53 Upper Cervical and Occipitocervical Arthrodesis

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SUMMARY OF KEY POINTS

- The craniocervical junction (CCJ) is the most mobile portion of the spine.
- Most pathologic events affecting the CCJ are traumatic and degenerative in origin, with very high morbidity and mortality rates.
- Establishing an early diagnosis, securing the airway, and immobilizing the head and neck with respect to the torso are the most important actions that can be taken to improve survival in patients who suffer an injury of the CCJ.
- The use of traction is not indicated in occipito-atlanto dislocation.
- The CCJ is a challenging region for surgery and requires expertise from the surgeon to be able to maneuver in this area.

The craniocervical junction (CCJ) is the most mobile portion of the spine.[1,2] It is integrated by three osseous structures (occiput, atlas, and axis) and multiple membranes and ligaments with a constant relationship in order to protect the spinal cord, medulla oblongata, and vertebral arteries[3] (Fig. 53-1). The tectorial membrane, bilateral alar ligaments, and cruciate ligament are the major stabilizing components of the CCJ. The bony articulations and the anterior and posterior atlanto-occipital membranes play a minor role in stability.[4-8]

The anatomy of the CCJ is surgically challenging and requires expertise from the surgeon to be able to maneuver within the region. The arrangement of the CCJ allows an extraordinarily broad range of motion, but extensive motion applies significant tension from the occiput to C2.[3] Disruption of any of the CCJ components may lead to instability requiring medical or surgical management[1,2,9-11]; certain disruptions, if not addressed promptly, may lead to permanent neurologic damage or even sudden death.[1,8,9,12-23] A working knowledge of this region and the structures within it is necessary to comprehend the mechanisms of injuries and how to successfully manage them.

Advances in imaging, spinal surgical techniques, and instrumentation techniques have provided novel means of approaching, stabilizing, and treating pathology at the CCJ.[24] Key advances in instrumentation, including novel occipital fixation devices, C1 lateral mass screws, and C2 pedicle screws,[25-27] have promoted the development of numerous methods for fixation of the upper cervical spine. This chapter provides a review of the most common types of injuries of the CCJ, along with current guidelines to manage these injuries[28] that emphasize the technical aspects of the different types of fixation and fusion of the upper cervical spine and CCJ, with a focus on the latest developments and instrumentation methods. Although a variety of techniques are mentioned in this text, several key points—described later—are common to all of the fixation methods.

PATHOLOGY OVERVIEW AND TREATMENT CONSIDERATIONS

Most pathologic events affecting the CCJ are traumatic in origin and range from an asymptomatic, benign, nondisplaced occipital condyle fracture alone to an occipito-atlanto dislocation, which results in a very high morbidity and mortality rate. On the other hand, large skull-base tumors requiring extensive manipulation of the high cervical vertebrae can also contribute to instability in this region, as can rheumatoid arthritis and other diseases.

All adult patients with an unstable lesion of the CCJ should be treated because most of the time ligamentous injuries will not heal by themselves, and, to recover spine stability, surgery is almost always required.[29] Patients with computed tomography (CT)-documented occipito-atlanto dislocation are unstable and require surgical fixation, if they survive their initial injuries (particularly traumatic brain injuries) and resuscitation.[16] Additional details are provided later in this chapter.

Transverse Ligament Rupture

Injuries involving the transverse ligament can be classified and treated in two categories according to Dickman.[30-32] Type I injuries are incapable of healing, and patients require surgical fixation of C1-2. In type II injuries, the ligament is intact but detached; patients have an 80% chance of healing with external orthosis (halo vest) only and surgery can be considered for nonunion injuries after 3 to 4 months of immobilization.[29] Clinical judgment is required in type II injuries in that the aforementioned study is based on a limited number of patients and was not a controlled analysis.

Occipital Condyle Fracture

Based on the Anderson and Montesano classification system[33] for occipital condyle fracture, nonoperative treatment with external cervical immobilization is almost always sufficient to obtain bony fusion, recovery, or neurologic deficit improvement (if any) in all types of unilateral fractures. A halo vest should be considered in patients with bilateral fractures. A type III occipital condyle fracture, with associated occipito-atlanto dislocation, requires surgical stabilization with posterior instrumentation[17,21,34-37] (Fig. 53-2).

Jefferson Fracture

Treatment of an isolated C1 fracture (Jefferson fracture) is based on the integrity of the patient's transverse ligament.[38-42] With use of the Landells and Van Peteghem's classification system[43] (Fig. 53-3), patients with nondisplaced isolated type I fractures, type II fractures with intact transverse ligament, and type III fractures can be effectively treated with external immobilization devices (rigid collars, suboccipital mandibular

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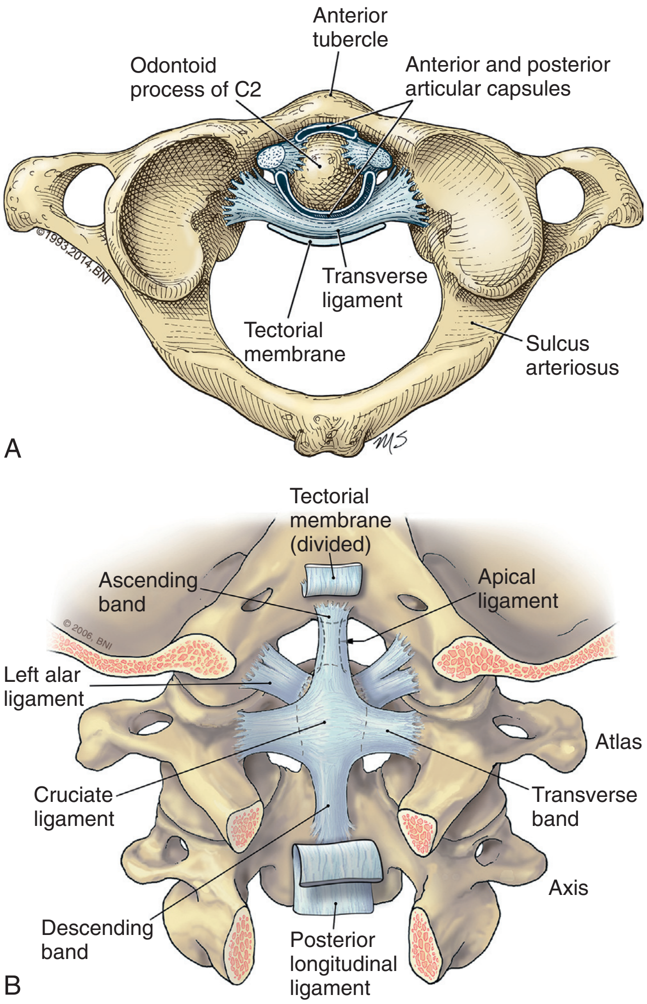

Figure 53-1. Ligamentous anatomy of the craniocervical region. A, Drawing of a superior axial view of C1 to the dens ligaments from caudal to rostral showing the tectorial membrane, transverse ligament, and articular capsules. **B,** Drawing showing posterior view of cruciate ligament (transverse, ascending, and descending bands), odontoid process and apical ligament (projected in discontinuous lines), and alar ligaments; the posterior elements are removed and the tectorial membrane and posterior longitudinal ligament are folded. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

immobilizer braces, and halo vest orthoses) for 2 or 3 months, with successful union/healing rates > 96%. Type II fractures with evidence of transverse ligament disruption are considered unstable, although some patients can be effectively treated with either rigid immobilization alone (halo vest) for a period of 3 months or with posterior surgical stabilization.[30,31,38,39,41-54] Some authors promote early surgical treatment of unstable atlas fractures due to the discomfort of prolonged treatment in halo vests and healing rates.[39]

Hangman's Fracture

Traumatic spondylolysis of the C2 isthmus, also known as hangman's fracture, can be treated surgically or with an external orthosis, depending on the extent of dislocation and angulation. There are three types of hangman's fractures, according to the classification devised by Effendi and modified by Levine and Edwards[47] (Fig. 53-4). Type I injuries can be treated with an external orthosis. Type II injuries can be treated surgically or by placing the patient in an external orthosis. A type III injury should be treated surgically. A type II hangman's fracture can be treated via ventral C2-3 discectomy and fusion using a plate-screw fixation. Postoperatively, the patient should wear a hard collar for 2 months. Direct reduction and fusion of a type II hangman's fracture is possible by placing a screw through the pars and into the vertebral body. However, this cannot be performed in most cases given the size of the pars and the morphology of the fracture. If dorsal fusion of a hangman's fracture is preferred, then screws are placed into the C1 and C3 lateral masses with the connecting rods and bone graft placed over the C1-3 dorsal arches, and a multistranded titanium cable is passed under the rods and over the graft. With appropriate tensioning of the cable, the fractured C2 pars can be reduced, which enhances the fusion (Fig. 53-5).

