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Minimally Invasive Posterior Cervical Arthrodesis and Fixation

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Evolution of the minimally invasive technique

Various techniques have been developed over the years for the posterior internal fixation of the subaxial cervical spine, including lateral mass metallic plates, interspinous wiring with bone graft, interlaminar clamps, hook plates, Daab plates, and Harrington rod constructs [1,2]. In the previously more commonly used technique for multilevel fusions, namely, interspinous wiring, three wires were passed through holes made at the spinolaminar junction and around the rostral border of the rostral spinous process [3–5]. The strength of this construct has been verified in biomechanical studies, and excellent union has been reported in case reviews [6–9]. In cases in which the dorsal spinolaminar sites were unavailable, such as in severe posterior column injury, Luque rectangles with facet wiring were often used. This triple-wire technique had several advantages, such as the ability to bridge large dorsal column defects (eg, after tumor resections), the capacity to perform segmental fixation at every level, and provision of greater rotational and torsional stability [10,11]. In 1979, a novel technique for posterior cervical instrumentation was described in which plates were fixed to the lateral processes of the cervical spine using screws, a technique that proved to be significantly stronger on biomechanical tests [12–17]. Subsequent authors described a 95% to 100% fusion rate in cases of cervical trauma with this technique when autogenous bone grafting was performed [15,18,19]. Dissatisfaction with the quality of lateral mass screw fixation at lower cervical and upper thoracic spine subsequently led to the use of pedicle fixation for this region by several authors [1,2,20–26]. This transpedicular method was shown to have more fixation stability compared with other midcervical reconstruction systems [27].

More recently developed instrumentation systems use two rods and variable screw islets at each level; these include the Axon systems (Synthes, West Chester, Pennsylvania), Summit (Depuy Acromed, Rayham, Massachusetts), and S4 OCT (Aesculap Vertex; Medtronic Sofamor-Danek, Memphis, Tennessee). These systems vary by the angulation of their screws and in the degree of the constraint placed at the screw-rod interface. The polyaxial tulip or islet connectors of the screws are able to angle medially, laterally, and straight, with varying degrees of rotational freedom in each direction, thus making segmental fixation more easily achievable from a top-loading approach and allowing for the possibility of minimally invasive posterior cervical fixation (MI-PCF).

With the advent of minimally invasive surgical techniques over the past decade, especially in the field of spine surgery, there have been significant improvements in the approach-related morbidities encountered with traditional techniques. Open surgery of the posterior spine requires subperiosteal muscle dissection, which devitalizes the affected tissue and detaches crucial muscular and ligamentous insertions that, in turn, disrupt the posterior musculoligamentous dynamic tension band. Standard exposures can also cause substantial blood loss, muscular atrophy, and large cosmetic defects. This extensive dissection and stripping of the posterior musculature and ligaments are associated with considerable

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postoperative disability, which may, in some cases, even exceed the intensity of the patient's preoperative symptoms (Fig. 1).

The problems of the open approach are, for the most part, circumvented by the use of minimally invasive posterior approach technologies. Although several systems are now commercially available, all these instruments essentially involve fluoroscopic-guided placement of a guidewire through fascial and muscular structures followed by sequential dilation, using serial tubular dilators, up to a final diameter of 14 to 24 mm. Visualization can then be accomplished through an operating microscope or via endoscopy through the established muscle-sparing working portal.

As an example of the superiority of the minimally invasive approach compared with the open technique, one can examine the evolution of the decompressive posterior cervical laminoforaminotomy for lateral recess and neural foraminal decompression. This procedure has been well documented as an effective treatment modality for patients who have isolated radiculopathy from a lateral disc or an osteophyte, achieving relief of symptoms in 93% to 97% of patients [28–32]. Enthusiasm for this operation, however, was tempered by the considerable cervical muscular pain and spasm that often followed, resulting in slower recovery, especially in cases in which the use of a wider incision was necessary for adequate visualization. Microendoscopic foraminotomy with a minimally invasive approach minimizes the amount of tissue trauma and muscle injury, thereby overcoming the problems of postoperative pain and muscle spasm with the same clinical results as those of the classic open procedure [33,34].

Through the same corridor of tubular access, the lateral mass of the posterior cervical spine can be readily visualized. Two adjacent lateral masses

