Rigid occipitocervical fusion

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Object. Despite 50 years of neurosurgical experience, occipitocervical fusion continues to present a technical challenge to the surgeon. Traditional nonrigid techniques applied in the occiput and cervical spine often fail secondary to postsurgical cranial settling or rotational deformity. Unlike widely used nonrigid and semirigid techniques, rigid fixation of the craniocervical junction should allow correction of deformity in any plane, provide immediate stability without need for external orthosis, and prevent cranial settling.

Methods. Since 1992, the senior author (D.W.C.) has used a rigid plate and screw fixation system for occipitocervical fusions. The technique proved to be more difficult than expected, and the procedure has evolved as experience was gained. The authors present a series of 24 patients and a technique that now involves the use of a custom-designed T-plate that is attached to the midline occipital “keel” at one end and to the spine at the other end by means of screw-fixed plates.

Conclusions. Although it is still evolving, the current technique for obtaining rigid occipitocervical fixation allows for immediate rigidity and stability of the spine without the use of an external orthosis (that is, in the absence of osteoporosis), may be extended to any level of the spine, may be used in the absence of posterior elements, prevents postsurgical cranial settling and restenosis, facilitates reduction of the spinal deformity in any plane, and sometimes eliminates the need for an anterior (transoral) decompressive procedure.

KEY WORDS • occipitocervical fusion • cervical instrumentation • craniocervical instability • rheumatoid arthritis • basilar invagination

OCCIPITOCERVICAL spine fusion procedures have been performed for more than 50 years; however, an ideal, universally applicable technique for such procedures has not been developed. Technical challenges unique to the occipitocervical junction have provided many impediments, leading to the use of suboptimal constructs in the majority of such procedures. Such challenges stem from the unique bony anatomy at the occipitocervical junction; the unique physiological mobility between the occiput and the first two cervical vertebrae; and the unique pathological processes that affect both the bony and neural structures encountered at this level.

The suboccipital skull joins the upper cervical spine posteriorly at a nearly perpendicular angle. The requirements for hardware at this level are therefore different from those at any other level in the spine. At least 50% of the rotational range of motion in the neck occurs between the occiput and C-2.18 Fusions that span this junction must resist this axial hypermobility. In addition, bone grafts placed between the skull and the upper cervical spine are usually not under any compressive force, and they easily dislodge if a patient’s rotational movements are poorly restrained postoperatively.

In patients with all six normal degrees of freedom (flexion–extension, lateral bending, and left–right rotation) a construct attached to the skull at one end and to the axis or subaxial spine at the other provides a long lever arm, which must be very solidly fixed at both ends if it is to resist failing as the skull moves in reference to the spine postoperatively. In addition to the normal six degrees of freedom, such constructs must also resist the motion of the spine in compression and distraction. Pathological processes at the occipitocervical junction are often associated with cranial settling or basilar invagination, and traditional nonrigid fixation techniques often fail in this mode. Cranial settling may be exaggerated by decompressive procedures, such as odontoidectomy or resection of the posterior arch of the atlas, which may be necessary to attain adequate neural decompression in the setting of such common bony anomalies as rheumatoid spondylitis with odontoid pannus or equally common neural anomalies such as Chiari malformation (Fig. 1). In atlantooccipital dislocation, distraction resistance must be restored. Hence, the anatomical, physiological, and pathological entities at the occipitocervical junction are unique. Constructs quite suitable for use elsewhere in the spine often fail when applied here.

Although to a lesser extent, construct failures also commonly occur after nonrigid, cable-fixed fusion procedures in the subaxial spine. In an effort to improve the results of fusion procedures, Roy-Camille and associates14 introduced cervical lateral mass plates almost 20 years ago. Such plates may be used to achieve far more rigid fixation.
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than wire-fixed constructs, allow for instrumentation to be placed in the absence of posterior elements, eliminate the risk to the neural structures posed by sublaminar cables, and often facilitate the restoration of normal lordosis. Magerl and Seeman subsequently improved the technique of placing screws in the subaxial cervical spine, developed a technique for placing long screws into the axial pars interarticularis, and finally developed a technique for placing transarticular screws for atlantoaxial fusion. Such screws have greatly improved construct rigidity and the success rate in C1–2 posterior fusion procedures.