PREOPERATIVE MANAGEMENT

Three major factors have improved the treatment of patients with CCJ lesions and directly improved their outcomes: (1) strengthened emergency medical response services and resuscitation maneuvers, (2) superior quality of images leading to more detailed diagnoses, and (3) more robust internal fixation due to better surgical techniques and hardware for these unstable lesions.[20,28,55]

Some lifesaving actions can and must be imparted even before the patient arrives at the trauma center, thereby increasing the odds for survival. The three most important actions to improve survival in patients who suffer an injury of the CCJ have been early diagnosis, prompt intubation (if needed), and immobilization of the head and neck with respect to the torso. Any delay in the diagnosis can be associated with an increased likelihood of neurologic deterioration and higher mortality.[20,55]

NONSURGICAL MANAGEMENT

Instability of the CCJ demands immediate multimodality management. The use of traction for patients with CCJ unstable injuries was controversial in the past. The purpose of this maneuver was to decompress the neural elements by realigning the osseous structure, especially for Traynelis types I and III[56] occipito-atlanto dislocation (Fig. 53-6). In 2013, guidelines on the management of acute cervical spinal injury were published[28] by a group of specialists, including the senior author of this chapter, and they reported that the frequency of neurologic deterioration after traction for occipito-atlanto dislocation is approximately 10%. Thus, the use of traction is now not advocated in patients with an unstable lesion of the CCJ. Traction for restoring the alignment or diminishing neural compression in pediatric patients is barely addressed in the literature, and enough information to emit a recommendation is not available.[57]

External immobilization alone should be used with discretion. According to the literature and in concordance with the most recent guidelines, up to 58% of patients who were handled only with external immobilization either deteriorated clinically or did not achieve spinal stability.[20,58-62] The authors favor removing the rigid cervical orthosis right after a diagnosis is made, and placing sandbags on either side of the head and taping the head down.

Pharmacologic Management for Acute Spinal Cord Injury

Since the 1980s, the medical management of acute spinal cord injury (SCI) has been a major topic of controversy. According

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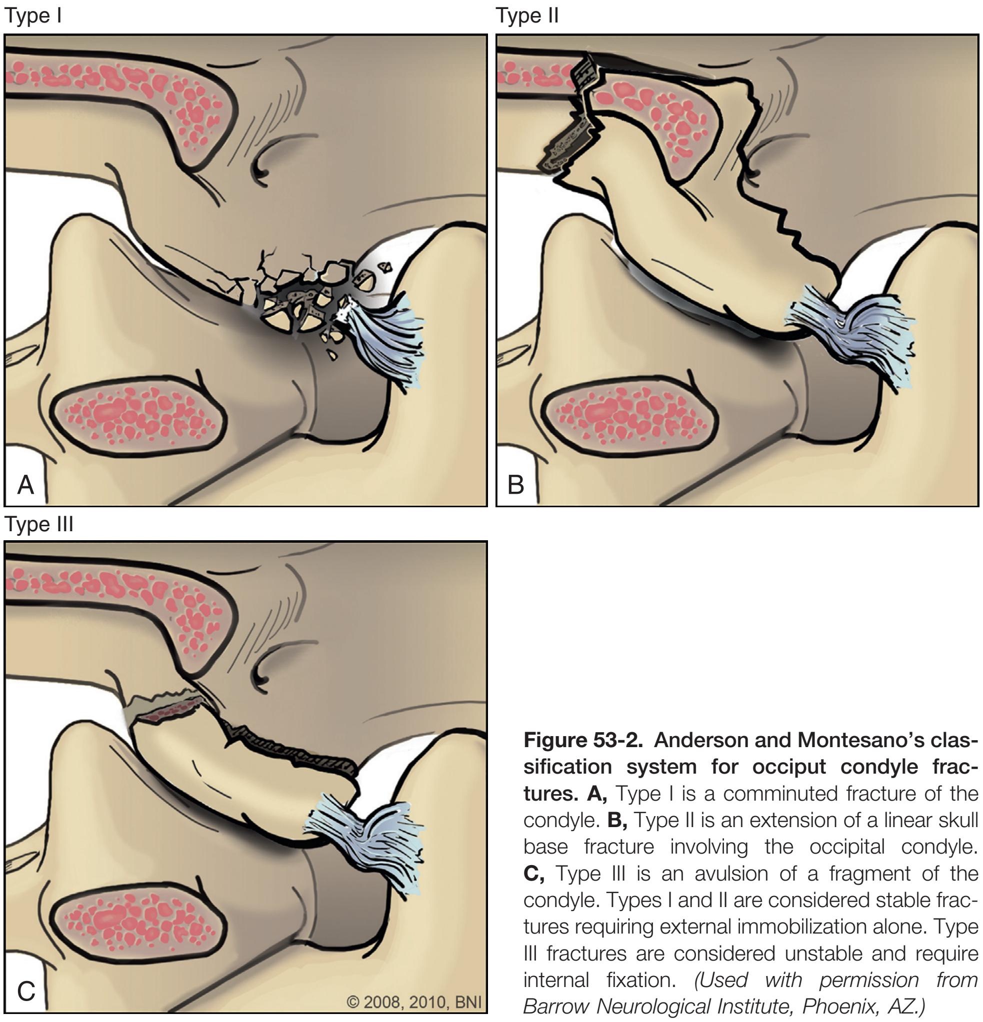

Figure 53-2. Anderson and Montesano's classification system for occiput condyle fractures. A, Type I is a comminuted fracture of the condyle. **B,** Type II is an extension of a linear skull base fracture involving the occipital condyle. **C,** Type III is an avulsion of a fragment of the condyle. Types I and II are considered stable fractures requiring external immobilization alone. Type III fractures are considered unstable and require internal fixation. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

to one study, more than 980 patients received steroids for acute SCI and more than 280 participated as control subjects within a prospective clinical trial, with negative results in all primary comparisons for efficacy of the drugs.[63] Between 1984 and 1998, three widely recognized prospective studies were published (National Acute Spine Cord Injury Study [NASCIS] I, II, and III); these attempted to address the potential benefit of using methylprednisolone (MP) for SCI.[64-70] NASCIS I reported negative results comparing "high" versus "low" doses of MP in 306 patients treated for acute SCI. A high dose was 1000 mg of MP as a loading dose and thereafter 1000 mg daily for 10 days, and a low dose had the same scheme but with doses of 100 mg of MP.[66,68] Later, NASCIS II was designed as a randomized, double-blind, controlled clinical study to explore the effect of MP and naloxone in 487 patients with acute SCI and to generate class I medical evidence for this treatment. MP was administered with a loading dose of 30 mg/kg and continued at 5.4 mg/kg/hour for the next 23 hours. During the study, many patients were excluded and the final conclusions were based on only 66 patients and 69 controls. Only motor function of the right side of the patients was reported, although bilateral testing was obtained, and sensory function showed no difference among MP and placebo 1 year after the injury.[63,65,67,71,72] Afterward, NASCIS III was conceived as a multicenter, multinational, double-blind, randomized study comparing 24- versus 48-hour MP administration and 48-hour tirilazad mesylate (a chemically developed super steroid) administration in 499 patients with acute SCI. Patients were divided in three groups: (1) MP infusion 5.4 mg/hour for 24 hours, (2) MP infusion 5.4 mg/hour for 48 hours, and (3) tirilazad mesylate 2.5 mg/kg every 6 hours for 48 hours. No control group was included. There were no significant differences among any group at 6 or 12 months follow-up, and NASCIS III provided negative class I medical evidence.[69,70,73-75] After these three large studies, a wide variety of studies have been conducted and published supporting the neuroprotective effect of MP in SCI.[70,71,76-80] In general, studies showing benefits have suffered from significant limitations including but not limited to modest sample size[76,78-80]; incomplete or omitted data reported[70,71,76-80]; and inconsistent results showing improvement in sensory but not motor function,[79] motor but not sensory function,[66,70,72,80] undefined type of neurologic recovery,[76,77] or no meaningful improvement, making the beneficial effects reported easily ascribed to random chance instead of a true effect.[63] However, harmful side effects of MP administration have been documented in several studies,[81,82] including peptic ulcer disease, gastrointestinal hemorrhage, hyperglycemia requiring insulin administration, higher risk of infection (respiratory, urinary, wound), sepsis, steroid-induced myopathy, and death due to respiratory failure.[67,69,78,83-87]

Although several prospective, controlled, randomized studies have been conducted in the past to elucidate the

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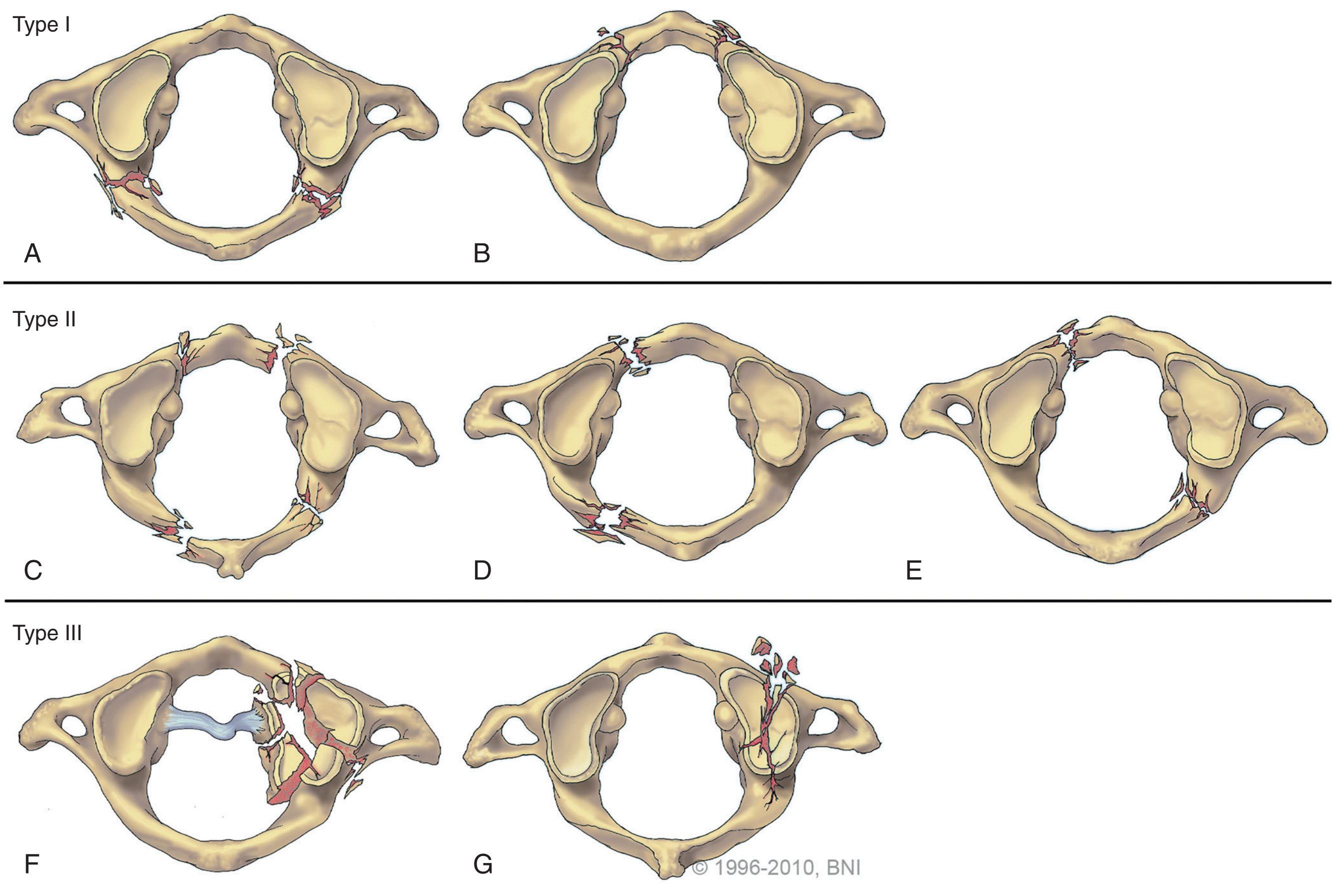