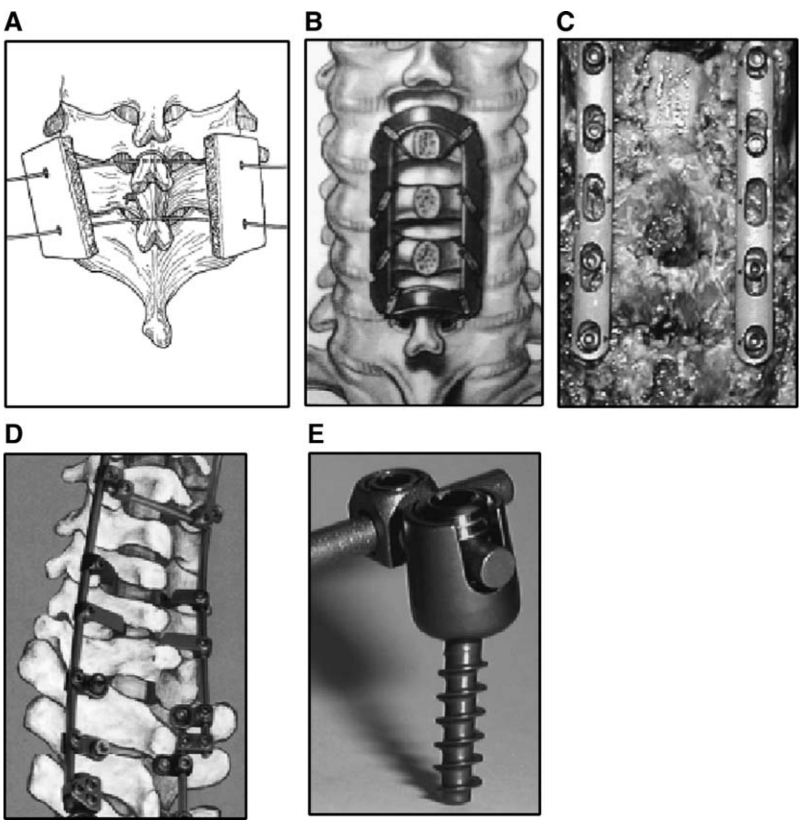

Fig. 1. Various posterior cervical fixation methods have been used over the years, such as the interspinous triple-wire technique (*A*) and sublaminar wiring, which could be combined with a Luque-type construct (*B*). (*C*) These semirigid constructs were eventually replaced by posterior lateral mass screw-plate fixation. (*D, E*) Original unconstrained lateral mass screw-plate systems have since been supplemented by the more rigid screw-rod and polyaxial screw-rod constructs.

can typically be accessed through a 20- or 22-mm portal; with the advent of some of the newer types of expandable access portals, such as FlexPosure (Endius, Plainville, Massachusetts) and Xpand (Medtronic Sofamor-Danek), up to three lateral masses can be instrumented through a single exposure. This allows for the placement of top-loading polyaxial screws through the tubular portals for the purposes of posterior cervical lateral mass fixation, which is a procedure successfully pioneered at our own institution and several centers nationally in 2001. Since that initial experience, this technique of MI-PCF has been applied in several other cases requiring lateral mass fixation with excellent clinical and radiographic results [35,36]. The widespread popularity of simple top-loading polyaxial screw systems has also greatly facilitated the MI-PCF procedure.

Minimally invasive posterior cervical fixation technique

Anatomic considerations

There are various methods for screw placement into the cervical lateral masses. The first report of the procedure described screw placement directed forward and outward 10° [12,15]. Subsequent modifications recommended placing the screw at a point slightly medial to the center of the facet and directing it 25° laterally and 40° to 60° cephalad [37]. Other authors advocated a technique in which the entrance point of the screw is 1 mm medial to the center of the lateral mass and aimed 15° to 20° cephalad and 30° laterally [38].

There are several advantages of lateral mass screw fixation over other techniques from C3 to C6 because of the typically generous and broad size of the lateral mass. First, this method can be easily applied in cases in which the posterior elements are compromised, such as lamina fracture, after laminectomy, and when no competent spinous process is present. Furthermore, many pathologic conditions of the cervical spine can be managed using this procedure, including neoplasms, posttraumatic or degenerative instability, and multilevel cervicothoracic stenosis. It is also biomechanically more resistant to rotation than constructs that use wires.

Although the lateral screw fixation method carries a risk of potential neurovascular injury, proper use of the technique is associated with an extremely low incidence of complication—only 4% to 6%. A disadvantage of lateral mass plating, however, is that it is primarily an in situ fixator and cannot be reliably used for reduction of significant kyphosis, which is why an anterior approach is recommended with posterior supplemental fixation as deemed necessary to enhance stability and maintain the operative correction for major anterior compression, kyphosis, or cases with poor bone quality in the lateral masses.

Although the C3-to-C6 lateral masses have similar anatomy as described previously, the C7 and most thoracic pedicles are slightly different in that they are oriented in a posterolateral to an anteromedial direction by approximately 10°, with the exception of T12, where there is a slight anterior and lateral angulation of the pedicle [39,40]. Regardless of the predictability of the anatomy, however, it is recommended that fluoroscopy be available to assist in the proper trajectory.

With regard to the surgical anatomy, the posterior neck musculature consists of three layers: superficial, intermediate, and deep. The superficial layer is composed of the splenius capitis, trapezius, and semispinalis capitis muscles. The intermediate layer is made up of the spinalis cervicis, levator scapulae, inferior oblique capitis, and longissimus capitis muscles. The deep layer is composed of the rotator cervicis longus, rotator cervicis brevis, and interspinalis cervicis muscles. The fibers for these muscles run in a longitudinal or oblique direction, which accounts for their primary role as the extensor, lateral flexors, or rotators of the neck. Because of this orientation of the muscle fibers, placement of sequential dilating tube retractors can be accomplished primarily by muscle splitting and stretching without the need for cutting, which minimizes tissue trauma and injury.

