28:24. The mean operative time was 142.2 min (90–185 min) and mean blood loss was 250.8 ml (100–320 ml). The mean hospital stay was 6.7 days range (4–10). The mean ± standard deviation follow-up duration was 65.17 ± 5.39 months.

Thirteen patients had RA, six patients had tuberculosis, four had secondaries to carcinoma, eight cases of trauma, two patients had giant cell tumor, and 19 cases having varied complex anatomy such as Arnold–Chiari Malformation (6), Os odontoideum (1), ankylosing spondylitistis (4), Downs syndrome (3), Klippel –Feil syndrome (3), and neurofibromatosis (2) [Figure 4].

Occipitocervical fusion was done in all cases of irreducible C1–C2 instability and in those C1–C2 reducible instability cases, in which C1–C2 fixation alone was not possible like cervical trauma cases (C1 lateral mass fracture or C2 isthmic or pedicle fracture) or occipital fixation had to be done (occipital bone fracture or basilar invagination). Furthermore, in some tuberculous and carcinomatous patients, in which C1–C2 fixation alone had not enough good strength, OC fusion was done. Maximum OCF was done up to the level of C2 vertebrae ($n = 30$) [Figure 5 and Table 1].

Nonparametric Mann–Whitney test was used for comparison of mJOA and ODI score [Table 2].

There was significant difference in the value of mJOA score between preoperative value as compared to post-6 months ($P < 0.05$). Also, there was significant difference between preoperative value as compared to post-5 years ($P < 0.05$). However, no significant difference between 6 months postoperative value as compared to 5 years postoperative ($P > 0.05$) was noted.

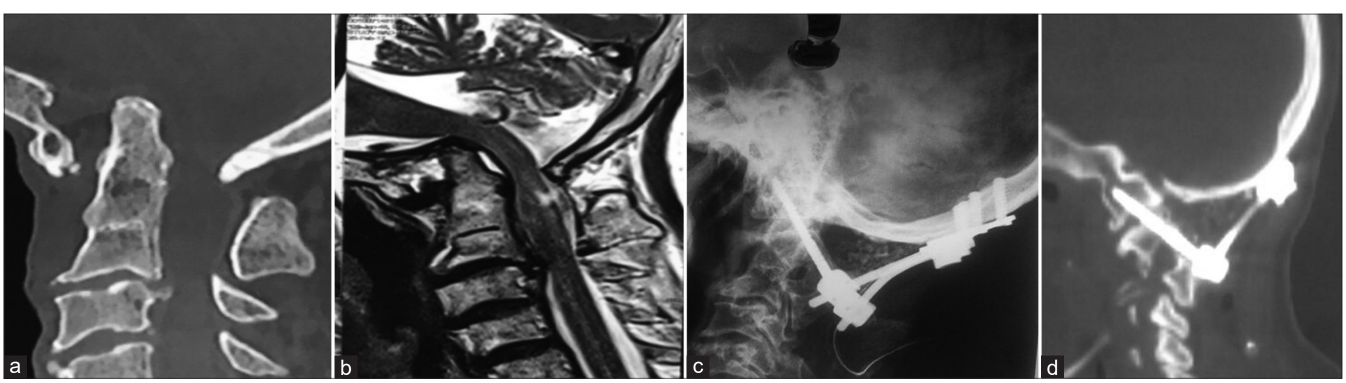

Figure 1: (a) Showing computed tomography scan of a patient with occipitocervical instability. (b) Showing magnetic resonance imaging with cord compression. (c) Indicating postoperative lateral X-ray after occipitocervical fusion. (d) Showing postoperative computed tomography scan with occipitocervical fusion

