Internal Fixation of the Cervical Spine: Current Indications and Techniques

Howard S. An, MD

Abstract

Numerous techniques for the internal fixation of the cervical spine have been developed in recent years. The indications for surgery must be strictly defined before the optimal type of implant can be selected on the basis of the advantages and potential risks. Wiring techniques are still commonly used for posterior stabilization. Anterior fusion can be accomplished without internal fixation in most cases. The halo vest is still widely used for the conservative management of cervical fractures and for postoperative external immobilization. Posteriorly, traditional wiring methods are still used, as well as newer techniques, such as C1-C2 screw fixation, occipitocervical plate fixation, and lateral-mass lower cervical plating. Anteriorly, meticulous Smith-Robinson surgical approach and grafting techniques are essential. Further studies are needed to define the exact indications for various new techniques, such as anterior odontoid screw fixation and anterior plating. The surgeon must choose an appropriate device on the basis of the mechanism of injury, the pathoanatomy of the lesion, and familiarity with the device, keeping in mind the goals of internal fixation—stabilization, reduction and maintenance of alignment, early rehabilitation, and perhaps enhancement of fusion and avoidance of the need to use an external halo vest.

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The technique for internal fixation of the cervical spine has been evolving for the past two decades.[1,2] Wiring techniques are still commonly used for posterior stabilization, and anterior fusion can be accomplished without internal fixation in most cases. The indications for various new internal fixation devices should be clearly defined, and their advantages and disadvantages should be delineated. The surgeon must choose an appropriate device on the basis of the mechanism of injury, the pathoanatomic characteristics of the lesion, and his or her own familiarity with the device. The goals of internal fixation are stabilization, reduction and maintenance of alignment, early rehabilitation, and perhaps enhancement of fusion.

The purpose of this article is to review the current status of various internal fixation devices for cervical fixation. Their indications, techniques, and potential complications will be emphasized.

Posterior Atlantoaxial Fusion

Indications

Most upper cervical spine injuries are best treated nonoperatively. Cervical orthoses, including the halo vest, are often used to provide stability until the bone and soft tissue heals. The primary indication for posterior atlantoaxial fusion is acute or chronic instability due to disruption of the transverse ligament, which jeopardizes the function of the spinal cord (e.g., in an isolated rupture of the transverse ligament or a Jefferson fracture with rupture of the transverse ligament). Less common indications include acute type II odontoid fracture, nonunion of odontoid fracture with atlantoaxial instability, and nontraumatic instability resulting from rheumatoid arthritis, congenital anomalies, and metabolic disorders.

Regardless of cause, an atlantodental interval of 3 to 5 mm is evidence of damage to the transverse ligament; displacement by more than 5 mm indicates deficient transverse and accessory ligaments in adults.[3] However, in nontraumatic disorders, an abnormal atlantoaxial interval alone is not necessarily an indication for surgery. Many patients with an increased atlantodental interval due to nontraumatic

Dr. An is Associate Professor of Orthopaedic Surgery and Chief, Division of Spine Surgery, Department of Orthopaedic Surgery, The Medical College of Wisconsin, Milwaukee.

Reprint requests: Dr. An, Department of Orthopaedic Surgery, The Medical College of Wisconsin, 8700 West Wisconsin Avenue, Milwaukee, WI 53226.

disorders function well because the disease process may be protracted and nonprogressive. In these conditions, such as rheumatoid arthritis, indications for stabilization include significant progressive neurologic deterioration, intractable pain, and an atlantodental interval usually greater than 9 mm.

More important than the atlantodental interval is the space for the spinal cord. A space that measures less than 14 mm is associated with a worse prognosis in patients with rheumatoid arthritis.[3] I recommend atlantoaxial arthrodesis for an acute injury where the atlantoaxial interval is greater than 5 mm. In a chronic condition, the clinical findings and the results of other tests, such as flexion-extension views and magnetic resonance imaging, should be considered first. Surgery is indicated if there are neurologic symptoms or if the space available for the spinal cord becomes less than 14 mm on either static or dynamic imaging studies.

The indications for surgery in cases of odontoid fracture are controversial, but I prefer prompt reduction and halo-vest immobilization as the first-line treatment. Surgery is reserved for failures of reduction or the later development of symptomatic nonunion.

Techniques

If halo-vest immobilization is planned after surgical treatment of an acute injury, the ring is applied before surgical stabilization to maintain traction during surgery and to facilitate vest application after surgery. Typically, preoperative halo traction is used for an acute injury if a significant deformity is present. If traction is not required, the patient can be fitted preoperatively with a posteriorly opened halo ring and vest.

A typical midline incision is made from the occiput to C3, exposing the lamina of C2 and the posterior arch of C1 by subperiosteal dissection. The arch of C1 should not be exposed beyond 1.5 cm from the midline in adults and 1 cm in children because of the risk of injury to the vertebral artery. Great care must also be taken not to fracture the posterior ring of C1 while dissecting the muscles and the ligamentum flavum. Muscular insertions on the spinous process of C2 should be preserved as much as possible to prevent instability at C2-C3.

Posterior atlantoaxial arthrodesis may be performed with the use of either the Gallie technique[4] (Fig. 1) or the Brooks technique[5] (Fig. 2). The Gallie technique is safer, because the spinous process of C2 is used in place of a sublaminar wire, but the Brooks technique provides additional rotational stability.[6] I recommend the Gallie technique for most flexion injuries, but the Brooks technique is preferred for extension injuries and for patients in whom more rigid fixation is deemed necessary.

Another segmental wiring technique gives a better fixation of the bone graft (Fig. 3).[7] Autogenous iliac-crest graft is recommended, but allograft material can be supplemented if the pelvic bone is insufficient or osteoporotic.

Postoperatively, I use halo-vest external support for 3 months if wiring techniques are utilized.

Other less commonly used C1-C2 fixation techniques have been recommended by some authors. Aprin and Harf[8] recommend internal fixation of C1-C2 by passing two 18-gauge stainless-steel wires beneath the posterior arch of the atlas and around a threaded Steinmann pin, which is drilled through the base of the spinous process of the axis. They report excellent results in eight patients treated with this technique.

