Rigid occipitocervical fusion

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For more than 50 years occipitocervical fusion has been performed for the management of craniocervical instability. Despite advances in technology, craniocervical fixation continues to be a technical challenge to the spine surgeon. The complex anatomy of the region and the frequent need for anterior and/or posterior decompressive procedures represent a mechanical disadvantage and are associated with a high failure rate. Numerous methods for spinal fixation have been developed, but none has gained widespread popularity. The use of plates and screws to obtain rigid fixation of the craniocervical junction is desirable because it allows correction of deformity, provides immediate stability, and precludes cranial settling. The technique is demanding and sometimes fraught with complications. Since 1992, the senior author (D.W.C.) has used a rigid plating technique to treat patients with craniocervical instability. This procedure proved more difficult than expected, and the operative procedure has evolved as experience has been gained.

The authors present a series of 24 patients and describe a technique that, in their experience, decreased the complication rate and improved the fusion rate. The technique involves a custom-designed "T-plate" that is attached to the midline occipital bone and to the cervical spine with lateral mass plates.

Key Words * occipitocervical fusion * cervical instrumentation * craniocervical instability * rheumatoid arthritis * basilar invagination

Occipitocervical spine fusion procedures have been performed for more than 50 years, and yet an ideal, universally applicable technique for such procedures has not been developed. Various technical challenges unique to the occipitocervical junction have presented many impediments, leading to the use of suboptimal constructs in the majority of such procedures performed to date. Such challenges stem, in part, from the unique bony anatomy at the occipitocervical junction; partly from the unique physiological mobility between the occiput and first two cervical vertebrae; and partly from 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 an almost perpendicular angle. Hardware requirements at this level, therefore, are markedly different from those used at any other level in the spine. Bone grafts placed between the skull and the upper cervical spine are usually not under compressive force, are of the onlay type only, and become easily dislodged if rotational movements are
poorly restrained in the postoperative period. At least 50% of the rotational range of motion in the neck occurs between the occiput and C-2.[18] Fusions that extend from the occiput to C-2 must resist this axial hypermobility. The degree of freedom in this motion plane is far greater than anywhere else in the spinal axis. The sagittal motion plane (flexion-extension) may also be excessive between the occiput and the atlas, especially if anterior or posterior decompressive procedures have been performed.

In patients with all six normal degrees of freedom (sagittal or flexion-extension, coronal or lateral bending, and axial or left-right rotation) a construct that is attached to the skull at one end and to the axis or subaxial spine at the other provides a long lever arm, and therefore, must be very solidly fixated at both ends to avoid failure as the skull attempts to move in reference to the cervical spine postoperatively. In addition to the normal six degrees of freedom, such constructs must also resist motion in another plane, compression, and distraction. Pathological processes at the occipitocervical junction are often associated with cranial settling or basilar invagination, which traditional, nonrigid fixation techniques often fail to prevent. The tendency toward cranial settling may be exaggerated by decompressive procedures such as odontoidectomy or resection of the posterior arch of the atlas, which may be required to obtain adequate neural decompression of such common bone anomalies as rheumatoid spondylitis with odontoid erosion and pannus, as well as equally common neural anomalies such as Chiari malformation (Fig. 1). In atlantooccipital dislocation, distraction resistance must be restored.

