55 Upper Cervical Screw Fixation Techniques

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SUMMARY OF KEY POINTS

- The upper cervical spine presents many unique challenges to successful stabilization, including complex anatomy and limited access corridors.
- Because of the high degree of mobility at these levels, internal screw fixation is often required to achieve successful bony fusion and stability.
- Odontoid screw fixation is the preferred motion-preserving option for repair of odontoid fractures, although dorsal fixation techniques without fusion are being adopted.
- Dorsal C1-2 fixation through the transarticular approach provides immediate stabilization and is especially useful in patients with atlantoaxial instability, such as those suffering from rheumatoid arthritis.
- The Goel-Harms construct is an alternative to transarticular screws that offers similar levels of stability and may have a superior complication profile, especially in relation to vertebral artery injury.

Internal fixation is often used to provide immediate stabilization to protect the vital neural and vascular elements rendered vulnerable by instability produced by trauma, disease processes such as rheumatoid arthritis or neoplasms, and surgical procedures such as transoral odontoidectomy. Immediate stabilization is especially important in the highly mobile cervical spine. The occipitocervical junction and atlantoaxial complex comprise a transitional region connecting the rest of the spinal column to the cranium. The vertebrae and joints in this region are anatomically unique, differing from those in the subaxial spine because of their special adaptations to allow additional degrees of motion. Arguably, the most important of these are at the C1-2 complex, where the flat lateral articulations, absence of an intervertebral disc, and lax ligaments permit appreciable rotation (about 50% of total head rotation) (Fig. 55-1).[1] This motion is safely tolerated because the spinal canal is more capacious, the instantaneous axis of rotation is located close to the spinal cord (minimizing distortion of that structure), and the vertebral arteries loop laterally (allowing for at least one to remain patent, even at the extremes of rotation). Potentially catastrophic translational movements are prevented by the strong transverse component of the cruciate ligament (usually 8 to 10 mm in diameter in adults) that contains the odontoid process of the axis in the ventral compartment of the atlas. Disruption of this ligament, with or without bursting of the ring of C1 (Jefferson fracture), or disruption of the odontoid process results in gross instability. The remaining ligamentous structures, if intact, may provide some support, but they are too weak intrinsically to protect the spinal cord from even relatively minor trauma.

The restoration of structural integrity is critical. If the instability is caused by bone disruption, healing can occur with proper external immobilization. Instability caused by ligamentous disruption, however, requires surgery to achieve a bony fusion between previously hypermobile motion segments to protect the spinal cord. For bone healing or fusion to occur, two criteria must be met: (1) the bone graft (or bone fragments) must be touching or in proximity, and (2) motion must be eliminated or minimized.

Internal fixation can provide immediate stabilization to optimize bone graft and fragment healing. It accomplishes this more effectively than rigid external immobilization (such as a halo vest or Minerva jacket), while avoiding the cost, discomfort, and complications associated with these devices. To achieve the degree of stability necessary to protect the neural elements, screw fixation is often helpful because most wiring techniques alone do not constrain rotation and are therefore inadequate.

GENERAL CONSIDERATIONS

Protection of the neural elements when instability exists is paramount. Before surgery, the patient must be properly immobilized. Depending on the degree of instability, this may be achieved with a rigid cervical collar or it may require skeletal traction, a halo vest, or a Minerva jacket. Ongoing spinal canal compromise, if present, should be corrected before fusion is attempted by restoring alignment with cervical traction via cranial tongs or by surgical removal of intraspinal masses. Once the nature of the pathologic condition has been fully investigated and restoration of the spinal canal and spinal realignment have been planned, strategies for surgical stabilization can be considered. Because some techniques require anatomic integrity in specific regions, careful assessment during the planning stage is necessary. The patient's general medical condition should be optimized and other associated injuries and traumatic situations evaluated and treated as appropriate.

ANESTHETIC CONSIDERATIONS

The degree of cervical spine instability and direction of movement that produce subluxation can impact the choice of anesthesia. For example, an odontoid process fracture is often unstable in both flexion and extension and requires an awake, fiber-optic intubation, whereas a transverse ligament rupture may be unstable only in flexion, in which case routine laryngoscopic techniques can be used. If C-arm fluoroscopy is planned for intraoperative guidance, it can be set up before anesthesia is induced to monitor spinal alignment during intubation and positioning.

Patients with spinal cord injury who have significantly reduced vasomotor tone may require substantial intravenous fluid volume replacement or vasopressors to maintain adequate circulatory volume and blood pressure.

Although it is uncommon, significant airway swelling after operative intervention that necessitates emergent reintubation can provide significant challenges to both the neurosurgeon and the anesthesiologist. Some authors have suggested delayed extubation for this reason, and the anesthesia team must be aware that a difficult airway should be expected in this population.[2]

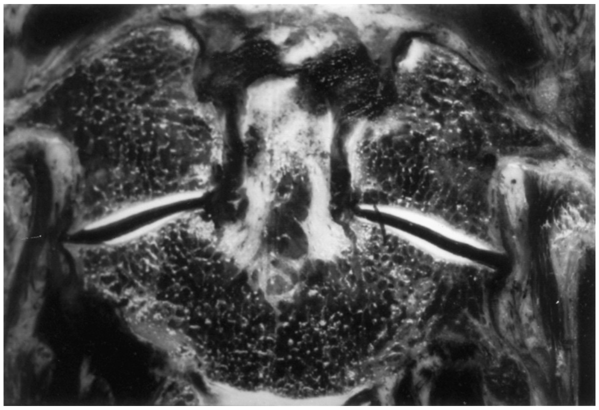


Figure 55-1. Coronal anatomic section through the atlantoaxial complex at the level of the odontoid process. Note the horizontal axis of the C1-2 articulation and absence of an intervertebral disc that contributes to the degree of rotatory motion at this joint. *(Courtesy of Dr. Wolfgang Rauschning, Uppsala, Sweden.)*

VENTRAL APPROACHES

Indications

Ventral techniques are primarily indicated for direct screw fixation of odontoid process fractures. C2-3 ventral fusion and plating is an option for treatment of a hangman's fracture.[3] It is no different from ventral cervical fusion and plating at lower levels other than the difficulty associated with the angle of approach to C2.

Odontoid process fractures, classified by Anderson and D'Alonzo[4] as types I, II, and III, have been associated with distinctive treatment algorithms. Type I fractures, involving the apical part of the odontoid process, are usually believed to be stable and may be treated with external orthosis; however, one report suggests otherwise,[5] and dynamic imaging may be used to assess stability. Type II fractures involve the neck of the odontoid process and are the most common. Type III fractures extend into the body of C2 and generally heal well with external immobilization. In a comprehensive review of fractures of the C2 vertebral body, Benzel and colleagues[6] noted, however, that the type III fracture described by Anderson and D'Alonzo is not an odontoid fracture at all. They have proposed a classification of C2 body fractures that is more comprehensive and more meaningful in regard to mechanisms of injury.

Debate continues regarding the optimal treatment of type II fractures. Nonunion rates of 21% to 45% have been reported frequently, and there are many other reports of nonunion in the 50% to 63% range.[7-11] A meta-analysis[12] found that halo vest immobilization produced a fusion rate of 65%, which was only slightly better than traction alone at 57%. The variable success of immobilization led some authors to try to define parameters that would predict failure with external immobilization. Extent of dislocation (approximately 65% to 90% nonunion if dislocation is greater than 4 to 6 mm),[13,14] patient age (higher failure rate in older patients),[13,15] and direction of subluxation (higher failure rate with dorsal subluxation)[15] have all been suggested as predictors of failure, as has a comminuted fragment of bone at the base of the odontoid process (type "IIA").[16] Among these, age appears to be the most valid indicator of the propensity for nonunion. In a randomized controlled prospective study, Lennarson and colleagues[17] found the nonunion rate in patients treated with halo immobilization was 21 times greater in those over the age of 50 years than in younger patients. This study was a key factor leading to a recommendation for surgery in the guidelines for management of acute cervical spine and spinal cord injuries published by the Joint Section of Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and Congress of Neurological Surgeons.[18]

Because nonoperative treatment of type II odontoid fractures clearly has a high nonunion rate, several methods of surgical fixation have been developed, each with distinctive advantages and pitfalls.

Contraindications

Absolute contraindications include comminuted fractures of the C2 body and transverse ligament disruption as defined by MRI or suggested by a C1 lateral mass fracture with extensive lateral displacement (greater than 7 mm total on anteroposterior radiographs) (Fig. 55-3),[30] pathologic fractures, and nonunions of more than 6 to 8 months duration that do not meet the aforementioned criteria. Severe osteoporosis is a relative contraindication. In addition, an oblique fracture of the odontoid process, angled caudally and ventrally so that it is parallel to the planned screw trajectory, may not be as suitable for ventral screw fixation because the odontoid process may slide down the fracture plane as the screw is tightened. Such anterior oblique fractures, while accounting for only 16% of the cases in one published series,[29] had a significantly higher failure rate.

