Operative management of the patient with cervical spinal instability depends on the specific anatomy and location of the injury. For example, the unique features of the occipito-cervical junction and the atlanto-axial complex require stabilizing procedures that are quite different from those used in the subaxial cervical spine. Accordingly, this article will focus on the different posterior instrumentation techniques as applied to these three anatomically distinct regions of the cervical spine.

**Posterior Instrumentation of the Atlanto-Axial Complex**

Posterior stabilization techniques of the atlanto-axial complex historically have made use of various wiring techniques. In 1939, Gallie described a relatively simple technique for controlling situations in which anterior instability of the atlanto-axial complex exists. The only requirement for this technique is that integrity of the C2 arch is maintained.

In this technique, a standard posterior approach is undertaken from the occiput through the fourth cervical vertebra. Using electrocautery, the posterior arch of the atlas and the lamina of C2 are subperiosteally exposed. The superior surface of the arch of C1 should be exposed no further laterally than 1.5 cm from the midline to avoid injury to the vertebral artery. The ligamentum flavum between the second and third cervical vertebrae may be left intact. A 20-gauge wire is then doubled, and the loop is passed in a cephalad direction beneath the arch of C1. The free ends of the wire are then passed through the loop. The dorsal surfaces of the C1 and C2 posterior elements are then decorticated. A corticocancellous iliac crest graft is then fashioned to fit wedged between the C1 posterior arch and the lamina and spinous process of C2. While the graft is placed beneath the wire against the C1 and C2 laminae, one end of the wire is passed through a drill hole in the spinous process of C2 and twisted on itself to secure the graft in position (Fig 1).

In 1978, Brooks and Jenkins described a more rigid wedge compression method for C1-2 fixation, which Griswold later modified. A similar posterior cervical approach as used with the Gallie fusion is undertaken during which the posterior elements of the atlas and axis are exposed. Using a Mayo needle, a no. 2 Mersilene suture is passed on each side of the midline in a cephalad to caudad direction, first under the arch of the atlas, and then under the lamina of the axis. These sutures serve as guides to pass two doubled 20-gauge wires beneath the arches of C1 and C2. Alternatively, two doubled Titanium soft cables may be used. Care should be taken to expose the underlying dura to prevent injury during the wire passage. Two rectangular corticocancellous bone grafts are then harvested from the iliac crest. The grafts are then contoured to fit within the interval between the arch of the atlas and each lamina of the axis. The grafts may be contoured to extend over the dorsal surfaces of the atlas and axis as well. The posterior elements of C1 and C2 are then decorticated with the use of a high speed burr. Two small notches are then fashioned into the cephalad and caudad aspects of each of the rectangular bone grafts. While holding the grafts wedged into position, thereby maintaining the width of the interlaminar space, the doubled wires are then tightened and twisted over the grafts, securing the bone wedges into position (Fig 2). Care should be taken to ensure that the fracture is completely reduced at the time of wiring and that it remains reduced as the cables are secured. Mechanically, the Brooks technique has been shown to provide stiffer rotational fixation when compared with the Gallie wiring technique. Solid fusion can be expected in between 90% and 96%, depending on the series reviewed.

More recently, Jeanneret and Magerl described operative stabilization of the atlanto-axial complex using posterior transarticular screws through the C1-2 facet joints. This technique has been suggested for the treatment of unstable type II and some unstable type III fractures of the odontoid. This technique may well be the best option for situations in which the posterior laminar arch of C1 or C2 is...
Figure 1. C1-2 posterior wiring using technique of Gallie. (Reprinted with permission.)
compromised by fracture and therefore posterior wiring is not an option.

Preoperatively, special attention must be given to the CT evaluation of the atlas and axis. Sagittal reconstruction of these images are helpful to assess the route of the vertebral artery. The CT scan allows the surgeon to preoperatively determine if screws measuring 3.5 or 4.5 mm can be placed without significant risk of vertebral artery injury, realizing that some patients cannot be treated with this technique because of anatomic variance.

The technique usually requires that the patient be positioned prone with the head stabilized in a Mayfield clamp with the neck in a slightly flexed position. Lateral fluoroscopy is used to determine the appropriate positioning of the atlanto-axial joint and will assist in determining the drilling direction so that the surgeon may establish the corresponding location of the skin incision. A posterior exposure of the occiput to C3 is then performed. The surgeon must then carefully expose the transition from the lamina to the isthmus of C2. This may be accomplished with a blunt elevator, staying strictly subperiosteally. By staying subperiosteal, the surgeon will avoid entering the venous plexus overlying the C1-2 facet joint. The medial border of the C2 pedicle isthmus will serve as an important landmark during drilling.