Fig. 1. Magnetic resonance imaging studies. Left: Image obtained in a 57-year-old woman with gross basilar invagination (white arrow) and Chiari malformation (black arrow) that produced ventral and dorsal compression of the cervicomedullary junction. Center: Immediate postoperative image obtained after transoral odontoidectomy, resection of the dorsal arch of C-1, dural expansion graft, and fusion in which wire and bone were used. The patient was immobilized in halo orthosis for 16 weeks postsurgery. Right: Image obtained 6 months after initial surgery revealing recurrent cranial settling and recompression both ventrally and dorsally despite fusion and halo orthosis.
Hence, the anatomy, physiology, and pathological processes of the occipitocervical junction are unique. Constructs that may be suitable for use elsewhere in the spine often fail when applied here. Since Otfrid Foerster first reported on occipitocervical fusion in 1927, a variety of techniques have been developed, and some have achieved greater success than others. Traditional techniques involving simple onlay grafts,[4] bone grafts fixed with wire,[12,17] and placement of a methylmethacrylate construct with or without wire[2,19] from the suboccipital bone to the cervical posterior elements are still widely used. Because such techniques are completely nonrigid and nonconstrained, they provide little, if any, immediate postoperative stability. Therefore, procedures in which these techniques are used are often supplemented with a rigid external orthosis. Even with provision of such orthoses, however, the failure rate of such constructs remains high.

Subsequently, other constructs have become popular, such as those in which bent rods, fixated with wire or cables,[1,3,5,10] are attached to the skull via burr holes and to the cervical posterior elements. Such constructs are partially constrained and provide more stability than wire and bone constructs, but they remain largely nonrigid and do not adequately resist cranial settling or rotation.[9] In addition, such constructs require intact cervical posterior elements, which are often unavailable after a patient has undergone a decompressive laminectomy. Moreover, there is significant risk involved in using multiple sublaminar wire or cable passage, which is necessary in any such construct.[1,10] Injury to the spinal cord after such procedures is not uncommon. Progressive postoperative deformity, fusion failure, and recurrent compression of the neural elements continue to plague patients treated with these techniques.

Although to a lesser extent, such failures also commonly occur after nonrigid, cable-fixated fusion procedures are performed in the subaxial cervical spine. In an effort to improve this failure rate, Roy-Camille and coworkers[14] introduced cervical lateral mass plates nearly 20 years ago. Fixated with nonconstrained screws in the subaxial cervical facet pillars, such plates provide far more rigidity than wire or cable-fixated constructs, allow instrumentation in the absence of posterior elements, eliminate the risks of neural damage when sublaminar cables are used, and often facilitate the restoration of normal lordosis. Magerl and Seeman[11] subsequently improved the screw-placement technique in the subaxial cervical spine, developed a technique for placing long screws into the pars interarticularis of the axis, and finally developed a technique for the placement of transarticular screws during atlantoaxial fusion. Such screws have greatly improved construct rigidity and fusion success rates in C1-2 posterior fusion.[9]

Once these techniques were mastered it seemed only logical to extend the lateral mass plates to the occiput to accomplish rigid occipitocervical fusion. Indeed, such techniques have been published in various texts and articles over the past 5 years. However, experience has taught us that such techniques are more complicated than first imagined. In this paper we report our experience, since 1992, with the first 24 cases in which we performed rigid occipitocervical fixation with plates and screws. Our technique has evolved since its earliest application and continues to do so. We will document that evolution and the lessons learned along the way.

**CLINICAL MATERIAL AND METHODS**

Prior to 1996, we used the technique, first developed by Magerl and described in 1994 by Sasso, et al.[15] in which posterior cervical lateral mass plates are fixated at the lower end by placing lateral mass screws or, in some cases, C-2 pars or C1-2 transarticular screws, and at the upper end by placing screws in the lateral suboccipital bone in the plane of the cervical lateral masses. This technique was applied in our first 10 cases. Significant problems were encountered and will be described. These difficulties led to
the development of a "T-plate" that is attached to the midline occipital "keel" by inserting three bone screws and to cervical lateral mass plates by placing machine screws and washers. We have applied this device in 12 of the 14 cases treated since 1996 (Fig. 2). In all fusion procedures we applied autologous iliac crest bone graft beneath the plates. Seven of the 24 patients underwent an additional transoral decompressive procedure. 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. We performed an Occiput-C2 fusion in eight cases, Occiput-C3 in one case, Occiput-C4 in four cases, Occiput-C5 in two cases, Occiput-C6 in one case, Occiput-C7 in one case, and Occiput to T-1 or T-2 with pedicle screw fixation of the lower end in seven cases.