Figure 53-3. Landells and Van Peteghem's classification system for Jefferson (atlas) fractures. Type I (**A–B**) is a fracture confined to a single arch that does not cross the equator of the atlas; each arch can be involved. Type II (**C–E**) is a fracture involving both arches that crosses the equator of the atlas; two or more fragments may be present. Type III (**F–G**) is a lateral mass fracture line that extends into one arch only. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

beneficial effect of steroids in the setting of an acute SCI, there exists no class I medical evidence supporting it[64-75,88-90]; on the contrary, the side effects of steroid administration in this setting have been profoundly proved (class I evidence).[81,82] According to the existing medical evidence, MP should not be used in the treatment of adult patients with acute SCI.[63] The administration of steroids in pediatric patients with SCI has not been well addressed.[63]

SPECIAL PEDIATRIC CONSIDERATIONS

Fortunately, severe spinal injuries in the pediatric population are relatively infrequent and most can be managed conservatively with external reduction and immobilization alone.[57] The mechanism of injuries in young patients slightly differs from those in adults. The ligamentous structures in children are more elastic and the bony structures more cartilaginous, leading to a scarceness of fractures in younger patients compared with adults. Also, the large head-torso ratio and immature supporting neck structures in conjunction with underdeveloped, less-stable, flat, and horizontally oriented articulation surfaces of the upper cervical region create an entirely different scenario for the surgeon when treating pediatric patients.[57] Accordingly, specific recommendations need to be addressed for the management of children with potential or demonstrated injuries of the CCJ, spinal cord, or the upper cervical region due to its unique features compared with adults, including but not limited to anatomic characteristics, immobilization methods, imaging interpretation, and normal and abnormal measurements.

As in the adult population, any procedure performed (reduction, immobilization, or definitive treatment) on a pediatric patient must be individualized to each child but differs in the fact that is mandatory to consider the patient's degree of physical maturation, ossification level, and facet angles. Immobilization techniques to obtain neutral cervical alignment in the pediatric population diverge from techniques used with adults, and the type of immobilization required depends on the patient's age and physical development due to the relatively larger head with respect to the torso in younger patients.

The optimal cervical immobilization, for prehospital transportation of young patients with trauma and potential spinal lesions, appears to be a combination of spinal board, rigid collar, and tape with strict respiratory function surveillance because it may be restrained.[30,91-95] After immobilization and transport to an appropriate facility for initial evaluation and hemodynamic support (if needed), the necessity of any type of imaging must be determined and obtained. If the patient is awake, alert, able to speak, and shows no neurologic deficit, neck tenderness, signs of intoxication, or cervical pain, imaging studies are not needed to exclude cervical spinal injury.[96-98]

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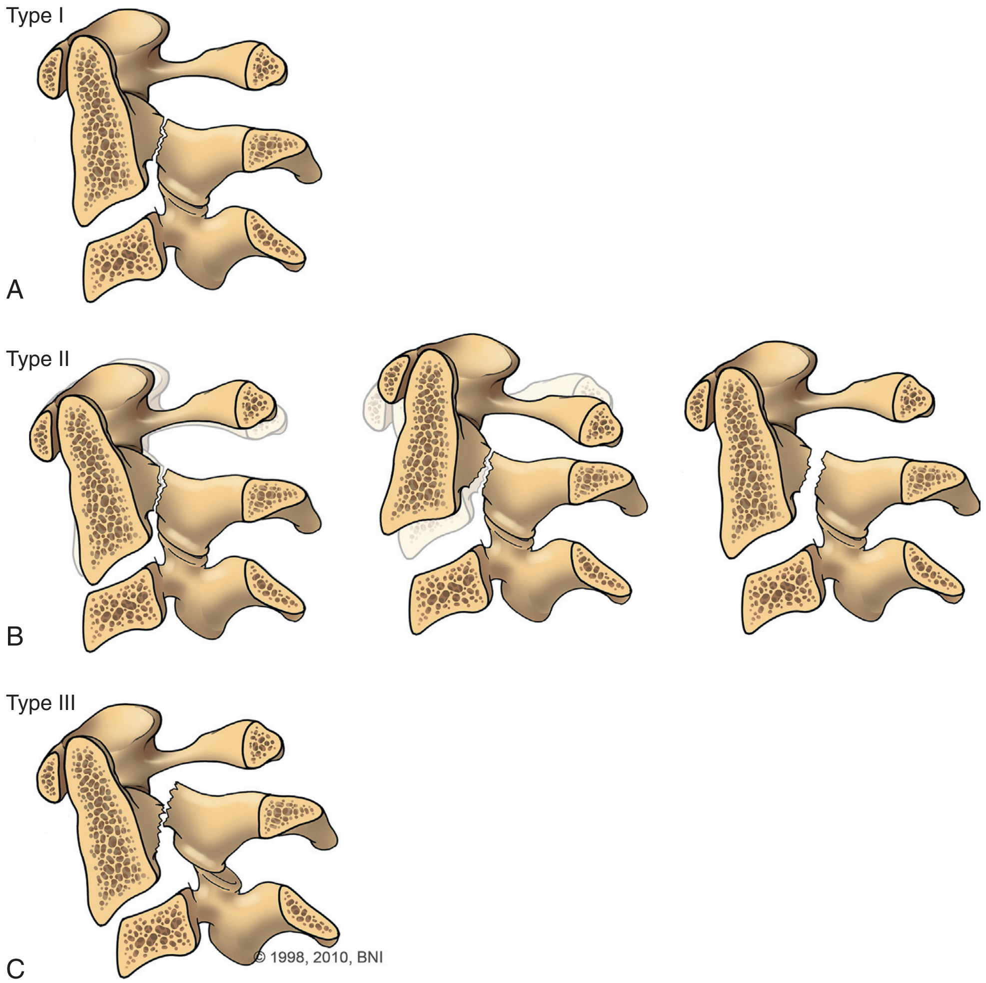

Figure 53-4. Effendi's classification system, modified by Levine and Edwards, for traumatic spondylolysis of the C2 isthmus (hangman's fracture). **A,** Type I is a fracture with a normal C2-3 intervertebral disc and less than 3-mm displacement without angulation. **B,** Type II is a fracture consisting of disruption of the C2-3 disc space and ventrally angulated or displaced fractures. **C,** Type III is a fracture that involves ventral displacement with hyperflexion of the axis associated with unilateral or bilateral facet dislocations. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

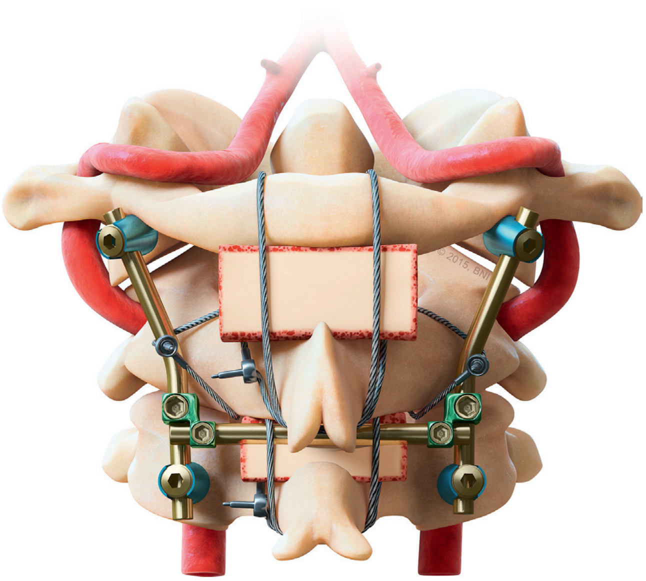

Figure 53-5. With a rib graft placed over the C1-3 dorsal arches, a multistranded titanium cable is passed under the rods and over the rib graft. With appropriate tensioning of the cable, the fractured C2 pars interarticularis is reduced and fusion is achieved. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

