Occipitoatlantal Dislocation

Mark Garrett, MD
Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona

Giacomo Consiglieri, MD
Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona

Udaya K. Kakarla, MD
Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona

Steve W. Chang, MD
Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona

Curtis A. Dickman, MD
Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona

Reprint requests:
Curtis A. Dickman, MD, c/o Neuroscience Publications, Barrow Neurological Institute, 350 W. Thomas Road, Phoenix, AZ 85013-4496.
E-mail: neuropub@chw.edu

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OCCIPITOATLANTAL DISLOCATION (OAD) can be devastating. This injury may be fatal in many cases, but more survivors are reported because of improvements in diagnosis and treatment. This article describes the diagnosis and treatment of OAD. To diagnose and treat OAD appropriately, neurosurgeons must have a detailed understanding of the anatomy of the craniocervical junction. Various radiographic criteria are used to establish the diagnosis of OAD. A destabilizing injury such as OAD requires surgical fixation. Many surgical techniques are available for fixation of the craniocervical junction. Future studies will continue to refine the diagnostic criteria for OAD and to develop improved methods for craniocervical stabilization.

KEY WORDS: Craniocervical anatomy, occipitoatlantal dislocation, occipitocervical fusion

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Traumatic occipitoatlantal dislocation (OAD) is an injury of the craniocervical junction associated with a high rate of mortality and significant neurologic morbidity.[1-13] The amount of force required to disrupt the occipitoatlantal junction often proves fatal to the victim of this type of injury. Historically, OAD was considered a rare entity, but studies have shown that this traumatic process is more common than once thought. Autopsy reports indicate that OAD accounts for 6% to 8% of all traffic fatalities. Of patients whose deaths are directly related to cervical spine injuries, 20% to 30% are the result of OAD.[14-16] OAD is also more common in the pediatric population than previously thought, making it a particularly important entity for neurosurgeons who treat pediatric spine trauma.[3] When the patient is managed appropriately, good neurologic outcomes have been documented in children and adults with this type of injury.[17]

Despite the high rate of mortality associated with OAD, an increasing number of reports have documented survivors.[1,17,18] This trend likely reflects the improvements in prehospital care as well as in diagnosis and management of OAD once patients reach a qualified trauma center. To manage OAD appropriately, surgeons must have a detailed understanding of the anatomy of the craniocervical junction, the radiographic criteria for the diagnosis, and the surgical techniques for craniocervical stabilization.

ABBREVIATIONS: BAI, basion-axial interval; **BDI**, basion-dens interval; **CCI**, occipital condyle-C1 interval; **CT**, computed tomographic; **MRI**, magnetic resonance imaging; **OAD**, occipitoatlantal dislocation

ANATOMY

The occipitoatlantal joint is formed by the articulating surfaces of the occipital condyles and the lateral masses of C1. On a coronal view, the lateral masses slope medially to match the shape of the occipital condyles. On a lateral view, the occipital condyles appear convex and sit within the concavity of the lateral masses. A loose capsule surrounds the joint.[18] In the pediatric population, the joint is less concave. This configuration partially explains the increased incidence of OAD in this group.

The ligamentous structures of the occipitoatlantal joint and atlantoaxial joints provide most of the structural stability for the craniovertebral junction (Figs. 1 and 2). The tectorial membrane is the craniocervical portion of the posterior longitudinal ligament, and it attaches to the upper cervical vertebrae and anterior aspect of the foramen magnum. Anterior to the posterior longitudinal ligament is the apical ligament, which attaches the tip of the dens to the anterior border of the foramen magnum. The alar ligaments are paired structures that extend from the tip of the dens to the medial border of the occipital condyles. The cruciate ligament consists of the transverse ligament, which attaches the dens to the C1 lateral masses, and a vertical portion, which attaches the tip of the dens to the anterior foramen magnum

