54 High Cervical and Occipitocervical Plate, Rod, Wire, and Bone Techniques

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SUMMARY OF KEY POINTS

- The craniocervical junction includes the occiput, atlas, and axis.
- Stability is provided by the cup-shaped configuration of the occiput and atlas, but it is mostly afforded by the ligamentous structures between the occiput, C1 and C2.
- Instability at the craniocervical junction may be vertical (cranial settling) or horizontal (atlantoaxial).
- Most of the rotation at the craniovertebral junction is lost with occipitocervical instrumentation.
- In patients with atlantoaxial instability with early cranial settling, an occipitocervical stabilization should be performed (especially in rheumatoid patients) to prevent an accelerated progression of the settling.

Abnormalities at the craniocervical junction were first reported in the early 19th century.[1] The craniocervical junction includes the occiput, atlas, and axis. Numerous pathologic conditions can lead to instability at the craniocervical junction. Common mechanisms of injury include trauma, rheumatoid arthritis, inflammatory and infectious lesions, tumors, and congenital anomalies.

The occipitoatlantoaxial joints are complex, both anatomically and kinematically. Anatomically, two synovial joints are found between the condyles of the occiput and the atlas; four synovial joints are found between the atlas and the axis; and there is a synovial joint between the ventral arch of the atlas and the dens, a second between the dens and the transverse ligament, and two at the dorsolateral joints. The opposing surfaces of the dorsolateral joints are convex and facilitate the rotatory movement.

Stability of the occipitoatlantal joint is provided by the cup-shaped configuration of the occipitoatlantal joint and the thick articular capsule, along with the anterior and posterior atlanto-occipital membranes.[2-4] The fibrous capsule of the occipitoatlantal joint is usually thickest laterally and posteriorly and thin if not deficient medially. The tectorial membrane, which is a continuation of the posterior longitudinal ligament, attaches to the ventral foramen magnum and laterally to the medial aspects of the occipitoatlantal joints, playing an important role in the stability of the craniovertebral junction (CVJ).[5] The alar ligaments are paired, arise on either side of the dens, and have two components: the atlantoalar and the occipitoalar ligaments. These two components connect the dens to the lateral mass of C1 and to the medial aspect of the ipsilateral occipital condyle, respectively.[6] These ligaments, together with the cruciform and apical ligaments, span from the axis vertebra to the occiput, and all provide some degree of stability to the occipitoatlantal joint.[7]

The occipitoatlantal joints allow 15 to 20 degrees of flexion-extension and 5 to 10 degrees of lateral bending. Head nodding occurs at the occipitoatlantal joint. The atlantoaxial joint allows 47 to 50 degrees of axial rotation, 15 to 20 degrees of flexion extension, and 15 to 20 degrees of lateral bending coupled with axial rotation.

CAUSES OF INSTABILITY IN THE UPPER CERVICAL SPINE

Instability of the upper cervical spine can be caused by congenital, traumatic, inflammatory, or neoplastic involvement.[8] Of the several congenital abnormalities that occur in the upper cervical spine, basilar impression (or cranial settling) is the most common. Basilar impression may be progressive and lead to cervicomedullary spinal cord compression. Congenital ligamentous laxity in the upper cervical spine (e.g., Down syndrome, Morquio syndrome) can cause instability and subluxation. Upper cervical spine involvement in patients with rheumatoid arthritis can also lead to atlantoaxial instability and cranial settling, both of which may require surgical decompression and stabilization. Trauma, however, is the most common cause of instability in the upper cervical spine. Most upper cervical spine injuries result from blows to the head (e.g., motor vehicle accidents and falls). The direction of the force vector determines the type of injury (i.e., blows to the head versus deceleration of the torso). Injuries of the occipitoatlantal junction are usually fatal and are only detected postmortem. Atlantoaxial instability, on the other hand, can result from disruption of the bony or ligamentous elements or both. Bony fractures often involve the dens. Fractures of the odontoid process of C2 are classified into three types: I, II, and III.[9] Type II odontoid fractures are unstable and notorious for nonunion with conservative management. Published reports of nonunion rates for conservatively managed type II odontoid fractures range from 30% to 60%. Type I fractures are always stable, and type III fractures may be unstable in 10% to 15% of cases.