The minimally invasive technique for screw placement does not significantly differ from the open methods once the lateral mass is exposed. The exiting nerve root is more likely to be encountered by a screw trajectory that is aimed too low, and the vertebral arteries are more likely to be damaged by screw trajectories that are excessively medial. Thus, to avoid the neurovascular structures, the technique focuses on placing the screw into the upper lateral quadrant of each lateral mass. Screw length should allow for full penetration of the outer cortex and cancellous bone and, in case of trauma, bicortical screw penetration. The lengths typically vary between 12 and 16 mm but are affected by factors like the patient's specific anatomy, the presence of dorsal osteophytes, and the exact screw trajectory. Although violations of soft tissues by an overly lengthy screw are seldom problematic if the trajectory is correct, preoperative measurements from CT scans can be helpful in determining the best screw length, especially if a bicortical screw purchase is desired.

Surgical procedure

Anesthesia and positioning

For the MI-PCF procedure, local anesthesia combined with intravenous sedation is inadequate because of the substantial risk of neurovascular injury in case of any accidental movement by the patient. Therefore, general endotracheal anesthesia is preferred for the operation, along with the head being rigidly affixed to the operating table using a three-point headholder. Depending on the exact nature of the pathologic findings, consideration should be given to fiberoptic intubation if the neck manipulation necessary for a routine endotracheal intubation may considerably increase the risk of spinal cord injury. For cases with a high risk of venous air aspiration, a central venous catheter should also be placed into the right atrium and precordial Doppler monitoring should be used by the anesthesiologist to detect such air emboli within the atrium. This also allows for rapid infusion of fluid and blood products in case of heavy blood loss.

Patients may be positioned in a prone or sitting arrangement; however, an intermediate semisitting position may be helpful because of the reduced epidural venous engorgement and consequent decreased intraoperative blood loss with a minimal risk of air embolic events. Before finalizing the head positioning, utmost care should be directed to ensuring that the cervical spine and neck musculature are not twisted or held in a grossly unusual position. Furthermore, the neck, chin, and chest must be allowed to remain loose and free of compression, and all routine pressure points should be adequately protected.

Intraoperative somatosensory evoked potential (SSEP) monitoring of the operated dermatome and distal distributions is highly recommended to monitor spinal cord integrity during operations in which decompression is to be combined with fixation. Electromyographic recordings can also be used to assess motor integrity of the involved nerve root and can be used to stimulate the drills and screws to increase safety and accuracy. This requires that the anesthesiologist refrain from the use of neuromuscular paralytics after induction to allow for improved feedback from the nerve root during the operation.

For most cases, a single intraoperative dose of cephazolin or vancomycin is used for prophylaxis against infection. The role of methylprednisolone or other steroids for neural protection during the MI-PCF procedure has not been adequately studied; therefore, the use of these medications is not recommended.

Intraoperative real-time imaging is a necessity for MI-PCF; therefore, a fluoroscopic C-arm should be brought into the surgical field. Although lateral imaging is most commonly used for this procedure, the C-arm should be positioned in a manner that allows for easy rotation into various positions, because visualization in other planes may become necessary. For example, anteroposterior fluoroscopic images can be helpful during the initial localization. Whereas lateral mass fixation can be accurately performed using anatomic landmarks, cervical pedicles should be cannulated with the use of supplemental fluoroscopic confirmation whenever feasible.

Tubular dilation and exposure

When planning the skin incision for the MI-PCF procedure, one should take into consideration the ultimate trajectory of the working portal, which should match that of the lateral mass screws: 20° to 30° laterally and 20° to 30° rostrally. As such, lateral fluoroscopy is essential for safe and appropriate guidance and to ensure proper ergonomic placement of the working portal directly on the target.

After the patient is properly positioned, a Kirschner wire (K-wire) is placed lateral to the neck to parallel the facet of interest exactly and to determine the center of the skin incision. Typically, this skin entry point is located two to three segments below the target level in the sagittal plane and at the midline in the axial plane, which closely approximates the typical trajectory used during open lateral mass fixation.

