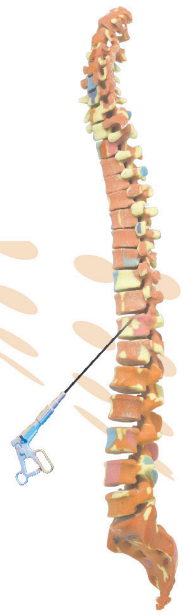
CHAPTER 18



Occipitocervical Fusion

Ben J Garrido, Rick C Sasso

INTRODUCTION

Occipitocervical fusion may be indicated for multiple disease processes that render the craniocervical junction unstable. The etiology may include trauma, rheumatoid arthritis, infection, tumor, congenital deformity and degenerative processes. This junctional area between the mobile cervical spine and the rigid cranium offers fixation challenges and has a high incidence of significant and devastating spinal cord injury. Historically, stabilization of this junction dates back to 1927 when Foerster[1] utilized a fibular strut graft construct. Since then, other nonrigid methods of stabilization have been tried including wire fixation, pin fixation, hook constructs and many others with onlay bone graft and halo immobilization.[2] Unfortunately, these options required cumbersome, prolonged, postoperative external immobilization including a halo-vest or Minerva jacket to improve fusion rates and sometimes extended bed rest with traction. In an attempt to improve fusion rates, clinical outcomes and reduce the use of external immobilization, rigid internal fixation has evolved.

In the early 1990s, occipitocervical plate and screw fixation was developed, which provided immediate rigidity to the spine thus eliminating postoperative halo-vest immobilization.[3-6] In addition, it was not necessary to pass a sublaminar wire, which was a risky aspect of the Luque fixation[7] technique. Despite these advantages, plate and screw constructs have some limitations. These include a fixed hole to hole distance, which may not match patient anatomy preventing optimal screw placement, plate bulk limiting space for graft material and inability to compress or distract across interspaces.[8] Occipital plate fixation also limited the ability to place occipital screws along the midline, the thickest and strongest bone area in the occiput.

In the mid 1990s with the advent of rod-screw instrumentation the limitations of plates were eliminated. Not only did screws provide excellent fixation, but the use of rods allowed unlimited screw placement. There was greater space for bone grafting, but also the ability to compress or distract became available.[8]

Occipital fixation has also improved dramatically due to the use of rigid fixation with contoured rod-screw instrumentation. Bicortical placement in the thickest and strongest bone along the occipital midline offers a biomechanical advantage and promotes stability, rigidity, thereby increases fusion rates. A technique that utilizes medial offset connectors and rods has been described, that allows placement of a total of six occipital screws in the parasagittal plane along the occiput midline.[9] Several studies have also compared the stability of various occipitocervical constructs[10-13] and demonstrated that rigid occipitocervical fixation is superior to wiring or other nonrigid techniques. A recent clinical comparison of short-term outcomes confirmed a statistically significant lower rate of complications and superior clinical outcomes with rigid versus nonrigid occipitocervical fusion constructs.[14]

With the development of universal screw-rod instrumentation, techniques for stable cervical screw anchors are proliferated. C1 lateral mass screw fixation, C2 pedicle screw fixation, C2 translaminar screw fixation, C1–C2 transarticular screws and subaxial lateral mass screws are now all attach either directly or through offset connectors to a longitudinal rod.[9] These common cervical anchors provide rigid stability and have been found to be biomechanically superior to previous nonrigid fusion constructs. Universal screw-rod internal instrumentation has improved the fusion rates and allowed immediate stability. The evolution of this instrumentation technology has resulted in the best opportunity to improve clinical outcomes and mitigate complications associated with nonrigid constructs.