Craniocervical instability can result from destructive tumors as well as iatrogenically, for example, following resection of such craniocervical tumors. Instability may depend on the extent of condylar destruction or resection in these cases.

INSTABILITY AT THE CRANIOCERVICAL JUNCTION

Several definitions of instability at the CVJ have been proposed. Craniocervical instability can be vertical or horizontal. Vertical instability or cranial settling usually occurs from a congenital or chronic inflammatory process. Destructive arthropathy of the occipital condyles and the lateral masses of the atlas and axis leads to progressive cranial settling in rheumatoid arthritis. Horizontal (ventrodorsal) instability usually results from acute traumatic situations that cause ligamentous disruption or bony disruption. A rotary component may or may not be present.

Common radiologic criteria used to document instability at the craniocervical junction include (1) predental distance greater than 5 mm in a child (< 8 years of age) and greater than 3 mm in an adult, (2) separation of more than 7 mm of the lateral masses of the atlas on the open mouth view, (3) greater than one third of the rostral dens above the ring of the foramen magnum, and (4) "bare occipital condyles," indicating an occipitoatlantal dislocation.

There is a paucity of reports in the literature regarding resection of the occipital condyle or the destruction of the condyle with tumors of the craniocervical junction causing instability and the necessity for stabilization in this group of patients. The recommendations to date have been to stabilize the occipitocervical junction when greater than 70% of the occipital condyle has been removed.[4,10]

MANAGEMENT OF INSTABILITY IN THE UPPER CERVICAL SPINE

Patients with instability of the upper cervical spine run the potential risk of fatal injury to the cervical spinal cord. Early recognition, reduction, immobilization, and stabilization are the goals of treatment.

Patients with upper cervical spine instability from congenital causes should be further evaluated for other associated congenital defects (e.g., Chiari malformation, spinal dysraphic lesions, and hydrocephalus). A magnetic resonance imaging (MRI) should be obtained to assess the soft tissue pathology. In addition, computed tomography (CT) and plain radiographs (with or without flexion-extension views) should also be obtained when appropriate.

Patients with rheumatoid arthritis should have an MRI to ascertain the presence of inflammatory pannus or bony encroachment of the neural elements (Fig. 54-1). Patients with spinal cord or brain stem compression and with significant neurologic deficits and occipitocervical instability should be considered for a ventral decompressive procedure before undergoing dorsal stabilization.[11]

Patients with radiologic evidence of subluxation on neutral radiographs should also be evaluated with dynamic, lateral flexion-extension radiographs to assess the reducibility of the subluxation. Patients with nonreduced subluxations should undergo a trial of cervical traction to reduce the dislocation before a decision is made about the appropriate surgical treatment. Patients with chronic instability should remain in traction for 4 to 5 days with muscle relaxation before being considered for surgical treatment. Patients with a reducible subluxation, reduction achieved with flexion-extension, or with axial traction (Fig. 54-2) and without compromise of the cervicomedullary cord may be safely stabilized by a dorsal approach.[12] In contrast, patients who have a ventral

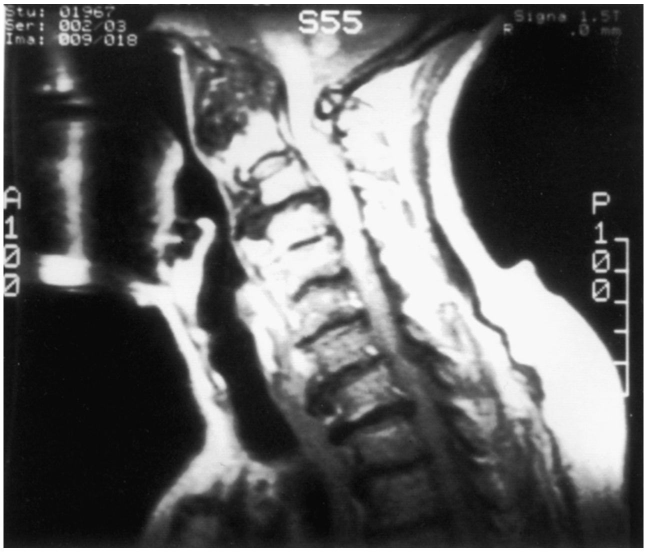

Figure 54-1. MRI of the cervical spine in a patient with rheumatoid arthritis showing atlantoaxial instability with pannus formation.