Fig. 2. Left: Photograph showing the "T plate" device (arrow), which can be attached to the midline suboccipital bone with three bone screws and to cervical lateral mass plates with machine screws (arrowhead) and washers. Right: Intraoperative photograph. This device allows rigid fixation to the occipital bone and allows rigid fixation with C-2 pars or C1-2 transarticular screws, as well as subaxial cervical fixation with lateral mass screws. The construct may be extended to the cervicothoracic junction, where C-7, T-1, or T-2 pedicle screws may be inserted. As seen in this case, because cervical posterior elements were not necessary for fixation, the decompressive laminectomy was performed as necessary (C1-5 in this case).

Nine patients, including all but one patient with rheumatoid arthritis and two additional patients with severe osteoporosis were maintained in halo orthoses after surgery. All other patients were immobilized in simple cervical collars for 8 to 12 weeks after surgery.

Preoperatively 16 of the 24 patients experienced moderate to severe myelopathy. Five patients were unable to walk without assistance. Six patients were neurologically intact preoperatively; two sustained deficits unrelated to the cervicomedullary junction (CMJ).

There were 14 women and 10 men, age 25 to 82 years, who underwent surgery to treat the following
In four of the 24 patients previous occipitoatlantoaxial surgical procedures had failed. In the initial three patients in the series instrumentation included stainless steel small fragment reconstruction plates (Synthes, Paoli, PA). In the remaining 21 patients instrumentation involved titanium hardware (Axis System; Sofamor-Danek, Memphis, TN).

**RESULTS**

In the initial 10 cases in the series (treated between 1992 and 1995), the lateral mass plates were fixed directly to the lateral suboccipital squama. In four of these patients, the presence of thin bone in the subocciput required that cables, not screws, be used in the occipital fixation of the plates, thus partially defeating our intent to obtain rigid fixation. In the six cases in which screws were fixed to the lateral subocciput, three patients suffered subsequent occipital screw pullout (Fig. 3).

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**TABLE 1**

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of Patients</th>
<th>Myelopathy</th>
<th>Decompressive Procedure</th>
<th>Halo Placement</th>
<th>Neurological Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rheumatoid arthritis</td>
<td>9</td>
<td>5</td>
<td>2</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Trauma</td>
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<td>6</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
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<td>2</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Congenital deformity/</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Basilar invagination</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Infections</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

* Both patients died of causes unrelated to this procedure.
Fig. 3. Left: Lateral radiograph obtained 6 weeks after an occiput-C4 fusion in which lateral mass plates were affixed to the lateral suboccipital bone. Both occipital screws of the left plate have failed by pullout. Right: A computerized tomography scan of the suboccipital region obtained after placement of lateral screws. Screw purchase is largely in cerebellar tissue because bone purchase is only 1 to 3 mm thick (arrows).

Of these same 10 initial cases, there were three patients in whom the cervical ends of the plates were fixated only with subaxial lateral mass screws. In each of these cases screw pullout of some or all of the four to eight screws occurred. Although fusion occurred in all of these patients, it was necessary for them to be placed in rigid external orthoses (Fig. 4).
Fig. 4. Lateral radiograph obtained in the recovery room in a patient with osteoporosis and rheumatoid arthritis after undergoing transoral odontoidectomy and occiput-C4 fusion. This elderly female patient extubated herself in the recovery room and promptly experienced upper airway obstruction (status post transpharyngeal approach). An anesthesiology resident immediately reintubated the patient, removed her halo attachments, hyperextended her neck, and pulled out all four subaxial lateral mass screws, as seen here. Remarkably, fusion was achieved while the patient was placed in a halo vest, without deficit and without further surgery. Subaxial lateral mass screws are inadequate in many cases of rigid occipitocervical fixation (see text).