ANATOMY

Stabilization of the occipitocervical junction requires comprehensive knowledge of the anatomy. For safe placement of occipital screws anatomical knowledge of regional occipital bony thickness and location of venous sinuses is essential. Anatomic studies of the occiput have demonstrated that the external occipital protuberance is the thickest in the midline and decreases as you move laterally and inferiorly.[15] Screw fixation is preferred below the level of the superior nuchal line to avoid a transverse sinus injury and along the dense midline ridge below the external occipital protuberance.[16] The superior sagittal sinus runs from the confluence of both transverse sinuses superiorly along the occipital midline (Fig. 1). The quality of this midline bone stock is optimal and is the ideal occiput screw fixation point desired.

For atlantoaxial instrumentation and fixation multiple fixation methods may be utilized including transarticular screws, C1 lateral mass screws, C2 pedicle, pars or translaminar screws. Transarticular screws require a drill trajectory that starts at the C7–T1 region. Thus, excessive kyphosis precludes the ability to obtain the approach angle. Likely the presence of an irreducible C1–C2 subluxation, deficient C2 bony pars or aberrant medialized vertebral artery excludes this option. These anatomical variations must be evaluated as part of the preoperative plan.

The atlas is a large ring comprised of two large lateral masses connected by an anterior and posterior arch. The lateral masses are wedge shaped and are congruent with the occipital condyles. The posterior arch contains a groove superiorly in which the vertebral artery lies.

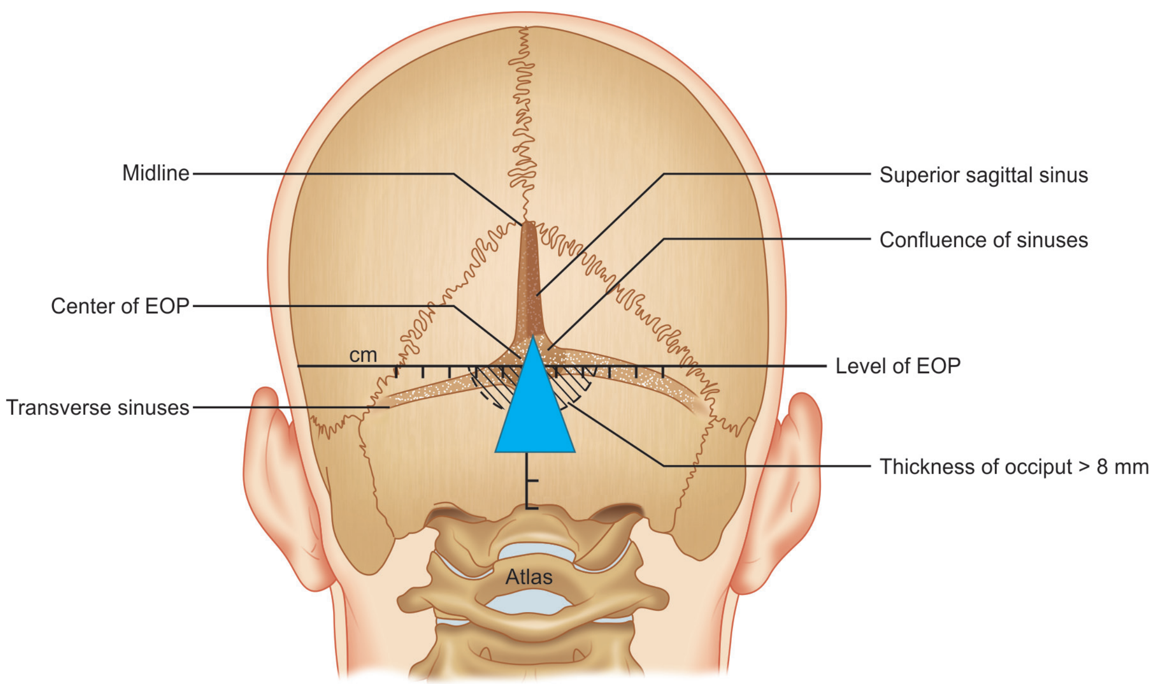


Fig. 1: Posterior occipital anatomy, transverse, superior sagittal and confluence of sinuses. Triangular area in the figure denotes ideal occipital screw placement