Another method[9] uses an interlaminar clamp for selected patients in whom sublaminar wires would be difficult or dangerous to use. The potential problems with such inter-

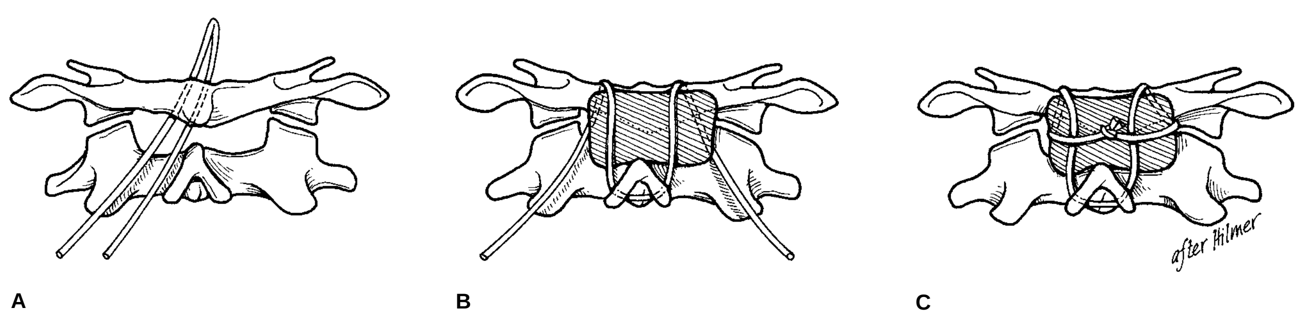

Fig. 1 A modified Gallie H graft from the iliac crest over the posterior arches of C1 and C2. **A,** A doubled, U-shaped, 18- or 20-gauge wire is passed under the arch of C1 from inferior to superior. **B,** A bone block is taken from the posterior iliac crest and shaped to fit between C1 and C2 and the wires. **C,** The loop of the wire goes over the bone block and the spinous process of C2, and the ends of the wire are tightened around the graft between C1 and C2.

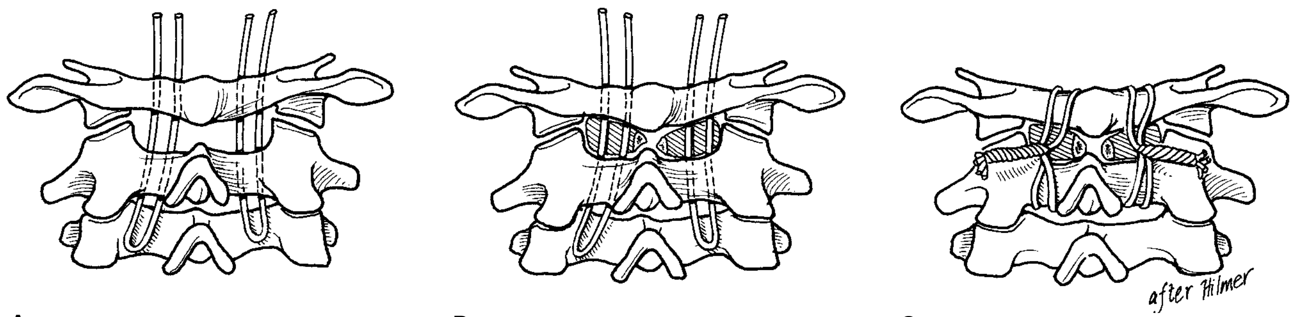

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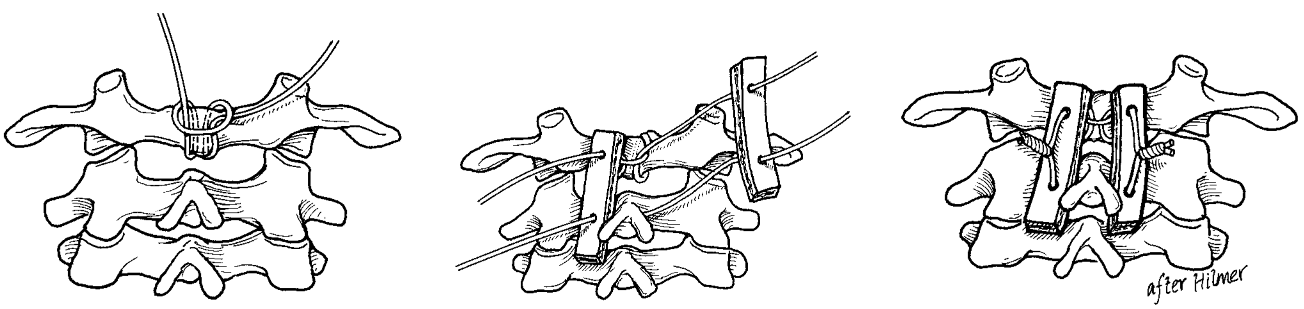
Fig. 2 The Brooks-type fusion. **A,** Doubled, twisted 24-gauge wires are passed under the arch of C1 and then under the lamina of C2. **B,** Rectangular iliac-crest bone grafts (1.25 cm X 3.5 cm) are harvested and beveled to fit in the space between the arch of C1 and each lamina of the axis. **C,** The wires are then tightened, securing the graft.

laminar-clamp fixation are implant slippage and difficulty with graft placement.

Another newer method of atlantoaxial stabilization is Magerl's transarticular screw fixation (Fig. 4). This procedure provides the most rigid fixation, but requires detailed knowledge of the surgical anatomy and technique.[8] In using this latter device, a midline approach is extended more distally to gain the appropriate angle for screw insertion. The subperiosteal dissection depends on careful exposure of the



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D E

Fig. 3 Meyer's technique of C1-C2 fusion. **A,** A sublaminar wire is placed under C1. Another wire is passed through the base of the C2 spinous process. **B,** Wires are threaded through holes in the grafts. **C,** Wires are tightened over the grafts. **D,** Lateral radiograph shows posteriorly displaced odontoid fracture despite use of halo vest. **E,** Lateral radiograph shows C1-C2 wiring fusion.

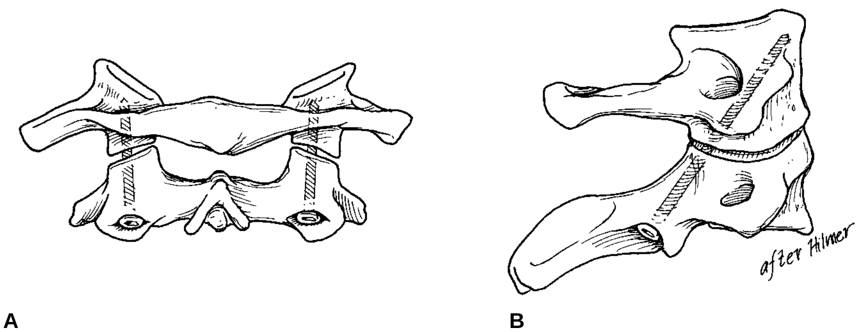

Fig. 4 Magerl's technique of C1-C2 screw fixation. **A,** The screws are inserted by entering C2 at the inferior aspect and exiting at the posterior aspect of the upper articular process. **B,** The screws are placed through the facet joints into the lateral masses of C1.

C1-C2 facet joints bilaterally. Magerl recommends the use of Kirschner wires to retract the soft tissues containing the greater occipital nerve and its accompanying venous plexus. The screws are inserted by entering C2 at the inferior aspect and exiting at the posterior aspect of the upper articular process. The screws are placed through the facet joints into the lateral masses of C1. Magerl recommends Gallie wiring and fusion in addition to placement of transarticular screws in patients with an intact C1 ring.[10] I favor wiring techniques over Magerl's technique in most cases, except when the C1 ring is deficient. This new type of rigid fixation device may obviate halo-vest immobilization, but the potential risks should be weighed against the expected benefits.