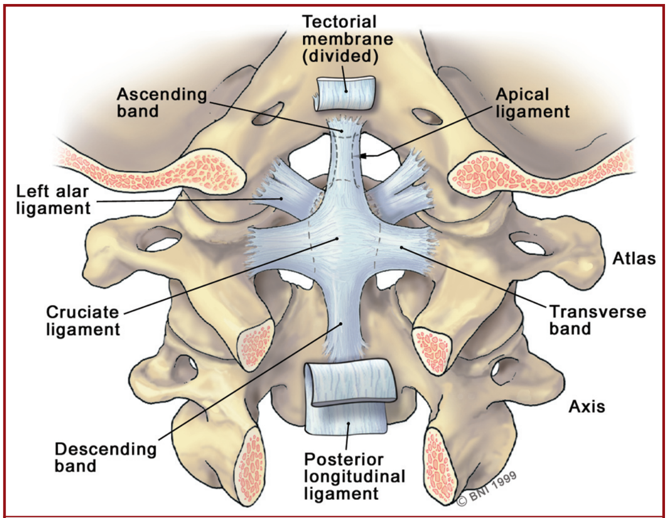

FIGURE 1. *Drawing (coronal view) of the ligamentous attachments of the craniovertebral junction. Critical ligaments to the occipitoatlantal joint include the tectorial membrane, the alar ligaments, and the cruciate ligament. (Used with permission from Barrow Neurological Institute.)*

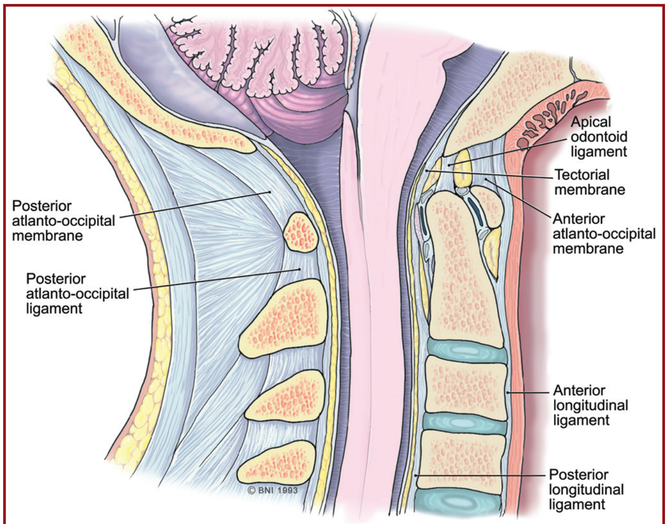

FIGURE 2. *Drawing (sagittal view) of the ligamentous attachments of the craniovertebral junction. (Used with permission from Barrow Neurological Institute.)*

just posterior to the apical ligament. An anterior and posterior atlanto-occipital membrane attaches the anterior and posterior aspects of the ring of C1 to the base of the cranium.

The most important ligamentous structures for the occipitoatlantal joint are the cruciate ligament, alar ligaments, and tectorial membrane. These ligaments are also primarily responsible for securing C2 to the occiput. Consequently, atlantoaxial distraction is often associated with OAD. In pediatric patients, these ligamentous structures are underdeveloped, which increases this population's susceptibility to OAD.

MECHANISM AND CLASSIFICATION OF OAD

Because of the complexity and strength of the attachment of the occiput to the upper cervical spine, ligamentous injury must be significant for OAD to occur. In general, it is thought that a combination of forces, namely hyperextension, lateral flexion, and/or hyperflexion, leads to OAD.[18]

Classically, OAD has been divided into 3 types, according to the Traynelis classification.[11] The type of injury is determined by the direction of dislocation of the occiput with respect to the atlas (Fig. 3). Type I injuries involve anterior displacement of the occiput with respect to the atlas; type II injuries are distraction injuries with vertical displacement; and type III injuries involve posterior displacement.

Many contemporary authors think that this classification scheme is descriptive but has little clinical relevance for management strategies.[19-22] The Traynelis classification does not address the severity of injury or other mechanisms, such as rotatory dislocations. Patient positioning alone can alter the relationship of the occiput to C1. More recent grading schemes have focused on the presence or absence of instability and its severity, without emphasis on the direction of the dislocation.[19,20]

PATIENT PRESENTATION AND INITIAL MANAGEMENT

Because considerable force is required to cause OAD, patients often present with significant head, spinal cord, or multisystem traumatic injuries. Mechanical ventilation, which can be needed owing to brainstem compromise, often makes neurologic assessment difficult. Cranial nerve deficits or a vertebral artery injury can be present. Despite the significant nature of the injury, some patients may also present with no neurologic deficits.[17]

Once OAD is suspected, on the basis of the examination or mechanism of injury, strict cervical spine precautions are mandatory to prevent further complications. Sandbags should be used for initial head immobilization, as rigid cervical collars can further distract the occipitoatlantal joint. We agree with other authors, who recommend early halo fixation once the diagnosis of OAD is confirmed.[18,23,24] Even if surgical fixation is planned, a halo vest minimizes motion of the cervical spine during intubation and positioning.