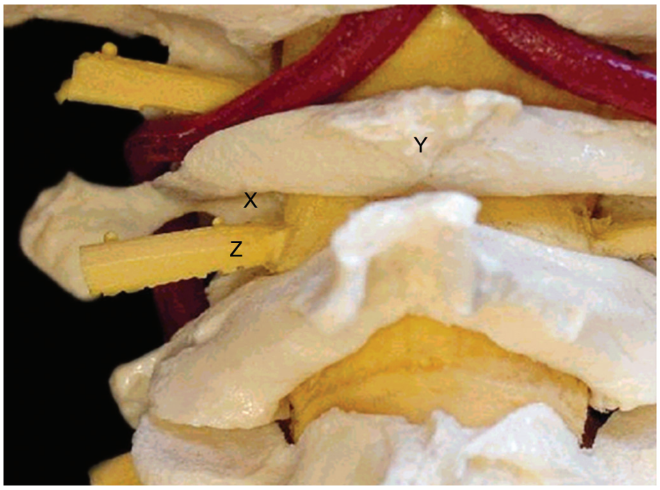


Fig. 2: Bony anatomy–C1 lateral mass, posterior arch, C1–2 joint. *Key*: X= C1: Lateral mass; Y= C1: Posterior arch Proper; Z= C1–2: Joint below the C2 nerve root

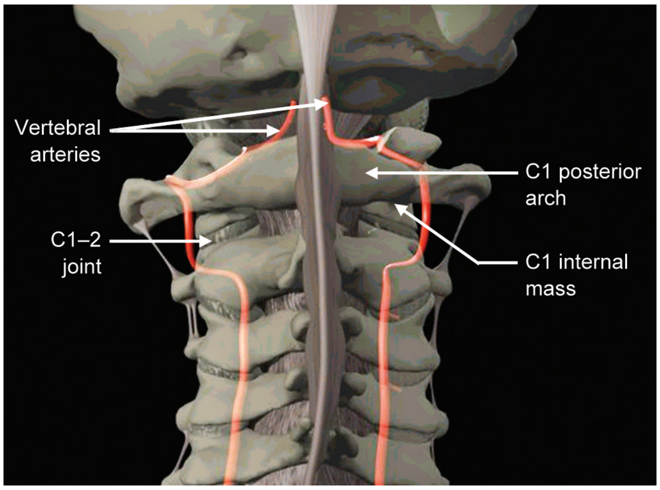


Fig. 3: Vertebral artery course through C1–2

The C1 lateral mass lies anterior to the C1 posterior arch and must be carefully exposed to avoid venous plexus bleeding between C1 and C2. Subperiosteal reflection along the C1 posterior arch lateral undersurface facilitates lateral mass exposure without bleeding (Fig. 2). Once exposure of the posterior aspect of the C1 lateral mass is achieved, the C2 nerve with its venous sinusoid can be retracted caudally to expose the joint. Width of the C1 lateral mass should be established to avoid medial or lateral screw placement and potential spinal cord or vertebral artery injury respectively. After perimeter margins are delineated, C1 lateral mass screw may be placed as popularized by Harms and Melcher.[13]

The axis is unique with the dens projecting cranially from the body to articulate with the anterior arch of the atlas and transverse ligament. Large lateral masses project laterally from the body. The lateral masses connect to the posterior elements through pedicles and a narrow bony isthmus or pars interarticularis. The C2 spinous process is bifid and serves as an attachment of the nuchal ligaments and cranial rotator muscles. The course of the vertebral arteries through the axis is variable and must be understood to minimize injury during surgery (Fig. 3). There are several options for axis screw fixation dependent on patient anatomy and surgeon preference. C2 pedicles should be evaluated on CT images for bony deficiency or a high riding vertebral artery that would exclude pedicle screw fixation as a viable option. It is mandatory to differentiate between a screw placed into the C2 pars interarticularis and one placed into the C2 pedicle. These screw sites are not identical and possess distinct challenges of insertion and different potential complications.