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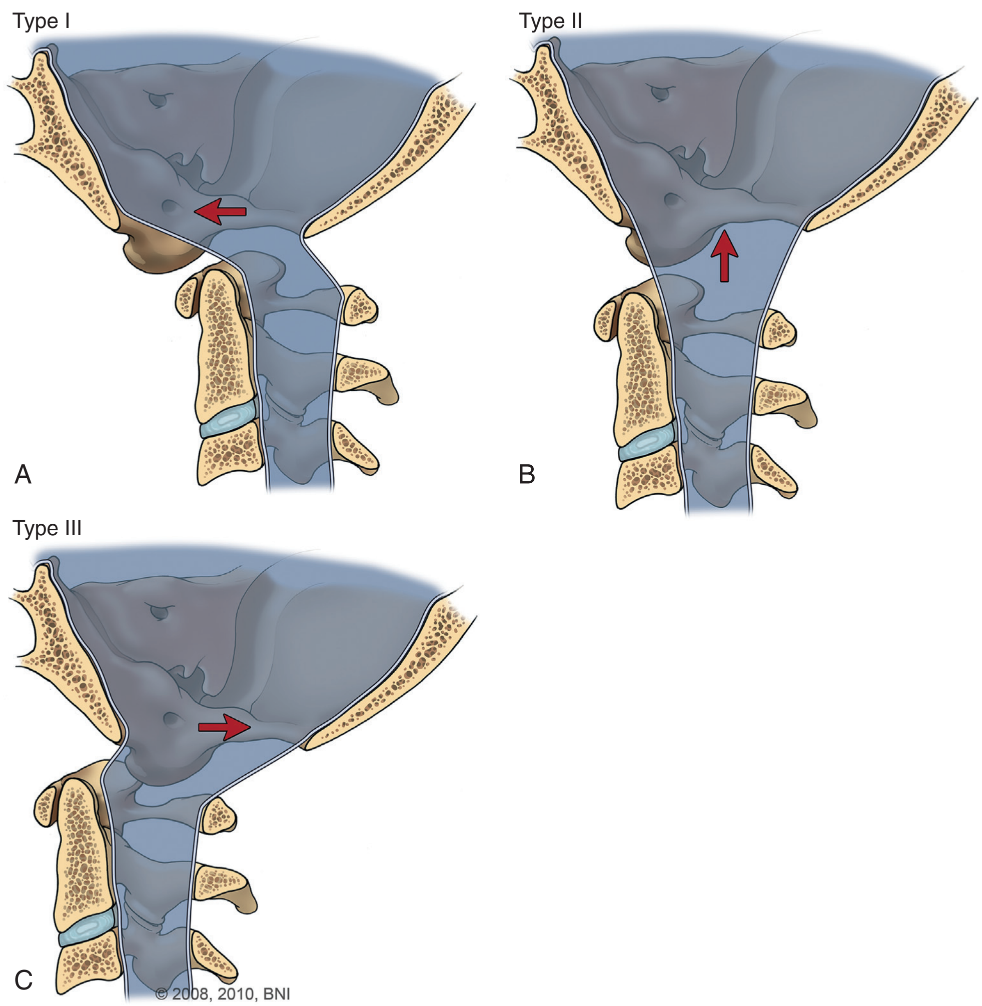

Figure 53-6. Traynelis classification of occipital-atlanto dislocations. A, Type I describes an anterior displacement *(arrow)* of the occiput with respect to the atlas. **B,** Type II is a distraction injury with vertical displacement *(arrow).* **C,** Type III involves posterior displacement *(arrow)* of the occiput. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

When imaging studies are obtained, their interpretation requires knowledge of the age-related development of the ligamentous and bony anatomy. As described by Pang and colleagues, the distance of anatomic landmarks differs between the pediatric and adult populations; the condyle cervical interval, obtained using coronal and parasagittal CT imaging, is the most sensitive and specific measurement when approaching a tentative CCJ injury for adults and pediatric patients, with a distance < 4 mm considered normal in pediatric patients.[99,100]

Many reports in the literature[101-107] have provided class III medical evidence regarding surgical criteria for children with cervical spinal injuries; according to these reports, indications for surgical management include isolated ligamentous injuries with associated deformity (primarily ligamentous injuries in children may be successfully treated with external immobilization alone, but can be associated with a higher rate of persistent or progressive deformity), unstable injuries, compression of the spinal cord, and the necessity of anatomic reduction.

According to the literature, the most effective external immobilization seems to be obtained with either halo devices or Minerva jackets. Halo immobilization has shown minor morbidity, with pin site infection and pin loosening the most common associated complications.[108-113] However, there is no class I medical evidence in this matter, and categorical surgical criteria are difficult to extract from the current literature.[57] Also, as mentioned previously, specific details of the operative techniques—including timing of intervention, selected approach and preferred method of fixation based on the age and development of the patient, changes on the normal growth in height, length, and width of the vertebrae due to the fixation devices,[114] and the efficacy of steroids in this population[63]—are scarce in the literature and further conclusions are not appropriate at this time.

SURGICAL APPROACHES

General Considerations

The best predictor of better patient outcomes after surgery is a meticulous preoperative patient selection based on symptoms, physical examination, and imaging studies.[115] Surgical planning and intraoperative CT-based navigation are valuable in an attempt to decrease complications and provide favorable outcomes for patients with SCIs.

A complete evaluation of the medical condition of all patients going into surgery is essential. Many potential complications can be prevented with a detailed examination.[115-119] Diverse medical conditions can negatively affect the outcome and fusion rate of patients who undergo an instrumented

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procedure of the spine, including patients who use steroids, oral contraceptives, and analgesics, and patients who are diabetic, immunocompromised, and tobacco users.[120-125] When feasible, medications and tobacco use should be discontinued before surgery.

Ventral Approaches

Odontoid Fixation

Odontoid fractures, a common injury of the cervical spine, are found in conjunction with almost 60% of atlas fractures and with 10% to 20% of all cervical fractures.[126,127] On the basis of the Anderson and D'Alonzo nomenclature for odontoid fractures,[128] almost 40% are type II fractures[129] (Fig. 53-7). Although conservative management should be considered, given the high rate of nonunion associated with these lesions, surgery is the gold standard of treatment. Historically, dorsal wiring techniques, such as C1-2 arthrodesis with halo vest immobilization for 3 months, offered an excellent fusion rate (as high as 97%).[130] The main shortcoming of wiring methods is the long-term loss of patient mobility from sacrifice of the atlantoaxial joint and prolonged halo vest immobilization immediately after surgery.[130] Odontoid screw fixation, introduced by Bohler's[131] and Nakanishi's groups (reported by Chiba and associates[132]), has eliminated the need for halo vest immobilization, while preserving motion at C1-2. The fusion rate can be 92% to 100%,[133] and it is one of the only motion-preservation stabilization procedures available in spine surgery.

As already mentioned, patient selection is the key to obtaining good outcomes. Odontoid screw fixation is indicated for patients with an acute (4 to 6 weeks) type II fracture. The high rate of sclerosis associated with fracture margins causes a high rate of nonunion in patients with chronic fractures.

Other key contraindications to this procedure include exclusion of patients with disruption of the transverse atlantal ligament as seen on magnetic resonance imaging,[32] osteopenia with poor bone quality, inability to reduce a displaced fracture, and the presence of a type II fracture that extends across the base of the odontoid in an oblique plane. A disrupted transverse atlantal ligament results in dorsal migration of the fusion fragment during screw insertion; it does not address rupture of the transverse ligament even if the fracture heals. The inability to reduce a fracture appropriately to restore alignment and the presence of an oblique fracture line make capture of the fractured dens challenging. Osteopenia is a key contraindication that can result in "windshield wiping" of the screw with the potential to cause neurologic injury.

In the case of a ventral dislocation, the patient is placed supine with the neck extended or hyperextended and in a