There are no clear guidelines for the use of cervical traction for the treatment of OAD. We believe that axial traction should be avoided in all cases of OAD because it reproduces the distractive mechanism of injury and is associated with a risk of damaging the spinal cord, medulla, or vertebral arteries. Traction is associated with a high risk of causing neurologic deterioration. Instead, gentle compression or minor repositioning of the head can be performed manually under live fluoroscopy with the patient awake so that neurologic changes can be recognized quickly.

RADIOGRAPHIC ANALYSIS AND DIAGNOSIS

A wide range of sensitivities has been reported for the techniques used to diagnose OAD,[25-28] and none of these criteria are

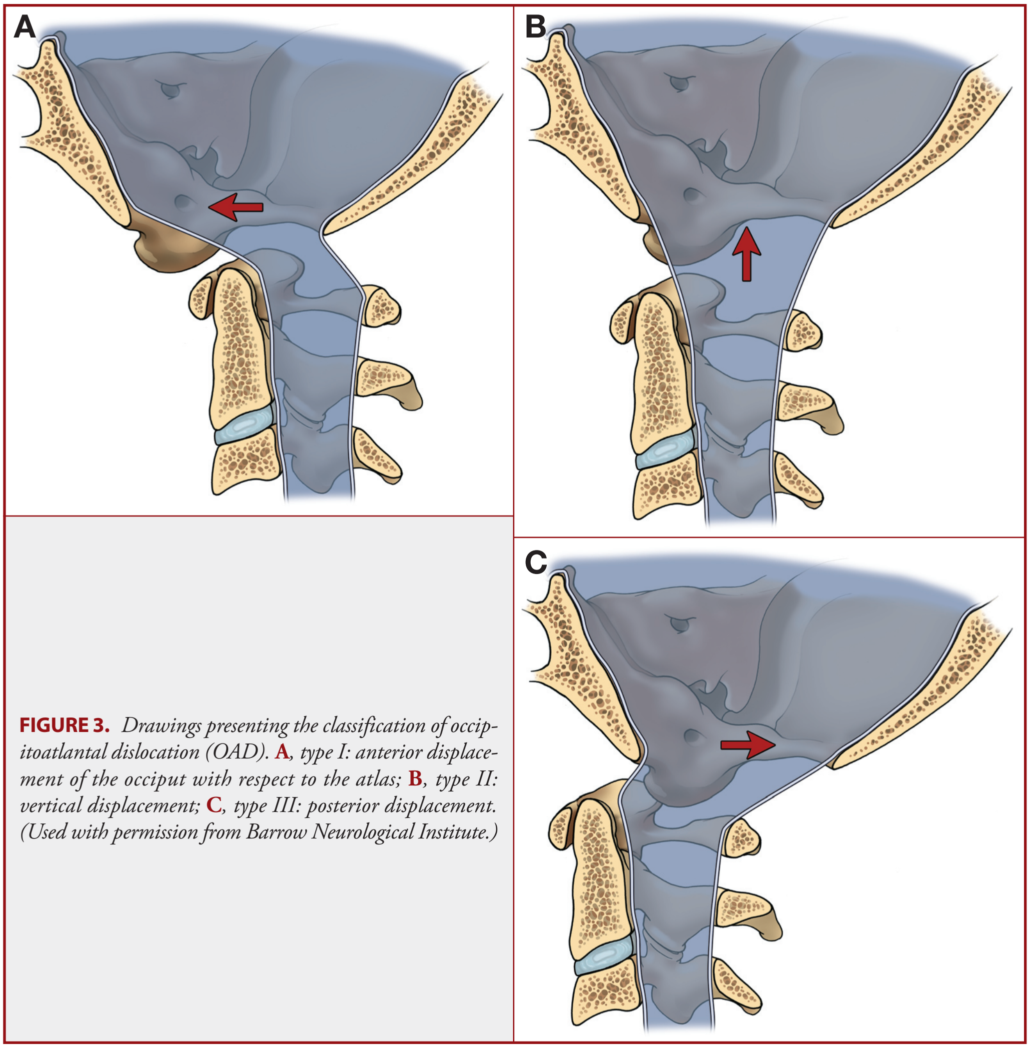

FIGURE 3. *Drawings presenting the classification of occipitoatlantal dislocation (OAD).* **A***, type I: anterior displacement of the occiput with respect to the atlas;* **B***, type II: vertical displacement;* **C***, type III: posterior displacement. (Used with permission from Barrow Neurological Institute.)*