Once this entry point is determined, under fluoroscopic guidance, the K-wire is inserted through the posterior cervical musculature and fascia to the target facet, taking care to remain parallel to the facet joint in the sagittal plane, with the pin trajectory directed in a superior and lateral direction, approximating the desired screw orientation (Fig. 2). Particular caution should be taken at this point to ensure that the guidewire is docked on bone to avoid inadvertent damage to the spinal cord by penetrating the wide interlaminar space. To decrease the chances of this type of injury, it is recommended to aim more laterally than

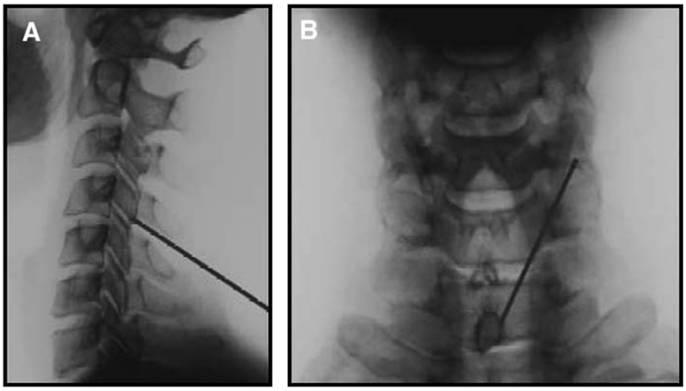

Fig. 2. (*A*) Using lateral fluoroscopic guidance, the K-wire is inserted in a trajectory parallel to the target facet joint. (*B*) Anteroposterior fluoroscopy confirms wire placement, which begins at the midline and aims superior and lateral.

medially during this docking maneuver. The K-wire should ideally rest in the medial aspect of the facet complex; this can be confirmed through anteroposterior radiographic imaging.

Once the guidewire is docked on the facet in question, the skin incision should be extended above and below the K-wire entry point for approximately 1 cm in each direction and deepened sharply to just below the level of the fascia, taking care not to cut muscle fibers during this procedure to avoid unnecessary blood loss. This sharp opening of the fascia allows for easier passage of the sequential dilating cannulas. At this point, if a barrier, such as Ioban, has been placed on the skin, it should be removed from the edges of the incision to prevent the plastic sequestra that can occur during placement of the tubular dilators.

The dilators are then sequentially inserted through the soft tissues and docked on the facet of interest, over which a final tubular working channel is inserted and docked at the junction of the lamina and the lateral mass (Fig. 3). Real-time lateral fluoroscopic images should be obtained as often as needed to ensure a proper working trajectory throughout this process of serial cannula insertion. A variety of working channels are available, including fixed 20- or 22-mm portals, such as the METRx MD tubular access system (Medtronic Sofamor-Danek) and Access system (Spinal Concepts, Austin, Texas). As an alternative, expandable cannulas, such as the Xpand system (Medtronic Sofamor-Danek) and the FlexPosure cannulas (Endius) can provide a greater working space and more flexible approach angles for hardware placement (Fig. 4). In such instances, the portal can be distally expanded to encompass the target fixation levels. Once the position of the working channel is confirmed using fluoroscopy, it is attached to a flexible retractor affixed to the side rail of the operating table and locked in position.

Visualization can be achieved using loupe magnification, an operating microscope, or an endoscope. Simple loupe magnification combined with an intratubular light source is especially recommended for cases of simple facet dislocation because it allows for the multiple viewing angles that are needed for drilling of the facet, reduction of the dislocation, and placement of the lateral mass screws. For cases in which extensive laminotomy, partial facetectomy, and foraminotomy are indicated, a high-quality operating microscope should be used. If employed, the endoscope should be white-balanced and an antifog agent should be applied to the lens, after which the endoscope is attached to the tubular retractor via a circular plastic friction couple or mounting stage.

Instrumentation. For the placement of lateral mass plates, care must be taken to expose the facet joints and lateral borders of the lateral masses fully, which can be readily accomplished with a shielded monopolar cautery combined with a pituitary rongeur. Although the capsular ligaments and soft tissue around the facets are removed, the facet joints above and below the involved ligaments should remain intact to prevent late instability or fusion at those levels. The monopolar cautery can be used to stop bleeding, such as that from the venous plexus lateral to the lateral masses; however, caution should be