The confusion between the positions of these screw types lies in the unique anatomy of the C2 vertebra. The pars interarticularis is the region of bone between the superior and inferior articular processes. The pedicle is the region of bone that connects the posterior elements to the vertebral body. Because the superior articular process of C2 is extremely far anterior, the pars interarticularis is very large. This anterior position of the superior articular process also creates a very narrow and short window for connection to the C2 body—the pedicle.

The C2 pars interarticularis screw is in the exact position as a transarticular C1–C2 screw, except it stops short of the joint. The entry point is the same [approximately 3 mm superior and 3 mm lateral to the medial aspect of the C2–3 facet joint, (Fig. 4)]. As with transarticular C1–2 screws, the greatest risk associated with placement of the C2 pars screw is injury to the vertebral artery. Although it is a shorter version of the transarticular screw it follows the same trajectory stopping short of the C1–2 joint.

The C2 pedicle screw follows the path of the pedicle into the vertebral body. For a screw to be inserted into the C2 vertebral body from the posterior elements, it by definition has to pass through the pedicle. The entry point is significantly cephalad to the entrance for the pars screw and slightly laterals (Fig. 4). The medial

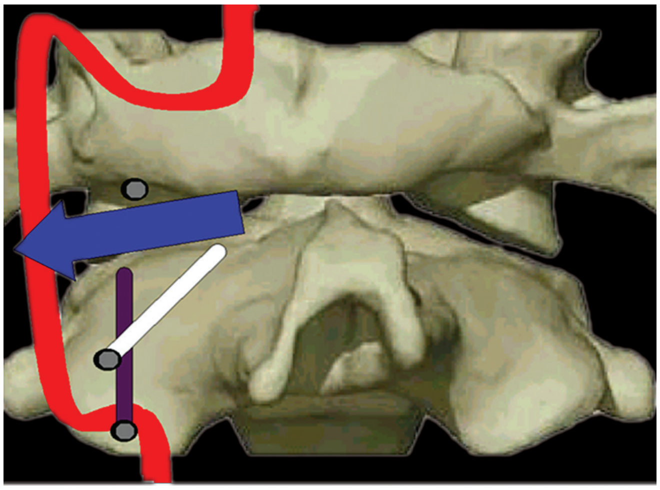


Fig. 4: Screw entry points for C1, C2, pars versus pedicle screw fixation and their relationship to the vertebral artery and C2 nerve root (In the figure starting points and trajectory for C2 pars (purple) and pedicle (white) screws. The vertebral artery is red. The blue arrow is the C2 nerve root. The gray dot above the arrow is the starting point for the C1 lateral mass screw)

angulation is significantly more than that of the pars screw, approximately 20–30°, while the pars screw is placed almost straight ahead. This cephalad-starting point and medial angulation makes the pedicle screw less likely to injure the vertebral artery. The artery runs from medial to lateral in front of the C2–3 facet joint. The pedicle screw starts cephalad from the artery compared to the pars screw where the artery may be medial or just anterior to the starting point (Fig. 4). In addition, the pars screw does not have a steep medial trajectory and is closer to the artery as it moves toward the superior articular process. The C2 pedicle screw cephalad trajectory is also not as steep; approximately 30° compared to over 45° with the pars screw, and can usually be placed through the incision. The pars and transarticular screws need to have a very steep cephalad trajectory to keep away from the vertebral artery, which usually requires placement through percutaneous stab incisions at the cervicothoracic junction.