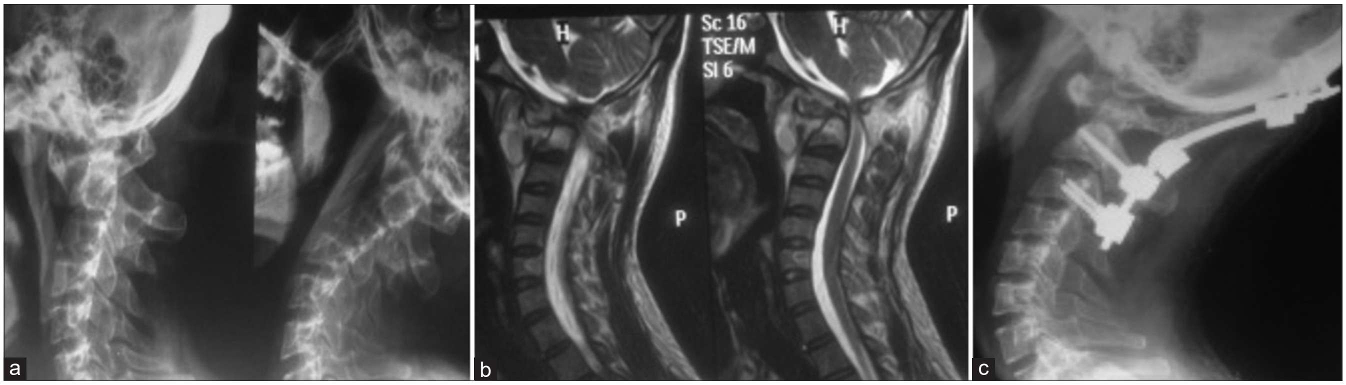

Figure 2: (a) Showing anteroposterior and lateral X-ray of a patient with tubercular occipitocervical instability with eroded C1–C2 lateral mass. (b) Showing magnetic resonance imaging scans with cord compression. (c) Showing postoperative X-ray with occipitocervical fusion

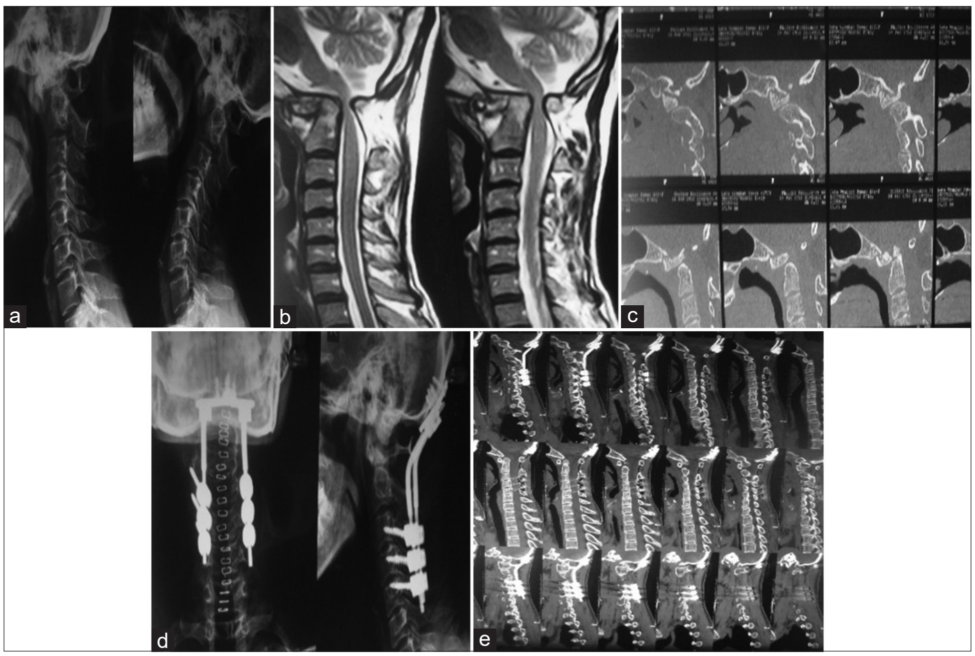

Figure 3: (a) Showing anteroposterior and lateral X-ray of a patient with occipitocervical instability (atlantoaxial dislocation). (b) Showing magnetic resonance imaging scans with cord compression. (c) Showing preoperative computed tomography scan images. (d) Showing postoperative X-ray treated with occipitocervical fusion. (e) Showing postoperative computed tonography scan with fusion

There was significant difference in ODI score between preoperative value as compared to post-6 months ($P < 0.05$) and between preoperative value as compared to post-5 years ($P < 0.05$). Furthermore, significant difference between 6 months postoperative value as compared to 5 years postoperative was noted ($P < 0.05$).