A barrel-shaped chest and short neck or an immobile or kyphotic spine because of cervical spondylosis can render the surgical approach more difficult, but these are relative contraindications that may be compensated for using specialized instrumentation. Finally, access to two quality C-arms during surgery is preferred, and the procedure should not be attempted without at least one.

Direct Odontoid Screw Fixation

Direct screw fixation of the odontoid process was first described in 1980 in the Japanese literature by Nakanishi, who began using this technique in 1978.[19] This was followed in 1981 and in 1982 by publications from Böhler,[20,21] who reported his experience dating back to 1968. Although others also[22-24] described their experiences with various approaches to achieve direct odontoid screw fixation, the procedure was not widely accepted. With the development of specialized instrumentation, facilitating accurate screw placement with minimal trauma to the patient,[25,26] the procedure has gained in popularity. The technique has the advantages of (1) decreased postoperative pain resulting from lack of extensive muscle dissection, (2) avoidance of bone graft harvest, and (3) maintenance of normal anatomy and rotation at the C1-2 joint.[27] Furthermore, many patients require no postoperative immobilization.

Direct odontoid screw fixation (Video 55-1) can be used as the primary approach to treat acute type II fractures or it can be used after failure to heal with external immobilization. Patients with type II dens fractures with concomitant C1 ring fracture may also be candidates for odontoid screw fixation; however, assessment of transverse ligament integrity by magnetic resonance imaging (MRI) preoperatively[28] (Fig. 55-2) and by flexion fluoroscopy postoperatively is essential. If the latter demonstrates continued C1-2 instability, either a ventral or a dorsal C1-2 fusion is necessary. The direct screw fixation technique may also be used in some patients with chronic nonunion of type II odontoid fractures. Candidates should have a relatively small gap between the odontoid process and the C2 body and a reasonably sized odontoid fragment that has not autofused to C1 and does not have sclerosis of the

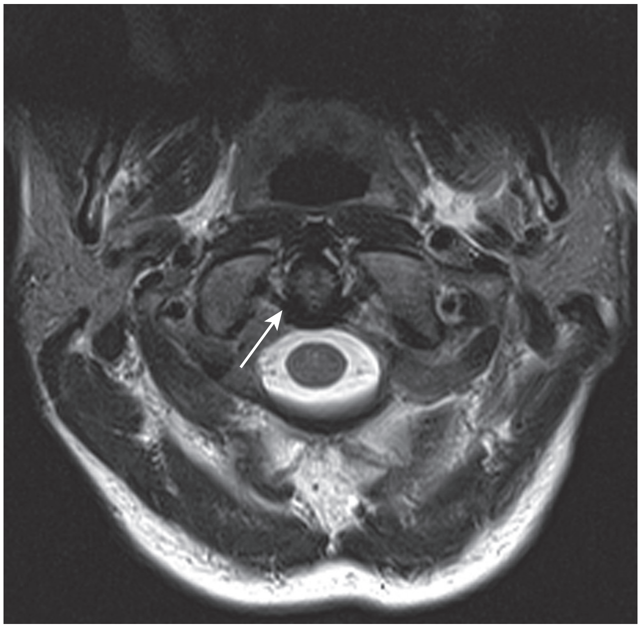


Figure 55-2. Axial T2-weighted MRI demonstrating intact transverse ligament *(arrow)*.

Figure 55-3. Anteroposterior/odontoid radiographic demonstrating significant lateral displacement of C1 lateral masses relative to C2 articulation.

surface opposing the body of C2. Chronic malunions that do not meet these criteria rarely fuse and will ultimately fracture the hardware and become unstable. The chance of successful bony union in one small series of such patients with fractures over 18 months of age was only 25%.[29] This sharply contrasts with an 88% fusion rate for type II and high type III fractures that are less than 6 months of age.[29] For this reason, we generally recommend posterior C1-2 fusion for chronically nonunited fractures. Unstable type III odontoid fractures that do not extend too far into the body of C2 are also candidates for direct screw fixation.

Patient Positioning

The patient is placed supine with the neck extended for proper screw trajectory. Padding is placed under the shoulders. If the neck cannot be initially extended, as judged by careful lateral fluoroscopic monitoring, the head is supported on folded towels in neutral neck alignment. Holter traction with a light

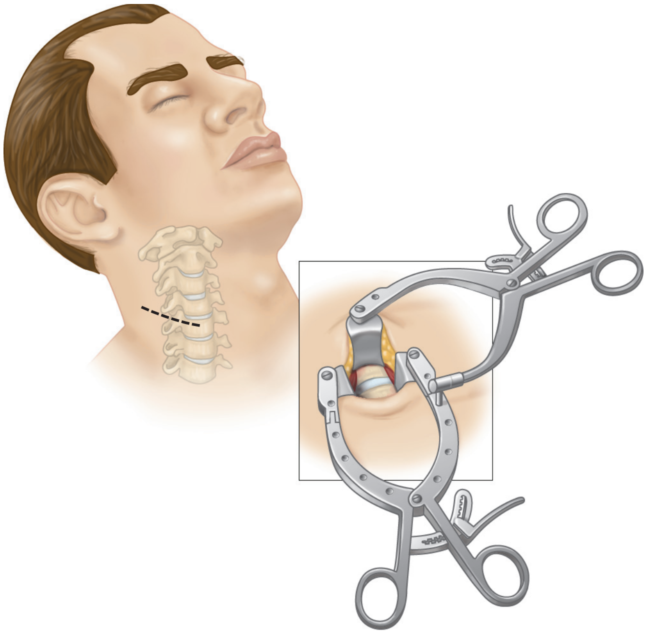


Figure 55-4. Skin incision in a natural skin crease at about the C5 level. Inset shows retractor in place.

weight (5 lbs.) hung over the Mayfield U-bar attachment to the operative table is useful for stabilizing the head.

For odontoid or ventral C1-2 screw placement, biplanar fluoroscopy is necessary. The anteroposterior view is obtained transorally. A wine bottle cork, notched for the teeth or gums, is an ideal radiolucent mouth prop. A single fluoroscope, swung back and forth frequently from the lateral to the anteroposterior position, can be used if necessary. It is much easier, however, to use a second C-arm fluoroscope if one is available. One C-arm unit is placed laterally with the arc horizontally or up to 45 degrees above the horizon. The other can be brought in at a 45-degree angle from the head of the table and positioned for the transoral view. Some adjustments may be needed to optimize the views, but once this is achieved, the remainder of the procedure is greatly facilitated. The C-arm should be positioned for optimal viewing by the surgeon, who stands on one side of the patient with the assistant on the opposite side. The anesthesiologist may remain at the head of the table. This provides optimal access to the patient's head and airway. Alternatively, the patient can be positioned 180 degrees from the anesthesiologist to facilitate optimal positioning of the two C-arm fluoroscopes. In this scenario, either nasotracheal intubation is planned or the endotracheal tube is secured to the left side of the patient's mouth and run along the left side of the body to the anesthesia.

Operative Technique

All ventral odontoid fixations begin with the same exposure. The initial approach to the spine is the same as for an anterior cervical discectomy. The spine is approached at about the C5 level through a unilateral natural skin crease incision (Fig. 55-4). We use a local injection with epinephrine (1 : 200,000) to minimize skin bleeding and complete hemostasis with bipolar cautery. The platysma muscle is elevated and divided with monopolar cautery. The sternocleidomastoid muscle fascia is opened along the medial side of the muscle with sharp dissection. Blunt dissection then opens the deeper tissue planes medial to the carotid sheath and lateral to the trachea and esophagus to expose the prevertebral space. Dividing the longus colli fascia and the anterior longitudinal ligament in the midline with electrocautery allows the bellies of the longus colli muscle to be elevated bilaterally over approximately 1.5 vertebral segments. Sharp-bladed Caspar retractor blades are set in place below the muscle and attached to the Caspar retractor.

The loose areolar tissue in the prevertebral space ventral to the longus colli muscles is easily opened with a Kittner or "peanut" dissector held in a curved tonsil clamp. It is swept from side to side while advancing up to the C1-2 level (monitored with lateral fluoroscopy). Several screw systems are available. The Apfelbaum system (Aesculap Instrument Corporation, Center Valley, PA) has an angled retractor blade that reaches into this space under the mandible and holds open the working tunnel. It attaches to one side of the previously placed modified Caspar retractors (see Fig. 55-4). Other systems use different retractors, such as a curved handheld retractor (Synthes) or small metal hook-shaped handheld Hohmann retractors that lock over the shoulders of C2 bilaterally alongside the dens, as initially described by Böhler.[20] The key to the retraction is to create a working tunnel up to the caudal edge of C2, without having any device caudally in the wound that restricts the low trajectory needed for proper screw placement.