Having mastered these techniques, it seemed only a small step to extend lateral mass plates to the occiput to accomplish rigid occipitocervical fusion. Indeed, descriptions of such techniques have been published in various texts over the past 5 years. However, experience has taught us that such techniques are more complicated than we first imagined. In this report we describe our experience since 1992 with the first 24 cases in which rigid occipitocervical fixation was performed using plates and screws. We document the evolution of our technique and the lessons we learned along the way.

Clinical Material and Methods

Prior to 1996, we used the technique developed by Magerl and described in 1994 by Sasso, et al. In this technique posterior cervical lateral mass plates are fixed in the spine with subaxial lateral mass, C-2 pars, or C1–2 transarticular screws and in the cranium with screws placed in the lateral suboccipital bone in the plane of the cervical lateral masses. This technique was applied in the first 10 cases. Significant problems were encountered and will be described in a subsequent section. These difficulties led to the development of a “T-plate” that is attached to the midline occipital keel with three bone screws and to cervical lateral mass plates with machine screws and washers. In 12 of the 14 cases treated since 1995, we have used this device (Fig. 2). In all fusions we applied autologous iliac crest bone graft beneath the plates. Seven of the 24 patients also underwent transoral decompressive surgery. Ten of 24 underwent resection of the posterior arch of the atlas. In four patients both anterior and posterior element resections were performed. Five patients underwent subaxial cervical laminectomies. The fusion levels included: occiput–C2 in eight cases, occiput–C3 in one, occiput–C4 in four, occiput–C5 in two, and the occiput–C6, occiput–C7, and occiput–T1 or T-2 in one case each, with pedicle screw fixation of the lower end performed in seven cases.

Seven of nine patients with rheumatoid arthritis and two other patients with severe osteoporosis were maintained in halo orthoses after surgery. As a precaution in the setting of severe osteoporosis, despite multiple-screw internal fixation, we routinely supplement all constructs with external fixation. All other patients were maintained in simple cervical collars for 8 to 12 weeks after surgery.

Preoperatively, 16 of the 24 patients suffered moderate to severe myelopathy. Five were unable to walk unassisted. Six patients were neurologically intact preoperatively; two had sustained deficits unrelated to the cervicomedullary junction.

Fourteen women and 10 men aged 25 to 82 years underwent surgery for rheumatoid arthritis in which spinal deformity or instability was present (nine patients); congenital deformity, dysgenesis, or basilar invagination (four patients); posttraumatic instability or deformity (seven patients); or osteomyelitis with instability or metastatic carcinoma with instability (two cases each) (Table 1).

Four of the 24 patients had undergone previous occipitoatlantoaxial surgical procedures that had failed. The initial three patients in the series underwent placement of instrumentation in which we used stainless steel, small-fragment reconstruction plates (Synthes, Paoli, PA). In the remaining 21 patients, a titanium hardware construct was placed (Axis System, Sofamor-Danek, Memphis, TN).

Results

In the initial 10 cases (1992–1995), the lateral mass plates were fixed directly to the lateral suboccipital squama. In four of these 10 patients, the presence of thin bone
in the subocciput led to the need for occipital fixation of the plates by using cables instead of screws, thus partially defeating our goal of obtaining rigid fixation. Of the six patients in whom screws were fixed to the lateral subocciput, in three subsequent occipital screw pullout occurred. Of these same 10 initial patients, there were three in whom the cervical ends of the plates were fixed only with subaxial lateral mass screws. In each of these cases screw pullout of some or all of the four to eight implanted screws occurred. In all of these patients, fusion was eventually achieved, but the patients were required to wear rigid external orthoses.