The entry point for drilling is usually just above the inferior facet of C2, approximately 2 to 3 mm lateral to the medial border of the C2-3 facet joint. Drilling is in the sagittal plane. The surgeon may place a micro Penfield or nerve hook at the inner concavity of the C2 isthmus as a guide during drilling. This same probe can also help to outline the lateral border of the C2 pedicle, being aware that any lateral deviation may endanger the vertebral artery. AP and lateral fluoroscopy is used to help identify the target point at the middle to upper portion of the ventral arch of C1. If the position of the neck necessary to maintain appropriate alignment of the atlanto-axial complex does not allow the proper drilling angle, the drill may be inserted percutaneous.
Posterior Instrumentation of the Subaxial Cervical Spine

Until recently, posterior stabilization of the subaxial cervical spine made use of various wiring techniques. Rogers’ technique of spinous process wiring was first described in 1942 and was later popularized in the late 1950s. Multiple techniques have since been proposed for achieving internal fixation of the cervical spine, including wiring facets to either spinous processes or to threaded and smooth rods, and interspinous triple wiring.

In situations in which integrity of the spinous process or lamina is not maintained, stabilization techniques must rely on fixation to intact facet articular processes. Typically, sequential facets are wired to either adjacent facets or to the more caudad spinous process. In this technique, the entire lateral mass of those levels to be fused are exposed. The facet articular cartilage is removed with the use of a curette. A 3-mm burr is then used to create a hole in the inferior facet in an anterolateral and inferior direction. A small elevator may be placed within the facet joint to protect the superior articular process of the next caudal articular process. An 18- or 20-gauge wire is then passed through the inferior facet, and cancellous bone graft is placed into the decorticated.

Figure 3. C1-2 stabilization using technique of Jeanneret and Magerl. (Reprinted with permission.)

osely through a drill sheath placed through separate stab incisions extending through the thoracic paraspinal musculature.

The entry site just above the inferior facet of C2 is then further defined by perforating the cortex with an awl. A 2-mm drill is then gently advanced under fluoroscopic guidance. Resistance as the drill bit passes through the facet joint may be noted. The drill bit may then be left in position as temporary fixation while the contralateral side is drilled. The appropriate screw length may be measured off of the inserted drill bit or with the use of a depth gauge. The drill hole is then tapped with a 3.5-mm tap and two 3.5-mm cortical bone screws are inserted (Fig 3). Screw position must be confirmed in both the AP and lateral fluoroscopic images. Stability of the C1-2 joint may be assessed by grasping the C2 spinous process with a clamp and observing coordinated movement with the arch of C1. When possible, C1-2 transarticular screw fusions should be augmented with a central wiring and grafting technique using either the Brooks or Gallie technique, previously described.

C1-2 transarticular screw fixation has been associated with a high success rate for fusion. In Jeanneret and Magerl’s original description of the technique, 12 acute odontoid fractures were managed in this fashion and, at follow-up, all fusions were united in the reduced position. Grob et al reviewed 161 patients who had undergone posterior cervical fusion with transarticular screw fixation of the atlanto-axial joint. These patients were followed up for a mean of 24.6 months. There were no vertebral artery or spinal cord injuries sustained with this technique. Complications directly related to the screws were noted in 5.9%. The rate of pseudoarthrosis was 0.6%. Compared with other fusion techniques, transarticular screw fixation has the advantage of providing increased stability, thereby allowing immediate ambulation with minimal head support.
facet joint. The facet wire may then be used to stabilize corticocancellous bone graft to the lateral mass or, alternatively, may be used with additional facet wires to secure a Luque or Harrington rod to the lateral mass. If stability of a single motion segment is desired, the facet wire may be affixed to the next caudad spinous process to improve torsional stability.