Posterior Occipitocervical Fusion

Indications

Fortunately, injuries and disorders that require occipitocervical arthrodesis are rare. They may include basilar impression, occipitocervical instabilities, and atlantoaxial instabilities with a deficient C1 ring.

Atlanto-occipital injuries are frequently fatal; therefore, the diagnosis is rarely made. If the patient survives the injury, the presentation may include respiratory distress, suboccipital hematoma or tenderness, and high or mixed quadriplegia. Radiographic indicators of an atlanto-occipital injury include a prevertebral soft-tissue swelling greater than 7 mm at the C2 level and a Powers ratio greater than 1.[11] The latter is determined by measuring the distance from the basion to the anterior border of the posterior arch of the atlas and dividing that by the distance from the opisthion to the posterior border of the anterior atlas arch.

Another indication for occipitocervical fusion may be basilar impression associated with cervicomedullary cord compression, which results from rheumatologic, posttraumatic, and neoplastic disorders and congenital malformations.

Techniques

Of the several techniques described in the literature, I prefer the method described by Wertheim and Bohlman[12] (Fig. 5). A midline posterior approach is used, exposing the posterior elements from the external occipital protuberance to C4. Sharp, subperiosteal dissection is completed, exposing the occiput and the cervical laminae. The external occipital protuberance is thick and is the ideal location for passage of wires, because it is not necessary to go through both tables of the skull. A high-speed diamond burr is used to create a trough on both sides of the protuberance at a level 2 cm above the foramen magnum. A towel clip is then used to create a hole in the ridge, and an 18-gauge wire is passed through the hole and twisted over the ridge. A second wire loop is passed around the arch of C1, and a third is passed through and around the base of the spinous process of C2. The posterior iliac crest is then exposed, and a large, thick, slightly curved graft of corticocancellous bone of appropriate width and length is obtained. The graft is divided into two parts, and three drill holes are placed in each graft. The occiput is decorticated, and the grafts are anchored in place by the wires. Additional cancellous bone is then packed between the two grafts. A halo vest is used for 3 months.

Occipitocervical fusion can also be achieved by using Luque segmental instrumentation. This technique provides a stronger fixation, but potential complications associated with sublaminar wiring prohibit routine use. Furthermore, Luque fixation is poor in resisting axial loading.

Recently, screw fixation into the occiput has been described[13,14] (Fig. 6). This technique may be advantageous in patients who undergo decompressive laminectomy or who require multiple-level fixation from the occiput to the lower cervical spine. Smith et al[13] reported the cases of 14 patients who underwent contoured plate fixation of the occipitocervical region; in all cases fusion occurred with minimal complications. Grob et al[14] presented their experience with occipitocervical fusion with a Y plate; their technique provides a secure fixation with screws in the thicker midline of the occiput and the lateral masses of the upper cervical spine.

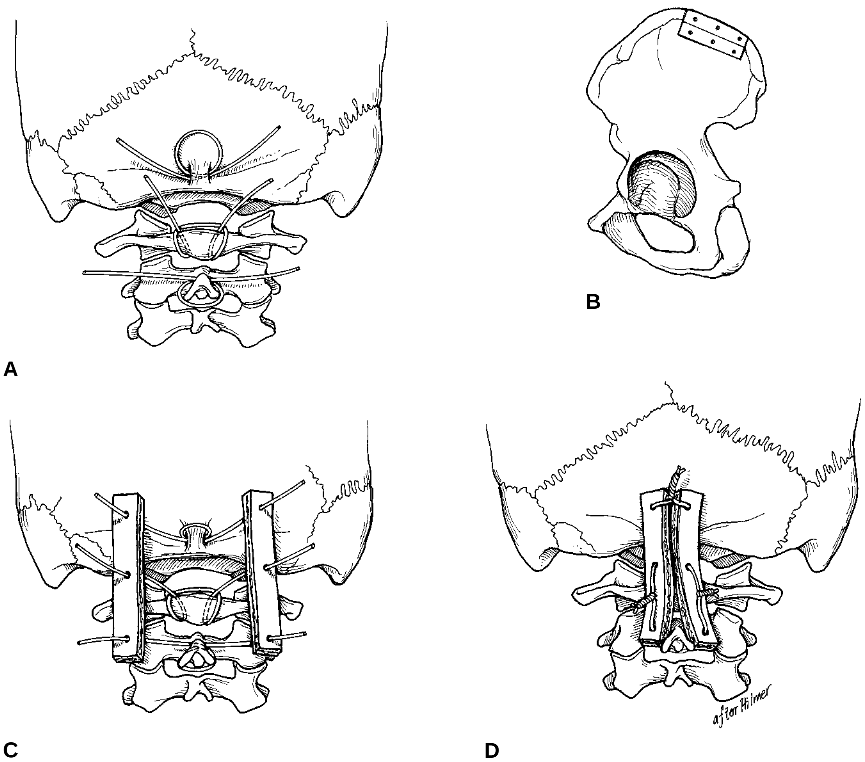

Fig. 5 Wertheim and Bohlman's method of occipitocervical fusion. **A,** A wire is looped around the external occipital protuberance at a level 2 cm above the foramen magnum. A towel clip is then used to create a hold in the ridge, and an 18-gauge wire is passed through the hole and twisted over the ridge. A second wire loop is passed around the arch of C1 and a third is passed through and around the base of the spinous process of C2. **B,** The outer iliac crest is used for bone grafts. **C,** Drill holes are made in the bone grafts, and wires are passed through the holes. **D,** The wires are tightened.

Methylmethacrylate has also been used as an adjunct fixation for occipitocervical stabilization, particularly in patients with malignant neoplasms. Recently, Stambough et al[15] described a technique of occipitocervical stabilization with bone cement in the osteoporotic spine. This technique should be regarded as temporary adjunctive fixation.

Posterior Lower Cervical Fusion

Indications

Posterior fusion of the lower cervical spine may be indicated in patients with facet dislocations or teardrop fractures, postlaminectomy instabilities, or neoplasms. Flexion-distraction injuries, such as unilateral or bilateral facet dislocations, are quite unstable. I manage them by prompt reduction with skull-tongs traction and posterior arthrodesis. In patients with subluxation or dislocation with an associated herniated disk, the spinal cord should be decompressed anteriorly first.

In a severely unstable injury, such as a teardrop fracture, a combined anterior-posterior fusion may be indicated. With the advent of more rigid fixation techniques, combined anterior-posterior fusion may not be necessary. In addition, the more rigid implants may obviate use of the halo vest postoperatively.

