Chapter 35

Occipitocervical Fusion

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Occipitocervical fusion may be indicated for multiple disease processes that render the craniocervical junction unstable. Causes include trauma, rheumatoid arthritis, infection, tumor, congenital deformity, and degenerative processes. This junctional area between the mobile cervical spine and the rigid cranium presents 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] used a fibular strut graft construct. Since then, other nonrigid methods of stabilization have been used, including wire fixation, pin fixation, hook constructs, and many others with bone graft and halo immobilization.[2] Unfortunately, these options required cumbersome, prolonged, postoperative external immobilization, extended bed rest in traction, and a halo vest or Minerva jacket to improve fusion rates. In an attempt to improve fusion rates and reduce the use of external immobilization, rigid internal fixation evolved.

In the early 1990s, occipitocervical plate and screw fixation was developed, providing immediate rigidity to the spine and eliminating postoperative halo vest immobilization.[3-5] In addition, it was not necessary to pass a sublaminar wire, which was the most risky aspect of the Luque fixation technique.[6] Despite these advantages, plate and screw constructs have multiple limitations. These include fixed hole-to-hole distances that may not match patient anatomy and can prevent optimal screw placement. The bulk of the plate construct limits space for graft material, and plates are unable to compress or distract across interspaces.[7] Occipital fixation with plates also limits the ability to place occipital screws along the midline, the thickest and strongest area of bone in the occiput.

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With the advent of rod–screw instrumentation in the mid-1990s, the limitations of plates were eliminated. Not only do screws provide excellent fixation, but rods allow unlimited screw placement. There is greater space for bone grafting, and compression or distraction is possible.[7]

Occipital fixation has also dramatically improved with the use of rigid fixation with contoured rod–screw instrumentation. Plates constrain the ability to place occipital screws along the midline, thus compromising strength because of the thinner and weaker bone laterally. Bicortical placement in the thickest and strongest bone along the occipital midline offers a biomechanical advantage and promotes stability, thereby increasing fusion rates. With the use of medial offset connectors and rods, a total of six occipital screws can be placed in the parasagittal plane along the midline.[8] Several studies have also compared the stability of various occipitocervical constructs.[8-10] They demonstrate that rigid occipitocervical fixation is superior to wiring techniques.

With the development of universal screw–rod instrumentation, techniques for stable cervical screw anchors proliferated. C1 lateral mass screw fixation, C2 pedicle screw fixation, C2 translaminar screw fixation, C1-2 transarticular screws, and subaxial lateral mass screws can now attach either directly or through lateral connectors to a longitudinal rod.[11] These common cervical anchors provide rigid stability. Universal screw–rod internal instrumentation has improved fusion rates and provided immediate stability. The evolution of this instrumentation technology has resulted in the best opportunity to improve clinical results.

INDICATIONS AND CONTRAINDICATIONS

The occipitocervical junction is susceptible to a wide variety of pathologic conditions that predispose it to instability. Patients with instability from trauma, rheumatoid arthritis, infection, tumor, or congenital causes who have a neurologic deficit will require arthrodesis. The most common causes of occipitocervical instability are rheumatoid arthritis and associated vertical migration of the odontoid, and trauma with incompetent ligamentous structures of the occipitocervical junction.

PREOPERATIVE ASSESSMENT AND EVALUATION

Occipitocervical instability can be a result of violent, high-energy deceleration-acceleration injuries. The integrity of the alar ligaments, their bony attachments, and the tectorial membrane may be compromised. On examination, there is a high incidence of coincident craniofacial trauma. Improvements in the response and management of trauma patients have increased survival from fatal brainstem injuries. Patients with less instability may have a variety of manifestations, including myelopathy, suboccipital pain, occipital headaches, cranial nerve dysfunction, paralysis, and paresis, or they can be asymptomatic. Surgeons must have a thorough knowledge of the associated anatomy and radiographic findings. After a traumatic event, patients may present obtunded or unconscious, and the diagnosis will depend on radiographic findings. Family and patients who present awake should be well educated on the variety of stabilization techniques, implants, and morbidities, including both internal rigid and external halo immobilization.