T-test was used for comparison between the means of VAS neck pain. There was a significant difference between preoperative value as compared to post-6 months ($P < 0.05$) and between preoperative value as compared to post-5 years ($P < 0.05$). However, no significant difference between 6 months postoperative value as compared to 5 years postoperative ($P > 0.05$) was noted.

Forty patients showed recovery in neurological outcomes at least in Grade 1 of Mc Cormick scale. Fifty percent ($n = 26$) patients showed significant myelopathic features and all of them undervent posterior decompression procedure based on the levels involved on MRI imaging. Out of them, 24 patients (92.31%) had improvement of the mJOA scores at last follow-up but did not improve in 2 patients (7.69%). However, the preoperative status of one of these patients was NURICK Grade II, and the other patient suffered from the most aggressive form of mutilating-type RA. No myelopathy or neurological deterioration was noted in any patient postoperatively or at final follow-up.

Apart from the clinical improvement, the radiological benefits of occipitocervical fusion were also well evident and the angles

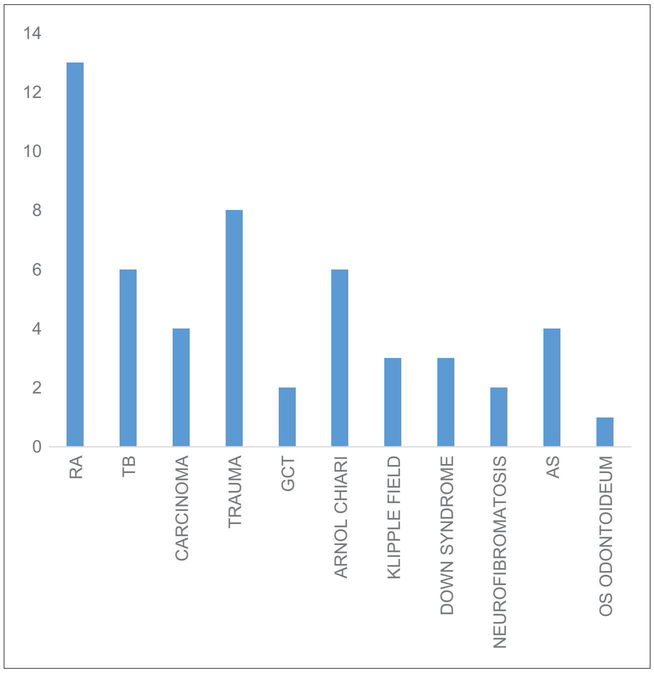

Figure 4: Showing number of various pathologies causing occipitocervical instability

at the cervicomedullary junction got in to the acceptable range postoperatively. Nonparametric Mann–Whitney test was used for comparison between the preoperative and postoperative values and found significant difference [Table 3].

Postoperative implant-related complications noted in 1 patient (1.92%) with distal screw loosening which was seen in a case of RA where fusion was extended later to include lower levels. The duration between surgery and implant failure was 10 months.

We had a left VA injury intraoperative, injured during the exposure of the C1 lateral mass. We dissected posterior arch of C1 by using bipolar coagulator and dissected too much of the lateral side. We controlled bleeding by using the thrombin-soaked gelform. This patient underwent a CT angiogram immediately after surgery, which showed complete occlusion of the VA at C2 transverse foramen with some retrograde flow from the contralateral VA. Special attention was paid to the patient after surgery, but no specific treatment was required since the patient showed no symptoms related to the VA injury from the admission to follow-up period.

We encountered two cases of superficial infection, that were well tackled with wound debridement and antibiotic.

In three of our cases, we encountered dural tear with inadvertent removal of ligamentum flavum while decompression procedure, that was well taken care of by fibrin glue and fat patch application.