At this point, the various instrument systems use somewhat different approaches for placing the screws. The Apfelbaum system consists of an outer guide tube with spikes that anchor it to C3 and that can be used to optimize spinal alignment. An inner guide tube, within the outer tube, guides the drilling. Once the pilot hole is drilled, the inner guide is removed, the hole is tapped, and the screws are placed through the outer guide tube. First, under biplanar fluoroscopic control, an entry site on the ventral caudal edge of C2 is selected and a K-wire is impacted into C2 (Fig. 55-5A). If one screw is to be placed, a midline location is chosen. If two are to be placed, a paramedian location is selected 2 to 3 mm from the midline. Care and patience in selecting the entry site and setting the K-wire will be rewarded by the remainder of the procedure being expedited. Once the K-wire is set, a 7-mm hollow drill is placed over the K-wire and is rotated by hand to create a shallow trough in the face of C3 and in the C2-3 annulus (Figs. 55-5B–D). No bone is removed from C2. The two guide tubes are then mated together, passed over the K-wire, and walked up the ventral face of the spinal column until the spikes on the outer tube are over the body of C3. The inner guide tube is then advanced in the trough to the ventral caudal edge of C2 (Fig. 55-6), and the K-wire is removed. Having the guide tube at the entry site prevents the drill from skipping off the edge of the bone and walking up the ventral face of C2. With the guide tube system firmly engaged in C3, the surgeon can then optimize the C2 alignment on the fluoroscopic images by either pushing C2 and C3 dorsally relative to the odontoid-C1 complex or pulling C2 and C3 ventrally. In the case of a retrolisthesed odontoid process, this realignment can be performed while gradually extending the patient's head and removing the supporting towels beneath it to obtain an ideal working trajectory.

A pilot hole is then drilled from the ventral caudal edge of C2 to the apex of the odontoid process, advancing the drill slowly under biplanar fluoroscopic control (Fig. 55-7). The dense cortical shell of the odontoid must be pierced to engage the screw properly and avoid splitting. Because the odontoid process is firmly held in position by its periosteum and attached supporting ligaments, it is not displaced as the drill enters from the soft cancellous fracture site. The angle of drilling is such that the drill can penetrate a substantial distance beyond the apex of the odontoid process into the apical ligaments without threatening the dural or neural structures. If, however, a more dorsal trajectory is needed, greater care must be taken not to penetrate too far into the spinal canal.

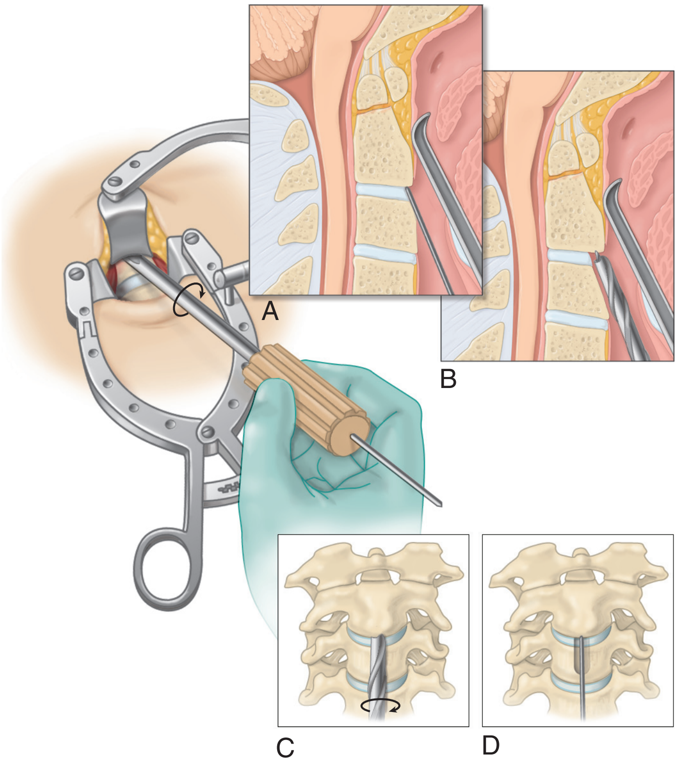


Figure 55-5. A, A guiding K-wire in place. **B–D,** Hollow hand drill creates trough in face of C3 and C2-3 annulus.

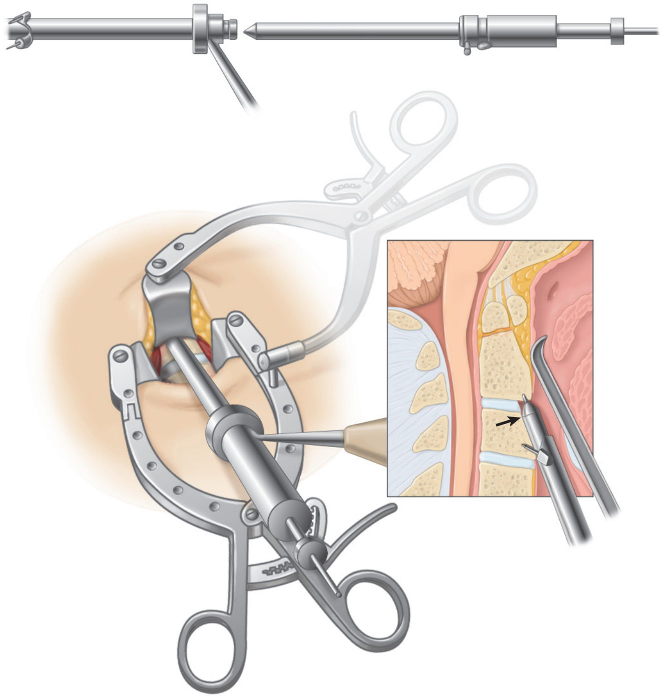


Figure 55-6. Illustration showing drill guide system. Inner and outer guide tubes mate together and are placed over the K-wire. The spikes on the outer guide tube are impacted into C3, and the inner guide tube is then advanced into the previously created trough *(arrow)* to the caudal edge of C2.

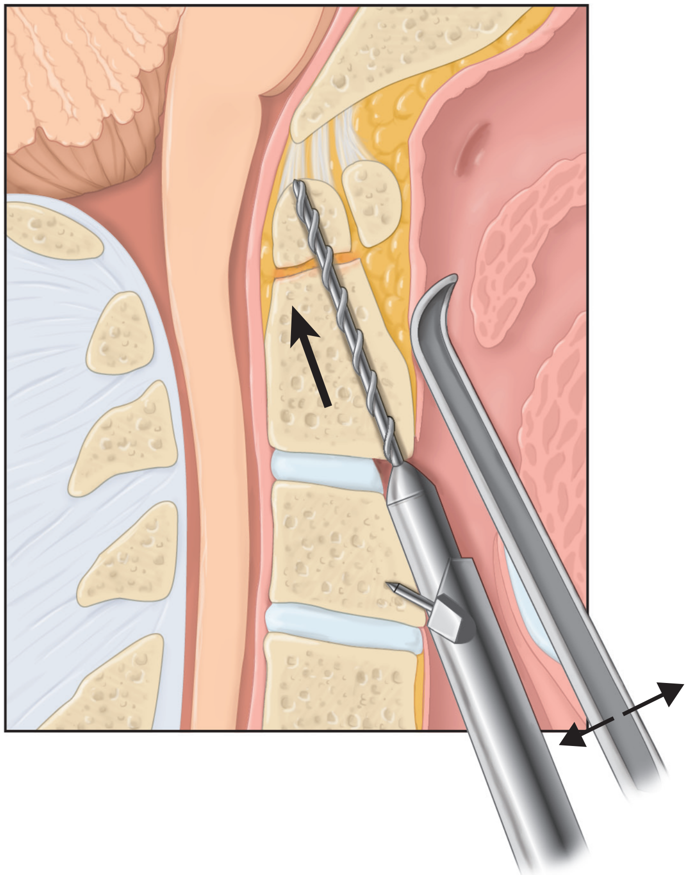


Figure 55-7. K-wire is removed and replaced with drill, which is guided fluoroscopically to apex of odontoid process after reducing dislocation of the odontoid process. The guide tube is kept in place by steady upward pressure *(vertical arrow)* to keep the spikes engaged in C3. The alignment of C2 and C3 relative to the odontoid process and C1 is optimized and maintained by lifting up or pushing down on the retractor as appropriate, as indicated by the oblique arrows, before crossing the fracture site with the drill.