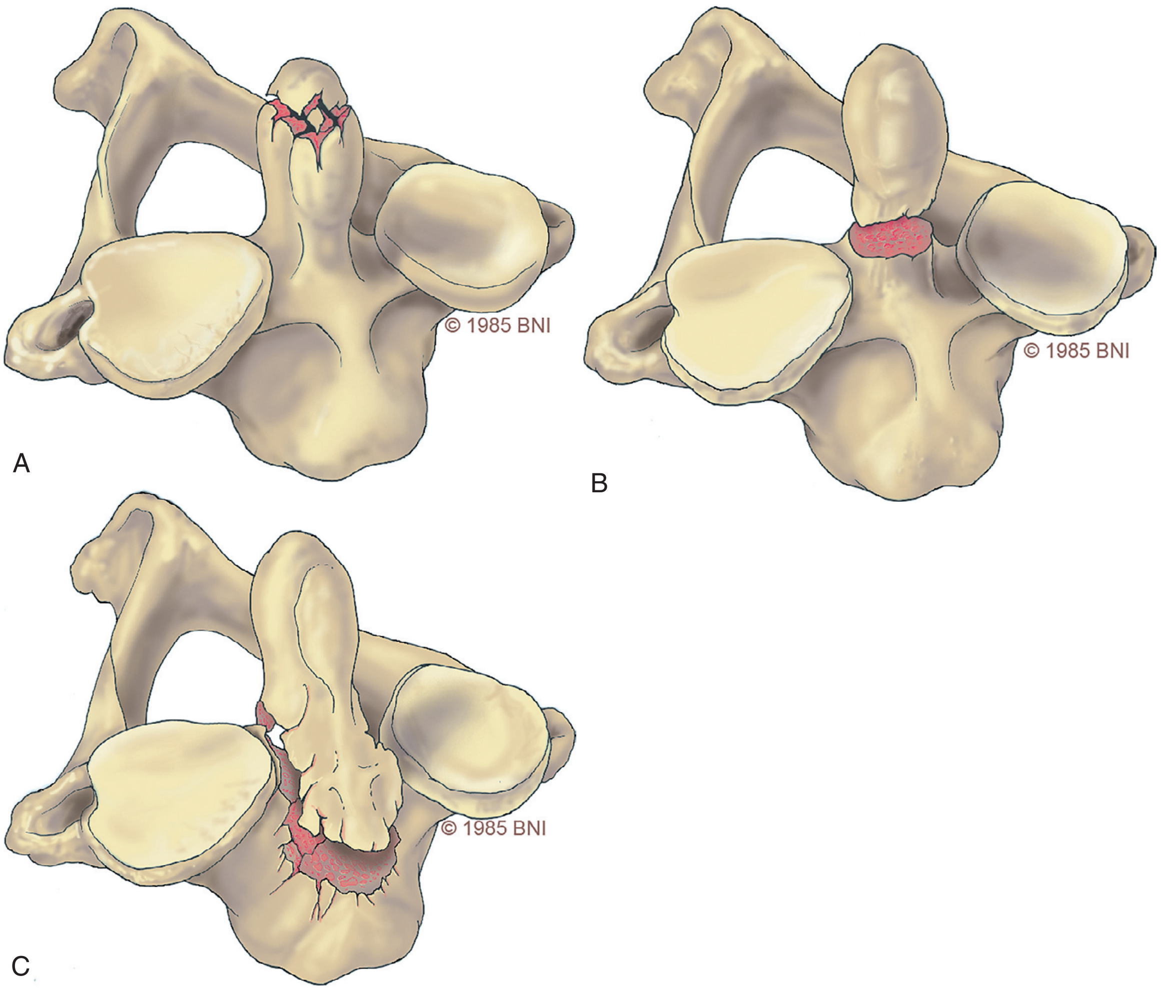

Figure 53-7. Anderson and D'Alonzo nomenclature for odontoid fractures. A, Type I fractures involve the odontoid tip. **B,** Type II fractures occur at the base of the odontoid. **C,** Type III fractures involve the body of C2. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

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three-pin holder or halo tongs if preoperative traction is necessary. In the case of a dorsal dislocation, the patient is placed in a military chin-tuck position under fluoroscopic guidance. The authors' institution uses intraoperative StealthStation (Medtronic, Inc., Minneapolis, MN) image guidance to visualize bony anatomy in the coronal plane, eliminating the need for two image intensifiers. In a patient with a large barrel chest, it is difficult to obtain the necessary sagittal trajectory for screw placement. This problem can be overcome by translating the head and neck ventrally and hyperextending the neck with direct visualization obtained using lateral fluoroscopy (Fig. 53-8). A large chest can make the procedures technically impossible.

A transverse skin incision is made at the level of the cricothyroid junction, and the platysma is divided longitudinally to the ventral border of the sternocleidomastoid muscle. The dissection is performed using natural planes to the level of C4-5 (Fig. 53-9). Blunt dissection proceeds rostrally to the level of the C2-3 disc space, and the retropharyngeal space is opened at C2. The medial borders of the longus colli muscles are coagulated and elevated laterally to maintain exposure. Next, it is important to expose the midline of the body of C2 because the midline keel of C2 is the landmark for screw placement. Doing so requires creating a midline trough through the anulus and disc at the C2-3 interspace. The placement of this entry site is critical because rostral placement of a screw can cause the shaft of the screw to lie too close to the overlying ventral cortex of C2. In this scenario the screw can cut out, or windshield wiper out, of the C2 body, and pseudarthrosis can then develop.

More recently, image-guided navigation for placing odontoid screws has been employed. When this technique is used, the patient's head is placed in a three-point fixation device and secured to the operating table. With isocentric C-arm fluoroscopy, intraoperative images are obtained and three-dimensional reconstruction is performed using the StealthStation. With the coronal trajectory on the StealthStation, the midline of the C2 body is identified and a K-wire is advanced through the odontoid fracture. Real-time lateral fluoroscopy is used to monitor progress in the lateral plane until the K-wire approaches the cortex of the odontoid tip. Although the sagittal trajectory on the StealthStation may be used, it is not reliable in the authors' opinion. As force is applied on the C2 body during K-wire insertion, the body is pushed down and an error in sagittal trajectory is introduced, which can result in misplacement of the screw. As a result, we use image guidance for the coronal trajectory of the screw and lateral

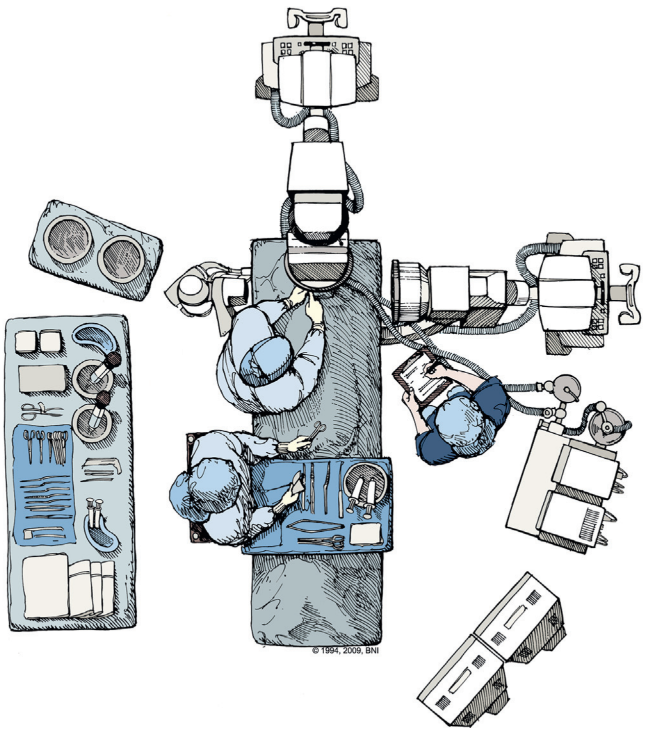

Figure 53-8. Positioning of two C-arm fluoroscopes for odontoid screw fixation. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

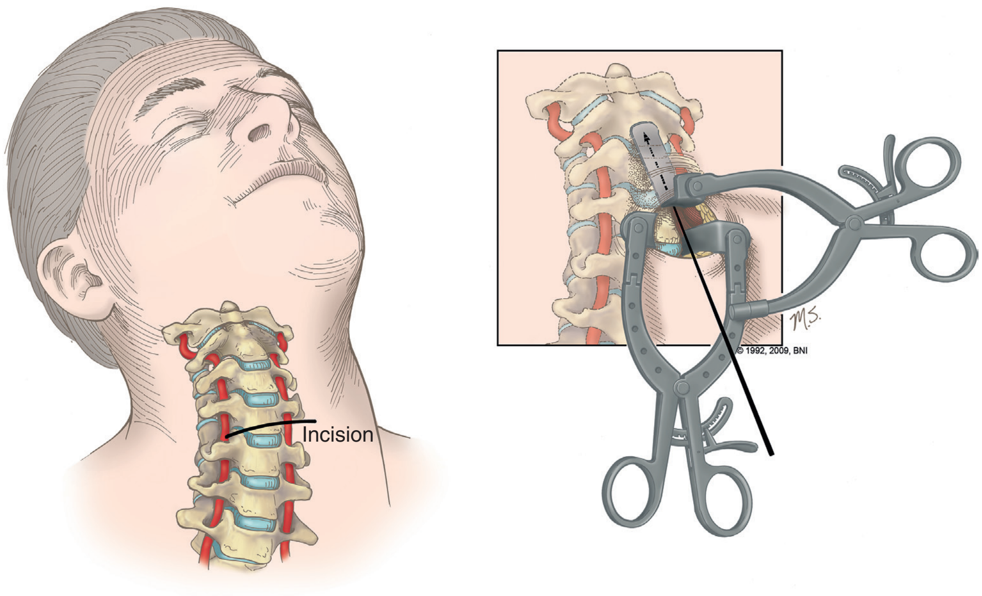

Figure 53-9. Incision used to expose the ventral cervical spine and pertinent anatomy of the vertebrae and vasculature. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

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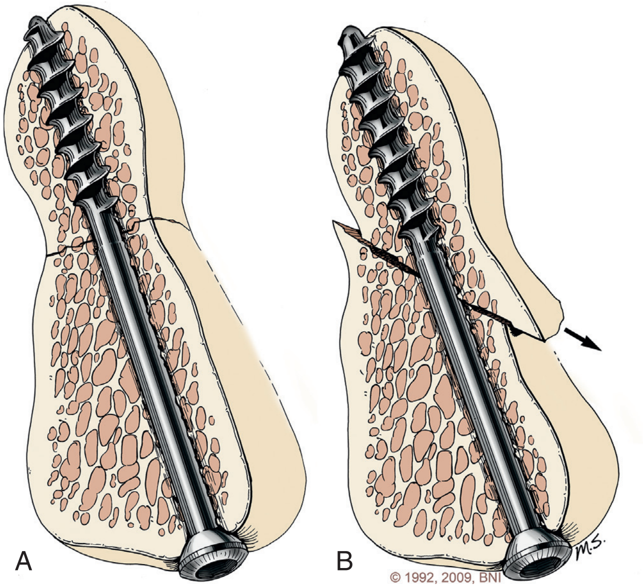

Figure 53-10. Ventral screw fixation of the odontoid with ideal (**A**) and suboptimal (**B**) screw placement. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