Based on our experience with these initial cases and with subsequent cadaver dissections, it became apparent that the only portion of the suboccipital bone that is consistently thick enough to be used for firm bone screw purchase is the midline “keel.” Similarly, we learned that the long moment arm applied across a plate or rod, extending from the suboccipital bone to the axial or subaxial cervical spine, was subjected to forces that were greater than could be resisted by routine subaxial lateral mass screws, even when they were applied at multiple levels. Hence, in all of the subsequent 14 patients the device systems were fixed using multiple-screw purchase of the suboccipital midline and by long C-2 pars, C1–2 transarticular, and/or upper thoracic pedicle screws in the spine. In these latter 14 patients there have been no cases of screw pullout or construct failure. Halo orthoses were used only to treat the four patients with rheumatoid arthritis among these latter 14 cases.

Twelve of the 14 latter patients (1996–1998) underwent occipital-end fixation in which we used a custom-designed “T-plate” device (Sofamor-Danek) that has allowed three-point screw fixation of the suboccipital midline and attachment to lateral mass plates with machine screws and washers. There have been no cases of screw pullout in any of the patients in whom this device was placed (Fig. 3). In two patients a prominent external suboccipital midline ridge precluded the use of the T-plate. In these cases, doubly curved (or twisted) lateral mass plates allowed us to obtain midline suboccipital purchase by using obliquely directed transverse screws (Fig. 4).

The follow-up period for the entire series ranged from 6 months to 6 years. Two patients died of causes unrelated to their surgery. Seventeen patients have been followed for more than 2 years. The mean follow-up period in the patients treated with T-plates is now 22 months. In these 17

### TABLE 1

Clinical characteristics and outcomes in 24 patients who underwent occipitocervical fusion

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of Patients</th>
<th>Myelopathy</th>
<th>Decompressive Procedure</th>
<th>Halo Brace</th>
<th>Neurological Outcome</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>Anterior</td>
<td>Posterior</td>
<td></td>
<td>Improved Same Worse Dead</td>
</tr>
<tr>
<td>rheumatoid arthritis</td>
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<td>5</td>
<td>2</td>
<td>8</td>
<td>7 4 3 0 2*</td>
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<tr>
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<td>6</td>
<td>3</td>
<td>2</td>
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<tr>
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<td>0</td>
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<td>2</td>
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<td>1</td>
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<td>1 1 0 0</td>
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* Both patients died of causes unrelated to this procedure.
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**Fig. 3.** Imaging studies obtained in a 17-year-old boy.  
*Left:* Lateral radiograph revealing atlantoaxial dislocation. The patient experienced hemiparesis and tongue weakness but was otherwise intact.  
*Center:* Lateral radiograph obtained immediately after an occiput–C2 fusion in which the T-plate was used for occipital-end fixation and C1–2 transarticular screws for cervical-end fixation. The patient wore a halo brace for realignment at admission that was removed postoperatively.  
*Right:* A computerized tomography scan obtained through the subocciput, demonstrating screw purchase of the thick (14 mm in this case) midline “keel” (arrow).

patients, the apparent fusion rate is 100%. We define successful fusion as the absence of movement on flexion-extension radiographs, the presence of intact hardware, and/or the obvious appearance of bridging bone between the occiput and cervical spine. There have been no deaths attributable to the surgical procedure. One wound infection was demonstrated in an elderly but healthy individual who had undergone a transoral odontoidectomy and posterior fusion after induction of a single anesthetic. Surprisingly, there was no incidence of infection in the patients receiving steroidal or other immunocompromising therapy, previous radiotherapy, or in other patients in whom transoral and posterior procedures were performed in a single sitting.

No direct cervical cord or nerve root injuries occurred in the series. Of the eight patients who were neurologically intact preoperatively, all have remained so as of last follow-up examination. Of the 16 patients who experienced mild-to-severe myelopathy preoperatively, two died of unrelated causes, eight have objectively improved, five remain unchanged, and one is clearly worse. (See subsequent paragraph for description of the complications.)

There were two major neurological complications attributable to the instrument placement procedure. The first occurred in a 49-year-old man with severe basilar invagination and cord compression at the cervicomedullary junction. He had undergone three previous operations and cranial settling had occurred, thus recompressing his spinal cord after a previous odontoidectomy and nonrigid occipitocervical fusion. The previous fusion mass was removed and rigid refusion of the occiput–C4 was performed. He did well initially, but on his 8th postoperative day he suffered a major cervicomedullary junction infarction that converted his already severe myelopathy into quadriplegia. Neuroimaging studies revealed an occluded left vertebral artery. Now 6 years after surgery, he is able to ambulate independently but is functionally worse than preoperatively.