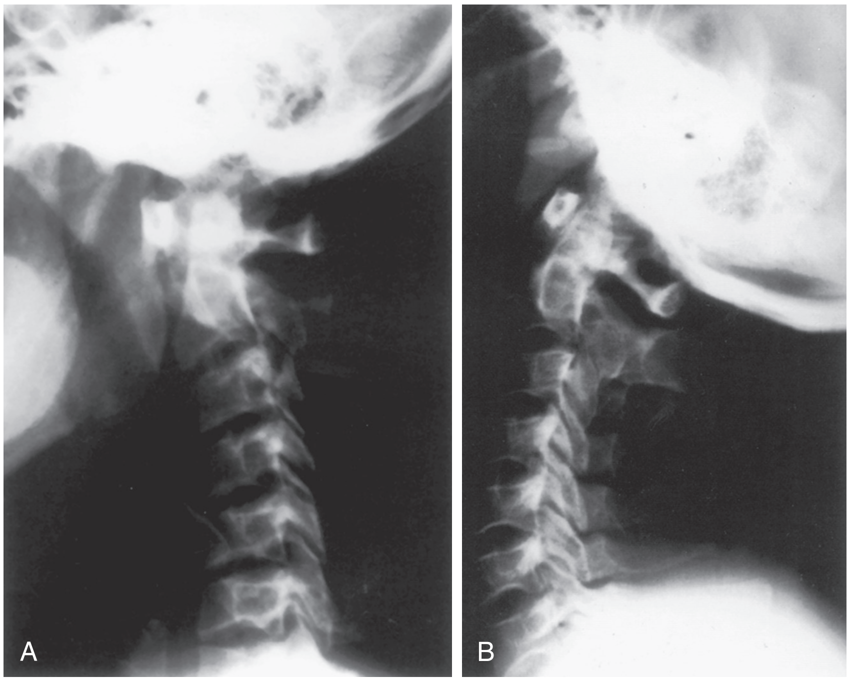

Figure 54-2. A, Plain lateral cervical spine radiograph in flexion showing ventrolisthesis of C1 on C2. **B,** Plain lateral cervical spine radiograph in extension showing reduction of the subluxation.

spinal cord compression with a nonreducible subluxation may require a ventral decompression before undergoing occipitocervical stabilization. Usually, patients with instability related to rheumatoid arthritis or with pannus, but without neurologic deficit, can be stabilized from a dorsal approach without undergoing an initial ventral decompression.[13] The pannus typically resolves in 6 to 12 months after abnormal movement has been eliminated.

INDICATIONS FOR INSTRUMENTATION IN OCCIPITOATLANTAL INSTABILITY

The majority of traumatic occipitoatlantal dislocations are fatal. Some patients who arrive in the emergency department are treated effectively in cervical traction followed by occipitocervical instrumentation and fusion. Chronic instability at the occipitoatlantal junction occurs with rheumatoid arthritis, with tumors, and following tumor resection.[14] Chronic instability at the craniocervical junction has been described as "glacial" instability in patients with chronic instability erosion of the occipitoatlantal articulation. This instability may result in cranial settling with associated rotary subluxation. In patients presenting with cranial settling with minimal or no neurologic deficits, reduction with cervical traction may be attempted, and if successful, dorsal occipitocervical instrumentation and fusion can be performed.[15,16] In patients with significant neurologic deficits, a ventral decompression may be necessary before dorsal stabilization and fusion. Patients with rheumatoid arthritis, atlantoaxial subluxation, and associated cranial settling are candidates for occipitocervical instrumentation and fusion.

In traumatic atlantoaxial subluxations with fractures of the dorsal elements of C1 and C2 in both reducible and irreducible subluxation, C1-2 lateral mass fixation techniques can be utilized. The screws are placed in the lateral mass of C1 and in the C2 pedicle or pars. In a reducible C1-2 subluxation with fractured dorsal elements, a C1-2 transfacet screw fixation technique can also be utilized.