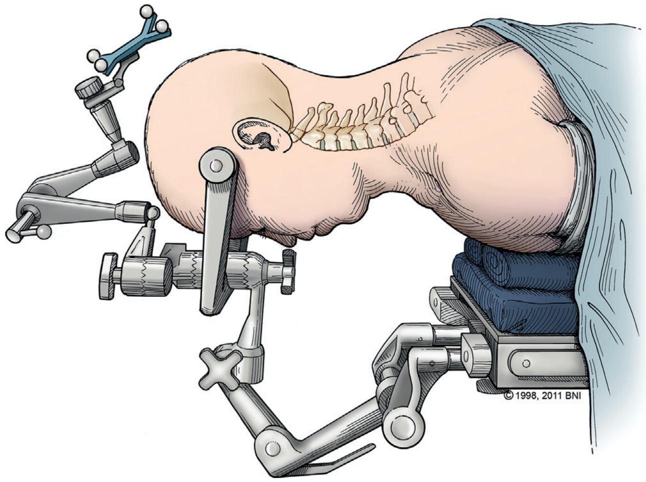

Figure 53-11. A patient placed in the prone position with the head secured in a Mayfield head-holder system. The reference frame for stereotactic navigation is attached to the clamp. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

fluoroscopy for the sagittal trajectory and to monitor real-time progress of the K-wire and screw. Once the K-wire is placed, the bone can be drilled if it is very dense. The path is then tapped and a 4-mm screw is advanced under fluoroscopic guidance until it approaches the distal cortex of the dens. At this point, a cannulated titanium screw is selected (lag or fully threaded 4 mm). The screw is advanced and tightened until the screw head is just countersunk with respect to the body of C2 (Fig. 53-10). The screw length can be customized by measuring the K-wire depth on the fluoroscopic image.

A screw protruding into the C2-3 interspace can cause a lever effect that results in screw loosening and failure. Although a two-screw technique can be used, one screw is sufficient to achieve a stable union in most cases. Closure involves copious irrigation and hemostasis followed by layer-by-layer closure. Placement of the screw does not ensure complete restoration of the strength of the dens, and the patient must wear a cervical orthosis for at least 6 to 8 weeks. In the presence of contraindications to odontoid screw fixation, standard dorsal atlantoaxial fixation is performed.

Ventral Atlantoaxial Facet Screw Fixation

Ventral atlantoaxial facet screw fixation is similar to its odontoid counterpart, but the screw trajectory differs. This technique should be performed only when the appropriate alignment of C1-2 can be restored before screw insertion. It can also be performed in cases of transverse atlantal ligament disruption or in the presence of dorsal arch fractures. It is primarily a salvage procedure when a dorsal C1-2 fusion has failed.

With the patient positioned supine and the neck extended, the surgeon makes a small incision at the level of C4-5. Dissection is carried out to expose the inferior lateral mass of C2. The trajectory used is parallel to the ventral surface of the cervical spine. Screws shorter (about 20 to 25 mm) than those used in odontoid fusion are inserted to enter the C2 vertebral body in the recess between the vertebral body and the inferior C2 facet. The screw is then directed rostrally and about 35 to 40 degrees laterally into the lateral mass of C1. Although not performed as frequently as dorsal C1-2 fixation methods, this technique rigidly stabilizes C1-2 and sacrifices all motion at C1-2. One disadvantage of ventral C1-2 fixation compared with the dorsal alternative is the inability to place a bone graft to promote fusion except to curettage the C1-2 facet. This procedure is not commonly performed.

Dorsal Upper Cervical Fixation

Occipitocervical Fixation

Occipitocervical fixation is used to correct deformities or instability at the occipitocervical junction. This fixation technique also can be used to treat atlantoaxial instability in patients who are not candidates for atlantoaxial fixation or for whom previous attempts at C1-2 fusion have failed.

Determining which cervical levels to include in an occipitocervical fusion depends on the patient's diagnosis, presentation, and radiographic findings. In cases of isolated occipitocervical instability associated with intact dorsal elements but no evidence of basilar invagination, an occipital-to-C1 or occipital-to-C2 fusion is sufficient for fixation in the authors' opinion. Isolated occipitoatlantal dislocation without atlantoaxial injury may be treated with occiput-to-C1 fixation alone.

When basilar invagination or ventral compressive deformities complicate a case, the fusion can be extended lower, possibly to C4, to provide sufficient fixation, depending on the degree of deformity or basilar invagination. If the dorsal arches are deficient, the fusion should extend at least two levels below the absent lamina. Alternatively, rigid external fixation can be used postoperatively.

Various methods can be used, but the general approach is as follows. After the patient is placed in a prone position in a three-point fixation device, it is critical to ensure appropriate neutral alignment of the head and the neck using lateral fluoroscopy or image guidance and direct observation. Eyes must be looking forward and without a lateral tilt. Extensive flexion or extension should be avoided. A military chin-tuck position may be used to aid in exposure of the CCJ and for placement of the C1 lateral mass screws (Fig. 53-11). Alternatively, the patient's head and neck should be realigned appropriately before the final securing of the construct.

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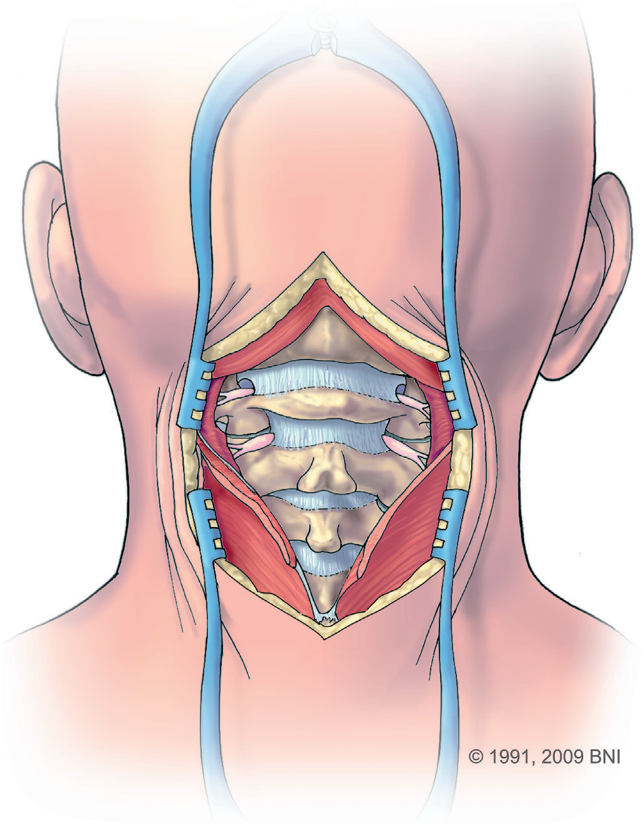

Figure 53-12. Incision used to expose the dorsal cervical spine. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

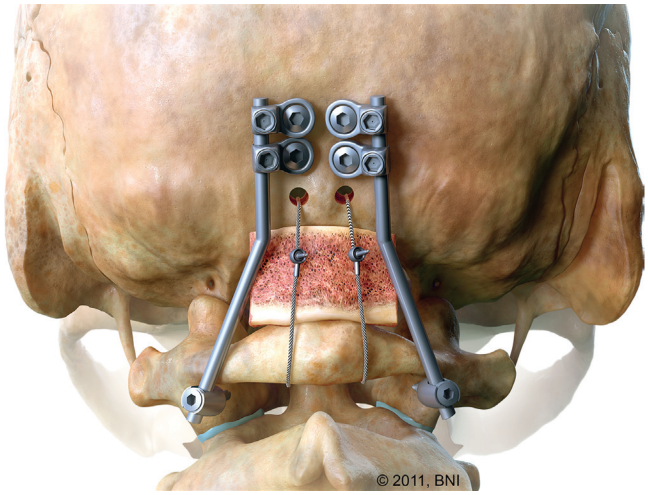

Figure 53-13. Representation of occiput-C1 fusion with occipital keel screws, posterior lateral mass screws, and rib graft, augmented with intralaminar wiring. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

A midline incision is made from the inion to the inferior aspect of the proposed construct. The length of the incision can be increased or decreased depending on the number of segments to be fused. Dissection proceeds within the midline avascular plane, ensuring adequate exposure of the foramen magnum and dorsal arches of the facet joints of the vertebrae to be fused (Fig. 53-12). The authors favor the use of the operating microscope to expose the C1 lateral masses. During dissection of the lateral mass of C1, frequent venous bleeding is encountered. FloSeal Hemostatic Matrix (Baxter International, Inc., Deerfield, IL) and a 1 × 1 cm cottonoid are often used to achieve hemostasis without difficulty in the authors' opinion. Injury to the vertebral artery as it emerges from the transverse foramen of the atlas and courses medially on the ventral portion of the rostral surface of the dorsal ring must be avoided. An angled curette is used to detach the dorsal occipitoatlantal membrane from the rim of the foramen magnum and C1. Subperiosteal resection of the muscle attachments using a Cobb elevator strips the muscle and veins with minimal bleeding. The facet joints are the lateral extent of the exposure. Preservation of the spinous process at the lowest level included in the fusion is recommended to preserve the interspinous ligaments, to sit the selected osseous graft, and to prevent the subsequent development of kyphosis below the fusion (Videos 53-1 and 53-2).

Adjunct Tools for Occipitocervical Fixation

Occipital Plate

An occipital plate system may be used as an adjunct for occipitocervical fixation. This technique depends on using the thick surface of the occipital keel to insert fixating bone screws and the use of a plate to provide stabilization between the upper cervical vertebra and occiput. Because the occipital bone is usually thick and a cortical thread screws is used, the screw holes must be drilled and tapped to the full depth before screw insertion. Although a bicortical screw is desirable, it is not necessary and it also increases the risk of bleeding and spinal fluid leak (Fig. 53-13).