In the presence of intact posterior elements, the triple-wire technique described by Bohlman provides fixation that resists tension while securing structural autogenous bone graft to the posterior elements. At the present time, this technique is the most well-established posterior wiring technique used in the subaxial cervical spine. The triple-wire technique requires that the patient be positioned securely in the prone position with the head stabilized in a Mayfield clamp. A lateral x-ray is then obtained to confirm the appropriate sagittal plane alignment of the segments to be fused. A standard posterior approach is then undertaken with care taken to avoid extension of the exposure beyond those segments intended for fusion. A 3-mm burr is then used to create a hole on each side of the base of the cephalad and caudal spinous processes to be fused. A towel clip may be inserted to enlarge the hole in preparation for passage of 18- or 20-gauge wires. The first wire is then placed through the interspinous ligament above the cephalad spinous process and looped back through the hole in the spinous process. In a similar fashion, the same wire is threaded through and around the caudad spinous process. This wire is then tightened securely into position compressing the spinous processes and facet joint in the desired lordotic position. A second wire is then placed through the hole of the cephalad spinous process, while a third wire is threaded through the hole in the caudal spinous process in preparation for securing the corticocancellous bone grafts to the posterior elements. The dorsal surfaces of the facet joints, laminae, and spinous processes are then decorticated with the use of a burr.

A tricortical bone graft of the appropriate length is then harvested from the posterior iliac crest and split between the inner and outer tables with the use of an oscillating saw. Two drill holes are then placed in each of the corticocancellous grafts to accept the remaining wires. The cephalad wire is then threaded through the superior hole in each of the corticocancellous grafts, while the caudal wire is past through the inferior holes of each graft. The grafts are then slid down the wires to about the spinous process and lamina. Additional cancellous bone may be packed around the corticocancellous grafts. The wires are then twisted, securely stabilizing the grafts to the posterior elements. This procedure may also be performed using three titanium soft cables securing the grafts into position with the use of a tensioning device and wire crimper.

Since the early 1990s, much interest in the literature has been directed at providing more immediate rigid stabilization through the use of plates and screws implanted into the articular masses of the cervical spine. The two most commonly used methods of lateral mass screw placement have been described by Roy-Camille et al and by Magerl et al. With the patient in the prone position and the head affixed to the operative table with a Mayfield clamp, a preoperative lateral x-ray is obtained to confirm satisfactory sagittal alignment and fracture reduction. A standard posterior approach is then undertaken with care taken to fully expose the entirety of the lateral masses to be fused. To place screws securely and safely in the lateral mass according to either the Roy-Camille or Magerl technique, the surgeon must completely understand the anatomic boundaries of the lateral mass. In the degenerated cervical spine, this may be more difficult than one would expect. The surgeon should attempt to identify the superior and inferior boundaries of the lateral mass, most readily identifiable by locating the cephalad and caudal facet joints. The medial border is defined by the depression that occurs at the junction between the lamina and lateral mass. The lateral border is the lateral-most edge of the lateral mass.

In the technique described by Roy-Camille, the center of the articular pillar is located, and the cortex is pierced with an awl. The pillar is then drilled with a 2-mm drill bit with an adjustable stop set at 16 mm. The drill bit is angled perpendicular to the vertebral and angled 10° laterally to avoid the vertebral artery. Penetration of both cortices is recommended. Screws are typically 16 to 18 mm in length and 3.5 mm in diameter. In the technique described by Magerl, the starting point is located 1 mm medial to the center of the most cephalad later mass to be fused. An awl is then used to create a cortical entry site. A 2-mm hand drill is then directed parallel to the facet joint, or approximately 30° to 40° in the cephalad direction, and 10° to 20° laterally (Fig 5). In this fashion, the vertebral artery which lies anterior to the medial border of the lateral mass, and the nerve root, which
exits obliquely across the anterior border of the lateral mass, will be avoided. The drill is then gently advanced in 2-mm increments until the anterior cortex is penetrated. A depth gauge is used to confirm the depth and location of the drill hole. With this technique as well, bicortical purchase is preferable unless the patient has very good bone quality.

Once the most cephalad screw hole is prepared, the lateral mass plate is then contoured to accommodate the patient's cervical lordosis. Hole interspaces
in the plate typically range from 11 to 15 mm. The appropriate interfacet distance is determined using intraoperative templates. Screws are then placed sequentially through the most cephalad and caudad holes of the plate and tightened down tandemly. The intervening screw holes are then drilled according to either technique and the remaining bicortical screws are placed. Before tightening down the plate, the facet joints are decorticated and filled with iliac crest bone graft. A lateral x-ray is then obtained to identify the location of the screws within the lateral masses.

Heller et al reported an anatomic comparison of the Roy-Camille and Magerl techniques of screw placement. Neither the spinal cord nor the vertebral artery were threatened by either method. The Roy-Camille technique had less risk of nerve root injury, whereas the Magerl technique had less risk of facet joint violation. Once the surgeon was beyond

Figure 5. Posterior lateral mass plate-screw construct using technique of Magerl. (Reprinted with permission.)
the learning curve, either technique was thought to be effective and safe. It is interesting to note that with the Magerl technique, the ability to aim the screws was identical in the axial plane but consistently less accurate in the sagittal plane because of the normal cervical lordosis in conjunction with the normal prominence of the cervico-thoracic junction.