The only scientific evidence for the assessment of instability at the craniocervical junction following tumor surgery comes from the biomechanical study by Shin and colleagues.[17] Based on our clinical series, the biomechanical studies available, and new concepts of instability applied to the CVJ,[18] we recommend that occipitocervical stabilization and fusion be performed when 50% or more of one condyle is resected or noted to have been destroyed by the tumor. A strong argument supporting this guideline can be made when using the extreme lateral transcondylar approach[18] for the resection of these tumors. This approach removes the thickest parts of the capsule of the occipitoatlantal joint, rendering the joint unstable (glacial instability). Thus, patients who have the condyle resected for surgical access and patients with tumor destruction of the condyle equal to or greater than 50% (but < 70%) who do not undergo stabilization and fusion may progress to a glacial instability and eventually to overt instability with severe neck pain and torticollis.

OCCIPITOCERVICAL TECHNIQUES

Several techniques exist for upper cervical spine stabilization, with or without instrumentation. Bony arthrodesis usually is the long-term goal of these techniques. With occipitocervical junction arthrodesis, a bony bridge must be established between the occiput and the upper cervical spine. Techniques may be divided into those that use bone alone and those that use internal fixation with bone.

In 1959, Perry and Nickel described a simple onlay graft for neck fusion for instability after severe poliomyelitis. In 1969, Newman and Sweetnam[19] described the technique for occipitocervical fusion in atlantoaxial instability. Fusion was achieved by decortication and laying down strips of corticocancellous bone obtained from the iliac crest. Patients were kept in cervical traction for 6 weeks and then placed in a high plastic cervical collar until bone fusion was observed.

The combination of internal fixation with onlay bone grafting has reduced the need for postoperative traction and rigid immobilization. Pseudarthrosis rates in a series of 302 occipitocervical fusions and 98 atlantoaxial fusions have been reported to be as low as 1%.[7]

Perioperative Considerations

Patients placed in traction for traumatic instability or those in whom a reduction of cranial settling was attempted are brought to the operating room in their bed with the traction in place. Extension of the neck is usually the position of safety for most patients with upper cervical instability. Thus, oral endotracheal intubation that requires some extension of the neck is usually safe, though most often these patients will be intubated fiberoptically. After intubation, a firm cervical collar is placed on the patient's neck. Traction on the cervical spine is applied manually by pulling the tongs while turning the patient to the prone position. The patient's head is maintained in a neutral to slightly extended position and supported in a horseshoe headrest or fixed in a three-pin head holder. Presently most of our patients, even those in preoperative traction are stabilized in the operating room in a three-pin head holder. During positioning, the head is placed in a military-tuck position to achieve some reduction of the subluxation, without extreme extension of the head. However, in patients undergoing an occipitocervical stabilization/fusion, the head and neck should be placed in neutral to slight extension with lateral cervical spine x-rays obtained to ascertain that the chin is not tucked in against the spine. This is an important step to prevent swallowing difficulties post-op.

Exposure

A midline incision is made from the inion approximately to the C4 spinous process. The length of the exposure varies, depending on the length of subaxial spine to be fused. The suboccipital bone around the foramen magnum and the spinous processes and laminae of C1 to C3 are exposed subperiosteally.

Occipitocervical Fusion

In occipitocervical junction arthrodesis, a bony bridge has to be established between the occiput and the upper cervical spine. The techniques may be divided into those using bone alone versus internal fixation and bone grafting. A simple onlay graft alone in occipitocervical fusions was used first by Perry and Nickel and later by Newman and Sweetnam.[19] The fusion extends from the occipital bone to the atlas and axis. Patients who underwent this procedure were placed postoperatively in a halo vest for 3 to 4 months until bony fusion was noted on radiologic studies. The authors reported good fusion rates; however, the patients in their series were young and healthy. These bone alone techniques are no longer utilized because of the superior results obtained with instrumentation and fusion.

Occipitocervical Fusion with Internal Fixation

Rigid metallic implants to obtain immediate fixation with generous onlay bone graft have produced successful fusion without the need for postoperative halo-vest immobilization. Techniques with contoured rods, cables, plates, and screws have been described.

Contoured Rod and Cable Fixation

Different smooth and threaded rods have been used for internal fixation in occipitocervical fusions. A titanium rod, contoured into a reverse "U" shape to conform to the craniocervical angle, has been used to keep the patient's head in a neutral position (Fig. 54-3).