Occiput-to-C1 Screw Fixation

In cases of isolated occipitoatlantal dislocation, an occiput-to-C1 fusion may be performed via an occipital keel plate and the insertion of lateral mass screws into C1 or via a transarticular screw placed into the O-C1 joint[134] (see Fig. 53-13). The technical difficulty with insertion of a C1 lateral mass screw rests in the approach and placement of an entry point into C1. The C2 nerve root and its associated venous plexus are intimately associated with C1, and identification of the medial border of C1, as well as preparation for insertion of the lateral mass screw, may result in injury or significant blood loss, especially in a small child.[135] The depth of the anterior tubercle of C1 varies considerably and should be studied carefully on preoperative CT scans before using lateral fluoroscopy of this structure to guide depth of C1 lateral mass screw placement.[136] The entry point for placement of the pilot hole for a C1 lateral mass screw is in the middle of the lateral mass. The entry point for an O-C1 transarticular screw is similar to placement of a C1 lateral mass screw but is aimed more rostrally (usually 1 cm above the tip of the odontoid) to avoid the hypoglossal canal. The screw is placed via a K-wire similar to the technique described in the section on dorsal C1-2 transarticular screws. The judicious use of fluoroscopic or isocentric C-arm guidance minimizes damage to underlying tissues.

In cases of traumatic occipitoatlantal or atlantoaxial dislocation, the C1 ring is often free-floating and unstable, which can preclude placement of C1 lateral mass screws. A free-floating C1 ring is easily susceptible to torsion during screw insertion and can result in vertebral artery injury, neurologic injury, or both. Therefore, during dissection and insertion of the lateral mass screw, it is imperative to stabilize the ring manually with a clamp to avoid complications. If this is not

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possible, C1 should not be instrumented. It can later be wired into the construct if desired.

C1-2 Lateral Mass Fixation

The bilateral insertion of polyaxial-head screws in the lateral mass of C1 and the pars interarticularis or the pedicle of C2, followed by a fluoroscopically controlled reduction maneuver and rod fixation, also known as the Goel or Harms technique, is a newer method for fixation of the C1-2 joint.[25] Dorsal exposure of the C1-2 complex is performed and 3.5-mm polyaxial screws are inserted into the lateral masses of C1. Next, using fluoroscopy, two polyaxial screws are inserted into the pars interarticularis or pedicle of C2.

The pars interarticularis of C2 is the portion of the vertebra between the superior and inferior articular surfaces. A C2 pars screw is placed in a trajectory similar to that of a C1-2 transarticular screw, except that it is much shorter. The entry point for the C2 pars screw is generally 3 mm rostral and 3 mm lateral to the medial aspect of the C2-3 facet joint. The screw follows a steep trajectory paralleling the C2 joint. There is a medial angulation of approximately 10 degrees. To avoid injury to the vertebral artery, the tip of the screw should end before the dorsal cortex of the C2 vertebral body. Although longer screws can be placed, stopping at the dorsal aspect of the C2 vertebral body as confirmed on fluoroscopy ensures avoidance of the vertebral artery in almost all cases. If necessary, reduction of C1 onto C2 can be accomplished after placement of two 3-mm rods. This step is routinely followed by C1-2 interspinous fusion.

Dorsal C1-2 Transarticular Screws

Initially described by Grob and Magerl,[137] this technique is used to fuse C1 to C2 by passing screws from the dorsal aspect of the C2 facet through the C1-2 joint so that it engages the middle of the ventral bone surface of the C1 lateral mass. When used in conjunction with an interspinous wired graft, this method of fixation is, biomechanically, a stable construct.[138]

After the patient is placed prone and C1 and C2 are aligned anatomically, the laminae and lateral masses of the first two vertebrae are exposed. Deep to the C2 nerve lies the C1-2 joint and its medial limit in the spinal canal. With gentle C1-2 interlaminar distraction and the C2 nerve retracted, it is possible to curettage and decorticate the C1-2 facet capsule to promote fusion. In cases of significant instability or deformity, we pass the cable around C1 so that the atlas can be reduced and held firmly in that position during drilling. An entry pilot hole is drilled on the lateral mass of C2, which is located 3 mm lateral from the medial border and 3 mm rostral to the C2-3 facet. With lateral fluoroscopy and aiming 5 to 10 degrees medially and toward the middle of the C1 tubercle, a K-wire is advanced through the C2 pars interarticularis into the C1-2 facet joint, capturing the C1 lateral mass. This is done under continuous fluoroscopic image guidance. The wire is advanced until the tip reaches the dorsal aspect of the C1 ventral arch. After lateral fluoroscopy, an appropriate screw tap is done for placement of a 4-mm titanium screw over the K-wire, and a cannulated titanium screw is placed. This step is routinely followed by C1-to-C2 interspinous wiring and bone grafting.

This technically challenging method of fixation is associated with significant hazards and potentials for complication. The technique is unsuitable for patients with a long-standing irreducible deformity, lateral mass destruction, torticollis, or rotatory subluxation of the joint. Vertebral artery injury is the most feared complication; therefore, an aberrant course of the vertebral artery in the C2 lateral mass is a strong contraindication for the procedure.[139] When the course or status of the vertebral artery is unclear, preoperative CT angiography is needed to study the vertebral artery to determine whether this technique is feasible. If the vertebral artery is damaged during placement of the first screw, it is important not to proceed with placement of the second screw. Unilateral transarticular C1-2 fixation, when combined with interspinous wire graft, provides sufficient immobilization and promotes fusion similar to bilateral fixation.[140]

C2 Intralaminal Fixation

Bilateral crossing C2 laminar screws have become popular as an alternative technique for C2 fixation.[141] The authors reserve this technique when other types of C2 fixation are not possible or as a bailout maneuver.

After the exposure, a high-speed drill is used to place a pilot hole pointed opposite the lamina to be fixated. The hole is drilled to a depth of 20 to 28 mm, and a 3.5- or 4.0-mm polyaxial screw is advanced into the lamina. To ensure that any possible cortical breakthrough is pointed dorsally through the laminar surface as opposed to ventrally into the spinal canal, the trajectory for screw insertion is kept less than the down slope of the lamina. A dental instrument is placed under the lamina during screw insertion to help detect any breakouts. In its correct final position, the head of the screw is at the base of the spinous process while lying flush within the lamina. A second screw is placed from the opposite base of the spinous process into the lamina similar to the first screw. Reported disadvantages of this technique include early hardware failure, breach of the dorsal lamina or ventral canal, and difficulty in bone graft or rod placements due to the position of the screwheads.[142]

Gallie-Brooks-Sonntag Fusion

The Gallie-Brooks fusion, as modified by Sonntag and published by Dickman and coworkers, allows fixation of atlantoaxial instability via preparation of the dorsal lamina of the atlas and axis and preservation of the C2-3 interspinous ligament.[143] Initially, the inferior aspect of C1 and superior aspects of C2 are roughened with a drill to create a suitable interface for fusion. A Kerrison punch is used to notch the inferior C2 hemilamina, and a loop of cable is passed under the dorsal arch of C1 in a caudal to rostral direction. A rectangular graft, approximately 1.5 × 3.5 cm, is then harvested (dorsal rib is now used instead of iliac crest) and trimmed to fit snugly between the dorsal arch of C1 and the lamina of C2. The loop cable is drawn over the spinous process of C2, and its ends are tightened. This one-point fixation construct does not counter rotatory or translatory movements. Therefore, it is recommended that this technique be used in combination with another form of fixation, such as placement of C1-2 transarticular screws or C1-2 lateral mass screws. Postoperatively, the patient wears a hard collar for approximately 6 weeks.

Lateral Mass Fixation (C3-6)

Lateral mass fixation does not depend on the spinous process or lamina for fixation. It can be used to treat laminar or spinous process fractures and overcomes the shortcomings inherent to wiring techniques. Lateral mass fixation can be achieved with a screw-plate or a screw-rod construct.

Screws are placed in the center of the lateral mass, which is defined by the groove between the lamina and the beginning of the lateral mass medially and the curving lateral edge laterally (Fig. 53-14). The trajectory is 30 degrees lateral and

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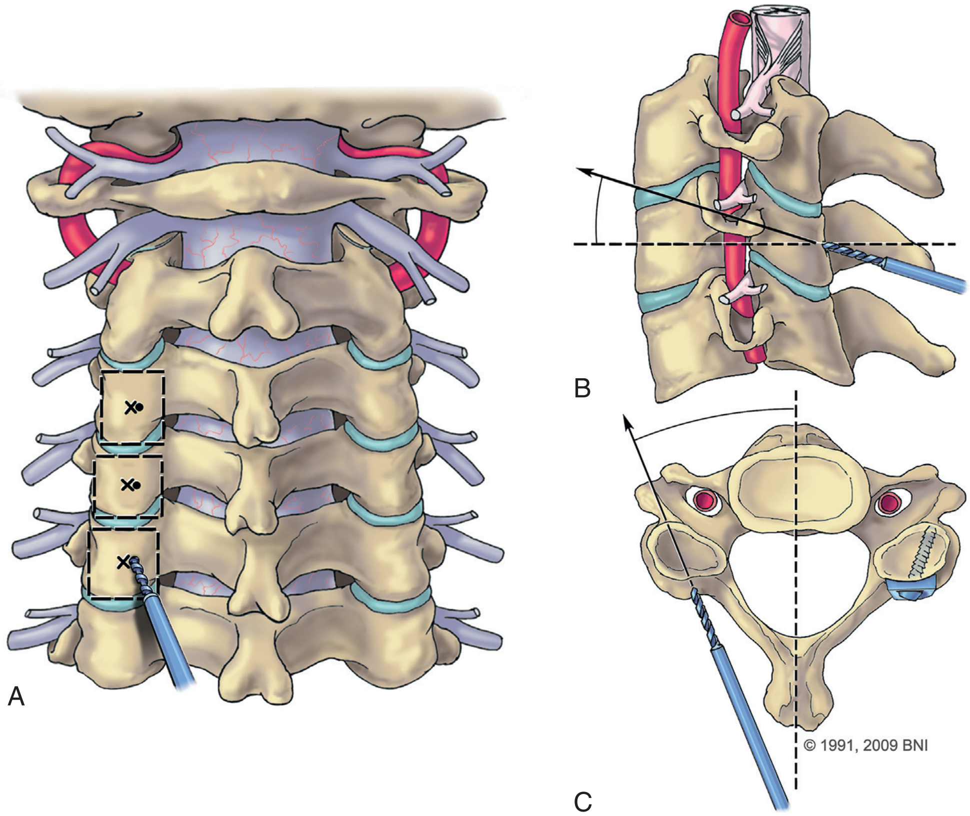