Based on experiences with these initial cases and subsequent cadaver dissections, it became apparent that the only portion of the suboccipital bone that is consistently thick enough to be used to obtain firm bone screw purchase is the midline keel.[7,8] Similarly, we learned that the long moment arm, when applied across a plate or rod that extended from the suboccipital bone to the axial or subaxial cervical spine, meant that the forces applied were greater than could be resisted by routine subaxial lateral mass screws, even when applied at multiple levels.

Hence, in the subsequent 14 cases devices were fixed by obtaining multiple screw purchase of the suboccipital midline at the cranial end and by long C-2 pars screws, C1-2 transarticular screws, and/or upper thoracic pedicle screws at the cervical end. There have been no cases of screw pullout or construct failure in any of these 14 cases. Halo orthoses were used only in the four patients with rheumatoid arthritis among these 14 cases.

Twelve of the 14 latter cases treated between 1996 and 1998 underwent an occipital-end fixation procedure in which a custom-designed "T-plate" device (DWC; Sofamor-Danek) enabled three-point screw fixation of the suboccipital midline and attachment to lateral mass plates with machine screws and washers. No cases of screw pullout have occurred after implantation of this device (Fig. 5).
Fig. 5. Imaging studies obtained in a 17-year-old boy. Left: Lateral radiograph showing atlantooccipital dislocation. The patient experienced hemiparesis and tongue weakness but was otherwise intact. Upper Right: Lateral radiograph obtained immediately after occiput-C2 fusion in which the T plate was used for occipital-end fixation and C1-2 transarticular screws for cervical end fixation. (A halo brace was worn for realignment on admission and was removed after surgery.) Lower Right: A computerized tomography scan obtained through the subocciput demonstrating screw purchase of the thick (14 mm in this case) midline "keel" (arrows).

In one case, a 6-month follow-up radiograph revealed a single loose machine screw, but this was of no clinical consequence. In two patients, a prominent external suboccipital midline ridge precluded the use of the T-plate. In these cases, placement of doubly curved (or twisted) lateral mass plates allowed us to obtain midline suboccipital purchase by using obliquely directed transverse screws (Fig. 6).
Fig. 6. Intraoperative photograph showing prominent external occipital protuberances that preclude the use of the T plate. As is seen in this case, lateral mass plates can be doubly bent and twisted to allow transverse oblique screw purchase of the thick occipital midline bone.

The follow-up period for the entire series ranged from 6 months to 6 years. Two patients died of causes unrelated to surgery. In the 17 patients who have been followed for more than 2 years, the apparent successful fusion rate is 100%. We define successful fusion as the absence of movement on flexion-extension radiographs, the presence of intact hardware, and/or obvious bridging bone between occiput and cervical spine. There have been no deaths attributable to the surgical procedure. One case of wound infection occurred. Interestingly, the single infection occurred in an elderly but otherwise healthy man who had not previously undergone radiotherapy or steroid therapy. He did undergo a transoral odontoidectomy and posterior fusion after induction of a single anesthetic. Surprisingly there was no incidence of infection in patients who underwent steroid or other immunocompromising therapy or previous radiotherapy, or in patients in whom transoral and posterior procedures were performed in a single session.

There were no direct cervical cord or nerve root injuries in the series. Of the eight patients who were neurologically intact preoperatively, all had remained so at last follow-up examination. Of the 16 patients who experienced mild to severe myelopathy preoperatively, two died of unrelated causes, in eight the symptoms had objectively improved, in five they were unchanged, and in one case they had clearly worsened.

The two cases of major neurological complications were attributable to the instrumentation procedure. The first occurred in a 49-year-old man with severe basilar invagination and cord compression at the CMJ. He had undergone three previous operations; however, cranial settling had occurred, thus recompressing his cord after a previous odontoidectomy and nonrigid occipitoaxial fusion had been performed. He underwent removal of the previous fusion bone and wires, traction realignment, and rigid
refusion in which occiput-C4 plates and screws were placed. Postoperatively, his initial recovery was good, and he was transferred to a rehabilitation facility. On his 8th postoperative day, however, he suffered a major CMJ infarct, which converted his already severe myelopathy to quadriplegia. Imaging studies revealed a left vertebral artery occlusion that had likely occurred secondary to screw injury at C-3. Now 6 years postoperatively, he walks without assistance but is functionally worse than he was preoperatively.