Rod and plate screw systems have become more popular and provide a more rigid fixation. Cortical screws are placed in the occiput close to the midline where the bone is thickest; this is combined with a rod or plate system at the occiput with lateral mass screws at C1 and pedicle/pars screws at C2. In the presence of an intact C2, a sublaminar cable at C2 can be utilized to pull the C1-2 construct into the posterior instrumentation and reduce the stress on the C2 screws.

Lateral cervical spine radiographs are obtained after the patient is positioned prone, as described previously. The head is maintained in a neutral position.

With the rod/cable technique, the contoured rod is placed on the back of the occiput, and sites for the bur holes are marked on either side of the occipital portion of the contoured rod closest to the midline. Four bur holes are thus made in the suboccipital bone—two on either side of the midline—ensuring an adequate bridge of bone between the bur holes.

The posterior fossa dura mater is separated from the inner table of the bridge of bone between the bur holes, and a double cable is passed from one bur hole to the other. This is repeated on the opposite side of the occiput. The use of a double cable on either side of the occiput provides two cables on either side to hold down the rod. Alternatively, a single bur hole on either side of the midline, with the cable passed around the rim of the foramen magnum, can be used.

After cable placement for cranial fixation, sublaminar placement for spinal fixation is achieved by passing a double cable under the dorsal arch of C1 and the lamina of C2. When separated, a single cable is available on either side of the dorsal arch of C1 and C2. If the stabilization was to be extended to C3 or C4, lateral mass screws are placed in the lateral masses of C3 and C4 on both sides.

The contoured rod is placed in the bed, and the cables are torqued sequentially. The distal end of the rod may be cross-fixed, just caudal to the C3 or C4 spinous process, to increase the rigidity of the construct. After decortication, bone graft is obtained through a separate incision from the dorsal iliac crest and is laid as an onlay graft of corticocancellous bone. Care must be taken during head positioning before internal fixation and fusion to obtain the best subluxation reduction with optimal head and neck position, compatible with normal function. Care must be taken to avoid dural perforation during wire passage at the suboccipital bur holes and at C1 or C2. Beveling the edges of the bur holes and meticulous dissection of the dura mater from the inner table should prevent dural laceration. The leader wire of the single cable should be bent back on itself to present a smooth surface during sublaminar passage. Monitoring the bony surfaces carefully during torquing can help prevent overtightening of the cable. Sequential cable tightening with torque not exceeding 4 to 5 inch-pounds with titanium cables and 8 inch-pounds with stainless steel cables is appropriate in healthy adults. In patients with soft bones and in those with rheumatoid arthritis, the torque is reduced as appropriate (i.e., when cable begins to cut into the bone).

All patients are treated postoperatively in a firm cervical collar for 6 to 12 weeks or until radiologic fusion is observed.

Figure 54-3. Intraoperative photograph of a contoured rod with occipital and sublaminar cables for occipitocervical stabilization.

Plate Fixation

Presently, plates and screws are used for occipital fixation; the limiting factor is the variable thickness of the occipital bone. Heywood and associates[1] reported that occipital bone thickness measured 9 to 16 mm in the midline and only 3 to 9 mm in the lateral suboccipital bone. No room exists between the dura mater and the cerebellum. Penetration of the inner table could lead to cerebellar injury. Therefore, it is possible that with bicortical purchase during plate fixation, especially laterally in the suboccipital bone, the tip of the screw could perforate the dura mater and the underlying cerebellum.

With the Y-plate system of plate and screws for occipitocervical fusion, the stem of the Y is laid over the midline of the occiput. The occipital screws are 2.7 mm in diameter and 8 to 10 mm long. If subaxial fusion is necessary, transfacet screws are placed in the C1-2 facet joint (Magerl technique) and in the lateral masses of the subaxial spine.

Several newer designs of occipital plates to accommodate the size and surface of the occipital bone are presently available. These plates can be combined with prebent rods or hinged rods to accommodate the occipitocervical angle. Because of the risk of screws perforating the dura matter and the cerebellum, the use of the Y plate and the lateral occipitocervical plate is limited due to the need to place screws in the lateral suboccipital bone. Occipital plates with screws placed in the midline and connected to rod systems that connect to the screws placed in the C2 pedicle and lateral masses in the lower cervical spine are more rigid biomechanically than the wiring techniques. The modern occipital plates allow screws to be placed in or adjacent to the midline keel of the occiput. The thickness of the occipital keel and adjacent bone can vary from 8 to 10 mm. The screws used are cortical in nature and can be unicortical or bicortical.