On the basis of class III evidence, *The Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries*[29] recommend applying the BAI-BDI (Harris method) to a plain lateral cervical x-ray. In the event of a nondiagnostic film in the presence of clinical suspicion or swelling of vertebral soft tissue, computed tomographic (CT) scanning or magnetic resonance imaging (MRI) is recommended. Additional diagnostic clues include the following: enlargement of the predental space; neurologic abnormalities, including lower cranial nerve paresis (particularly cranial nerves VI, X, and XII); monoparesis, hemiparesis, and quadriparesis; respiratory dysfunction including apnea; complete high cervical cord motor deficits in the setting of normal plain spinal x-rays; subarachnoid hemorrhage at the craniovertebral junction on CT scans; ligamentous abnormalities of the tectorial, alar, and transverse ligaments; and short tau inversion recovery changes of the posterior interspinous ligament of the occipitoatlantal joint capsule on MRI.[22,29]

failproof. Available methods include Powers' ratio, X-line method, condylar gap method, basion-dens interval (BDI), and basion-axial interval (BAI) (Fig. 4). The BDI and BAI measurements are also known as Harris lines. We most commonly use the BDI, BAI, and Powers' ratio.

A universal theme underlying the difficulties in diagnosing OAD using plain lateral cervical x-rays is the ability to visualize the anatomic landmarks required for application of these methods. Diagnostic tests rely on bony landmarks that are remote from the injured occipitoatlantal joint. During patient positioning, these landmarks could inadvertently align and conceal actual disruption of the joint. With respect to the initial cross-table lateral x-ray of the cervical spine, landmarks may be indistinct, and magnification error may invalidate several of the indices commonly used for diagnosis. Poor visualization of the relevant anatomic structures on lateral cervical x-rays may lead to missed injuries. Congenital anomalies of C1 and C2 and at the foramen magnum and immature or delayed ossification of the odontoid segments also preclude use of many radiologic criteria.

Since these guidelines were published, the number of publications documenting the use of CT scanning as the diagnostic imaging of choice in patients suspected of having OAD has increased.[17,21,22,25] Dedicated studies using CT scanning to diagnose OAD have supported the use of the BDI (with 10 mm as the cutoff)[25] and the occipital condyle-C1 interval (CCI) (>4 mm is abnormal) as the diagnostic tests of choice.[22]

Pang et al[21] described normative data for the occipitoatlantal joint in 89 children, in whom the normal occipitoatlantal joint was tightly apposed, with a mean CCI of 1.28 mm. There was considerable left-right symmetry, and the CCI was stable from ages 0 to 18 years. On high-resolution CT scans in all individual joint measurements, the normal CCI was less than 2 mm. No single measurement among all 1424 data points was greater than 2.5 mm. Similar to the lateral mass interval as a diagnostic standard for atlantoaxial distraction injuries,[30] the CCI is the only test that directly measures the integrity of the actual joint injured in OAD. Furthermore, a widened CCI cannot be concealed by positioning after injury.

Pang et al[22] subsequently applied the CCI method to 16 patients with OAD and found pathologic widening ranging from 5 to 34