The second major complication occurred in a 61-year-old woman with rheumatoid arthritis in whom C1-2 instability, moderate myelopathy, and multisegmental subaxial stenosis and kyphosis had been demonstrated. She underwent subaxial decompressive surgery, realignment, and occiput-C5 fusion in which doubly bent plates were fixed with transverse, oblique, midline suboccipital screws, C-2 pars screws, and multiple subaxial lateral mass screws. Although the procedure was uncomplicated, she did not awaken in the recovery room. An emergency CT scan revealed an acute right cerebellar subdural hematoma. Returned immediately to the operating room, she underwent evacuation of the hematoma that was found to be secondary to bleeding from a small, superficial cortical vessel, just off the midline, which had probably been inadvertently nicked by the drill. After surgery she awoke and moved all extremities well. Two days later she became comatose, at which point we obtained a CT scan that revealed cerebellar contusion with edema. She was returned to the operating room to undergo emergency removal of all hardware from the subocciput, as well as cerebellar debridement. Maintained in a halo vest after surgery, she now has only onlay grafts that were placed in the subocciput lateral to the craniectomy. Remarkably, now 2 years after complications, the patient has no detectable cerebellar deficit, her myelopathy has clearly improved, 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. 7). 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 were able to eliminate the need for ventral (transoral) decompressive surgery in four patients with rheumatoid arthritis and in three patients with congenital deformity in whom postoperative imaging studies revealed resolution of all ventral compression after traction alignment. No cases of postoperative cranial settling, with reinvagination into the foramen magnum, were associated with this technique.

**DISCUSSION**

The advantages in the cervical and thoracolumbar spine of rigid fixation for the enhancement of fusion have been well established. These methods allow for correction of deformity and maintenance of alignment until solid bone fusion occurs. Insertion of hardware into the spinal canal is not required, and as a result, the risks of spinal cord injury are lower. Because the rigidity of the construct enables the incorporation of involved segments only, it prevents further loss of motion (in the incorporation of each motion segment, a loss of 10% of flexion, extension, and lateral bending occurs). Additionally, fixation can be performed in the absence of the posterior elements. Postoperative stability allows for early ambulation, eliminates the need for rigid external orthoses in most cases, and appears to decrease the risk of pseudarthrosis. It also appears to prevent postoperative cranial settling and recompression. More recently, the in vitro biomechanical advantages of rigid instrumentation at the occipitocervical junction have been delineated.[9] We believe that the results of this initial series support the use of such constructs in many cases of occipitocervical instability secondary to a variety of pathological processes.

Plate and screw instrumentation, as described by Sasso, et al.,[15] requires lateral suboccipital bone purchase at the cranial end to obtain rigid fixation. Although the fusion rate is increased, the potential for complication remains high. The lateral occipital bone thickness is between 3 mm and 6 mm. Thus, bone purchase is often inadequate, and screw pullout has been documented in our experience and that of others [16] (Fig. 6). Results of biomechanical studies in which occipital screw fixation was examined have demonstrated that the strength of the screw fixation device was proportional to the bone thickness.[13] Midline occipital purchase in which unicortical screw fixation is used offers greater pullout strength without the need for bicortical screws or wire fixation and their potential complications.[7]