Preoperative thin cut CT scans should be obtained to measure the thickness of the suboccipital bone. The drills and drill guides have been developed to allow safe drilling of the occipital bone. Flexible drill guides and drills as well as flexible screwdrivers allow us to access some of the difficult angles encountered at the occipitocervical junction.

Several newer techniques have been proposed to reduce craniocervical instability intraoperatively. In patients with cranial settling, spacers placed intraoperatively within the atlanto-occipital joints to reduce the cranial settling are combined with occipitocervical stabilization.

Another novel technique was reported in a series of patients with cranial settling, assimilation of the atlas, and C1-2 instability. After placement of the occipital plate and screws and lateral mass screws down to C6, anterior-posterior compression was used to reduce the C1-2 displacement, and vertical distraction was used to pull the odontoid out of the cranial cavity.

ATLANTOAXIAL FUSION

In 1910, Mixter and Osgood described the first atlantoaxial stabilization procedure using internal fixation. Gallie popularized wiring and bone grafting techniques for dorsal atlantoaxial arthrodesis.[20] A loop of wire is passed beneath the dorsal arch of the atlas from caudal to rostral. The loop of wire is then pulled caudally over the spinous process of C2. The free ends of the wire are run downward and around the spinous process of C2 and are twisted together. The dorsal surfaces of C1 and C2 are decorticated, and onlay bone graft from the iliac crest is placed to achieve bony union. This construct provides minimal rotational stability. In 1978, Brooks and Jenkins modified this technique.[10] They described passing two wires on either side, underneath the dorsal arch of C1 and the lamina of C2. Two unicortical wedges of iliac crest bone are placed between C1 and C2. This improves rotational stability. A modification of the Gallie technique described by Papadopoulos and colleagues[21] uses a bicortical H graft placed between the dorsal arch of C1 and the spinous process and lamina of C2.

Preoperative evaluation and management for this technique is identical to that described with occipitocervical fusion. In the modified Gallie technique, a loop of cable is passed under the dorsal arch of C1 from caudal to rostral. The caudal edge of the dorsal arch of C1 and the rostral edge of the C2 lamina and spinous process are decorticated. A bicortical graft, notched on its caudal surface to hug the contour of the spinous process and lamina of C2, is placed between C1 and C2. The cancellous surfaces of the graft abut the decorticated areas of C1 and C2. The cable passes as with the Gallie technique. The loop is dorsal to the graft, and the free ends run ventral to the graft. This ensures that the graft does not migrate dorsally or ventrally while providing the necessary rotational stability. Further decortication and onlay bone grafting of the dorsal surfaces of C1 and C2 will now take place. Overtightening of the cable around the graft can lead to graft erosion and loosening. In the presence of dorsal subluxation of the dens, there is a risk of pulling the dens dorsally into the spinal cord during wire tightening. Using a larger wedge of bone between the dorsal elements of C1 and C2 minimizes this risk. The tip of the leader wire should be doubled back to present a smooth surface during sublaminar wire passage to prevent dural laceration.

Several techniques have been described for wiring the atlas to the axis vertebra, with varying degrees of success. The disadvantage for patients undergoing wire and cable techniques alone is that in the presence of significant instability they must be placed in a halo body vest postoperatively for 3 to 4 months.

C1-2 transfacet screw fixation and C1 lateral mass/C2 pedicle or pars screw-rod fixation techniques are more commonly utilized presently for atlantoaxial instability. C1-2 transfacet screw fixation is suitable in patients with reducible subluxations and in patients who have either fractured or absent posterior elements of C1 and C2. The limitations of this technique are irreducible subluxations and the fact that 20% of patients have an anomalous vertebral artery in the path of the transfacet screw. Lastly, this technique is technically more demanding with a high incidence of vertebral artery injury. The procedure is often combined with the modified Sonntag/Papadopoulos wiring technique when the posterior elements are intact.