Figure 53-14. Target area for placement of lateral mass screws. Screws are inserted into the bone 1 mm medial to the center of the lateral masses (**A**) and directed 20 to 30 degrees cephalad (**B**) and 20 to 30 degrees laterally (**C**). *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

30 degrees rostral (see Fig. 53-14). Screw lengths may be measured on a preoperative CT or intraoperatively by stopping the drill before it reaches the dorsal aspect of the lateral mass on lateral fluoroscopy. Placing the screws from the contralateral side of the table helps achieve correct angles. Good bone quality is key, and poor screw fixation invariably results in early screw pullout. Lateral mass screws are relatively contraindicated in patients with poor bone quality. The technique is associated with a risk of damage to a nerve root or vertebral artery. With appropriate rostral and lateral trajectories, both risks are minimized. Bicortical screw purchase is unnecessary and offers no biomechanical advantage compared to unicortical screws.[140]

BONE-GRAFTING TECHNIQUES

The techniques described in this chapter all rely on the support of a bone graft. The type of bone graft used depends on the surgical procedure and the surgeon's and patient's preferences. The options for bone graft include autografts and natural and synthetic allografts. Grafts may be cortical, cancellous, or mixed. Cortical bone is the strongest form of graft and is typically used when strong structural support is required. Pure cancellous bone is quite weak and should only be used in cases that do not require the graft to withstand compressive forces. Autografts are the gold standard and are associated with the highest rates of fusion. Obtaining autograft, however, is associated with complications such as pain and infection. At times the quality of autografts can be inadequate, and the risks of complications can be too high. In such cases, cadaveric allografts can be used. Compared with autografts, allografts tend to revascularize more slowly; the rate of bone fusion is slower; and the risk of bone resorption, infection, or rejection is higher. When neither autographs nor cadaveric allograft can be used, methyl methacrylate is an option. Methyl methacrylate is used as an immediate stabilizing method and should be reserved for patients with a short life expectancy because its usage does not lead to bony fusion.

Possible sites for harvesting autologous grafts include the ribs, iliac crest, skull, and fibula. Grafts from the rib and iliac crest, which are good sources of tricortical, bicortical, or cancellous chips, are preferred. The rate of arthrodesis for grafts from ribs or the iliac crest is the same, but the rate of complications associated with harvesting a rib is lower.[144]

Rib grafts are harvested by making a linear incision in the skin over the rib surface (Fig. 53-15A). Blunt dissection with a Doyen rib dissector is used to detach the intercostal muscles and parietal pleura from the undersurface (Fig. 53-15B). The ends of the rib graft are cut sharply using a rib cutter or oscillating saw and smoothed to avoid a pneumothorax.

In the young child, the iliac crest is largely cartilaginous and ribs are small. In such cases, bone from the parietal skull can be harvested through a bicoronal flap. If identical free flaps are taken and split carefully, half-thickness skull bone replacements at both sites facilitate solid and cosmetically acceptable reconstruction within 3 months.

Bone grafts also can be harvested from the fibula. As a graft source, the fibula offers a high cortical-to-cancellous bone ratio; long segments up to 25 cm can be harvested safely. For a fibula graft, the leg is prepared and a tourniquet is applied to the thigh. After a straight lateral incision over the fibula is made, the peroneal muscle is separated from the ventral aspect

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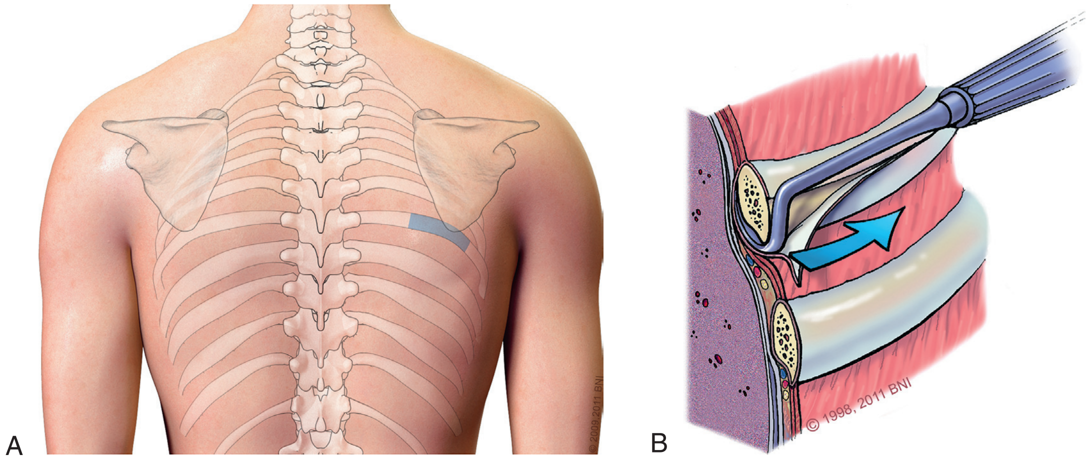

Figure 53-15. Harvesting a rib graft. A, Extent of rib needed for harvest. **B,** Technique of graft harvest. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

of the fibula. The muscles of the dorsal compartment of the leg are also dissected free, and a Gigli saw is used to divide the fibula, paying due attention to the peroneal artery and nerve. The fibula is elevated in a distal-to-proximal fashion, and the fibular diaphyseal segment and peroneal vessels are ligated and dissected. The site is closed with a drain in place.

The dorsal iliac crest can serve as another source to obtain tricortical grafts, cortical-cancellous plates, cancellous bone strips, or cortical matchstick grafts. Using a curved skin incision beginning at the posterior iliac spine and extending superolaterally, dissection is carried out through the fascia and opened over the iliac crest. Dissection is continued subperiosteally to minimize damage to the gluteal artery, sciatic nerve, ureter, and ilioinguinal nerve. The graft is obtained using bone curettes, and the incision is closed in layers. It is important not to remove graft of more than 8 cm from the iliac spine to avoid damaging the superior cluneal nerves. It is also important not to harvest the graft too medially because this can place the sciatic notch and the sacroiliac joint in danger.

After harvesting a structural autograft, careful carpentry comes into play. The graft must be fashioned to maximize the bony contact between the surfaces needing to be fused. At C1-2, for example, a notch in the bone is often fashioned to allow the graft to "sit" on the spinous process of C2. At the occipitocervical junction, the graft should be fashioned so that there is solid contact with the skull, C1, and C2 (Fig. 53-16). This can be done by cutting an oblique angle into the graft and drilling a trough into the suboccipital bone into which the graft is wedged. All structural grafts should be augmented by wiring to ensure that the bone is under compression.

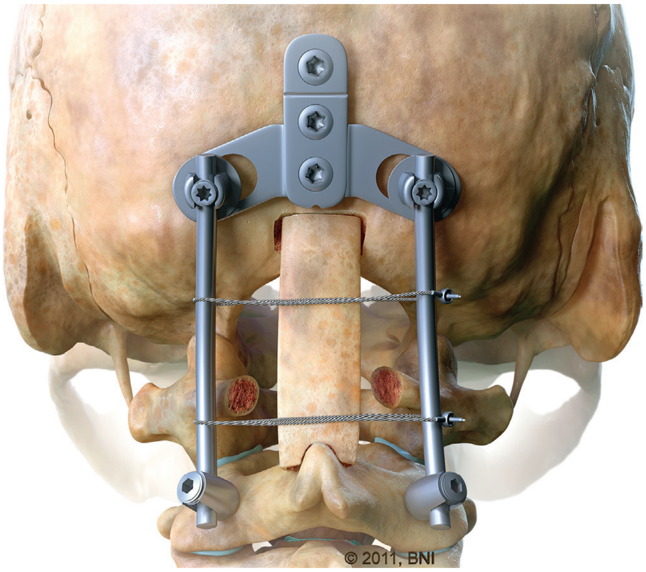

Figure 53-16. Occipital keel screws with plate system coupled with C2 lateral mass screws and rib graft wired, C1 posterior arch removed. *(Used with permission from Barrow Neurological Institute, Phoenix, AZ.)*

CONCLUSION

In conclusion, CCJ injuries have a high mortality rate, mostly related to associated upper cervical spinal cord or brain stem injury. Nonetheless, patients surviving the first 2 days after the CCJ injury may have a favorable outcome. Up to 25% of the surviving population may be neurologically intact; another 25% may have mild to moderate neurologic deficits or complications.[16,145] Surgical planning and intraoperative CT-based navigation are valuable in an attempt to decrease complications and should be used in every case.

This chapter presents an overview of the most common upper cervical lesions and their current management. The CCJ is a challenging region for surgery. In-depth knowledge of the anatomy, diagnosis, treatment options, and outcomes is mandatory, and dexterity and expertise are required from the surgeon in charge of these particularly complex cases.

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