This is controlled by visualizing the drill's progress on the fluoroscope.

Once the drill is into the distal odontoid cortex, its depth of penetration is read on the calibrated shaft, and the anteroposterior and lateral fluoroscopic images are saved on the monitor screens. Comparison of future live images with these saved images allows reestablishment of the identical alignment in successive steps.

The drill is then withdrawn, and the inner guide tube is removed. A tap is placed through the outer guide tube, and the pilot hole is tapped. This cuts threads in the bone, allowing a more precise bone–screw junction that may reduce bone absorption around the screw caused by pressure necrosis if a self-tapping screw is used. The tap is then removed, and a screw is placed through the guide tube (Fig. 55-8). A screw that is a few millimeters shorter than the measured drill depth may be chosen to allow for reduction at the fracture site, but it is important that the screw fully engages the apical cortex. Extending the screw a few millimeters beyond the cortex into the apical ligaments is safe and preferable to having one too short, as the latter may back out. To achieve some fracture reduction, a partially threaded screw (lag screw) is used to pull the odontoid back toward the body of C2.

If a second screw is to be placed, the identical series of steps is followed on the contralateral paramedian site, except that either a partially threaded lag screw or a fully threaded screw can be used, because no further lagging action would be expected to occur.

After removal of the guide tube, bleeding from C3 can be controlled with bone wax or a slurry of Gelfoam powder and thrombin. Lateral fluoroscopy in flexion and extension confirms stability. Closure is routine and is performed in layers, closing the platysma muscle and subcutaneous tissue with absorbable sutures and the skin with sterile tape strips or

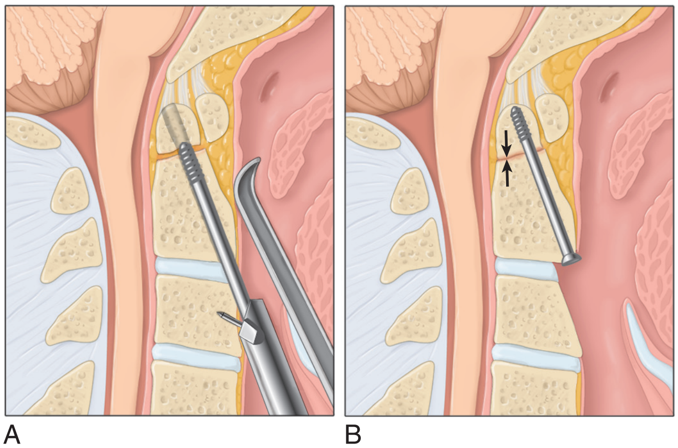


Figure 55-8. A lag screw is placed through the guide tube (**A**) and advanced through the tapped pilot hole to its final position (**B**). In fresh fractures, the gap at the fracture site will be reduced *(arrows)* by the lag effect of the screw pulling the odontoid back toward the body of C2.

Dermabond. No drains are placed. External collars are not usually recommended unless there is concern about the patient's bone quality, and patients are allowed to return to work and resume nontraumatic activities promptly.

Several alternative systems have been proposed that are based on existing long-bone screw fixation techniques. These use a K-wire to drill the pilot hole and then pass a hollow overdrill over this, followed by a cannulated screw.[23] Theoretically, once the K-wire is placed, it does not have to be removed so that precise reentry into the same trajectory is assured; however, a drawback of these systems is that they do not appear to have any provision for optimizing alignment with the drill guide. Furthermore, K-wires are suboptimal drills because they lack the torsional rigidity of drill bits and can be deflected by irregular densities within the bone. To redirect them, one must remove the K-wire and select a new starting point.[31] In addition, great care must be taken when drilling over the K-wire because the drill can bind to the K-wire and advance it into the spinal canal or cut the K-wire.

Controversies

One-Screw versus Two-Screw Constructs. Theoretically, with one screw, the odontoid process could rotate on C2, although the interdigitation of the irregular fracture surfaces may prevent this with fresh fractures. This may explain why constructs with either one or two screws have been reported to have similar clinical success.[32-34] Laboratory studies also show no greater resistance to screw fracture from bending with one- or two-screw constructs. A more recent clinical study by Dailey and coworkers,[35] however, found a significant difference in fusion rates among 57 patients over the age of 70 with odontoid fractures: a 56% success rate was seen if one screw was placed, whereas a 95% fusion rate was achieved when two screws were placed.

The demographics of patients with odontoid fractures are changing. Elderly patients who sustain odontoid fractures after relatively minor trauma, often a ground-level fall, now constitute the majority of patients with odontoid fractures, highlighting the importance of considering placement of two screws in older and possibly middle-aged patients.

When two screws are placed, the entry site for each is located paramedially a few millimeters off the midline and the screws are angled toward each other at the odontoid apex. The diameter of the odontoid process should be assessed on the preoperative computed tomography scan to ensure adequate bone volume for a second screw. Some patients may not have a sufficiently wide odontoid process to accommodate two screws side by side,[36] but the odontoid process may be deep enough that the screws can be placed is such a way that they end up in front of and behind each other to achieve the same fixation.

Screw Size and Type. Biomechanical data suggest that cannulated screws are only about 5% to 10% weaker than solid screws.[31] Screw diameters usually range from 3.5 to 4 mm. The initial experience was with cancellous threaded screws, which have a deeper thread (smaller minor diameter or core) and are better at resisting pullout. However, pullout forces on odontoid screws are minimal. An odontoid screw has to primarily resist bending and translational forces. Screw failure, if it occurs, is almost always due to fracture at the level of the bone fracture. Cortically threaded screws (4-mm outer diameter) with a larger minor diameter (2.9 mm versus the previously used 2 mm) would therefore seem optimal. An additional benefit is that the pilot hole is drilled larger (3 mm versus 2 mm). This makes the drill much more directionally stable, allowing precise correction of pilot hole trajectory to optimize screw placement.

Results

Type II odontoid fractures less than 6 months old treated with this technique have a high rate of fusion. The combined published series[29] of Veres in Hungary and Apfelbaum and colleagues in Salt Lake City, Utah, encompassed 147 patients whose ages ranged from 15 to 92 years. Successful bony union was achieved in 88% of patients, with an additional 3% achieving stability via fibrous union. These results agree with those of other published series with fewer patients.[23,31,37-39] Failures usually occur in elderly patients with poor quality bone. If this complication is recognized early, manipulative realignment and external immobilization has been successful. If not, additional surgery is required.

Other series have shown similar low complication rates; however, there has been a high incidence of dysphagia from the retropharyngeal approach in elderly patients, and some of these patients required temporary feeding tubes.[35]

Although they are rare, serious and even fatal complications can result from the K-wire being driven beyond the odontoid tip as mentioned in the alternate technique. One published report also describes K-wire bending and eventually breaking within a cannulated system, necessitating abandonment of the fractured tip within the patient.[36]

The high degree of success achieved by using this straightforward, easily mastered technique, usually with minimal complications, merits its consideration as the primary treatment for many type II odontoid fractures. By allowing the patient to quickly resume normal activity while avoiding the cost and medical and social morbidity of a halo vest, screw fixation appears to be a cost-effective treatment for this problem.

Ventral C1-2 Transarticular Screw Fixation

Ventral C1-2 transarticular screw fixation may provide an alternative if odontoid screw fixation is not possible or if successful odontoid screw fixation fails to stabilize C2 because of unrecognized concomitant transverse ligament incompetence. This approach also allows for resection of odontoid lesions. Stabilization is accomplished by inserting two screws through the lateral masses of C2 into the lateral mass of C1.[40] The entry site is just medial to the vertebral artery, which is placed at risk by this approach. The screws angle laterally approximately 20 degrees and dorsally at a similar angle (Fig. 55-9).[41] The entry site is selected by following the lateral edge of the vertebral body rostrally from the C2-3 interspace to its junction with the lateral mass, staying as medial as possible in that structure. The drill guide system used for odontoid screw fixation can be used for this as well, although the screw length is considerably shorter.

Although it achieves fixation, this technique does not permit placement of bone graft. Rather, long-term stabilization is achieved by promoting arthrodesis of the C1-2 lateral articulation, primarily by immobilization. This may be enhanced by curetting the joint, but overall, the construct is less likely to succeed than dorsal screw fixation with dorsal grafting. Additionally, this approach may be complicated by injury to either the superior laryngeal or hypoglossal nerves (or both), potentially resulting in hoarseness, dysphagia, and dysarthria.[41]

Other Ventral Techniques

There are a few reports of surgeons placing plates and screws transorally.[42] The obvious risk of infection and, to a lesser extent, the limited working space seem to have deterred most surgeons from these approaches.