As experience is gained with the application of lateral mass plates, the efficacy of the technique is becoming clearer. In a retrospective study, Fehlings et al analyzed long-term outcome in 44 consecutive patients treated with posterior cervical plates. Most commonly, the plates were applied in the setting of post-traumatic instability. The mean follow-up for this group of treated patients was 46 months. The study reported that the technique was highly effective as successful stabilization was achieved in 93% of the treated population. Plate failure and screw loosening were noted in 3.8% and was considered to be related to faulty screw placement, failure to include sufficient motion segments into the fusion, or noncompliance by the patient with the postoperative orthosis. It was thought that a halo vest was not required, and that supplemental iliac crest bone graft was not necessarily required if the procedure was performed in the setting of acute trauma.

As experience has been gained with the lateral mass plating technique, it has become apparent that purchase of lateral mass screws placed at C6 or below may be suboptimal as the lateral masses tend to thin out at these levels. This may account for the recent observation of screw loosening at the ends of long lateral mass plate fusions. This observation has led to the investigation of transpedicular screw placement in the cervical spine to improve purchase at the ends of long posterior cervical lateral mass plate constructs.

In 1991 Panjabi et al published the first three-dimensional anatomic study of the human cervical vertebra in which the capacity for cervical pedicles to accept transpedicular fixation was demonstrated. Biomechanical feasibility of transpedicular cervical fixation was addressed by Kotani et al in 1994. In his cadaver model, transpedicular screw fixation offered increased stability over conventional anterior and/or posterior constructs when addressing 2- and 3-column, multilevel cervical instability. In the same year, Abumi et al successfully applied transpedicular instrumentation in 13 patients with subaxial cervical trauma without complication. These studies have suggested that transpedicular stabilization in the cervical spine is not only anatomically possible, but is also biomechanically sound.

Using a cadaver model, the authors of this review recently performed a morphometric analysis of the subaxial cervical pedicles and assessed the accuracy of pedicle screw placement using three techniques. Based on the morphometric analysis, guidelines for pedicle screw placement relative to cervical topography were derived. Twelve human cadaveric specimens were then instrumented with pedicle screws from C3-C7 according to one of three techniques. In the first group, screws were placed using the topographic guidelines obtained from the morphometric study. In the second group, foraminotomies were performed at each level to allow visual and tactile information to assist with pedicle screw placement. In the third group, screws were placed using a computer-assisted image-guided surgical system that applied stereotactic principals to preoperative CT scan data, allowing transformation of “real-time” data from the operative site into the “virtual world” data of the CT image. Cortical integrity was then assessed by obtaining postoperative CT scans of each specimen (Fig 6A, B).

Although a statistical analysis of morphometric

![Figure 6. Transpedicular screws placed in the subaxial cervical spine using (A) foraminotomy technique, and (B) computer-assisted image-guided surgical system.](image-url)
data obtained from the cervical spine could provide guidelines for transpedicular screw placement based on topographic landmarks, sufficient variation existed to preclude safe instrumentation without additional anatomical data. Although foraminotomies did improve visual and tactile access to the cervical pedicle, the technique was thought to be safe only at the C7 level. The use of the stereotactic guidance system did enhance accuracy of screw placement, most notably at C6 and C7 (Fig 7). Fixation of a bone screw in the pedicle of C2 has been described by Roy-Camille, and follows a similar technique to that of transarticular screw placement previously described. Based on these early investigations, it would appear that pedicle screw placement in the cervical spine is indeed possible but carries a significant risk of cortical breech between C3 and C6. Pedicle screw placement in the cervical spine may best be reserved for anchoring long lateral mass plate screw constructs into the larger pedicles of C2 and C7.

**Conclusion**

Successful instrumentation of the posterior cervical spine requires a sufficient three-dimensional understanding of the anatomy of the occipito-cervical junction, the atlanto-axial complex, the boundaries of the lateral mass, and the morphology of the cervical pedicle. When a posterior approach is chosen to provide stabilization, there is usually more than one surgical option available to restore stability. Each technique has its advantages and disadvantages regarding biomechanical strength and ease and safety of application. It is paramount that the surgeon should choose that technique with which he or she is most comfortable and is technically able to perform.

**References**

Posterior Cervical Instrumentation