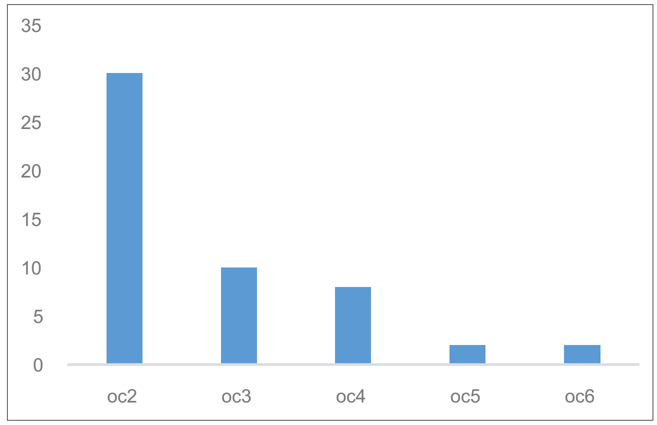

Figure 5: Levels up to occipitocervical fusion done

Table 1: Cervical spine levels up to occipitocervical fusion was extended

Level	*n*
OC2	30
OC3	10
OC4	8
OC5	2
OC6	2

Table 2: Comparison of modified JOA, visual analog score - neck pain and Oswestry Disability Index score at preoperative, 6-month postoperative, and 5-year postoperative period

Clinical parameters	mJOA	Neck pain	ODI
Preoperator	13.83±2.734	6.6538±1.1005	77.98±9.45
6 months postoperative	15.076±2.2126	2.673±0.733	51.15±13.33
5 years postoperative	15.67±1.854	2.423±0.4988	38.94±11.64

ODI - Oswestry Disability Index; JOA - Japanese orthopedic association score

Table 3: Change in radiological parameters postoperatively as compared to preoperative values

Radiological parameters	Preoperator	Postoperator	Nonparametric Mann-Whitney test (*P*)
ADI	4.2±1.7 mm	2.5±1.9mm	<0.085
POCA	118.67±12.29	107.15±12.05	*P*<0.007
OC2 angle	15.81±1.88	21.673±1.089	*P*<0.007

ADI - Atlantodens interval; POCA - Posterior occipitocervical angle; OC2 angle - Occipitocervical 2 angle

Fusion was achieved in 46 cases with mean time for fusion was 11.039 months. Out of six pseudoarthrosis patients, three patient underwent radiotherapy and chemotherapy for secondary carcinomas, that might be the reason for nonunion.

DISCUSSION

Occipitocervical fusion, first reported by foerster, has revolved from early techniques of *in situ* stand-alone bone grafting and prolonged immobilization to current plate–screw–rod constructs.[15-18] *In situ* stand-alone grafting was associated with high pseudoarthrosis rate and led to inception of supplementary fixation techniques such as wire-securing procedures, countoured rods, plate screw, and finally, rod-screw fixation constructs.[19-21]

To relieve the pressure off the cord and reduce the deformity at the CVJ, several authors have advocated the use of cervical traction in patients with basilar invagination before surgery.[22-24] Peng *et al*.[23] used the Gardner-Wells Traction Tongs several days before the fusion was performed. In contrast, Goel and Shahl[25] observed the loss of reduction in patients who underwent fusions after correcting the deformities with cervical traction. We used cervical traction in traumatic and some irreducible instability cases preoperatively. Use of intraoperative cervical traction was almost universal.

Before the introduction of anterior decompression by odontoidectomy, foramen magnum decompression along with *in situ* fixation with pins and wires was the only option available. Unfavorable neurological outcomes from *in situ* fusions led to the development of ventral decompression through anterior approaches[6,26] by a transoral- or mandibular-splitting approach with odontoidectomy.[27] Furthermore, if atlantoaxial (AA) dislocation is irreducible and the dislocation is a causative factor of neurologic deficits, anterior decompression and fusion has been advocated in the past.[28,29] However, those procedures involve complicated perioperative management, and it is difficult to obtain solid fusion with those procedures without support by rigid external fixation using a halo vest or cast. Improved functional results from odontoidectomy are also associated with a high incidence of complications. Close proximity to oral bacterial flora makes the procedure prone to postoperative infection. Wound dehiscence, aspiration pneumonia, CSF leakage, and dysphagia are other common complications.[30] Moreover, posterior reconstruction using varied instrumentation techniques becomes mandatory after transoral resection.[31,32]

The advantages of posterior approach are manifold; first, anterior release is not required bypassing the complications of anterior surgery and reduction can be achieved with intraoperative maneuvers of distraction, assisted by preoperative traction methods. The construct is strong enough to hold the unstable segment without any additional support postoperatively.