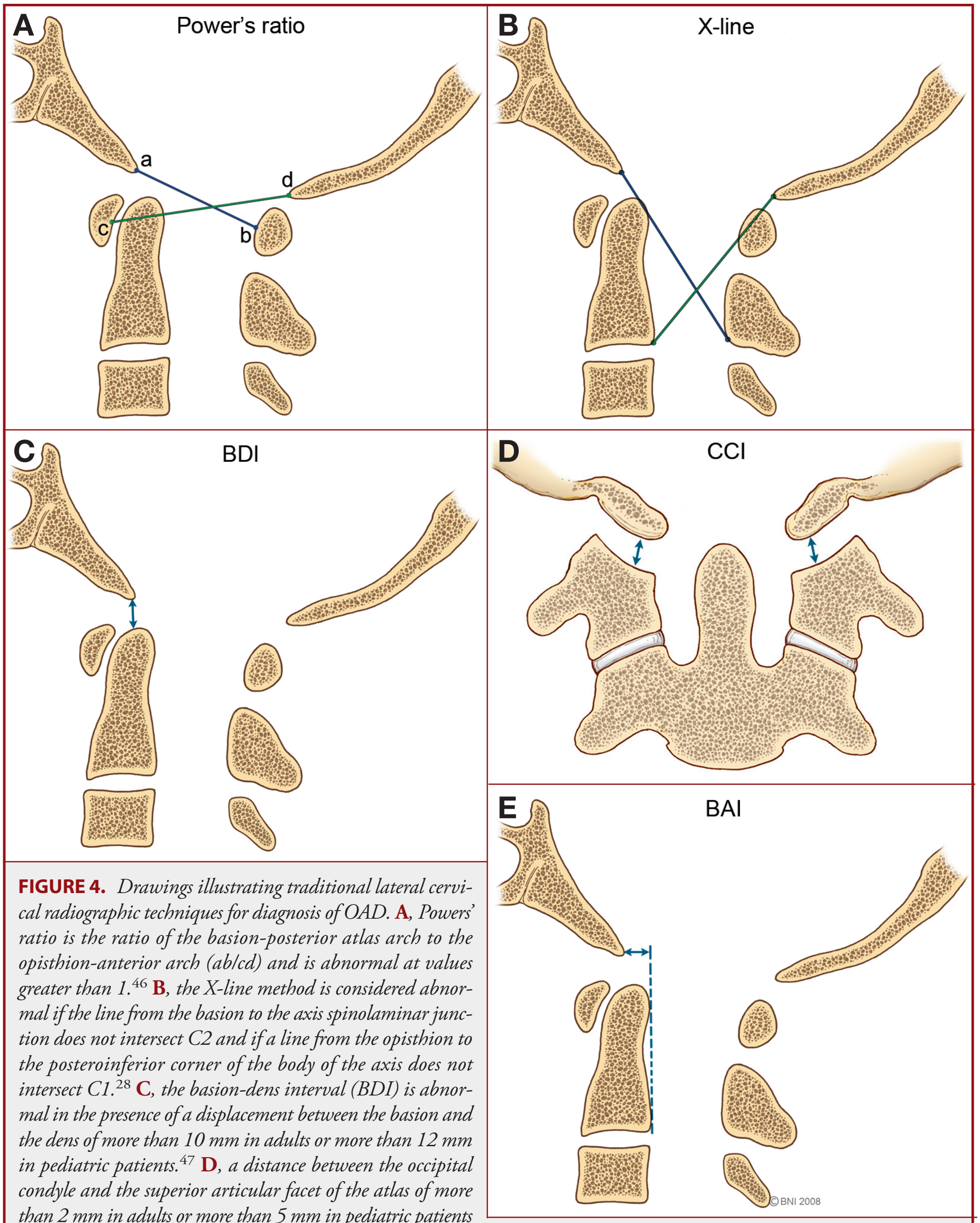

FIGURE 4. *Drawings illustrating traditional lateral cervical radiographic techniques for diagnosis of OAD.* **A**, *Powers' ratio is the ratio of the basion-posterior atlas arch to the opisthion-anterior arch (ab/cd) and is abnormal at values greater than 1.*[46] **B**, *the X-line method is considered abnormal if the line from the basion to the axis spinolaminar junction does not intersect C2 and if a line from the opisthion to the posteroinferior corner of the body of the axis does not intersect C1.*[28] **C**, *the basion-dens interval (BDI) is abnormal in the presence of a displacement between the basion and the dens of more than 10 mm in adults or more than 12 mm in pediatric patients.*[47] **D**, *a distance between the occipital condyle and the superior articular facet of the atlas of more than 2 mm in adults or more than 5 mm in pediatric patients is considered abnormal for the condylar gap method.*[47] **E**, *anterior displacement of 12 mm or more or posterior displacement of 4 mm or more between the basion and posterior C2 line is considered abnormal by the basion-axial interval (when combined with the BDI, this is known as the Harris method).*[26] *(Used with permission from Barrow Neurological Institute.)*

mm. The CCI criterion was positive in all of their 16 patients with OAD, with a diagnostic sensitivity of 100%. The authors advocated treatment of patients with pathologic widening greater than the upper normal limit of CCI of 4 mm. Given the variability in ossification and fusion at the craniocervical junction, this method is especially applicable to the pediatric population.

Harris et al[26] found the BDI diagnostically unreliable in children under the age of 13 years. However, the BAI was reproducible and normally did not exceed 12 mm. In fact, the CCI may become the diagnostic criterion of choice even in adults as the normative data reported did not show a statistical change from birth to 18 years. Current studies are under way to determine the diagnostic sensitivity and specificity of the CCI method in adults.