SURGICAL INDICATIONS

The occipitocervical junction is susceptible to a wide variety of pathologic conditions, which predispose it to instability. Any patient with instability, either from trauma, rheumatoid arthritis, infection, congenital or tumor etiologies experiencing a neurologic deficit will require arthrodesis. All cases with dislocation require primary surgical stabilization with a posterior occiput to cervical fusion. The most common causes of occipitocervical instability are due to rheumatoid arthritis with associated vertical migration of the odontoid and from trauma with incompetent ligamentous structures of the occipitocervical junction; although these cases are becoming less common due to improved antirheumatic medications.

SURGICAL TECHNIQUE STEP BY STEP

Initial evaluation of head position in relation to the chest is important and can determine a potential dislocation and its direction. Anterior, posterior or vertical displacement injuries can occur and will require reduction. Although, tong traction can play a role in reducing deformities or dislocations, it has potential for harm if not used judiciously. For vertical displacement injuries it is important not to further distract them with tong placement and perform expeditious definitive fixation. Anterior dislocations can be reduced via a roll under the shoulders allowing the head to fall back. Likewise, posterior dislocations reduce simply by placing the head on a pillow or blankets allowing it to translate forward. This reduction across the occipitocervical junction should occur under direct fluoroscopic visualization of the occiput and upper cervical spine. If surgical stabilization is delayed following any reduction close and frequent evaluation both clinically and radiographically must be performed until definitive fixation. Patients with a cervical or occipitocervical injury can initially be placed in tong traction until operative fixation. No significant traction needs to be applied to this system; 2–3 lbs will suffice in maintaining a neutral anatomic position. Tong traction also denotes the severity of the injury to other health care personnel and offer a head handle for facilitating transfers and intraoperative head positioning.

Patients should be considered for an awaken fiberoptic nasal or endotracheal intubation while neuromonitoring is performed. Patients need spinal cord monitoring throughout the procedure. Prone positioning on the Jackson table using either a Mayfield 3-pin head holder or Gardner-Wells tong axial traction with Mayfield headrest are author's preferred method.

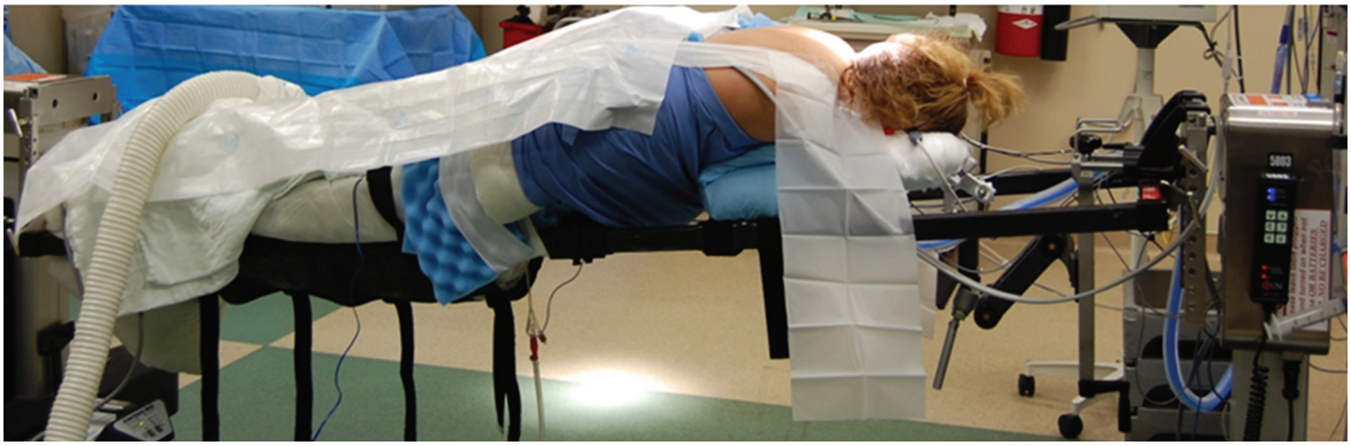


Fig. 5: Intraoperative patient positioning. Prone position, reverse Tredenlenburg, Mayfield headrest. Although an option, no axial traction is used in this example

After the patient is positioned, radiographic studies are performed to confirm satisfactory anatomical alignment.