The second complication occurred in a 61-year-old woman with rheumatoid arthritis, C1–2 instability, moderate myelopathy, multisegmental subaxial stenosis, and kyphosis. She underwent subaxial decompression, spinal realignment, and an occiput–C5 fusion in which we used doubly bent plates fixed with oblique midline suboccipital, C-2 pars, and multiple subaxial lateral mass screws. Although the procedure was uncomplicated, she did not wake up in the recovery room. An emergency computerized tomography scan revealed an acute right cerebellar subdural hematoma. The patient was immediately returned to the operating room to undergo evacuation of the hematoma, which was found to be secondary to bleeding from a small, superficial cortical vessel that had probably been inadvertently nicked by the drill. Postoperatively, she was maintained in a halo vest; only onlay grafts to the subocciput, lateral to the craniectomy, are now in place. Remarkably, 3 years after this ordeal, the patient has no detectable cerebellar deficit, her myelopathy has clearly improved over the preoperative state, and a solid occiput–C5 fusion has formed.

Rigid occipitocervical instrumentation has allowed correction of sagittal plane deformities that existed preoperatively in 22 of our 24 patients (Fig. 5). Axial plane (rotational) deformities were corrected in five cases, and coronal plane (scoliotic) deformities secondary to congenital anomaly, infection, or tumor were corrected in four cases.

In combining pre- and intraoperative traction with rigid instrumentation, we eliminated the need to perform ventral (transoral) decompressive surgery in four patients with rheumatoid arthritis and in three patients with congenital spinal deformity whose postoperative studies revealed that all ventral compression was relieved after traction alignment. Using this technique, there have been no instances of postoperative cranial settling with reinvagination into the foramen magnum.

**Discussion**

Since Foerster first described occipitocervical fusion in 1927, a variety of techniques have been developed, of which some have been more successful than others. Traditional techniques in which the surgeons used simple onlay grafts and bone grafts fixed with wire and/or methylmethacrylate are still widely performed. Because such techniques are completely nonconstrained, they provide little immediate postoperative stability and, therefore, must usually be supplemented with a rigid external ortho-
sis. Even with the provision of such orthoses, the failure rate of these constructs remains high.

Subsequently, constructs in which bent rods were fixed with wire or cables and attached to the skull via burr holes at one end and to the cervical posterior elements at the other became popular. Such constructs are partially constrained and surely more stable than wire- and bone-fixed constructs, but they remain largely nonrigid and do not adequately resist cranial settling or rotation. In addition, these constructs require the presence of intact cervical posterior elements, which may be unavailable after a decompressive laminectomy has been performed. Moreover, the risk of multiple sublaminar wire or cable passage is significant. It is not uncommon for the spinal cord to be injured during such procedures. Progressive postoperative deformity, fusion failure, and recurrent neural element compression continue to plague patients treated with these techniques.

The advantages of rigid fixation for the enhancement of fusion have been well established in the subcranial spine. The results of such methods allow for correction of deformity and stable spinal alignment until bone fusion occurs. No hardware is inserted into the spinal canal, and a fixation procedure can be performed in the absence of posterior elements. The rigidity of the construct allows for the incorporation of involved segments only and, hence, prevents further loss of motion. This immediate stability allows the patient to ambulate early, and there is no need for rigid external orthoses in most cases.

More recently, the in vitro biomechanical advantages of rigid instrumentation at the occipitocervical junction have also been delineated. However, the plate and screw instrumentation as described by Sasso, et al., requires cranial-end lateral suboccipital bone purchase. Because lateral occipital bone thickness is often between 3 mm and 6 mm, bone purchase may be inadequate. The incidence of screw pullout has been documented in our series and that of others. In biomechanical studies of occipital screw fixation the results have demonstrated that the strength of the construct was proportional to bone thickness. In anatomical studies Heywood and coworkers have demonstrated that the maximum thickness of the subocciput is encountered under the external occipital protuberance (11–17 mm). Midline occipital purchase in which unicortical screw fixation is used offers greater pullout strength and precludes the need for bicortical screws or wire fixation and their potential complications.