The increased use of MRI in trauma patients raises the question of how to interpret equivocal findings in the occipitoatlantal region. There is considerable variability in patients suspected of OAD, and determining treatment on the basis of these findings can be problematic.[31,32] The primary dilemma is how to treat patients with equivocal occipitoatlantal joint disruptions on MRI whose measurements on CT scanning are normal. It could be argued that these patients do not need treatment, especially based on the inability of MR I to accurately predict cervical instability in trauma patients.[20,32] Further research may uncover a less severe but still unstable occipitoatlantal joint injury that threatens the neural structures enough to warrant internal fixation of the occiput to the cervical spine.[33]

In patients with a normal CT scan and equivocal changes on MRI, treatment with halo fixation is effective.[17] Such findings on MRI could include mild signal changes or no abnormal signal at the occipitoatlantal joint combined with abnormal signal from the posterior ligament and soft tissue. Like the patients identified by Pang et al,[22] these patients fall into a potential category of OAD that may not need surgical fixation. Pang et al[22] postulated that a child with a CCI of 3 to 4 mm, without left-right asymmetry or joint dislocation and no evidence of a ruptured tectorial membrane or alar ligament, would qualify for this subgroup of patients. However, the potential for catastrophic neurologic injury in untreated patients may never allow us to elucidate the best treatment paradigm for those falling into this challenging diagnostic category.

TABLE 1. Proposed Classifications and Treatment Recommendations for Occipitoatlantal Dislocation[a]

Series (ref. no.)	Grade	CT/Radiographic Findings	MRI Findings	Provocative Traction Results	Treatment
Horn et al,[17] 2007	I	Normal based on established criteria (Powers' ratio, BDI, BAI, X-line, CCI)	Moderately abnormal (high signal in posterior ligaments or occipitoatlantal joints)	NA	External orthosis
	II	≥1 abnormal finding based on established criteria	Grossly abnormal findings in occipitoatlantal joints, tectorial membrane, alar ligaments, or cruciate ligaments	NA	Internal fixation
Bellabarba et al,[19] 2006	I[b]	Alignment within 2 mm of normal	MRI evidence of craniocervical osseoligamentous stabilizers	<2 mm distraction of occipitoatlantal joint	External orthosis
	II	Alignment within 2 mm of normal	MRI evidence of craniocervical osseoligamentous stabilizers	>2 mm distraction of occipitoatlantal joint	Internal fixation
	III	Craniocervical malalignment of >2 mm	MRI evidence of craniocervical osseoligamentous stabilizers	NA	Internal fixation

[a] Combined and modified from Horn EM, Feiz-Erfan I, Lekovic GP, Dickman CA, Sonntag VK, Theodore N. Survivors of occipitoatlantal dislocation injuries: imaging and clinical correlates. *J Neurosurg Spine*. 2007;6(2):113-120[17] and from Bellabarba C, Mirza SK, West GA, et al. Diagnosis and treatment of craniocervical dislocation in a series of 17 consecutive survivors during an 8-year period. *J Neurosurg Spine*. 2006;4(6):429-440.[19] (Used with permission from *Journal of Neurosurgery*.) CT, computed tomographic; MRI, magnetic resonance imaging; NA, not applicable; BDI, basion-dens interval; BAI, basion-axial interval; CCI, occipital condyle-C1 interval.
[b] Represents an injury not defined as occipitoatlantal dislocation by the authors.

Horn et al[17] published the largest series of survivors of OAD.[17] Our current treatment paradigm follows the guidelines presented in that study (Table 1). Grade I injuries are indicated by normal CT findings in relation to established methods of diagnosis (Powers' ratio, BDI, BAI, X-line, and CCI) and equivocal MRI findings: high posterior ligamentous or occipitoatlantal signal and mild to no signal change at the occipitoatlantal joint. We support nonoperative treatment, halo or cervical collar, in patients with grade I injuries. Grade II injuries are defined by a minimum of 1 abnormal finding on computed tomography-based criteria or grossly abnormal MRI findings in the occipitoatlantal joints, tectorial membrane, alar ligaments, or cruciate ligaments. For these patients, surgical fixation is the treatment of choice.

Bellabarba et al[19] proposed an alternative grading method that uses provocative traction to identify instability in patients with normal findings on static imaging (Table 1). Patients with a BDI or BAI greater than 2 mm beyond the upper limit of normal on static imaging are considered to have instability, and internal fixation is recommended. Patients with normal static measurements but abnormal MRI findings undergo cervical traction. If traction results in a BDI greater than 2 mm beyond the upper limit of normal, these patients require fusion. If traction fails to elicit abnormal measurements, conservative treatment is recommended.[19]

OCCIPITOCERVICAL FIXATION: SURGICAL TECHNIQUE

Once occipitoatlantal instability or OAD has been diagnosed, many factors must be weighed when deciding which levels to include in a fusion construct and which construct is most appropriate. These factors include the underlying pathology, any unique anatomic considerations, and the patient's age.