The patient is positioned prone in pins, and the patient's head is positioned in as much extension as is feasible to afford access to the C1-2 facet with a "military tuck" position. A midline incision is made to access the C1-2 elements, and a separate stab wound is made on either side at the C7-T1 level. The C2 lamina, the dorsal surface of the C2 pedicle, and the inferior facet of C2 are exposed bilaterally. The starting point for screw insertion is in the medial half of the inferior facet of C2. A trocar is brought in from the C7-T1 incision, followed by an awl and drill. With lateral fluoroscopic guidance and visualizing the mediolateral pedicle, drilling begins, keeping the drill in the medial and superior aspect of the pedicle, toward the back of the anterior arch of C1 as visualized on lateral fluoroscopy. This will carry the drill to the anterior wall of the lateral mass of C1. Tapping and placing a screw of the appropriate length, we typically place a fully threaded screw. The procedure is repeated on the opposite side. Intraoperative reduction of a reducible subluxation can be achieved by placing a sublaminar cable at C1 and pulling the C1 arch posteriorly before traversing the C1-2 facet.

C1 lateral mass C2 pedicle/pars screw–rod fixation is the most commonly adopted technique for the treatment of C1-2 instability. This technique can be used in irreducible subluxations, is technically not as demanding, and is reported to be biomechanically as strong as the transfacet fixation.

Patient positioning is similar to that described previously, and the posterior elements of C1 and C2 are exposed. Some surgeons routinely divide the C2 nerve for better access to the lateral mass of C1. We typically protect and keep the C2 nerve. We use a starting point 2 to 3 mm in and 2 to 3 mm up from the medial and inferior aspect of the lateral mass of C1, just below the posterior arch. The drill is directed 0 to 10 degrees lateral to medial and toward the back of the anterior arch of C1 as shown on the lateral fluoroscopy image. This will carry the screw to the anterior wall of the lateral mass. The C2 pedicle screw starting point is more lateral over the middle to inferior aspect of the joint with lateral fluoroscopy into the body of C2. A contoured 3.5-mm rod is placed in the heads of the polyaxial screws. Bone fusion is achieved with bone graft material placed across the C1-2 posterior elements.

With the latter two procedures, the patients are typically managed with a firm cervical collar for 8 to 12 weeks. An adjunctive technique in patients either with C1-2 or occipitocervical stabilization is the use of C2 laminar screws. They can be placed bilaterally, though they are difficult to line up with the more laterally placed screws.

SUMMARY

Upper cervical spine stabilization can be achieved using a variety of techniques, depending on the surgical indications. Controversy abounds regarding the use of occipitocervical fusion versus atlantoaxial fusion in the presence of atlantoaxial instability. Some surgeons continue to perform occipitocervical fusions in patients with instability at the atlantoaxial joint, arguing that the loss of 15 to 20 degrees in flexion-extension by including the occiput in the fusion is negligible. However, the 15 to 20 degrees of movement at the occipitoatlantal joint is responsible for the nodding or chin-tuck movement in the cervical spine, and the loss of this movement may be a cause of significant morbidity. We recommend that occipitocervical fusions be reserved for patients with occipitoatlantal instability or cranial settling with atlantoaxial instability. All other patients with instability at the atlantoaxial articulation alone should undergo the appropriate stabilization technique at C1-2. Rigid internal fixation techniques reduce the need for cumbersome and rigid external orthotics and increase the rate of bone fusion.

Guidelines for occipitocervical stabilization following resection of tumors at the CVJ have been based on anecdotal evidence with very little reported in the literature. Based on our clinical series[21] and the biomechanical studies available, we recommend that occipitocervical stabilization and fusion be performed for cases in which 50% or more of one condyle is resected or noted to have been destroyed by the tumor.

KEY REFERENCES

Bohlman HH. Acute fractures and dislocations of the cervical spine: an analysis of three hundred hospitalized patients and review of the literature. *J Bone Joint Surg Am*. 1979;61:1119-1142.

Menezes AH. Surgical approaches to the craniocervical junction. In: Frymoyer J, ed. *The adult spine*. New York: Lippincott-Raven; 2003:523-551.

Menezes AH, VanGilder JC. Transoral-transpharyngeal approach to the anterior craniocervical junction: 10-year experience with 72 patients. *J Neurosurg*. 1988;69:895-903.