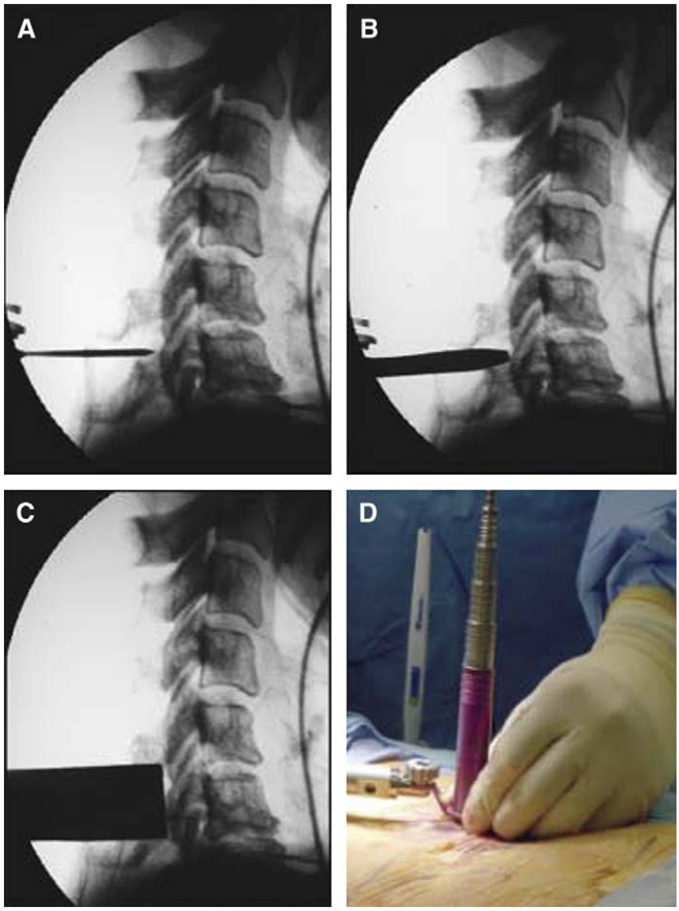

Fig. 3. After placement of the K-wire (*A*), serial tubular dilation is completed to achieve a final tube diameter of 20 to 22 mm (*B–D*).

exercised to avoid inadvertent injury to the vertebral artery by avoiding overly aggressive cautery in this region. Alternatively, gentle tamponade with Gelfoam or Surgifoam can often effectively stop bleeding from this venous plexus.

For cases in which facet realignment is not necessary, the lateral mass screws can simply be placed in an in situ fashion. If open reduction is needed, a high-speed drill can be used to remove a portion of the superior articular process of the

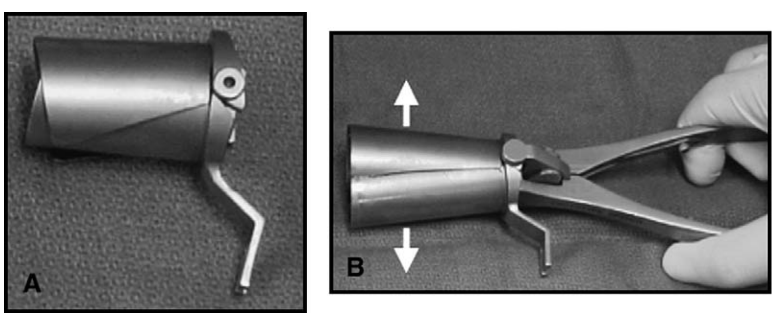

Fig. 4. (*A, B*) Expandable access devices, such as the Xpand tube (Medtronics Sofamor-Danek, Memphis, Tennessee) allow for minimally invasive tubular access with significantly increased working space at depth.

inferior vertebrae, and a Penfield-type instrument can then be inserted within the facet and rotated to elevate and posteriorly displace the subluxed lateral mass into proper anatomic alignment. An alternative method for open reduction involves disengaging the headholder after drilling of the facet edges, followed by gentle in-line traction, appropriate anterior translation, and counterrotation opposite to the mechanism of injury for proper facet realignment. The headholder is then relocked, and the facet complex is fused in situ. It is highly recommended that SSEP monitoring combined with nerve root surveillance at the pathologic level be used during such maneuvers.

For the screw placement, the entry point is approximately 1 mm medial to the center of the lateral mass. The outer cortex should be pierced with an awl or a high-speed drill to prevent the drill from sliding over the lateral mass instead of entering the bone during screw placement. As described earlier, for C3 to C6 (and sometimes C7), it is recommended that the drill holes be made with a cephalad angle of 15° to 20° and a lateral trajectory of 30°. This rostral angle targets the transverse process and decreases the chance of damage to uninvolved joints. By starting the drill hole 1 mm medial to the center of the lateral mass and aiming laterally, there is less risk of damage to the vertebral artery, which usually lies anterior to the junction of the lamina and the lateral mass. After drilling, the dorsal cortex can be tapped using the 3.5-mm cancellous tap. Because most new polyaxial screws are self-tapping, this step is not essential.

Should neural decompression be necessary, it is recommended that the screw sites be marked, drilled, and tapped before removing the laminae. This method protects the dura and spinal cord during the drilling process [35].

The joint cartilage from the facets should be removed before instrumentation, and the joint should be decorticated using a high-speed drill with a small bit. Although there is a large body of literature demonstrating successful arthrodesis without the use of bone graft, it is generally recommended to use bone grafts, such as cancellous autologous bone from the iliac crest, within the facets as well as over the decorticated laminofacet junctions. Given the postoperative pain syndrome associated with iliac bone harvesting, the dust obtained during facet drilling, laminotomy, and foraminal decompression can be used as an alternative source of autologous bone. This graft can then be combined in a 1:1 ratio with an appropriate bone extender, such as demineralized bone matrix or calcium triphosphate substitutes.

After denuding the facet and placement of bone graft, a lateral mass screw of appropriate length is inserted under direct visualization and fluoroscopic guidance. Depending on the size of the lateral mass, 14- or 16-mm long and 3.5-mm diameter screws are typically used. The exact size can be measured on the CT scan or estimated from lateral intraoperative fluoroscopy. The tubular retractor arm usually must be relaxed at this point to allow easy acquisition of the second screw trajectory, after which the second screw is placed in the manner detailed previously.