Rod and Screw Fixation

Occipitocervical instability in the presence of intact posterior elements and no evidence of spinal cord compression can be treated with an occiput-to-C2 fusion or occiput-to-C1 fixation with occiput-to-C1 transarticular screws or lateral mass screws. This strategy spares C1–C2 motion. If the posterior elements have been removed or disrupted, the fusion should extend at least down to the last absent posterior element.[34]

Occipital Fixation

Occipital fixation should occur via midline occipital keel screws; typically, a 10-mm screw is used.[35-38] The lateral squamous portion of the occiput is too thin for the necessary screw purchase. Occipital keel screws are strongest when placed bicortically. Screw fixation via diploic bone parallel to the occipital table has also been described.[39]

C1–C2 Fixation Techniques

C1–C2 transarticular screws[40] provide excellent biomechanical stability at the C1–C2 segment.[41] These screws can be used in the absence of C1 and C2 posterior elements. The risk of construct failure related to caudal screw pullout is eliminated. C1–C2 transarticular screw placement does place the vertebral artery at an increased risk for injury, and each patient's individual anatomy should be considered. Preoperative CT angiography and intraoperative image guidance can be used to increase the safety of transarticular screw placement. C1 lateral mass and C2 pars interarticularis screws are being used with greater frequency as an alternative to transarticular screws.

Subaxial Cervical Screw Placement

If the fusion is extended below C2, then lateral mass screws are placed at subsequent levels. When the construct extends to the thoracic spine, typically, C7 is skipped, and thoracic pedicle screws are placed at subsequent levels.

Isolated Occipitoatlantal Instability

Given that the occipitoatlantoaxial ligaments span the occipital-C1 segment and the C1–C2 segment, instability should affect both segments. However, in the presence of an isolated OAD, instability has manifested itself primarily at the occipital-C1 joint without instability at the C1–C2 segment.[30] In appropriate cases, occipital-C1 fusion alone can be considered.[42,43] Occiput-C1 fusion can be performed using either occiput-C1 transarticular screws or occipital keel-C1 lateral mass screws (Fig. 5). In biomechanical studies, the occiput-C1 transarticular screw construct has been the most stable.

Rod and Wire (Contoured Loop) Fixation

Rod and wire occipitocervical fixation uses a contoured, threaded Steinmann pin connected to sublaminar wires and to the occiput, axis, atlas, and any additional subaxial levels.[44] Although rod-screw constructs typically offer more stability than rod-wiring fixation,[41] the latter has been used with excellent results. It is often used when the anatomy, underlying pathologic process, or patient's age makes a rod-screw construct either unsafe or infeasible.

Achieving Bony Fusion

A critical factor in the long-term viability of a stabilization procedure is achieving a solid fusion across all involved levels. After instrumentation, all exposed bone at the levels to be fused should be decorticated, and autologous bone should be placed. The iliac crest is our preferred donor site for autograft in adults. In children, rib or calvarial autografts are viable alternatives.

Pediatric Population: Special Considerations

The pediatric population frequently presents with occipitocervical instability related to trauma, congenital bony/ligamentous