Other instabilities of the cervical spine may be more subtle, and White's criteria of 11 degrees of sagittal angulation and 3.5 mm of sagittal-plane translation may be used as part of the indication for stabilization.[16] However, the patient's symptoms should also be taken into consideration. For example, some patients' symptoms can be managed well with conservative treatment despite the presence of 11 degrees of angulation and 3.5 mm of translation on the radiographs.

Progressive cervical kyphosis associated with trauma, laminectomy, or neoplasms may necessitate either anterior or posterior cervical fusion. If the kyphotic deformity is rigid, anterior fusion is required. If the kyphotic deformity is flexible, either anterior or posterior fusion may be used.

Techniques

There are numerous methods of posterior stabilization of the cervical spine. Each has its advantages and disadvantages, and the surgeon should choose the appropriate procedure on the basis of the particular circumstances of the individual patient. Wiring techniques are quite effective in preventing flexion, but less effective in preventing extension or rotation. I favor a triple-wire technique, which secures the spinous processes and the bone grafts (Fig. 7). This triple-wire technique has been shown to be safe, effective, and biomechanically superior to many other constructs.

The prone positioning requires careful attention to details to maintain optimal alignment of the cervical spine and to avoid pressure to the eyes. The use of the Mayfield frame provides secure positioning of the head without any pressure to the eyes. Occasionally, the Stryker frame may be used with cranial-tongs traction to maintain alignment.

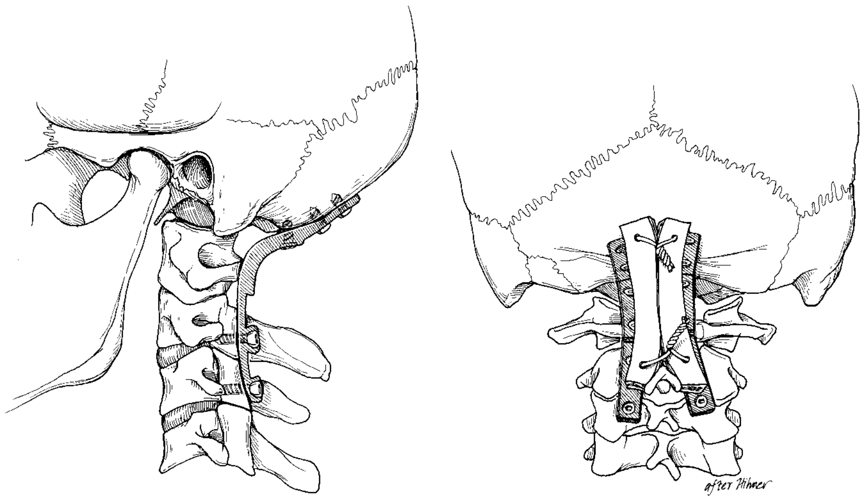

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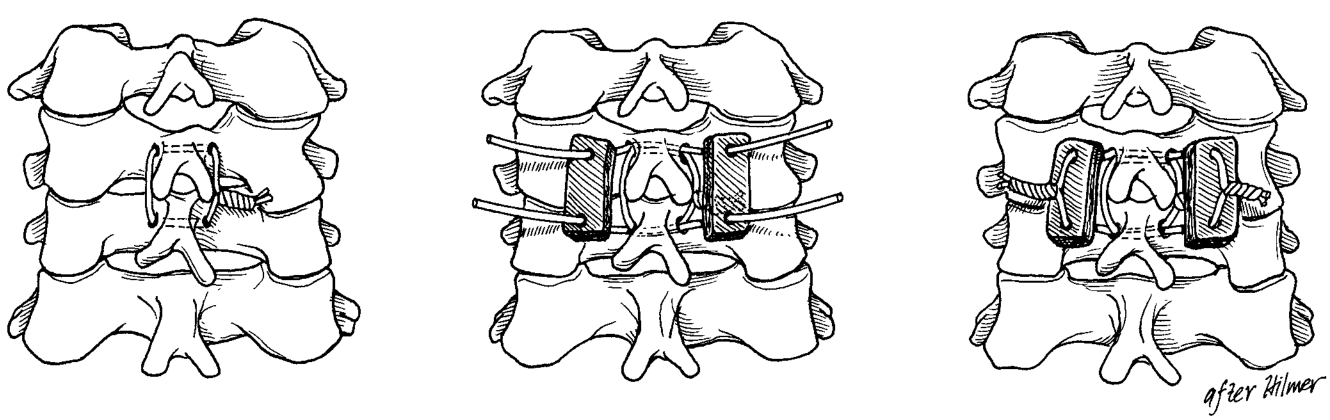
Fig. 6 Roy-Camille technique of occipitocervical fixation. Lateral **(A)** and posterior **(B)** views illustrate contoured plate-and-screw fixation.

After preparation and draping of the patient, the skin and subcutaneous tissue are dissected down to the midline fascia. A lateral radiograph is obtained to be certain of the level. Subperiosteal dissection is then completed to expose the spinous processes, laminae, and facet joints at the level of interest. Caution is taken to avoid damage to the adjacent facet capsules and to avoid dissection beyond the extent of the desired fusion, to prevent fusion extension.

A 3-mm burr is used to drill a hole at the base of the spinous process on both sides. The drill-hole site should be at the proximal aspect of the cephalic spinous process and at the distal aspect of the caudal spinous process. A towel clip is gently passed through the holes to create a tunnel for wires. A single 18- or 20-gauge wire is then passed through both spinous processes and is tightened for a single-level fusion. If more than one level is to be fused, figure-eight wiring is used to incorporate the middle spinous process in the wiring construct. If the middle spinous process or lamina is fractured, wiring should be avoided at that level. The second and third wires are passed through the cephalic and caudal holes in the bases of the spinous processes, respectively. Decortication of the laminae and facets is done carefully with the use of a power burr.

Two corticocancellous bone grafts of appropriate length are next taken from the outer table of the iliac crest. Two drill holes are placed in each graft for passage of wires. The wires are then passed through the holes in the graft, and a firm contact is made between the graft and the



A B C

Fig. 7 A triple-wire technique with interspinous process wires. **A,** A wire is passed from the cephalic part of the superior spinous process to the inferior part of the caudal spinous process. **B,** The second and third wires are passed through the cephalic and caudal holes in the bases of the processes, respectively. After decortication of the laminae and facets, corticocancellous bone grafts from the outer table of the iliac crest are placed. **C,** Wires are tightened over the grafts, and additional cancellous chips are laid down on the exposed laminae or facets.

underlying lamina. The posterior cortical edge of the graft should be placed just under the bulbous spinous process to enhance stability and maximize graft-lamina contact. The wires on each side of the spine are then simultaneously tightened. Additional cancellous chips are placed on the exposed lamina or facets. The patient is usually kept in a cervicothoracic orthosis or halo vest for 6 weeks, depending on the stability of the construct and the compliance of the patient.