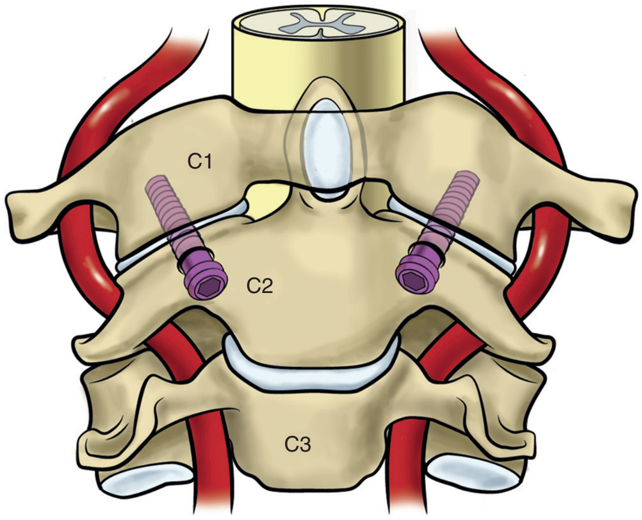


Figure 55-9. Anteroposterior illustration of anterior C1-2 transarticular screws (purple). *(Reproduced with permission from Department of Neurosurgery, University of Utah.)*

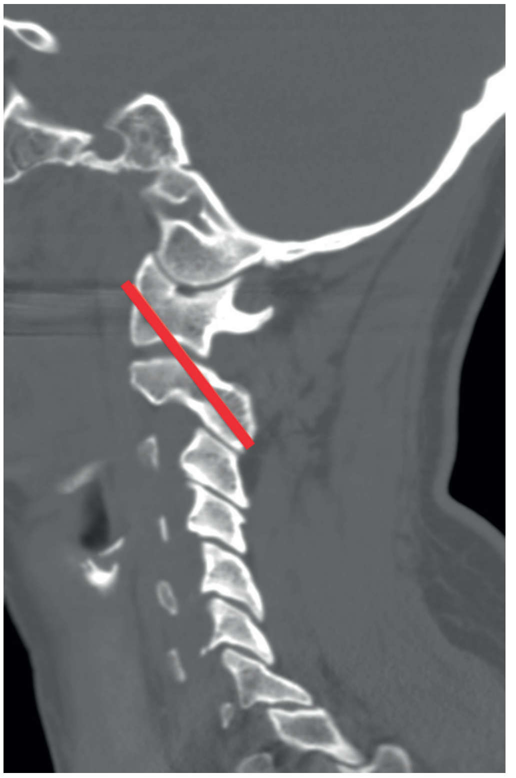


Figure 55-10. Sagittal computed tomography (CT) demonstrating adequate trajectory for C1-2 transarticular screw.

More recently, minimally invasive, percutaneous anterior transarticular screw fixation techniques have been developed that allow for access to the C1-2 joint with minimal tissue disruption. Although early reports on the use of this technique are promising, with good results achieved in young patients with traumatic injuries,[43] its use is limited because most surgeons lack familiarity with minimally invasive approaches to the upper cervical spine, and there is a dearth of large case series with long-term follow-up.

DORSAL APPROACHES

The dorsal approach is used to stabilize C1 to C2. Rather than providing stabilization and fixation of a fractured bone, it stabilizes what was previously a normal motion segment and provides an optimal environment for bone healing. Bone grafting, however, is almost always required for long-term stabilization, as hardware in nonfused segments will ultimately fatigue and fail.

Traditional techniques have used a variety of C1-2 wiring strategies with interposed or onlay bone grafting (Gallie,[44] Brooks,[45] and interspinous [Sonntag][46] fusions). Because these impart limited stability that deteriorates significantly with cyclical loading,[47] an external rigid orthosis is usually necessary. Fractured or absent dorsal elements can preclude the use of these techniques. Even in optimal situations, nonunion rates of up to 30% are reported.[47]

Transarticular Screw Fixation

Transarticular screw fixation, pioneered by Magerl in 1979, offers immediate stabilization, often without external orthosis.[48] By optimizing bone graft union with a high chance of success, it is a major advance in treating instability in this area. The construct can be extended with various devices to include the occiput and the subaxial spine if needed.

Indications

This procedure is indicated for atlantoaxial instability from almost any cause: traumatic disruption of the transverse ligament, rheumatoid or other degenerative diseases, iatrogenic instability after transoral decompression, congenital or acquired absence of a united odontoid process (os odontoideum), ligamentous incompetence associated with various genetic diseases (Down syndrome, Larsen disease), or chronic nonunited odontoid fractures. Occiput-C1 instability can occur from many of the same causes and, if present, can be treated by extending the stabilization and fusion up to the occiput.

Contraindications

Poor bone quality is always of concern during intraosseous fixation and must be evaluated carefully. It is not an absolute contraindication to surgery but may necessitate using both internal and external immobilization. Of paramount importance for transarticular screw fixation is an adequate pathway for the screw that traverses the pars interarticularis (isthmus) of C2 to the lateral C1-2 articulation before crossing that joint into the lateral mass of C1 (Fig. 55-10). Variations in anatomy and secondary effects of vascular elongation coupled with bone softening can result in the vertebral artery looping up into the pars of C2. Placing screws in such circumstances has resulted in vertebral artery injury with potentially serious neurologic sequelae.

Understanding the patient's anatomy and the availability of a safe bony pathway for screw placement prior to proceeding with surgery is critical. Careful evaluation of preoperative imaging can also allow the identification of important anatomic variants in this region. One such variant is the ponticulus posticus, a bony ridge arising from the C1 posterior arch that encircles the vertebral artery, which is seen in up to 16.7% of patients.[49] Failure to identify this anomaly can lead to a false intraoperative assessment of the size of the posterior arch and subsequent vertebral artery injury.[50]

Patient Positioning

A Mayfield three-pin head holder is placed as well as a cervical collar. The patient is then rolled into prone position on bolsters while the surgeon keeps the neck stable with axial traction and maintains it in a neutral position. The best reduction position is often with the neck in extension, but this may preclude C1-2 transarticular screw placement in many cases because lordosis would often dictate a screw trajectory starting within the thoracic cavity. The patient therefore should be positioned with the chin slightly flexed but with the head pulled dorsally (Fig. 55-11). This position will usually reduce C1-2 dislocations via dorsal translation yet leave the rest of the cervical spine in a flattened or even slightly kyphotic posture so the needed screw trajectory can be achieved. Careful monitoring of the fluoroscopic image facilitates safe positioning.

The low angle of screw trajectory needed to traverse the C2 pars interarticularis and enter C1 dictates a starting point at about the T1-3 level. Magerl's original technique called for an incision and paraspinal muscle retraction down to this level; however, percutaneous tunneling techniques make this unnecessary.[48]

Operative Technique

A dorsal midline incision extending from just below the inion to C3 is usually adequate (Fig. 55-12A). The paraspinal muscles are dissected off the dorsal elements of C1, C2, and the occipital bone and are held back with angled Weitlaner retractors. The exposure may require sharp dissection assisted with electrocautery if the spine is unstable. The full extent of the dorsal elements of C1 and C2 should be exposed, with definition of the lateral aspect of the C2 dorsal elements and the C2-3 facet joint, as well as of the C2 isthmus extending rostrally beneath the C2 nerve root and the associated venous complex (Fig. 55-12B). Bleeding can usually be arrested with small Gelfoam pledgets soaked in thrombin or a slurry made with Gelfoam powder and thrombin. It is neither necessary nor desirable to disconnect the inferior midline attachments to the bifid C2 spinous process.

Once the anatomic structures are fully exposed, fixation screws are placed. The entry site on each side is just rostral to the C2-3 facet joint and in line with the midpoint of the previously defined pars interarticularis. Standing back from the wound to reduce parallax, a line representing the inferior extension of the trajectory may be drawn on the drapes. A straight instrument such as a K-wire placed along the patient's neck and superimposed over the desired screw path on the fluoroscopic view provides the intersecting skin coordinates, usually at about T2.

A 1- to 1.5-cm skin transverse incision carried down through the dorsal fascia provides an entry for the drill apparatus (see Fig. 55-12A). As with odontoid fixation, a guide tube system (Aesculap Instrument Corporation or Medtronic Vertex Max) may be used. With these systems, a smooth tube fitted with a conical tipped obturator is passed from the skin incision up to the drill entry site at the C2-3 junction (Fig. 55-12C). Once the guide tube is in place, the obturator is removed. A starting hole is made in the C2 laminar bone using either an awl passed through the guide tube or a high-speed bur. The guide tube assembly allows precise control of drilling direction.