The posterior cervical approach is facilitated with slight cervical kyphotic positioning and minimal traction. It is critical to correct sagittal alignment prior to fusion. The patient is also placed in a reverse Trendelenburg position to decrease venous bleeding (Fig. 5). Fusion is done using a variety of fixation techniques; rod and screw fixation is authors' preference.

Rigid screw fixation is widely accepted for the occipitocervical junction and provides excellent stability and increases construct rigidity.[8-10] Authors place their cervical fixation in the form of C2 laminar or pedicle screws with C1 lateral mass screws. Posterior C1 arch lateral exposure should not extend beyond 15 mm from midline on the cephalad aspect; any further dissection could result in vertebral artery injury (Fig. 4). Dissection to the lateral mass of C1 at the C1–2 joint requires a significant anterior course from the lateral posterior C1 arch (Fig. 2). During this exposure an extensive venous plexus surrounding the C2 nerve root can be a significant source of bleeding. Subperiosteal dissection to this anterior C1 lateral mass is critical in order to mobilize the C2 nerve and its venous plexus. The screw entry point is at the cephalad, center aspect of the lateral mass and exposure is facilitated by caudal C2 nerve root displacement (Fig. 2). Lateral fluoroscopic images are then used to facilitate correct drill trajectory, medial angulation is usually 10–15°. It is important to note that the inferior rim of the C1 posterior arch may obstruct adequate visualization of the C1 lateral mass and appropriate drill trajectory. Authors recommend meticulously removing this inferior rim with a kerrison rongeur or burr without cephalad penetration to avoid vertebral artery injury. This will improve drill and screw placement angle.

Once the cervical spine anchors are in place author preferred occipital fixation that includes placement of three paired screw just off midline in the parasagittal plane. Rods are bent to the appropriate occipitocervical sagittal lordotic angle, contoured to lie flat on the occiput and cut so not to pass the superior nuchal line. Three medial offset connectors (Fig. 6), the preferred technique of the authors, are inserted onto the cephalad aspect of each rod and the best zone for occiput screw insertion is defined. The most cephalad screws are placed immediately lateral to the external occipital protuberance (EOP) below the superior nuchal line and close to midline. Subsequent caudal screws are placed as close to midline as possible to maximize bone purchase (Figs 7A and B). Screws should not be placed inferior to the inferior nuchal line where the bone is thin. Bicortical occipital fixation is attained for both stronger purchase and avoidance of screw abutment against the far cortex and risk of stripping proximal cortical threads. During hole preparation, if CSF leaks or venous bleeding develops, quick placement of the screw will suffice. Upon completion a total of six occipital bicortical paramedian fixation points are established with an average screw length of 10 mm. After occipital and cervical screws are placed a rod is bent to match a neutral sagittal occipitocervical angle, contoured to lie flat on the occiput and cut to not pass the superior nuchal line. Attention to head position for fusion should avoid extension, flexion or rotation and requires a neutral occipitocervical angle; defined as a mean angle of 44° between a line intersecting the basion and opisthion and a line parallel to the superior endplate of C3. With the contoured rod sagittal apex about the posterior arch of the atlas, the cephalad aspect of the rod can easily be rotated toward the midline. Rod rotational variability and offset connectors provides great coronal plane versatility optimizing connection to the occiput. The rod is then connected to cervical fixation points directly or with offset connectors, if required.

Lastly, an optimal environment for fusion is prepared by decortication using a high-speed burr and bone graft is placed underneath and lateral to the rod construct. Many options exist for bone graft; however, autograft remains the gold standard in most cervical fusions despite associated morbidity of harvest sites including the iliac crest. If decompression is performed it is important to avoid graft placement into the defect and on the dura. With rigid internal fixation, occipitocervical pseudarthrosis is extremely rare even with local bone graft and graft extenders. Thus, harvesting iliac crest autograft is becoming less common.