Sublaminar fixation is generally not recommended in the lower cervical spine because this technique is associated with a greater risk of neurologic injury compared with the spinous-process wiring method. An alternative fixation is the Dewar procedure, in which Kirschner wires are inserted through the bases of the spinous processes and secured with wire in a loop fashion.[17] Facet fracture or subluxation can be managed with an oblique-wiring technique or wire loop, by passing the wire through the lateral mass.[18]

In patients who have undergone laminectomy, interfacet wiring and fusion can be performed.[19] In the oblique-wiring technique, the facet wire is passed by placing a small Penfield dissector into the facet joint. An inferiorly directed 2-mm drill hole is then made in the facet. A 20-gauge wire is passed through this hole and looped around the inferior spinous process for single-level fusion, as is required in most unilateral facet dislocations. Facet wires may be extended to adjacent facets for multiple-level facet stabilization, as is done for postlaminectomy instability. The facet wires may be tied to bone grafts for fusion; they can also be tied to metallic rods for additional stability.

Although most patients with instability of the cervical spine can be treated with wiring methods, more rigid internal fixation techniques may have a role in selected patients. Most apparent are instances in which the spinous processes are fractured or deficient because of laminectomy. More rigid fixation may also allow early rehabilitation and decrease the need for use of a halo vest postoperatively.

There are a variety of fixation devices that may be used, including Luque rods with sublaminar wires and the pediatric Cotrel-Dubousset and TSRH systems.[20,21] Posterior stabilization of the cervical spine with the use of screws and plates was pioneered by Roy-Camille in Paris (Fig. 8). Louis[22] uses a similar type of plate-screw fixation onto the lateral masses. Magerl devised a plate-screw system for the cervical spine in which the inferior end of the plate has a hook configuration.[23] Recently, Anderson et al[24] reported on their treatment of 30 patients with unstable cervical spines who underwent a posterior arthrodesis with AO reconstruction plates. All had a solid fusion with no neurologic or vascular complications. Three patients had screw loosening without clinical sequelae. Both the biomechanical strengths of these plates and the clinical reports to date are quite encouraging.[24-26] These reports show that lateral-mass plates provide excellent immediate stability and good maintenance of alignment.

Potential problems associated with posterior plating with screws include injury of the vertebral artery or cervical nerve roots. Thorough familiarity with the articular pillar anatomy and surgical technique are important in the prevention of these complications.

Cadaveric studies have indicated that the safest screw direction is 30 degrees lateral and 15 degrees cephalad, starting 1 mm medial to the center of the lateral mass for C3 to C6.[27] The lateral mass is quite thin at the transitional C7 level, and there is a danger of injuring the C8 nerve root as well as disrupting the facet joint. Therefore, hook-plate designs are preferred in the C7 region. The cadaveric studies have also shown that the interfacet distances vary widely among individuals, ranging from 9 mm to 16 mm (average, 13 mm). A new plate design with oblong holes is necessary to better accommodate the variation in interfacet distances among patients and at different levels.

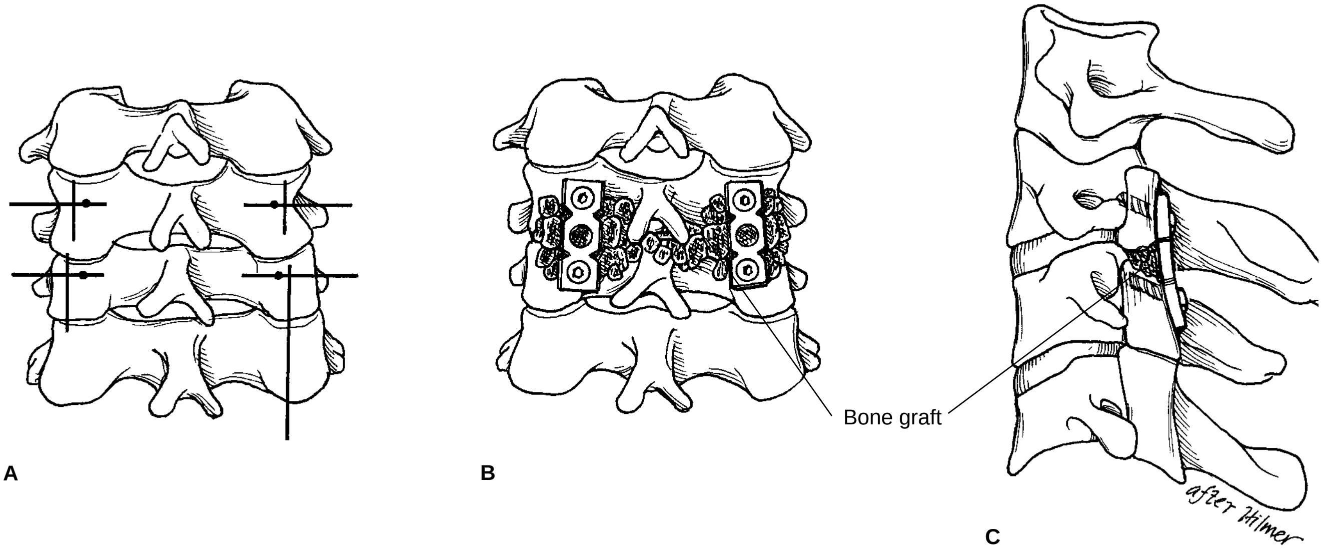
To insert these devices, bilateral exposure to the limits of the lateral masses is made. The center of the articular pillar is located, and the cortex is pierced with an awl or a small burr 1 mm medial to the center of the lateral mass (Fig. 8). As already mentioned, there are many techniques of drilling, but the underlying anatomy of the nerve root must always be borne in mind, to avoid nerve injury. A drill with a stop guide should be used. At C3-C6, I direct the drill 25 to 30 degrees laterally and 15 degrees cephalad. At C2, drilling should be directed about 10 to 15 degrees medially and 35 degrees superiorly to avoid injury to the vertebral artery. The opposite cortex is usually penetrated, and the drill hole is tapped with a 3.5-mm tap. A contoured posterior cervical plate and 3.5-mm-diameter cortical screws of appropriate length are placed and secured.

In addition to Roy-Camille plates, other plates, such as AO-Anderson reconstruction plates, Haid plates, and Axis posterior cervical plates, are becoming available, but it is too early to determine specific advantages of one over another. A titanium device has the advantage of magnetic resonance imaging compatibility after implantation.