The evolution of novel reduction techniques and the development of newer implants for OCFs have made decompression far easier than before. Goel *et al*.[33] described a CVJ realignment method, in which a wide resection of the AA capsule and distraction of this joint manually along with the placement of a metal spacer reduces the basilar invagination and AA subluxation. Distraction of the AA joint reduced the vertical deformity more efficiently, but the inconsistent correction of the ADD was a major limitation of this method.[34] To overcome the shortcomings of the CVJ realignment method, Jian *et al*.[35] described an intraoperative distraction technique. However, the reduction of deformities with the distraction-only methods could achieve restoration of ADD in only 85% of the cases. Second, distraction without the spacer also caused resettling in some cases. To achieve more efficient realignment and prevent the loss of reduction, Chandra *et al*.[34] devised a new technique called distraction, compression, and extensive reduction. In this technique, the first step was to insert a metal spacer to distract the joint to correct the basilar invagination. Compression and extension through C1–C2 and/or occipital screws using a metal spacer as a fulcrum corrected the AA instability and restored the ADD more efficiently (complete reduction in 94% of patients). The application of the recent techniques of reduction has obviated the need for odontoidectomy. We had reduced maximum of our cases by traction and manipulation (extension and distraction). Only five cases remained irreducible which were fixed *in situ*.

In our study, the combined use of cervical screws and occipitocervical rods provided sufficient correction of malalignment at craniovertebral junction with significant improvement in radiological parameters such as O-C2 angle and CMA angle with maintainence of reduction resulted in decrement of mechanical stress to the anterior portion of the medulla oblongata and lead to indirect ventral decompression with relieved medullary compressive symptoms.

Occipital plate cervical screw–rod construct with bone grafting typically allows higher fusion rates than posterior wiring method and provides superior biomechanical rigidity and immediate postoperative stability obviating the need for rigid external immobilization. This is primarily because of the increased stiffness, same time, the complication with the wiring techniques are reduced significantly[12,13] Winegar *et al*.[36] reviewed the techniques on OC fusion with results showing the lowest failure rate following plate–screw–rod construct when compared with other techniques. In contrast, 56 RA patients who had undergone occipital-cervical-thoracic fusions with unit rods, sublaminar wiring, or multiaxial cervical pedicle screw and rod systems were reviewed by Kirano *et al*.[37] They reported that implant failure occurred in 13 (23.2%) patients and that the failure rate was 15.8%

in unit rod group and 38.9% in cervical pedicle screw and rod group. However, there have been no studies reporting long-term follow-up.[18,38-42] We had also used bicortical lateral mass screw construct in C3-C6 construct or C1-C2 transarticular screw or C2 pedicle/isthmic screw and occipital plate stabilized by 4/6 screws in occiput. This provided a superior clinical outcome with corrective forces and better fusion rates compared to other studies.[10,18,21]

We had long-term follow-up of 5 years and had only one case of implant failure at 10 months postoperatively (1.92%) as compared to the study by Kei Ando *et al*.[43] where 8 cases of implant failure were noted, 6 occurred within 24 months of surgery (22.22%), and Kukreja *et al*.[44] showed 3 cases with implant failure. The overall complication rates of our study are comparable to those done by Lee *et al*.[45] (6.25%) and those of Sung Ho chui *et al*.[46] (18.75%).

Although the ideal substrate for bony fusion in posterior cervical arthrodesis is provided by autograft; however, significant association of donor-site morbidity remains a concern and is associated with increased operative time, greater blood loss, ambulation difficulties, chronic donor-site pain, iliac wound infection, and a jejunal perforation.[47,48] Same osteoconductive conduit for bony fusion is provided by allograft as that of traditional autograft and may have equivalent biomechanical properties and arthrodesis but with less donor site morbidity.[49] We had used morselized allograft in all cases.