With an unstable injury, flexion-extension radiographic views are not recommended because of the risk of spinal canal compromise with these maneuvers. Radiographic parameters, including "Power's ratio" and the "rule of 12," help define normal radiographic relationships on lateral views and can suggest occipitocervical injury. Power's ratio helps diagnose an anterior dislocation and is defined as basion–posterior atlas interval/opisthion–anterior atlas arch interval. It is equal to 1 or less in normal individuals on lateral radiographs. If the value is greater than 1, the patient most likely has an anterior occipitocervical subluxation or dislocation (Fig. 35-1). This ratio cannot diagnose a posterior occipitocervical dislocation or a pure vertical distraction injury.

The rule of 12 is more sensitive and defines normal relationships. According to this rule, there should be less than 12 mm of distance between the basion and the tip of the dens, and the basion should be within 12 mm of the posterior cortex of the axial body (Figs. 35-2 and 35-3). Unfortunately, determining these landmarks and visualizing occiput-C1 alignment and magnitude of dislocation can be difficult on plain films.

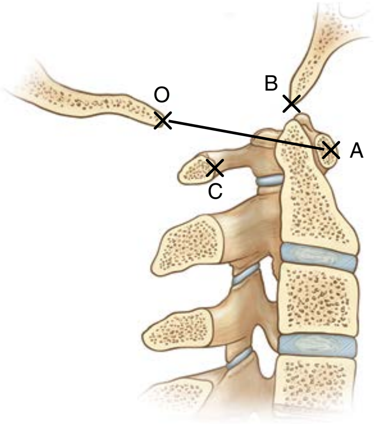

Fig. 35-1 Power's ratio = BC/AO. (*A,* Anterior arch of atlas; *B,* basion; *C,* posterior arch of atlas; *O,* opisthion.)

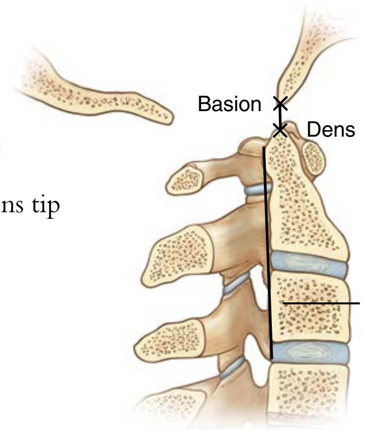

Fig. 35-2 The distance from the basion to the dens tip should be less than 12 mm.

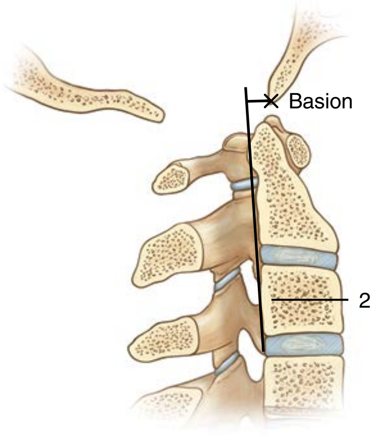

Fig. 35-3 Fig. 35-3 The distance from basion to the posterior axial body line should be less than 12 mm.

With soft tissue shadows overlying bony structures, artifacts, and poor radiographic technique, occipitocervical dislocations can be missed. CT is more sensitive and can confirm the diagnosis of atlantooccipital dislocation and precisely evaluate magnitude of displacement.[12] In addition, MRI can clearly show ligamentous disruption and details about soft tissue swelling and identify spinal cord edema and epidural hematomas.