Anterior Screw Stabilization of the Odontoid

Indications

The traditional approach for the treatment of odontoid fractures is



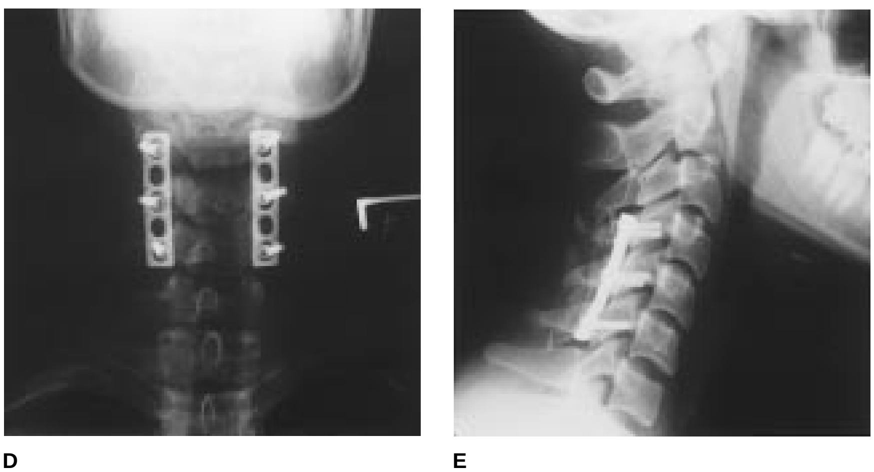


Fig. 8 Posterior plate-screw fixation of the cervical spine. **A,** The ideal drilling technique for safety of the nerve root. The starting point is 1 mm medial to the center of the lateral mass. The drill is directed 25 to 30 degrees laterally and 15 degrees cranially. **B,** Plate-screw fixation on the lateral masses of the cervical spine with bone grafts between the facet joints. **C,** The plates should be slightly contoured to cervical lordosis. **D** and **E,** Radiographs of a patient who underwent C4-C6 plate-screw fixation for fracture-dislocation. Anteroposterior **(D)** and lateral **(E)** views show anatomic reduction and proper screw placement and bone grafts posteriorly.

conservative management with halo immobilization; a large percentage of these fractures heal uneventfully. However, for widely displaced type II fractures, early surgical stabilization may be contemplated to enhance the potential for fracture healing and the patient's functional recovery.

The rationale for direct anterior fixation is the preservation of C1-C2 rotation while providing rigid internal fixation and avoiding restrictive bracing and the complications associated with bone-grafting techniques. Advocates of this approach believe that morbidity is lessened and that operative blood loss is minimal. Böhler[28] has reported the largest series of odontoid fractures treated in this manner. On the basis of his results in patients with nonunion and acute fracture, he advocates only anterior screw fixation for the treatment of acute fractures.

The specific indications for this technically demanding procedure are a displaced odontoid fracture that cannot be reduced adequately by skeletal traction, use of a halo device, or a fracture of the odontoid associated with a concomitant C1 ring fracture. I must stress that this is a relatively new technique, and more studies should be done to assess potential benefits and risks.

Technique

The surgical approach begins with a standard anteromedial approach to the cervical spine. Usually, a right-sided transverse incision is made just above the level of the cricoid cartilage, which extends 6 to 8 cm laterally. The platysma muscle is split in a longitudinal fashion at the medial border of the sternocleidomastoid muscle. The contents of the carotid sheath are identified, and the retropharyngeal space is accessed just medial to the palpable carotid pulse. Blunt finger dissection is then continued to the prevertebral fascia and anterior longitudinal ligament. The anterior tubercle of the atlas is identified by palpation. The prevertebral fascia and anterior longitudinal ligament are then split in the midline over the body of the axis, and the dissection is extended craniad, exposing the odontoid process and fracture site if open reduction is needed. If the fracture is reduced, exposure of the C2 body will allow placement of Kirschner wires and screws up into the odontoid with use of biplanar fluoroscopy.

In the operating room, before initiating the actual surgery, time must be taken to obtain sufficient radiographic imaging in both anteroposterior and lateral planes. The use of biplanar fluoroscopy facilitates the imaging of the position of the odontoid.

Reduction of the fracture may be completed by closed means through application of skeletal traction, but should not be vigorously pursued. In the case of a displaced fracture that is not reduced by skeletal traction, the odontoid process may require mobilization and realignment before fixation.

Once reduction of the odontoid process is complete, the anterior inferior border of the C2 body is used as the starting point for drilling. I prefer to use 2.0-mm Kirschner wires, which are placed under image intensification through the body of C2 into the odontoid process. Two such wires are placed across the fracture site to obtain rotational stability. Once secured in this position, one wire is removed, the hole is tapped, and a 3.5-mm cortical screw is placed with use of a lag technique and stabilized. The second wire is then removed, and the process is completed. The average length of the screw is usually 40 mm. One-screw fixation may be sufficient, particularly in small patients. I generally advise placing the tip of the screw through the apical cortex of the odontoid. This seems to greatly enhance fixation. Postoperatively, either a halo vest or a cervicothoracic orthosis is used for 2 months.

Anterior Instrumentation of the Lower Cervical Spine

Indications

Over the past 20 years, several devices have been developed and implemented for osteosynthesis of the anterior cervical spine.[1,2] The most common indication for anterior cervical surgery remains degenerative conditions. Techniques such as Cloward and Smith-Robinson fusions have been widely accepted and successful for these degenerative conditions, which rely on the bone graft to supply stability to the affected motion segment. However, when applied to the acutely unstable cervical spine, these techniques do not offer sufficient stability and have been associated with complications.

Because of these problems, additional methods and techniques for augmentation of cervical immobilization have been sought. These methods include concomitant posterior arthrodesis, prolonged immobilization in a halo-vest device or other external cervical orthosis, and prolonged bed rest with cranial-tongs traction. These alternatives, however, do not allow early patient mobilization and rehabilitation, which are recognized to be important factors in the treatment and survival of the patient with a spinal cord injury. Anterior decompressive procedures followed by these new reconstructive techniques potentially offer sufficient stability through a single surgical approach and minimize patient morbidity.

The specific indications for anterior cervical plating may include reconstruction of the spine after vertebrectomy for tumor, fracture, or spondylosis. In patients with a flexion-distraction injury requiring anterior diskectomy first, the use of anterior-plate fixation may obviate a secondary posterior approach. After corpectomy, the defect is usually reconstructed with a strut bone graft. No further procedure may be required if the graft is well positioned with adequate stability. I recommend the use of the halo vest postoperatively for 6 weeks. If the graft is deemed unstable or if the patient is not willing to wear, or is not capable of wearing, a halo vest postoperatively, anterior plating may be used.

Techniques

Proper preoperative planning, including consideration of intubation, positioning, and stabilization during the operative period, is imperative. For most fractures and dislocations, degenerative disorders, and tumors, cranial tongs are applied to secure the head, control the cervical spine, and apply traction. Most acutely injured patients are brought to the operating room in traction and on a Stryker frame, which facilitates patient care. This frame may also be used as the operative table, allowing atraumatic transport and turning of the patient.