With this knowledge, other authors have designed instrumentation to obtain midline occipital purchase. The T plate (no resemblance to our instrumentation) described by Heywood and colleagues is restricted to short-segment fusions and requires the presence of intact posterior elements. Grob, et al. have described a Y-plate that allows midline occipital purchase at the cranial end with long C1–2 or C–2 screws at the cervical end. However, because Y-plates often do not fit the axial vertebral width in a given case and may not adequately resist rotational movements, they tend to fail by divergent pivoting of the suboccipital screws. Olerud has designed a device that accomplishes the same goals as our system (S. Olerud, personal communication, 1993), which is currently in use in Europe. Sutterlin uses an occipital plate similar to the one described here (C. Sutterlin, personal communication, 1993). At least three major spinal instrumentation companies are working to develop rod or plate devices in which screw fixation is used in the occiput and cervical spine.

We believe that there are several important lessons to be gleaned from this experience.

**Geometry and Physics of the Occiput and Cervical Spine**

The shape of the human occipital skull and its apical vertical position on the upper cervical spine produce unique geometrical requirements. A plate or rod attached to the midline suboccipital bone will be several centimeters posterior to its cervical attachment point. The moment arm length between the occipital and cervical ends may range from 6 to more than 20 cm, depending on the size of the patient and the span of the construct.

**Requirements for Motion Resistance**

Greater than 50% of the total range of motion in the cervical spine lies between the occiput and C-2. There are six normal and eight pathological degrees of freedom. Normal sagittal motion at occiput–C1, rotation at C1–C2, and small
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amounts of lateral bending in both directions must be countered. In many pathological processes, compression or distraction also occurs and must be restrained. In disease processes such as rheumatoid arthritis, the initial pathological movement usually occurs in flexion. With further progression of the disease, compression with basilar invagination occurs. In cases of posttraumatic deformity, the spine may be dislocated into either a flexed or an extended posture. In cases of rheumatoid arthritis or congenital deformity, rotational dislocation or scoliotic deformity is not unusual. In atlantoccipital dislocation, the deformity is in distraction. Hence, a uniformly successful occipitocervical fusion construct must resist movement in eight degrees of freedom.

Iatrogenic Exacerbation of Instability

Not uncommonly, in cases of rheumatoid arthritis or chronic posttraumatic pannus, tumor, congenital anomalies, and other pathological processes, an adequate decompression requires resection of the anterior elements of the atlas, axis, basal skull anteriorly or posteriorly, or even subaxial cervical elements. Such procedures often increase preexisting spinal instability and worsen the tendency toward sagittal plane deformity or cranial settling. Traditional wire-fixed constructs do not adequately resist this tendency.

Conclusions

Although it is not without risks, rigid occipitocervical fusion with instrumentation of the type reported herein satisfactorily addresses the aforementioned demands. Rigid purchase of the suboccipital midline with multiple screws and of the cervical spine with long C-2 pars, C1–2 transarticular, or lower cervical/upper thoracic pedicle screws produces constructs capable of resisting the geometrical loads applied at the cervicomedullary junction and may be used without rigid external orthoses in cases in which osteoporosis is not present. Such constructs also resist postsurgical cranial settling and may eliminate the need to perform a ventral decompressive procedure in some cases. The constructs may be used for fusions that span any level of the cervical or thoracic spine and are therefore more versatile than devices that are limited to occipitoaxial fusions. They may be used in the absence of some or all cervical posterior or elements and even in the setting of small suboccipital craniectomies. Last, they also eliminate the risks associated with sublaminar wire or cable passage.

Although technical complications may not be completely eliminated, experience and image-guidance techniques should decrease risks in the future. We believe that the experience reported here and elsewhere suggests that a new era of more successful occipitocervical reconstructions is dawning.

References


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