Because the C7 lateral mass is much thinner than that of the more rostral levels, placement of a lateral mass screw may prove to be excessively difficult; therefore, a pedicle screw may need to be used at this level instead. Furthermore, cervical pedicle screws may attain greater pullout strength than lateral mass screws because of the greater length and circumferential cortical penetration. Cervical pedicle screws may also be used at levels in which the lateral mass is fractured or unusable. There is usually no vertebral artery in the transverse foramen at this level, which permits safe pedicle screw placement at this level and at T1. For C7 pedicle screw placement, the drill is generally angled medially 25° to 30° and perpendicular to the rostral-caudal plane. At the T1 level, the angle is usually 10° to 15° medially and 5° caudally. A careful examination of the preoperative CT scan is important to determine the pedicle size and to gauge the appropriate angle. Usually, a 4.0-mm cortical screw 20 to 22 mm in length is sufficient in size. A small laminotomy can be made to palpate the pedicle directly for safe placement of the screw.

After placement of the screws, an appropriately sized rod is inserted into the top of the polyaxial screws and locked into place (Fig. 5). The rod diameter generally varies from 3.2 to 3.5 mm, depending on the specific system used. Rod placement is more technically challenging when fusing three adjacent segments, but careful dorsal elevation of the tubular retractor system away from the facet joints usually creates adequate space for rod manipulation and placement. For this reason, the expandable retractors in conjunction with modern top-loading polyaxial tulip head fixation systems, such as the CerviFix or StarLock (Synthes), Summit (Depuy Acromed), or Vertex (Medtronic Sofamor-Danek), are particularly useful at providing a larger working space. For such third-generation posterior cervical

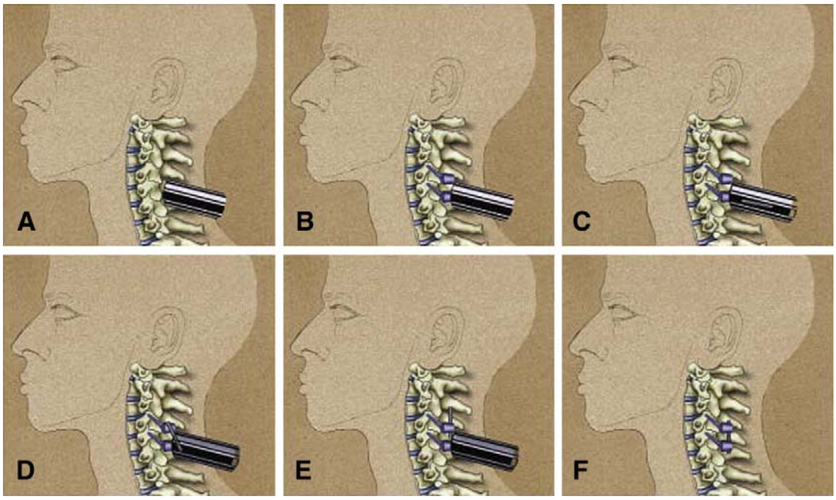

Fig. 5. After placement of the lateral mass screw (*A, B*), the rod is advanced through the tubular dilator (*C–F*).

instrumentation systems, there are subtle variations in the exact types of connectors, offsets, and locking devices used, all of which are explained in the individual instrumentation guides from each manufacturer. Once the rods are locked into place, the construct is completed. Appropriate lateral and anteroposterior fluoroscopy should be used at this point to confirm proper bony alignment and construct placement, after which the tubular retractor is removed (Fig. 6). For cases in which bilateral fixation is needed, these steps can be repeated through the same midline incision, using a contralateral trajectory.

Another method of posterior cervical fixation is through a transfacet approach using a facet compression device. For this procedure, the optimum entry point for the screw is on the center of the lateral mass with a trajectory that is perpendicular to the facet joint (Fig. 7). As such, the incision should be placed more rostrally to allow for the insertion of the K-wire in such a manner that it docks at 90° to the facet and parallel to the spinous process. Once the entry point and trajectory have been confirmed, the K-wire is driven into the superior articular process to a depth that is determined by the length of the specific compression device to be used. Fluoroscopy should be used to ensure appropriate depth and trajectory.