PREOPERATIVE PLANNING

Stabilization of the occipitocervical junction requires comprehensive knowledge of the anatomy. For safe placement of occipital screws, it is essential to understand the regional anatomy and occipital bony thickness and location of venous sinuses. Thorough assessment is a prerequisite for restoring occipital spinal alignment, improving or stabilizing neurologic status, and maximizing the goal of fusion. The quality of bone stock, the presence of irreducible subluxation, and the medical condition of the patient should help guide the preoperative plan. Patients should also be considered for an awake, fiberoptic nasal or endotracheal intubation while somatosensory evoked potentials are monitored.

The head position in relation to the chest can determine the direction of dislocation. Anterior, posterior, or vertical displacement injuries can occur and will require reduction. Although tong traction can help reduce deformities or dislocations, it has potential for harm if not used judiciously. In our opinion, every patient with a cervical or occipitocervical injury should initially be placed in tongs. This helps stabilize them in rotation and shear, denotes the severity of the injury to other health care personnel, and offers a head handle for facilitating transfers and intraoperative head positioning. No significant traction needs to be applied to this system; 2 to 3 pounds will suffice to maintain a neutral anatomic position. Heavyweight traction of even 20 to 30 pounds can result in severe and devastating overdistraction.

Because these injuries are frequently highly unstable, anterior dislocations can often be reduced with a roll under the shoulders, allowing the head to fall back. Likewise, posterior dislocations may reduce simply by placing the head on a pillow or blankets, allowing it to translate forward. Tong or halo traction should be applied until operative fixation is achieved. After reduction and immobilization, close and frequent clinical and radiographic evaluation must be performed until definitive fixation has occurred.

For vertical displacement injuries, it is important to avoid further distraction after tong placement and to perform expeditious definitive fixation. This reduction across the occipitocervical junction should occur under direct visualization of the brainstem and upper cervical spinal cord dura intraoperatively.

All cases with dislocation require primary surgical stabilization with a posterior occiput to C2 fusion. Prone positioning on the Jackson table using either a Mayfield three-pin head holder (Integra LifeScience Corporation, Cincinnati, OH) or Gardner-Wells tong axial traction (Rudolf Storz, Emmingen GMGH, Germany) is our preferred method.

{AUTHOR: Please confirm or revise manufacturer names/locations.}

For patients in halo traction, the halo ring can often be connected directly to the operating table. After the patient is positioned, radiographic studies are performed to confirm satisfactory anatomic alignment.

Patients require spinal cord monitoring throughout the procedure for long-tract function, including somatosensory and motor evoked potentials, if available and not contraindicated. The posterior cervical approach is facilitated with slight cervical kyphotic positioning and minimal traction. It is critical to correct sagittal alignment before fusion. Postoperative kyphosis can increase subsequent subaxial degeneration and cause axial neck pain. Patients are also placed in a reverse-Trendelenburg position to decrease venous bleeding. Fusion can be performed using a variety of fixation techniques; rod and screw fixation is our preference.

SURGICAL TECHNIQUE

Understanding the osseous anatomy of the occiput and upper cervical spine is critical. Anatomic studies of the occiput have demonstrated that the external occipital protuberance is thickest in the midline and thins laterally and inferiorly. It is important to understand the safe working zone to avoid the dural sinuses, both the transverse and superior sagittal sinuses. The transverse sinus runs horizontally at the level of the superior nuchal line, and the superior sagittal sinus runs from the confluence of both sinuses superiorly along the occipital midline. Our preferred technique is placement of three paired screws just off midline in the parasagittal plane (Fig. 35-4). They should lie as close to the external protuberance and midline as possible. As one proceeds caudally, screws should be directed toward the protuberance to maximize purchase in the thick bone and minimize dural or venous sinus injury. Screws should not be placed inferior to the inferior nuchal line, where the bone is thin. Medial offset connectors can then be used to connect to rods (Fig. 35-5). Bicortical purchase is recommended, because it is stronger; however, studies have also suggested that unicortical fixation is sufficiently strong at the external occipital protuberance, because the inner cortical table is thin and contributes little additional strength.[13,14] During hole preparation, if CSF leakage develops, quick placement of the screw will suffice.