Analysis of anatomical studies demonstrates that the maximum thickness (11-17 mm) of the subocciput is found under the external occipital protuberance.[8] With this knowledge, other authors have designed instrumentation with midline occipital purchase. The "T plate" (no resemblance to our instrumentation) described by Heywood, et al.,[8] takes advantage of this fact. This plate is restricted to short segment fusions and requires intact C-2 posterior elements. Grob, et al.[6] have described a Y plate that allows midline occipital purchase at the cranial end and placement of transarticular C1-2 or C-2 pars screws at the cervical end. The Y plate often does not fit the axial vertebral width in a given case. Moreover, rotational movements applied postoperatively are poorly resisted by such constructs, which tend to fail by divergent pivoting of the suboccipital screws. Olerud (personal communication, 1998) has designed a device that accomplishes the same goals as our system. It is currently in use in Europe. Sutterlin uses an occipital plate similar to the one described here (personal communication, 1998). At least three major
spinal instrumentation manufacturing companies are developing rod or plate devices with screw fixation for the occiput and cervical spine.

We believe that there are several important lessons to be gleaned from our series and those of others. The requirements for a successful rigid occipitocervical fixation system are based on the unique geometry of the normal human anatomy, the unique motion patterns between the normal occiput and C-2, the unique pathological processes that affect this region, and the further destabilization that may accompany anterior or posterior decompressive operations.

**Geometry and Physics**

The shape of the human occipital skull and its apical vertical position on the upper cervical spine produce geometrical requirements that are not present elsewhere. When a plate or rod is attached to the midline suboccipital bone, it will be several centimeters posterior to its cervical attachment point when viewed in the sagittal plane. Additionally, the moment arm length between the occipital and cervical ends may range from 6 to greater than 20 cm depending on the size of the patient and the length of the construct.

**Normal Range of Motion**

More than 50% of the total range of motion in the cervical spine lies between the occiput and C-2.[18] There are six normal and eight pathological degrees of freedom. The primary movement between the occiput and the atlas occurs in flexion and extension positions. The primary movement between the atlas and the axis occurs in the left or right rotation position. In addition, small degrees of lateral bending in both directions occur both in the supra- and subaxial spine. In many pathological processes, compression or distraction also occurs and must be resisted.

**Pathological Processes**

In processes such as rheumatoid arthritis, the initial pathological movement usually occurs in flexion. With further progression of the disease, compression occurs with basilar invagination and telescoping of the upper cervical spine into the foramen magnum. In chronic posttraumatic deformity, the dislocation may have forced the cervical spine into a flexed or extended posture. In rheumatoid or congenital deformity, rotational dislocation or coronal-plane (scoliotic) deformity is not unusual. In atlantooccipital 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, to decompress adequately the rheumatoid pannus, tumor, chronic traumatic fracture with pannus, congenital anomalies, and other pathological processes requires resection of the anterior elements of the atlas, axis, basal skull anteriorly or posteriorly, or even subaxial cervical elements with their associated ligamentous attachments. Such procedures often increase preexisting instability and worsen the tendency toward sagittal-plane deformity or cranial settling. Traditional wire-fixated constructs do not adequately resist this tendency.

Although not without risks, the procedure of rigid occipitocervical fusion with instrumentation that we describe here satisfactorily addresses the aforementioned requirements. By obtaining 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, we have produced constructs that are
capable of resisting the geometrical loads applied at the CMJ. Additionally, these constructs may be used without rigid external orthoses when the patient does not suffer from osteoporosis. Such constructs also resist cranial settling and postsurgical invagination, and they may eliminate the need for performing ventral decompressive surgery in some cases. Because they may be used in fusions that extend to any level of the cervical or upper thoracic spine, they are, therefore, more versatile than devices that are limited to occipitoaxial fusions. They also may be used in the absence of some or all cervical posterior elements and even after small suboccipital craniectomies have been performed. Furthermore, they eliminate the risks of sublaminar wire or cable passage.

Although technical complications may not be completely eliminated, experience and various image-guidance techniques will likely decrease risks in the future. Technical improvements in the instrumentation hardware used in these constructs will facilitate its widespread adoption. We believe that the experience reported here and elsewhere suggests that we are entering a new era in which more successful occipitocervical reconstruction is feasible.

References


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