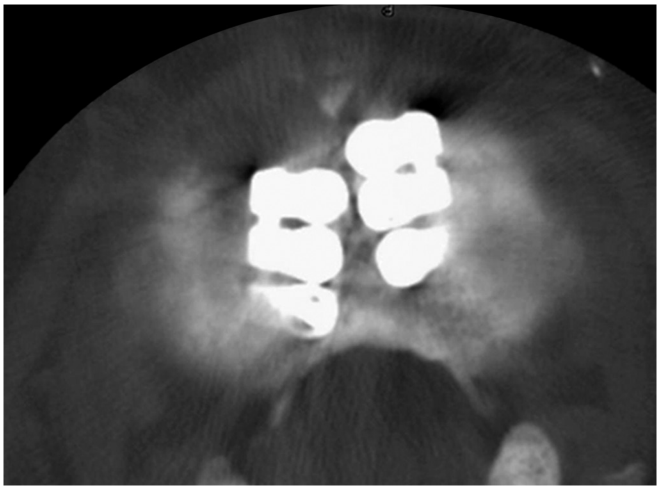
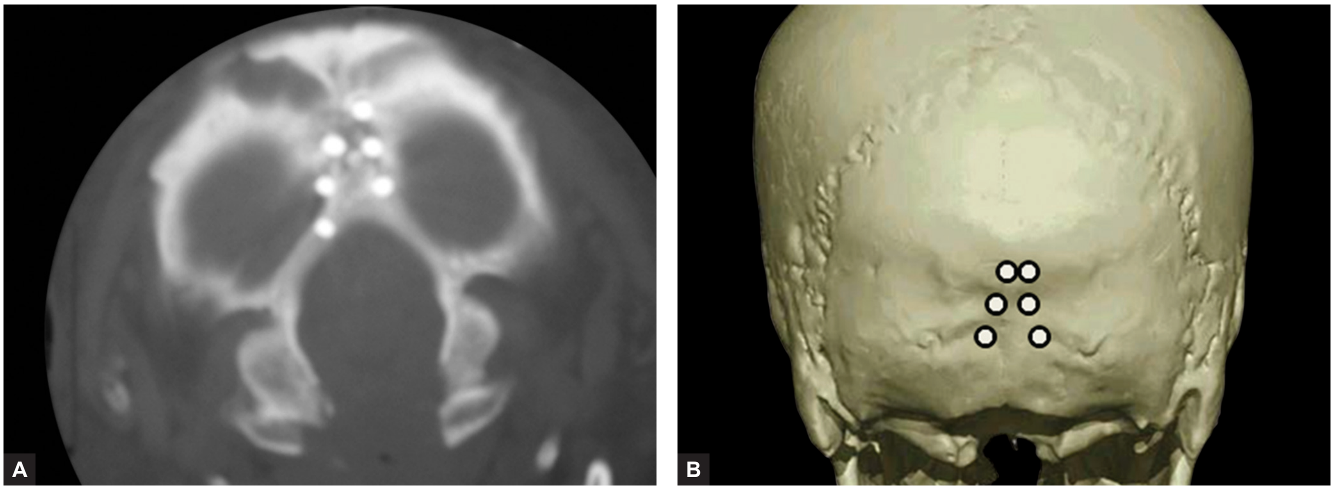


Fig. 6: Medial offset connectors for occipital fixation

POTENTIAL COMPLICATIONS

Complications of occipitocervical fusion can be serious. Many of the early adverse events were associated with nonrigid fixation including placement of sublaminar wires and halo external immobilization required afterward. Complications with sublaminar wire placement including loss of fixation, acute or chronic spinal cord and brainstem injury and associated halo immobilization problems including pin tract infections, osteomyelitis, nerve injury, pulmonary complications and death have been described.[2,8,14] Nonrigid fixation lacks rotational stability and has been shown to have higher complication rates compared to rigid fixation.[14] Biomechanical studies have also shown superior stability with rigid screw fixation.[10-12]