The surgeon must visualize the dorsal lateral and medial borders of the pars interarticularis and direct the drill bit accurately between these limits. A tool, such as a small Penfield dissector held by an assistant, can help the surgeon to visualize this area. Because it is placed on the dorsum of the pars, it serves as a fluoroscopic marker for that boundary. A low-angled trajectory to carry the drill bit just below the dorsum of the pars and across the C1-2 lateral articulation, as far dorsally as possible, engages the maximum amount of the lateral mass of C1 and keeps the drill above the vertebral

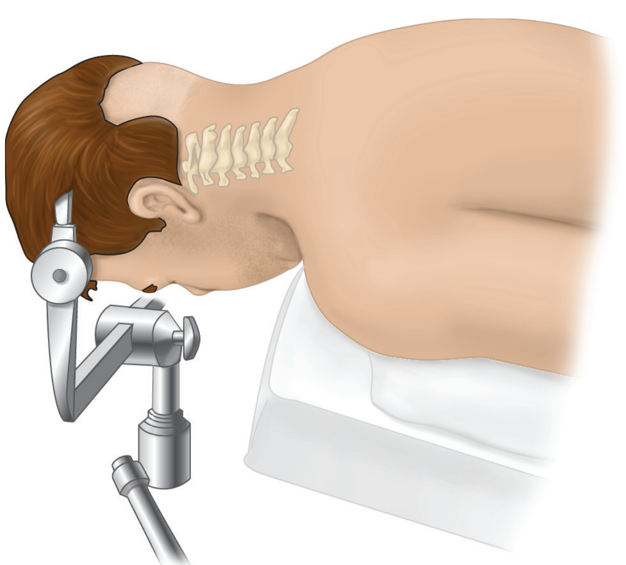


Figure 55-11. Patient positioning for transarticular screw fixation. The head is fixed in a three-pin head holder. Translating the head dorsally with the chin tucked reduces atlantoaxial dislocation and allows the lower spine to be kept in a straight or even flexed position. This facilitates the trajectory for C1-2 screw placement. The patient is positioned while monitoring vertebral alignment via lateral fluoroscopy.

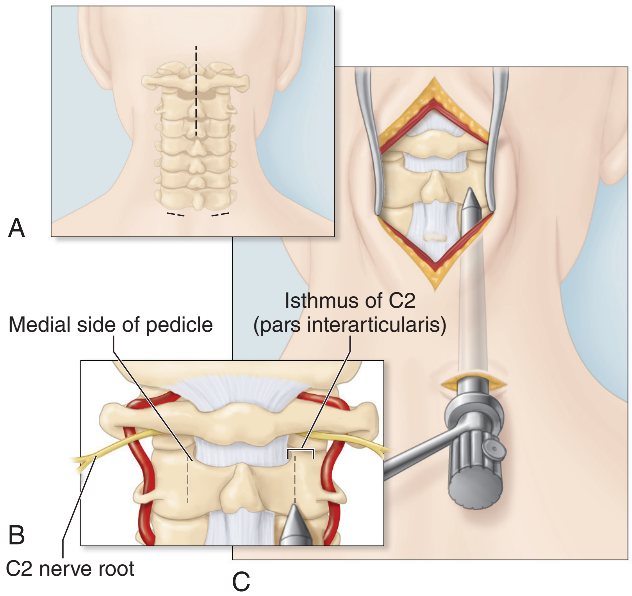


Figure 55-12. A, Site of surgical incisions. The level of the stab wound sites inferiorly for placement of the drill guide tube is determined fluoroscopically. **B,** Details of the surgical anatomy. The desired screw placement is just lateral to the lateral edge of the spinal canal. It will traverse the isthmus (pars) of C2 and the C1-2 articulation. The screw does not go down the pedicle, which would take it into the body of C2 and not across the C1-2 joint into C1. (**C**) Placement of the guide tube (with obturator) through the stab wound and into the field.

artery. On the lateral fluoroscopic image, the projection of the ventral arch of C1 is a helpful target to aim for, especially at its rostral margin (Fig. 55-13). Generally, the screw trajectory should be in a straight paramedian direction or slightly medially as dictated by the bone anatomy and location of the vertebral artery foramen. Aiming too far medially results in a smaller area of C1 lateral mass engagement, whereas aiming laterally can jeopardize the vertebral artery. Intraoperative imaging using the O-arm, a three-dimensional fluoroscopic technique, and the Stealth Neuronavigation coupled with the registered, navigated instrumentation may also be used to establish the appropriate multiplanar trajectory (Fig. 55-14). Considerations to using navigation in this area include the inherent hypermobility, which may not be accurately captured by the image-guided system. Despite these difficulties, using image guidance is a good way to evaluate and understand this complex anatomy and obtain the precision necessary to place screws safely.

When drilling, increased resistance is felt at the cortical margins of the C2 joint surface and then at the C1 joint surface, as well as at the ventral cortex of C1. If necessary, C2 can be translated ventrally or dorsally before drilling across the joint space by grasping the spinous process of C2 with a towel clamp, thus assuring optimal alignment. After the hole is tapped, except in very soft bone, a fully threaded screw is placed. If the construct needs to be extended cephalad to the occiput or caudally to the subaxial spine, a polyaxial screw is used.

Figure 55-13. Intraoperative lateral fluoroscopy with superimposed arrow demonstrating ideal trajectory aimed at rostral aspect of ventral arch of C1.

Bone bleeding may occur, particularly in patients with inflammatory disease. If, however, brisk arterial bleeding ensues from the drill hole, suggesting a vertebral artery injury, placement of one screw for fixation and tamponade is recommended, but a contralateral screw should not be attempted. If this occurs, it would be prudent to obtain postoperative angiographic images to ascertain the status of the vessel and to detect fistula formation.[51]

C1-2 Screw/Rod Constructs

An alternative technique devised by Goel[52] and Harms[53] uses screws placed in the lateral masses of C1 and into the C2 pars or pedicle, which are then connected posteriorly with rods. This is applicable in cases in which a safe pathway through the C2 pars to C1 does not exist. Another approach using translaminar screws in C2 that are coupled to C1 lateral mass screws has been proposed by Wright.[54] These techniques are illustrated in comparison with transarticular screw trajectories in Figure 55-15.

The Goel-Harms technique involves placing a polyaxial screw directly into the lateral mass of C1 and coupling it with a rod to a separate C2 screw. The anatomy of the individual bones must be studied before placing these screws to avoid vascular or neural injury. The C1 lateral mass is accessed by depressing the C2 nerve root where it traverses over the posterior aspect of the lateral mass of C1 below its junction with the posterior arch of C1. The screw will usually extend above the bone for a centimeter or more, so a partially threaded screw with a smooth shank proximally is recommended to avoid irritation of the C2 root by the screw threads.

Another option for C1 fixation in a Goel-Harms construct is a C1 posterior arch screw, which is placed starting from a point 20 mm lateral to the midline of the posterior arch of C1. From here, a path directed 5 degrees cephalad and perpendicular to the coronal plane is drilled.[55] One study has suggested that the biomechanical pullout strength of the posterior arch screw may be superior to that of C1 lateral mass screws, although there appears to be little clinical significance to this difference in terms of fusion rates.[56]

Depending on the patient's anatomy, the C2 screw can be a short pars screw aimed in the same trajectory as a transarticular screw, which will not reach a prominent vertebral artery foramen, a pars screw aimed anteriorly with a more flat angle, a C2 pedicle screw, or a translaminar screw (see Fig. 55-15).

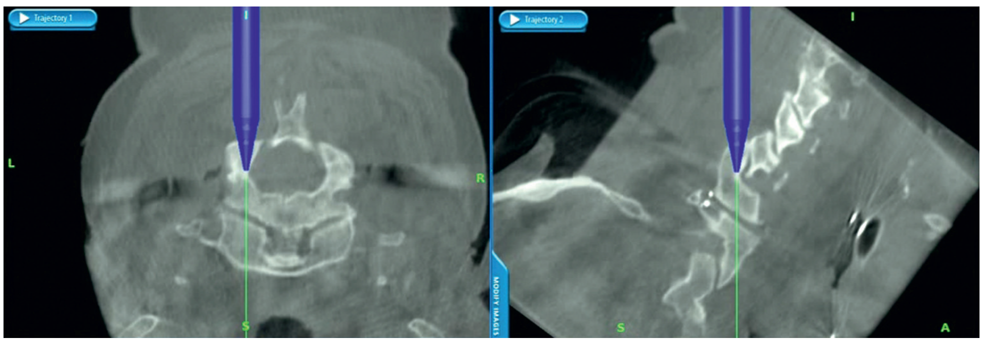


Figure 55-14. Intraoperative Stealth Neuronavigation screenshot showing ideal trajectory views for transarticular screw placement.