We had one left VA injury, that happened during dissection of C1 arch, which was not too far away from midline. This could have been a anomalous tortuous course of VA missed during the preoperative evaluation on the C1 arch. No serious clinical sequale was noticed in this patient. There was no neurological deterioration in any patient seen postoperatively.

Fusion rates, ranging from 80% to 96%, has been seen in plate–screw–rod construct. In our study, solid bony fusion was achieved in 46 of 52 pts (88.46%) which is comparable to other studies. Kukreja[44] reported 4 out of 49 patients with nonunion at final follow-up and Nockels *et al*.[42] showed 2 out of 69 patients with nonunion. Excellent results have been reported by Grob *et al*.[11] (n = 14 with all patients showed fusion), Wertheim *et al*.[50] (n = 13 with 100% fusion), and Lee *et al*.[45]

Limitations

Our study included all the pathologies occurring at craniovertebral junction causing instability; since, all pathologies has different natural course and entity, so it can bias our results. However, we aim only to discuss about the outcomes of OCF.

CONCLUSION

Posterior occipitocervical reconstruction with cervical screws and occipital plate–rod construct provided excellent clinical outcomes with biomechanically sound fixation, high fusion rate using allograft, and optimal correction of misalignment in the occipital-AA region. However, surgical skill and an understanding of 3D anatomy of cervical spine are imperative to correctly place screws within the occiput and upper cervical spine to avoid potential intraoperatively and postoperative adverse events.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Pait TG, Al-Mefty O, Boop FA, Arnautovic KI, Rahman S, Ceola W. Inside-outside technique for posterior occipitocervical spine instrumentation and stabilization: Preliminary results. J Neurosurg 1999;90:1-7.
2. Sandhu FA, Pait TG, Benzel E, Henderson FC. Occipitocervical fusion for rheumatoid arthritis using the inside-outside stabilization technique. Spine (Phila Pa 1976) 2003;28:414-9.
3. Ebraheim N, Rollins JR Jr., Xu R, Jackson WT. Anatomic consideration of C2 pedicle screw placement. Spine (Phila Pa 1976) 1996;21:691-5.
4. Luque ER. The anatomic basis and development of segmental spinal instrumentation. Spine (Phila Pa 1976) 1982;7:256-9.
5. Smith MD, Anderson P, Grady MS. Occipitocervical arthrodesis using contoured plate fixation. An early report on a versatile fixation technique. Spine (Phila Pa 1976) 1993;18:1984-90.
6. Ebraheim NA, Lu J, Biyani A, Brown JA, Yeasting RA. An anatomic study of the thickness of the occipital bone. Implications for occipitocervical instrumentation. Spine (Phila Pa 1976) 1996;21:1725-9.
7. Grantham SA, Dick HM, Thompson RC Jr., Stinchfield FE. Occipitocervical arthrodesis. Indications, technic and results. Clin Orthop Relat Res 1969;65:118-29.
8. Hamblen DL. Occipito-cervical fusion. Indications, technique and results. J Bone Joint Surg Br 1967;49:33-45.
9. Vaccaro AR, Lim MR, Lee JY. Indications for surgery and stabilization techniques of the occipito-cervical junction. Injury 2005;36 Suppl 2:B44-53.
10. Itoh T, Tsuji H, Katoh Y, Yonezawa T, Kitagawa H. Occipito-cervical fusion reinforced by Luque's segmental spinal instrumentation for rheumatoid diseases. Spine (Phila Pa 1976) 1988;13:1234-8.
11. Grob D, Dvorak J, Panjabi M, Froehlich M, Hayek J. Posterior occipitocervical fusion. A preliminary report of a new technique. Spine (Phila Pa 1976) 1991;16:S17-24.
12. Oda I, Abumi K, Sell LC, Haggerty CJ, Cunningham BW, McAfee PC. Biomechanical evaluation of five different occipito-atlanto-axial fixation techniques. Spine (Phila Pa 1976) 1999;24:2377-82.
13. Fehlings MG, Errico T, Cooper P, Benjamin V, DiBartolo T.