Occipital screw misplacement can also lead to problems. If not positioned close to the superior nuchal line then inadequate occipital thickness may be encountered and poor purchase may result. Also, if the far cortex of the occipital bone is not drilled or tapped the screw can strip its proximal cortex threads when it reaches the far cortex. If a significant amount of occipital bone has been resected or lost, placing three screws below the superior



Figs 7A and B: Midline occipital screw fixation points nuchal line may be very difficult. If screws are then applied cephalad to the superior nuchal line the transverse venous sinus may be encountered penetrating the intracranial venous sinus. An attempt to repair this sinus is problematic and the best option is to simply place the screw.

Transarticular C1–2 screws require anatomic reduction intraoperatively to avoid complications of vertebral artery injury, neurologic deficit or inadequate bony purchase. A precise drill trajectory is critical and is performed under biplanar fluoroscopic imaging or the use of a navigation system. These screws are potentially the most dangerous screw because of the potential for vertebral artery injury.[17,18] They may be contraindicated if anomalous vertebral artery anatomy exists, pronounced thoracic kyphosis inhibiting drill angle or proper C1–2 reduction is not feasible. This technique is technically demanding and has had variable vertebral artery injury rates reported in the literature. Wright et al.[17] have reported a 4% risk of injury. If vertebral artery injury does occur, place the screw across the joint and obtain an angiogram postoperatively. Do not drill across the contralateral joint if one vertebral artery is compromised.

C1 lateral mass screw placement can also result in C2 nerve root injury and extensive venous plexus bleeding. Precise knowledge of the anatomy and entry point for the C1 lateral mass screw is required. Caution must be taken to avoid a medial starting point or medial penetration which could result in dural or spinal cord injury. Bicortical fixation is not required and avoids potential injury to either the hypoglossal nerve or the internal carotid artery, which lie anterior to the C1 lateral mass.

C2 pedicle screws can also be a potential hazard to the vertebral artery, if incorrect entry point is confused for that of the pars screw. C2 pedicle anatomic location must be clearly differentiated from the pars (Fig. 4). The C2 pedicle entry point is more cephalad and lateral than the pars screw entry point. Most importantly, the greater medial trajectory of the C2 pedicle screw makes it less likely to injure the vertebral artery. Avoiding spinal cord injury through a medial cortical breech is also critical hence the medial border of the pedicle is usually palpated to triangulate appropriate drill trajectory.

After instrumentation and/or decompression is performed the optimal environment for fusion must be established. Autograft bone is the gold standard and should be placed into a bleeding decorticated cancellous bed. Decortication must be performed with a high-speed burr and grafts placed underneath and lateral to the rod construct. If decompression is performed it is important to avoid graft placement into the defect and on the dura. Meticulous technique must be implemented when using the high-speed burr over an exposed spinal cord.

KEY POINTS

- The evolution of occipitocervical fixation and new rigid universal screw-rod construct technology has allowed secure anchorage at each level of the occipitocervical junction with the elimination of rigid external orthoses.
- Rigid occipitocervical instrumentation constructs have achieved higher fusion rates and less postoperative immobilization associated complications. Outcomes have improved compared to former nonrigid instrumentation techniques.
- With the advances of rigid occipitocervical stabilization capability has come with new challenges, risks and operative techniques. A thorough understanding of the relevant cervical bony and soft tissue anatomy is essential for safe implantation and a successful outcome.
- Early ambulation is encouraged. A Miami J or Philadelphia collar can be used for 12 weeks postoperatively. These patients should be followed closely for any progressive deformities or neurologic deficit that may develop.

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