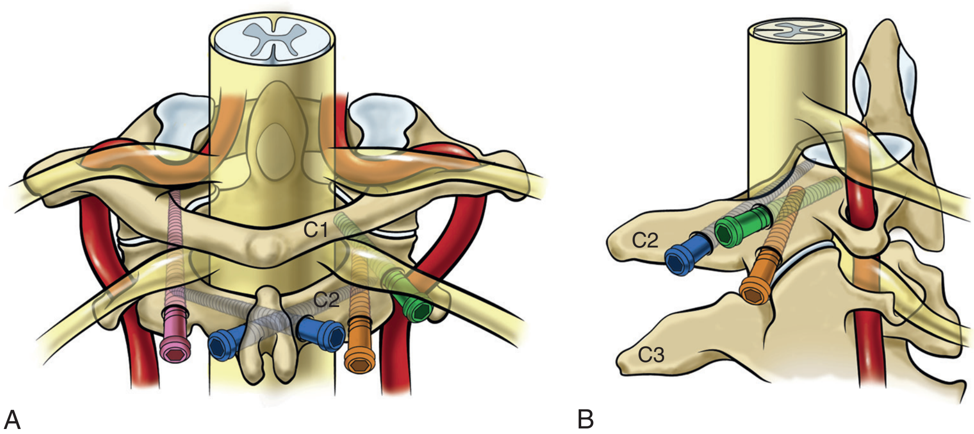


Figure 55-15. Anteroposterior (**A**) and lateral (**B**) illustrations showing transarticular (pink), translaminar (blue), pars (orange), and pedicle (green) ideal screw trajectories. *(Reproduced with permission from Department of Neurosurgery, University of Utah.)*

For pedicle screw placement, an entry site is drilled at a point approximately 4 mm inferior to the juncture of the C2 isthmus and lateral mass and 4 mm from the lateral border of the lateral mass. The screw trajectory should be parallel to the superior isthmus of C2 and should follow a line that intersects the medial C2 isthmus as it enters the C2 vertebral body.

Laminar screws are inserted by drilling an entry point in the cortical bone close to the rostral limit of the C2 lamina at the point where the C2 spinous process and lamina join. The screw trajectory from this point follows the path of the contralateral lamina. A second laminar screw is placed on the contralateral side via the same technique. Use of this technique compromises the ability to use the C2 lamina for the inferior end of a subsequent bone graft in the manner discussed in the following section.

The Goel-Harms technique widens the options for screw fixation if the C2 pars is not suitable for placing a transarticular screw, but the surgeon must be aware that the vertebral artery can also be injured with the C1 screw so a thorough understanding of its location and the bone anatomy of C1 is important. The procedure is more complex than transarticular screw placement because four polyaxial screws as well as the connecting rods must be placed. Some evidence suggests, however, that the addition of extra stabilizing elements may reduce the incidence of hardware fracture and, in cases of partial hardware failure, obviate the need for surgical intervention.[57]

Bone Grafting

Screw fixation functions as an internal splint. For long-term stability, bone fusion is required, as all hardware will ultimately fail without it. Magerl and Seeman[48] suggested curetting and then packing bone chips into the C1-2 articulation to encourage arthrodesis. Access to this joint is limited, however, and only a small portion of it can be treated in this manner even in the best of circumstances. Therefore, we use a dorsal fusion construct if at all possible.

With intact dorsal elements, Sonntag's group suggested a modified construct consisting of a combined interpositional and onlay bicortical iliac crest graft.[46] The graft has ventral and dorsal cortices. After the mating surfaces have been denuded with a high-speed bur, the contact sites at the caudal surface of C1 and the laminar surface and rostral edge of the spinous process of C2 are to cancellous bone. The graft and donor surfaces are also contoured for maximum opposition. The graft is secured with a braided titanium cable placed sublaminarly at C1 and around the spinous process of C2, so that the graft is sandwiched between the two layers of cable (Fig. 55-16). This construct provides excellent three-dimensional stability. The screws resist translation and rotation, whereas the graft prevents extension, and the cable prevents flexion. Additional bone chips and curettings may be placed around the construct to enhance fusion.

There are significant advantages to being able to use allograft bone, including elimination of donor site pain and complications, reduced bleeding, and ability to select more optimal bone. Although allograft has usually not been successful in onlay constructs, by further modifying the C1-2 posterior graft placement so that the graft is notched to fit in close apposition to both the dorsal and inferior edges of C1 and also is mortised into the lamina of C2, we achieve a true interpositional graft. Coupling this with internal screw fixation to eliminate all motion has resulted in equivalent fusion results with autograft, which allows us to avoid graft harvest and thereby significantly reduced patient morbidity.[58]

Lasso Technique

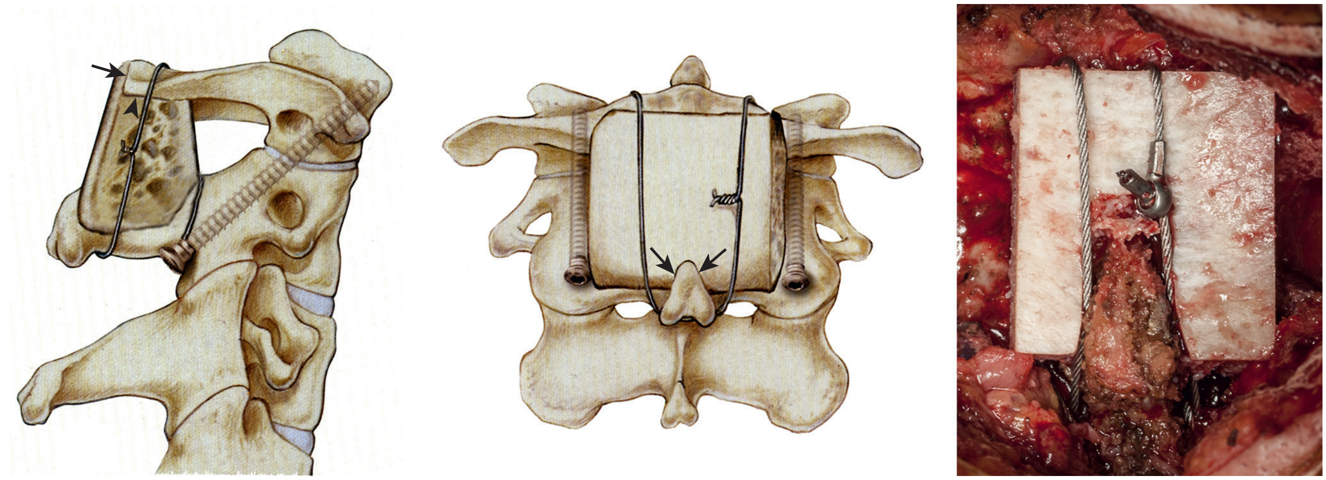
In the absence of an intact C1 arch, the same construct can be used with a modification, termed the *lasso technique*, provided that there are adequate remaining stumps of C1 (Fig. 55-17).[59] As diagrammed, the cable encircles and is cinched to each stump to secure it, and the graft is then pulled down to contact the bone.

Screws

Screws measuring 3.5 to 4 mm or slightly larger in diameter have been used. As in odontoid screw fixation, there is little pullout force but significant bending and translational forces. Cortical screws with a larger minor diameter, as described earlier in this chapter, have replaced the smaller minor diameter cancellous screws previously used. This has been a significant improvement that has eliminated screw breakage. The screw requires a larger drill (3 mm) because of its larger minor diameter. This drill provides more directional control and has resulted in the unexpected benefit of allowing more precise corrections to the trajectory as the drill is advanced.

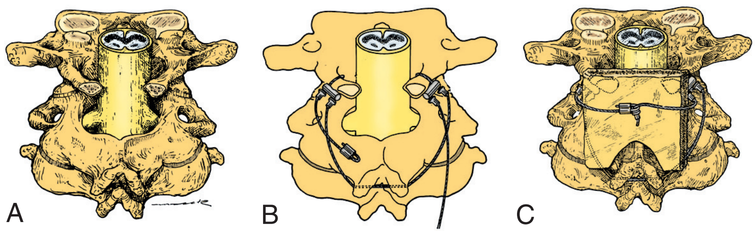
Postoperative Care

Some surgeons prefer to use a cervical collar, but unless there is a question of bone quality or if only one screw is placed,



A B C

Figure 55-16. Lateral (**A**) and posterior (**B**) views showing the modified grafting technique to increase the graft contact along the inferior aspect of the C1 ring as well its dorsal aspect *(arrows).* Both of these surfaces of C1 are decorticated and flattened to maximize graft contact. The bicortical graft is also mortised into the decorticated lamina of C2 and contacts the decorticated spinous process (*arrows* in **B**). (**C**) Photograph demonstrating interpositional bicortical iliac crest bone graft secured with titanium cable.