Occipitocervical fusion with a five-millimeter malleable rod and segmental fixation. Neurosurgery 1993;32:198-207.
14. Ahmed R, Traynelis VC, Menezes AH. Fusions at the craniovertebral junction. Childs Nerv Syst 2008;24:1209-24.
15. Elia M, Mazzara JT, feilding JW. Onlay technique for occipitocervical fusion. Clin orthop Relat Res 1992;280:170-4.
16. Apostolides PJ, Dickman CA, Golfinos JG, Papadopoulos SM, Sonntag VK. Threaded Steinmann pin fusion of the craniovertebral junction. Spine (Phila Pa 1976) 1996;21:1630-7.
17. Moskovich R, Crockard HA, Shott S, Ransford AO. Occipitocervical stabilization for myelopathy in patients with rheumatoid arthritis. Implications of not bone-grafting. J Bone Joint Surg Am 2000;82:349-65.
18. Singh SK, Rickards L, Apfelbaum RI, Hurlbert RJ, Maiman D, Fehlings MG. Occipitocervical reconstruction with the ohio medical instruments loop: Results of a multicenter evaluation in 30 cases. J Neurosurg 2003;98:239-46.
19. Dvorak MF, Fisher C, Boyd M, Johnson M, Greenhow R, Oxland TR. Anterior occiput-to-axis screw fixation: Part I: A case report, description of a new technique, and anatomical feasibility analysis. Spine (Phila Pa 1976) 2003;28:E54-60.
20. Haher TR, Yeung AW, Caruso SA, Merola AA, Shin T, Zipnick RI, *et al.* Occipital screw pullout strength. A biomechanical investigation of occipital morphology. Spine (Phila Pa 1976) 1999;24:5-9.
21. Jones EL, Heller JG, Silcox DH, Hutton WC. Cervical pedicle screws versus lateral mass screws. Anatomic feasibility and biomechanical comparison. Spine (Phila Pa 1976) 1997;22:977-82.
22. Botelho RV, Neto EB, Patriota GC, Daniel JW, Dumont PA, Rotta JM. Basilar invagination: Craniocervical instability treated with cervical traction and occipitocervical fixation. Case report. J Neurosurg Spine 2007;7:444-9.
23. Peng X, Chen L, Wan Y, Zou X. Treatment of primary basilar invagination by cervical traction and posterior instrumented reduction together with occipitocervical fusion. Spine (Phila Pa 1976) 2011;36:1528-31.
24. Simsek S, Yigitkanli K, Belen D, Bavbek M. Halo traction in basilar invagination: Technical case report. Surg Neurol 2006;66:311-4.
25. Goel A, Shah A. Reversal of longstanding musculoskeletal changes in basilar invagination after surgical decompression and stabilization. J Neurosurg Spine 2009;10:220-7.
26. Sutterlin CE 3rd, Bianchi JR, Kunz DN, Zdeblick TA, Johnson WM, Rapoff AJ, *et al.* Biomechanical evaluation of occipitocervical fixation devices. J Spinal Disord 2001;14:185-92.
27. Rodgers WB, Coran DL, Emans JB, Hresko MT, Hall JE. Occipitocervical fusions in children.Retrospective analysis and technical considerations. Clin Orthop Relat Res 1999;(364):125-33.
28. Dvorak MF, Sekeramayi F, Zhu Q, Hoekema J, Fisher C, Boyd M, *et al.* Anterior occiput to axis screw fixation: Part II: A biomechanical comparison with posterior fixation techniques. Spine (Phila Pa 1976) 2003;28:239-45.
29. Zipnick RI, Merola AA, Gorup J, Kunkle K, Shin T, Caruso SA, *et al.* Occipital morphology. An anatomic guide to internal fixation. Spine (Phila Pa 1976) 1996;21:1719-24.
30. Landeiro JA, Boechat S, Christoph Dde H, Gonçalves MB, Castro Id, Lapenta MA, *et al.* Transoral approach to the craniovertebral junction. Arq Neuropsiquiatr 2007;65:1166-71.
31. Ransford AO, Crockard HA, Pozo JL, Thomas NP, Nelson IW. Craniocervical instability treated by contoured loop fixation. J Bone Joint Surg Br 1986;68:173-7.