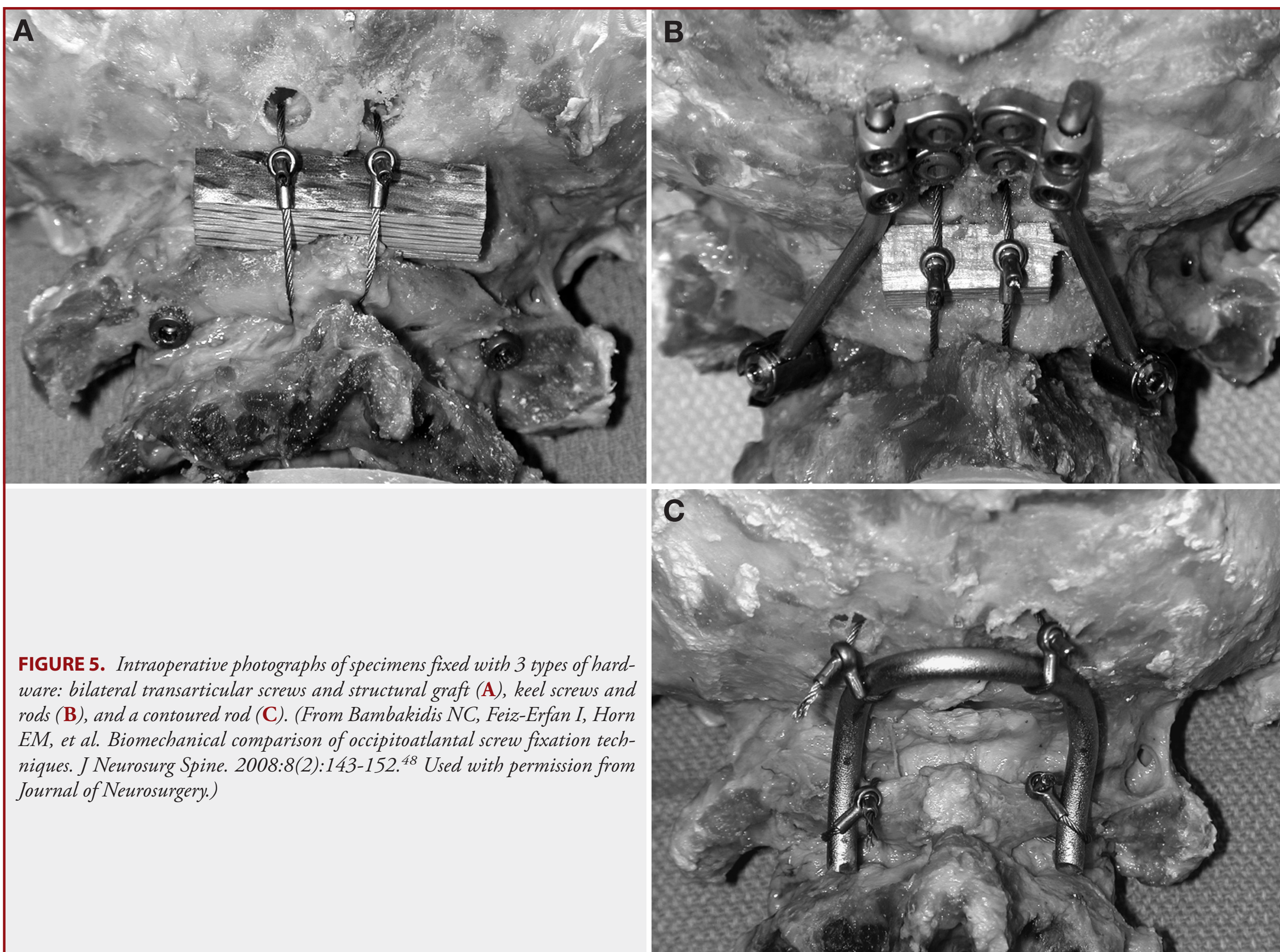

FIGURE 5. *Intraoperative photographs of specimens fixed with 3 types of hardware: bilateral transarticular screws and structural graft (**A**), keel screws and rods (**B**), and a contoured rod (**C**). (From Bambakidis NC, Feiz-Erfan I, Horn EM, et al. Biomechanical comparison of occipitoatlantal screw fixation techniques. J Neurosurg Spine. 2008:8(2):143-152.[48] Used with permission from Journal of Neurosurgery.)*

abnormalities, tumor, and degenerative bone disease. The possibility of limiting future growth, the small size of the bony and ligamentous structures, and the anatomic variety seen in syndromic children complicate internal fixation in this population. Ahmed et al[45] reviewed their experience and recommended using rib grafts alone in children age 6 years or less, contoured rod-wire constructs in children age 7 years or older, and rigid instrumentation in children over the age of 10 years. Autologous rib should be used instead of iliac crest because it offers lower rates of graft site morbidity (3.7% versus 25.3%, respectively).[13] Ahmed et al[45] saw no abnormal cervical spine growth in children who underwent craniocervical stabilization when younger than 5 years of age.[45]

CONCLUSIONS

OAD is a devastating injury and more prevalent than once thought. Neurosurgeons, especially those who encounter pediatric spinal trauma on a regular basis, need a detailed understanding of OAD. Improved recognition of spinal injury and prehospitalization management has helped increase the number of patients who survive this type of injury. OAD is diagnosed when abnormalities are found at the occipitoatlantal joint on CT scanning and MRI. Because OAD is a highly unstable ligamentous injury, surgical fixation of the craniovertebral junction is the treatment of choice once the diagnosis is established. Future studies will help define the treatment paradigm when the diagnosis of OAD is less certain, such as in patients with normal CT findings and equivocal findings on MRI. Many surgical options are available for craniocervical fixation, and the approach should be tailored to the unique situation of each patient.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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