A B C

Figure 55-17. Lasso technique. A, Posterior exposure of C1 to C3 showing the incomplete atlantal arch. **B,** The loop is made in the braided titanium cable using a double-crimp device, and the cable is passed around and secured to the remnant of the left C1 arch. The cable is tensioned to securely grasp ("lasso") the stump of C1. The long end is then passed behind the spinous process of C2 and through the interspinous tissue *(dotted line).* A second loop is then made around the right C1 posterior arch remnant, again using a double-crimp device, and secured in the same fashion. **C,** The free ends of the multistrand cable from the two lassoed C1 remnants are passed over the bone graft, tensioned appropriately, and secured with a crimp. *(Reproduced with permission from Klimo P Jr, Binning M, Brockmeyer DL, et al: The lasso technique for posterior C1-2 fusion.* Neurosurgery *61(3 Suppl):94-99, discussion 99, 2007.)*

this is probably not necessary. With the immediate elimination of motion, postoperative pain is significantly reduced, and most patients can be discharged from the hospital in about 2 days. They are monitored with serial radiographs until fusion is assured (Fig. 55-18). Nontraumatic activities, including driving, are allowed as soon as the patient is comfortable and off of narcotic medications.

Results and Complications

Numerous series report excellent stabilization and fusion rates with transarticular fixation. Magerl and Seeman's initial series reported a 100% fusion rate,[48] whereas Grob and colleagues[60] reported a 99% success rate in 161 patients, Stillerman and Wilson[61] had a 95% rate of successful fusion (21 out of 22 patients), and Marcotte and associates[62] had a 100% rate of fusion (in 18 patients). Gluf and coworkers[63] reported successful fusion in 98% of 191 adult patients and had similar results in an additional 78 patients after publication.

The Goel-Harms construct has also been shown to be highly effective in promoting stabilization and fusion. Biomechanically, transarticular screw fixation with posterior wiring remains the most stable construct,[64] but fusion rates and clinical outcomes between transarticular screw fixation and various C1-2 screw-rod constructs appear to be similar.[65]

The techniques used to place either transarticular screws or screw-rod constructs are technically demanding and require a good knowledge of nuances in anatomy and thorough preoperative evaluation.[66] Neurologic complications from direct injury have not been reported; however, vertebral artery injuries have occurred, and in one case bilateral vertebral artery injuries resulted in a fatal brain stem infarction.[67] Unilateral injuries often do not result in neurologic sequelae but have produced arteriovenous fistulas, which may present as delayed spinal cord compromise from epidural venous engorgement.[50] Although risk of vertebral artery injury exists for both transarticular and Goel-Harms techniques, multiple studies suggest that this risk is significantly higher for transarticular screw placement.[68,69]

Fusion of C1 to C2 will, of necessity, restrict head rotation by about 50%. In a normal patient, this leaves a residual motion of ±45 degrees. Younger patients can regain some lost motion, often to a surprising degree, presumably by gaining extra motion in the subaxial facet joints. Less limber older patients must learn to compensate by torso rotation, and usually they will do so without difficulty. Paradoxically, some patients have improved motion almost immediately after surgery, because the pain-provoked cervical muscle spasm subsides. Occasionally, patients complain of occipital numbness. This is presumably the result of C2 nerve root trauma during

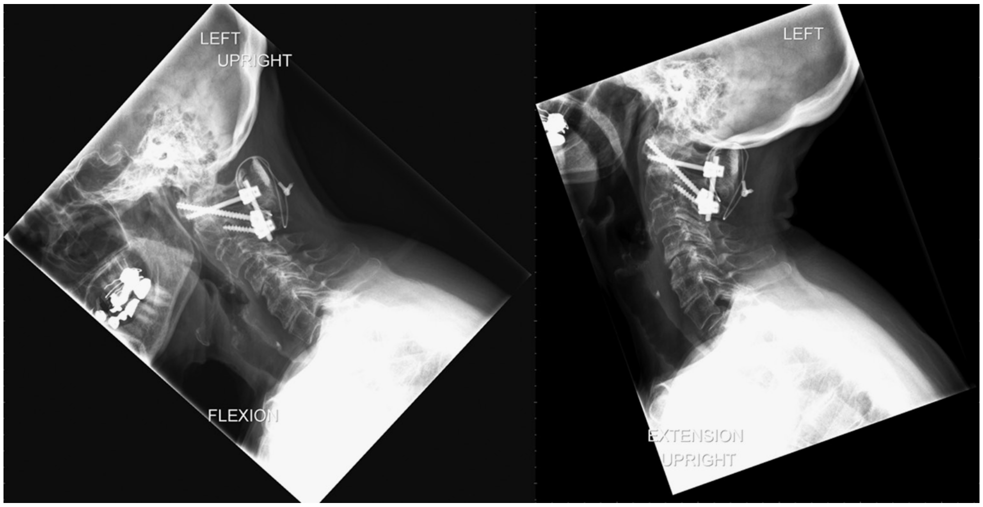


Figure 55-18. Postoperative dynamic radiographs demonstrating fusion across C1-2.

surgery and usually resolves within 3 to 6 months. Transection of the C2 nerve can also lead to persistent occipital neuralgic pain that remains refractory to medical treatment.[70]

OCCIPITOCERVICAL FUSION

Instability or degeneration of the occiput-C1 joint or basilar invagination may require incorporation of the occiput into an upper cervical fusion. In the past, various plates or rod/plate devices were used to extend the hardware up from the C1-2 screws. The disadvantages with these systems have been resolved by using polyaxial screws at C1-2 (or individually at C1 and C2 if the Goel-Harms or Wright techniques are used). A contoured or hinged rod from these can then be attached to a plate that is secured to the occiput (Fig. 55-19). Besides being easier to apply, the occipital plate can be fixed to the midline bone, which is the thickest and strongest portion of the occiput. A longer graft secured in the same manner as described for C1-2 fusions can be extended to the occiput and apposed to a denuded area to maximize incorporation potential. A small bone screw inserted through the graft into the occiput can enhance this contact.

For calvarial fixation, 4.5- to 5.5-mm screws can be used in a bicortical manner. In the midline, 10- to 12-mm (or longer) screws may be used, but often only 6- to 8-mm screws can be accommodated laterally. Screw depth is determined by a combination of sensation when drilling, using a special drill guide that allows advancing the drill bit in millimeter increments, and by probing the hole with a depth gauge. The construct can also be extended subaxially, if needed, by using a longer contoured rod connected to lateral mass screws.

Inclusion of the occiput into an upper cervical construct may be complicated in situations where an occipital plate cannot be used, such as in patients who have previously undergone posterior fossa decompression. In these patients, alternative techniques incorporating the occipital condyle into the construct may be used. One method utilizes occipital condyle screws placed 4 to 5 mm lateral to the condylar/occipital junction and directed 10 to 20 degrees medially toward the basion.[71] The second method incorporates occiput-to-C1 transarticular screws inserted at the center of the inferior C1 lateral mass at its junction with the C1 posterior arch, directed 10 to 20 degrees medially and 45 degrees superiorly.[72] Both techniques have shown similar biomechanical properties in cadaveric testing to standard occipital plate constructs. Caution must be used as these techniques increase exposure of the vertebral artery, placing it at risk of direct injury. Furthermore, the hypoglossal nerve remains at risk if its canal is violated, although the risk is lower because of the bony confinement of the screw in the condyle, if the appropriate trajectory is maintained.[71]

Figure 55-19. Lateral radiograph demonstrating occipital plate with midline screws connected by contoured rods to bilateral C2 pars screws. Structural bicortical iliac crest bone is placed between the rods and held in apposition to the bone with the braided titanium cable.

SUMMARY

Screw fixation techniques have proved to be safe and extremely effective in the upper cervical spine, whereas previously used operative and nonoperative techniques have been only partially effective in this highly mobile region. In addition, earlier and nonoperative techniques have often required prolonged rigid external immobilization, resulting in prolonged inability to function normally or sacrifice of more normal motion than necessary to protect the neural elements.

The major screw fixation techniques in this region include both ventral and dorsal, as well as motion-sparing, approaches. Ventrally, if appropriate, direct screw fixation of the odontoid yields high fusion rates with excellent clinical outcomes. Among other ventral approaches, the ventral transarticular fixation has not gained favor because it does not allow for bone graft placement. Dorsally, C1-2 fixation using transarticular screws or C1 lateral mass screws coupled with C2 pars, pedicle, or laminar screws provides immediate stabilization. When combined with structural bone grafting, these techniques yield high fusion rates with excellent clinical outcomes.

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