32. Anderson PA, Oza AL, Puschak TJ, Sasso R. Biomechanics of occipitocervical fixation. Spine (Phila Pa 1976) 2006;31:755-61.
33. Goel A, Pareikh S, Sharma P. Atlantoaxial joint distraction for treatment of basilar invagination secondary to rheumatoid arthritis. Neurol India 2005;53:238-40.
34. Chandra PS, Kumar A, Chauhan A, Ansari A, Mishra NK, Sharma BS, *et al.* Distraction, compression, and extension reduction of basilar invagination and atlantoaxial dislocation: A novel pilot technique. Neurosurgery 2013;72:1040-53.
35. Jian FZ, Chen Z, Wrede KH, Samii M, Ling F. Direct posterior reduction and fixation for the treatment of basilar invagination with atlantoaxial dislocation. Neurosurgery 2010;66:678-87.
36. Winegar CD, Lawrence JP, Friel BC, Fernandez C, Hong J, Maltenfort M, *et al.* A systematic review of occipital cervical fusion: Techniques and outcomes. J Neurosurg Spine 2010;13:5-16.
37. Hirano K, Matsuyama Y, Sakai Y, Katayama Y, Imagama S, Ito Z, *et al.* Surgical complications and management of occipitothoracic fusion for cervical destructive lesions in RA patients. J Spinal Disord Tech 2010;23:121-6.
38. Shin H, Barrenechea IJ, Lesser J, Sen C, Perin NI. Occipitocervical fusion after resection of craniovertebral junction tumors. J Neurosurg Spine 2006;4:137-44.
39. Deutsch H, Haid RW Jr., Rodts GE Jr., Mummaneni PV. Occipitocervical fixation: Long-term results. Spine (Phila Pa 1976) 2005;30:530-5.
40. Motosuneya T, Hirabayashi S, Yamada H, Sakai H. Occipitocervical fusion using a hook and rod system between cervical levels C2 and C3. J Clin Neurosci 2009;16:909-13.
41. Grob D, Schutz U, Plotz G. Occipitocervical fusion in patients with rheumatoid arthritis. Clin Orthop Relat Res 1999;(366):46-53.
42. Nockels RP, Shaffrey CI, Kanter AS, Azeem S, York JE. Occipitocervical fusion with rigid internal fixation: Long-term follow-up data in 69 patients. J Neurosurg Spine 2007;7:117-23.
43. Ando K, Imagama S, Ito Z, Kobayashi K, Yagi H, Shinjo R, *et al.* Minimum 5-year follow-up results for occipitocervical fusion using the screw-rod system in craniocervical instability. Clin Spine Surg 2017;30:E628-32.
44. Kukreja S, Ambekar S, Sin AH, Nanda A. Occipitocervical fusion surgery: Review of operative techniques and results. J Neurol Surg B Skull Base 2015;76:331-9.
45. Lee SC, Chen JF, Lee ST. Clinical experience with rigid occipitocervical fusion in the management of traumatic upper cervical spinal instability. J Clin Neurosci 2006;13:193-8.
46. Choi SH, Lee SG, Park CW, Kim WK, Yoo CJ, Son S, *et al.* Surgical outcomes and complications after occipito-cervical fusion using the screw-rod system in craniocervical instability. J Korean Neurosurg Soc 2013;53:223-7.
47. Roberts DA, Doherty BJ, Heggeness MH. Quantitative anatomy of the occiput and the biomechanics of occipital screw fixation. Spine (Phila Pa 1976) 1998;23:1100-7.
48. Menezes AH. Complications of surgery at the craniovertebral junction – Avoidance and management. Pediatr Neurosurg 1991;17:254-66.
49. Hsu YH, Liang ML, Yen YS, Cheng H, Huang CI, Huang WC. Use of screw-rod system in occipitocervical fixation. J Chin Med Assoc 2009;72:20-8.
50. Wertheim SB, Bohlman HH. Occipitocervical fusion. Indications, technique, and long-term results in thirteen patients. J Bone Joint Surg Am 1987;69:833-6.