Menezes AH, VanGilder JC. Abnormalities of the craniovertebral junction. In: Youmans J, ed. *Neurological surgery*. 3rd ed. Philadelphia: WB Saunders; 1990:1359-1420.

Menezes AH, VanGilder JC, Graf CJ, et al. Craniocervical abnormalities: a comprehensive surgical approach. *J Neurosurg*. 1980;53:444-455.

Shin H, Barrenechea IJ, Lesser J, et al. Occipitocervical infusion after resection of craniovertebral junction tumors. *J Neurosurg Spine*. 2006;4:137-144.

The complete list of references is available online at ExpertConsult.com.

REFERENCES

1. Heywood AW, Learmonth ID, Thomas M. Internal fixation for occipito-cervical fusion. *J Bone Joint Surg Br*. 1988;70:708-711.
2. Beighton P, Craig J. Atlanto-axial subluxation in the Morquio syndrome. *J Bone Joint Surg Am*. 1979;61:478-481.
3. Dawson EG, Smith I. Atlanto-axial subluxation in children due to vertebral anomalies. *J Bone Joint Surg Am*. 1978;61:582-587.
4. Fielding JW, Hawkins RJ, Ratzan SA. Spine fusion for atlanto-axial instability. *J Bone Joint Surg Am*. 1976;58:400-407.
5. Grob D, Dvorak J, Panjabi M, et al. Posterior occipitocervical fusion: a preliminary report of a new technique. *Spine (Phila Pa 1976)*. 1991;16(suppl 3):S17-S24.
6. Graham A, Hockley AD, McMillan JJ, et al. A new method of occipitocervical fusion, using internal fixation. *Neurosurgery*. 1987;21:947-950.
7. Menezes AH. Surgical approaches to the craniocervical junction. In: Frymoyer J, ed. *The adult spine*. New York: Lippincott-Raven; 2003:523-551.
8. Bohlman HH. Acute fractures and dislocations of the cervical spine: an analysis of three hundred hospitalized patients and review of the literature. *J Bone Joint Surg Am*. 1979;61:1119-1142.
9. Anderson LD, D'Alonzo RT. Fracture of the odontoid process of the axis. *J Bone Joint Surg Am*. 1974;56:1663-1674.
10. Brooks AL, Jenkins EB. Atlanto-axial arthrodesis by wedge compression method. *J Bone Joint Surg Am*. 1978;60:279-284.
11. Menezes AH, VanGilder JC. Abnormalities of the craniovertebral junction. In: Youmans J, ed. *Neurological surgery*. 3rd ed. Philadelphia: WB Saunders; 1990:1359-1420.
12. Menezes AH, VanGilder JC. Transoral-transpharyngeal approach to the anterior craniocervical junction: 10–year experience with 72 patients. *J Neurosurg*. 1988;69:895-903.
13. Menezes AH, VanGilder JC, Graf CJ, et al. Craniocervical abnormalities: a comprehensive surgical approach. *J Neurosurg*. 1980;53:444-455.
14. Pierce DS, Barr JS. Fractures and dislocations at the base of the skull and upper cervical spine. In: Cervical Spine Research Society, ed. *The cervical spine*. Philadelphia: Lippincott-Raven; 1983:196-205.
15. Hadley MN, Dickman CA, Browner CM, et al. Acute axis fractures: a review of 229 cases. *J Neurosurg*. 1989;71:642-647.
16. Rana NA, Hancock DO, Taylor AR, et al. Atlanto-axial subluxation in rheumatoid arthritis. *J Bone Joint Surg Br*. 1973;55:458-470.
17. Shin H, Barrenechea IJ, Lesser J, et al. Occipitocervical infusion after resection of craniovertebral junction tumors. *J Neurosurg Spine*. 2006;4:137-144.
18. Cregan JC. Internal fixation of the unstable rheumatoid cervical spine. *Ann Rheum Dis*. 1966;25:242-252.
19. Newman P, Sweetnam R. Occipitocervical fusion: an operative technique and its indications. *J Bone Joint Surg Br*. 1969;51:423-431.
20. Gallie WE. Fractures and dislocations of the cervical spine. *Am J Surg*. 1939;46:495.
21. Papadopoulos SM, Dickman CA, Sonntag VK. Atlantoaxial stabilization in rheumatoid arthritis. *J Neurosurg*. 1991;74:1-7.