At this point, the bone is drilled through the superior lateral mass, across the facet, and into the inferior lateral mass to a depth of approximately half to two thirds of the inferior lateral mass width as guided by lateral fluoroscopy. This procedure is facilitated by systems that supply cannulated drills with depth-limiting contacts that are designed to be passed over the K-wire, such as the 3.8-mm CS Facet Compression Device (Triage Medical, Irvine, California). For this system, after the proper depth has been achieved, the drill hole is tapped and the compression device is passed over the K-wire,

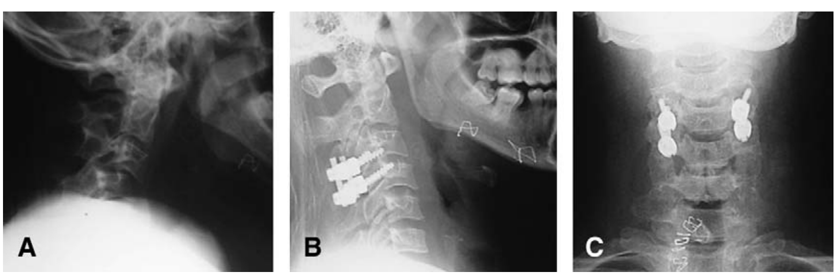

Fig. 6. (*A*) Preoperative lateral radiograph demonstrates C3-to-C4 subluxation. The patient was taken to the operating room after partial reduction in traction, where drilling of the C4 superior facets allowed intraoperative reduction with placement of C3-to-C4 lateral mass screws. Postoperative lateral (*B*) and anteroposterior (*C*) radiographic views confirm proper cervical realignment and screw placement.

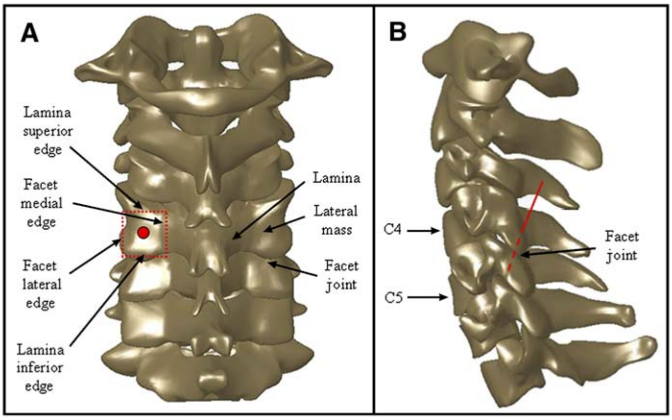

Fig. 7. The optimum entry point for the screw in the transfacet instrumention approach is marked as the center of the lateral mass of C4 (*A*) with a trajectory that is perpendicular to the C4-to-C5 facet (*B*).

engaged, and locked in place (Fig. 8). The K-wire is then removed, and the procedure is repeated for the contralateral side in a similar manner.

Although this transarticular fixation system allows for fixation at all cervical levels, including C1 and C2, a modified version of the this procedure can also be used for arthrodesis in cases of trauma, such as operative cases of Hangman's type fractures. The initial approach for this type of surgery is similar to the transarticular procedure described previously in that the entry point for the drill is at the center of the C2 lateral mass with a trajectory that is parallel to the spinous process in the lateral plain. Instead of the device being aimed inferiorly, however, the trajectory in the cephalad-caudad direction is toward the superoanterior border of the C2 pedicle at a depth that allows for bicortical purchase (Fig. 9). Once this trajectory is confirmed by lateral fluoroscopy, the remainder of the operation is completed as described previously.

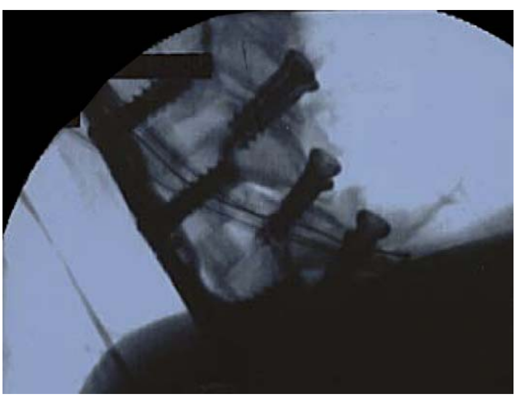

Fig. 8. Lateral cervical fluoroscopic image shows multilevel transfacet fusion in a patient with previous anterior cervical instrumentation.

Closure

Before closure, meticulous hemostasis should be obtained by a combination of bipolar cautery and gentle tamponade with thrombin-soaked Gelfoam or Surgifoam. The entire wound is then copiously irrigated with lactated Ringer's solution impregnated with bacitracin antibiotics. Although optional, a small pledget of Gelfoam soaked with methylprednisolone can be placed over the decompression defects, if present, to decrease local inflammation. The use of epidural morphine paste or similar cocktails is reasonable if there is no evidence of dural erosion or tear. Such agents may help to reduce postoperative pain and allow for more rapid recovery and ambulation.