The surgical approach for most conditions includes a standard anteromedial Smith-Robinson technique. A transverse incision generally suffices, although a longitudinal incision along the anterior border of the sternocleidomastoid may be required in some cases. After the skin is incised, the platysma muscle is split in line with its fibers. Alternatively, it may be incised transversely. The carotid artery is palpated, and the contents of the carotid sheath are retracted laterally. Blunt finger dissection is then carried down to the prevertebral fascia and anterior longitudinal ligament. Once the proper level has been identified, the longus colli muscles are elevated in a subperiosteal fashion, starting in the midline of the cervical spine. Self-retaining retractor blades are then placed under the longus colli muscle to protect the vital structures. Once the retractor has been placed, the temporal artery pulse is palpated by the anesthesiologist to ensure the patency of the carotid artery. Decompression is then performed, depending on the pathologic changes identified preoperatively. Fusion may simply involve an interbody arthrodesis, rather than a vertebral body reconstruction with a fibular strut or a tricortical iliac-crest graft. The grafting technique is more important than the instrumentation procedure; poor grafting technique may result in graft dislodgment, graft collapse, or instrumentation failure.

Once the graft has been inserted, a decision must be made concerning the need for supplemental anterior fixation. For three-column injuries to the cervical spine, anterior plating is necessary when attempting to avoid either a concomitant posterior arthrodesis or complications associated with anterior grafting without fixation. In cases in which simultaneous reconstructive procedures are needed because sufficient stability has not been obtained with graft implantation and in many neoplastic conditions in which methylmethacrylate spacers are used, adjunct stabilization with fixation devices is also useful.

The process of instrumentation is first started with selection of a cervical plate of appropriate size, which must extend from the midportion of the superior noninvolved vertebra to the midportion of the adjacent inferior uninvolved vertebra. The plate is then contoured to the anterolateral surfaces of the cervical spine, maximizing contact with the plate. When osteophytes are present on the vertebral bodies, their removal with a high-speed burr or rongeur is required to maximize bone contact with the plate and thus enhance the stability of the construct. At this point, the plate is stabilized with screws implanted at the proximal and distal poles of the plate. With the Caspar system, holes may be drilled manually or with an air-driven adjustable drill guide. When using an air-powered drill, it is important to measure the anterior-posterior depth of the adjacent intact vertebrae, which most often approximates 16 to 20 mm.

With the plate stabilized, the hole is drilled through a drill guide, allowing no more than 16 to 18 mm of penetration. The drilling should parallel the endplates of the vertebral body and be directed slightly toward the midline. Some prefer the use of a Kirschner wire, which may give the surgeon a better feel for the posterior cortical wall. The Kirschner wire or drill bit is then removed, and the drill hole is palpated with a depth gauge. If the posterior cortex has not been successfully penetrated, the drill guide is readjusted to allow an additional 2 mm of drilling. This sequence is repeated as necessary until the posterior wall is perforated. When the hole is completed, it is tapped with a 3.5-mm cortical tap through both the anterior and the posterior vertebral walls. A 3.5-mm cortical screw is then inserted and tightened only lightly until the remaining screws are placed.

This sequence is repeated for each of the remaining three holes. Bicortical approaches are advocated at each involved vertebra to obtain maximal purchase and prevent complications. Once all screws have been placed, an intraoperative radiograph is taken to verify the position and length of the screws. Once the position of the screws has been confirmed, they are firmly tightened. If for any reason there is less than adequate purchase into the vertebral body, the screws should be removed and redirected.

The Caspar and AO-Orozco plate systems are made of stainless steel. The plates come in various sizes. The AO-Orozco plate is available in 5- to 20-hole configurations and ranges in length from 23 to 133 mm. Screw-hole placement is also variable, ranging from 16 to 21 mm in each of the various lengths. The plates can be cut and contoured easily to the surfaces of the anterior cervical spine. This system utilizes 3.5-mm screws and allows variable placement of the screws through the holes of the plate at angles up to 45 degrees.

The AO-Morscher pure-titanium cervical plate (Fig. 9) is available in 5- and 8-hole configurations, in lengths ranging from 24 to 63 mm. Hole spacing is also variable, ranging from 16 to 55 mm. At one end of the plate, screw direction is set at a 12-degree angle to facilitate insertion of the screw where the anatomy does not allow right-angle application. There are several screws available for application with this plate. A standard 3.5-mm titanium screw is available for conventional bicortical purchase, as described earlier. However, the most commonly used screw with this plate is the 14-mm expansion-head screw, which comes in a 4-mm diameter. This expansion-head screw comes in perforated and nonperforated forms. The proximal portion of the screw is hollowed out and has an expansile shoulder. Once the 4-mm-diameter expansion-head screw has been placed through the plate and into the vertebral body, it is locked to the plate with use of a smaller expansion screw. The expansion screw fits into the hollowed-out cylindrical portion of the expansion-head screw and, with tightening, widens the shoulder of the expansion-head screw, locking it to the cervical plate. The benefits of this screw are primarily related to the fact that bicortical purchase is not required. The stability of this configuration, however, is dependent on the unity of the screw with the plate and the quality of the bone.

On completion of the procedure, drains are placed, and the wound is closed in a routine fashion. Postoperatively, consideration must be given to the patient's respiratory status. With prolonged operative procedures, there is a risk of paratracheal edema, which may lead to respiratory compromise. Therefore, for procedures exceeding 6 to 8 hours, it is often wise to keep the patient intubated for a period of 24 to 48 hours. Before the patient is awakened from the anesthetic, adjunct external stabilization of the neck is required with an appropriate cervical orthosis. For most patients, operative time is much less than 6 hours. The patient can be extubated directly after surgery and mobilized the day after surgery with an external orthosis, which remains in place for 6 weeks.

Complications

The complications associated with posterior fusion of the cervical spine are many. Care is required during passage of the wires or application

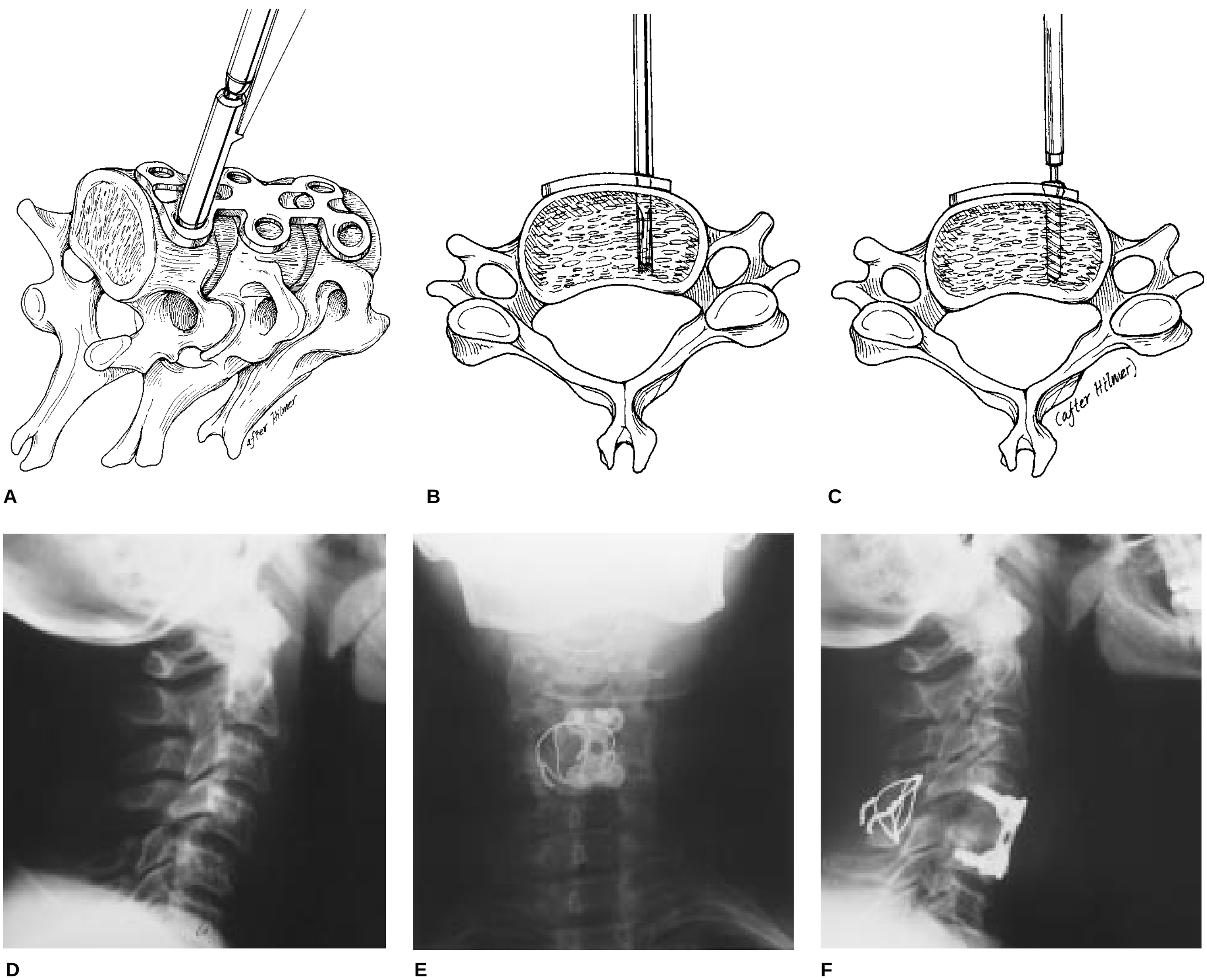


Fig. 9 AO-Morscher titanium cervical plating. **A,** Plate of appropriate size is centered over the vertebral body. **B,** Drilling and tapping is done down to 16 mm. **C,** Screw is inserted, followed by expansion screw. **D-F,** Images of fracture-dislocation at C4-C5 in a quadriplegic patient. **D,** Lateral view was obtained before surgical treatment. Anteroposterior **(E)** and lateral **(F)** views obtained after anterior decompression, grafting, and AO-Morscher plating and posterior wiring at C4-C5 show anatomic reduction. (Posterior triple wiring was performed because the construct was unstable even after anterior plating.)

of the screws to prevent injury to the spinal cord. In the upper cervical spine, dissection on the ring of the atlas must be done gently, as direct pressure may result in fracture or slippage of an instrument. At C1, one should limit the dissection to about 1.5 cm from the midline, as the vertebral artery is at risk.

Complications associated with posterior interspinous wiring in the cervical spine are relatively infrequent. One must avoid unnecessary exposure of the spine beyond the fusion area to prevent creeping fusions to adjacent vertebrae. Inadvertent penetration into the ligamentum flavum and the spinal canal can occur if one is not careful during subperiosteal dissection. Dural penetration can also occur during drilling or passage of wires if the holes are placed too close to the dura.

The most common complication associated with wiring procedures in the cervical spine is loss of fixation and subsequent recurrence of deformity. This complication is often related to the surgeon's technique and the type of postoperative external support. If a relatively rigid construct is created, the patient can be managed simply with a cervicothoracic orthosis. However, if the surgical construct is not quite stable, or if the patient's compliance is questionable, a halo-vest orthosis should be used postoperatively.

Complications associated with rigid posterior fixation of the cervical spine may include screw impingement on the nerve root, vertebral artery injury, and hook impingement in the spinal canal. Laminar hooks should be avoided at the level of injury, where the spinal cord has already been compromised by edema or mechanical compression.

The complications inherent to the anterior cervical approach also apply to attempts at anterior cervical instrumentation. Meticulous technique during surgical exposure, without undue pressure on the vital structures of this region, will allow easy access to the spine. Placement of self-retaining retractors with blunt tip blades under the longus colli muscle, coupled with additional retraction with similar self-retaining blades in a superior and inferior fashion, will facilitate this portion of the operative procedure.

There are several potential complications directly referable to anterior instrumentation, the most feared of which is iatrogenic neurologic injury. This complication can result from use of excessively long screws, which penetrate the posterior cortex and directly injure the dura and underlying neurologic structures. Such an injury may also occur during the drilling process. Thus, it is important to use a drill guide that prevents inadvertent posterior penetration. An alternative to using a power drill is utilizing a hand-held drill bit. This may provide the surgeon with additional tactile and proprioceptive feedback, which can prevent such penetration.

An additional and relatively common complication of anterior cervical plating is misplacement of the screw into the supra-adjacent or infra-adjacent disk space. This complication should be recognized intraoperatively. Radiographs should be obtained after screw placement for confirmation. With penetration into a disk space, one can be relatively sure that loosening of the screw may eventually occur, due to movement across that particular motion segment. Such a screw should be removed and redirected when possible. Screw misplacement often occurs as a result of improper plate sizing. It is critical that the chosen plate extend only from the midportion of the vertebral bodies above and below the decompressed segment. If the operating surgeon is uncertain of the superior and inferior borders of these vertebral bodies, the plate may be appropriately placed on the anterior surface of the cervical spine, and a radiograph can be taken to verify the position and length of the plate before screw insertion. This may prevent improper plate sizing and penetration of the screw into the disk space.

Another serious complication associated with anterior instrumentation of the cervical spine is hardware loosening and subsequent injury to surrounding vital structures and organs. Esophageal erosion secondary to screw or plate loosening can be disastrous.

Hardware loosening may be the result of osteoporosis with insufficient bone purchase, technical difficulties when multiple attempts at insertion have led to inadequate purchase, or improper postoperative immobilization of the patient. Anterior cervical plate fixation should be avoided in the osteoporotic patient.

Summary

Cervical spinal fixation is continually evolving, and better and more stable constructs are becoming available. With experience and proper patient selection, use of such instrumentation may help patients avoid postoperative halo-vest immobilization, enhance early rehabilitation, and preempt the need for an additional surgical approach. In stabilizing the cervical spine, proper fusion remains the most important procedure. Spinal fixation devices may be used to augment the stability of the construct and enhance the fusion rate.

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