After hemostasis, the tubular retractor and endoscope are cautiously removed, and the soft tissue corridor is washed with antibiotic irrigation before routine closure of the fascia with 1-0 or 2-0 Vicryl or similar absorbable sutures. Because the defect is typically small, only a limited amount of closure needs to be performed, and a drain is not needed. Bupivacaine (0.25%) may be injected into the skin edges and superficial musculature before closure to minimize immediate postoperative pain. Inverted 2-0 Vicryl stitches are usually used to close the subcutaneous layer with a 4-0 Monocryl subcuticular closure to reapproximate the skin edges meticulously. Steri-Strips or Dermabond can then be used to cover the skin. The latter is an

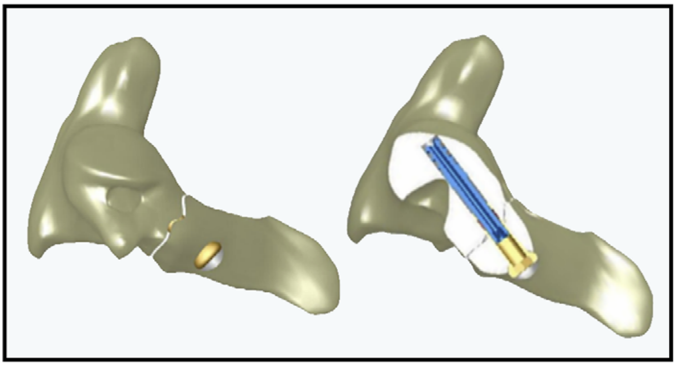

Fig. 9. Lateral and cutaway lateral images show the entry point and trajectory of screw placement for a Hangman's type fracture.

attractive option because it keeps the skin edges closely approximated for a 7- to 10-day period and provides a waterproof barrier, allowing the patient to shower almost immediately after surgery, if desired.

When a cerebrospinal fluid (CSF) leak occurs, direct repair is often difficult, because the durotomy is usually small and access is limited. Thus, the use of a lumbar drain is advocated in these cases for 2 to 3 days after surgery, combined with elevation of the head of the bed, to help closure of the small dural tear. Such adjuncts as fibrin coagulation products, fat, or muscle grafts can also be used. Spinal headaches and nausea associated with the lumbar drainage can be treated symptomatically with nonsteroidal anti-inflammatory drugs and bedrest. For large dural tears, direct repair can be attempted if specialized instruments are available for use through the endoscopic tube. Fine-tipped needle holders and long forceps are particularly useful in this regard. In rare instances, conversion to an open procedure may be necessary to close large dural violations.

Clinical experience

The initial experience with minimally invasive cervical fixation at the University of California, Los Angeles (UCLA) consists of 10 patients followed to radiographic fusion: 6 patients with a single-level fusion and 4 patients with two-level fusions. Instrumentation was performed at the C3-to-C7 segments with bilateral screw placement, with the exception of three cases in which lateral mass screws were placed unilaterally because of bony fractures on the contralateral side. Seven cases were posterior supplementations of anterior fusions, and three were stand-alone posterior constructs. Seven of the 10 patients underwent surgery because of traumatic pathologic findings with cervical burst fractures and fracture dislocations treated with combined anterior and posterior fusions. In three cases with bilaterally jumped facets, treatment consisted of drilling and removal of the superior facet, followed by intraoperative reduction and hardware placement with fusion. Three cases were posterior supplements to an anterior vertebrectomy for neoplasia.

All procedures were accomplished successfully with the use of 18- to 22-mm tubular dilator retractors. There were no complications or new neurologic deficits, and proper hardware placement was confirmed with a postoperative CT scan. In one case, the C6 screw was positioned fairly laterally with penetration of the lateral cortex of the lateral mass; however, no additional procedure or follow-up studies were deemed necessary, because this was still thought to provide a stable construct. Fusion was confirmed in all cases with dynamic radiographs and CT scans.

Current tubular dilator dimensions limit the feasibility of this minimally invasive approach to one- or two-level fusions, because longer segment constructs pose a problem with rod placement. The development of elliptic expandable tubular dilators may allow longer constructs to be placed safely, however. Furthermore, strategies similar to the arc rod systems and polymerizing connecting rods, which currently allow true percutaneous transpedicular instrumentation in the lumbar spine, may also prove to be beneficial in the cervical spine, where they may ultimately allow placement of longer segment cervical constructs in a minimally invasive fashion.

Radiographic guidance is essential for safe screw placement, and fluoroscopic images may be inadequate for the lower cervical spine in patients with a short neck, large body habitus, or muscular shoulders. Image-guided systems surmount this problem and allow for virtual representation of the spine without the need for real-time radiographs. These systems are limited in accuracy with regard to the differences in the intersegmental relations between vertebrae in preoperative image acquisition and final operative positioning, however. These inaccuracies are especially exaggerated in cases with abnormal intersegmental motion or in patients who require reduction of a fracture.

The emergence of three-dimensional fluoroscopic imaging allows for intraoperative acquisition of axial CT renderings of the spinal column. These images are less hampered by superimposed soft tissues, which allows access to the lower cervical spine for the purpose of minimally invasive screw placement. Furthermore, because the images are acquired during surgery, screw trajectories can be more reliably confirmed by guidewire placement before final instrumentation. Amalgams of three-dimensional intraoperative imaging modalities with frameless navigation systems should ultimately make percutaneous placement of cervical instrumentation safe and accessible.

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