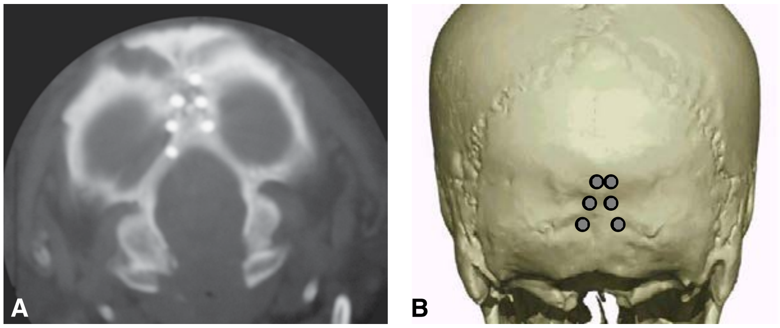

Fig. 35-4 **A** and **B,** Proper occipital screw placement close to the midline.

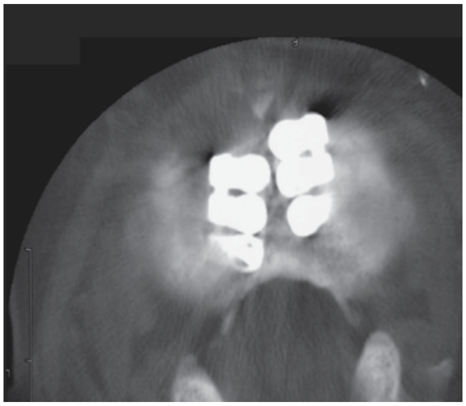

Fig. 35-5 Occipitocervical rods are bent to the anatomic sagittal angle, with three occipital screws attached to each longitudinal member through offset connectors that place the screws medially into the thickest bone.

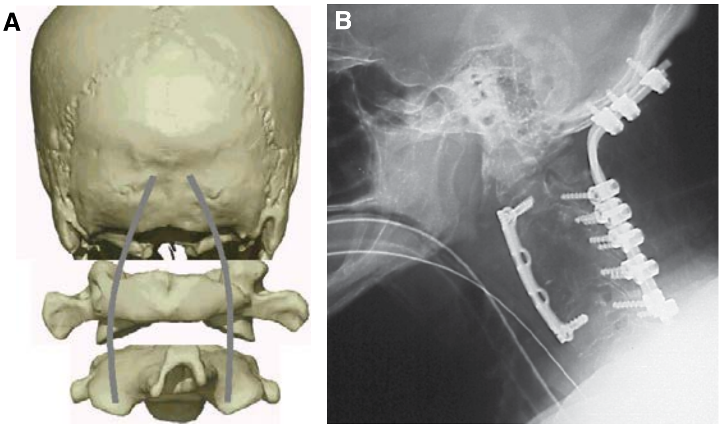

Fig. 35-6 **A** and **B,** Occipitocervical rods pivot on the apex at C1 with cephalad angulation toward the midline, allowing anchorage of the medially positioned occipital screws by offset connectors.

It should be noted that given the density of bone in the midline occiput, many commercially available systems use cortical bone screws, which differ from the more frequently used cancellous screws. These screws require precise drilling and tapping to depth and size. This prevents stripping the available bone and allows proper purchase and placement.

The caudal subaxial anchors in the cervical spine are usually the weakest link in the construct.[10,15,16] Transarticular C1-2 screws and C2 pedicle screws significantly increase construct rigidity compared with wires and hooks.[8-10] Rigid screw fixation is widely accepted for the occipitocervical junction and provides excellent stability. We first place our cervical fixation in the form of C2 translaminar or pedicle screws with C1 lateral mass screws. Attention to posterior C1 exposure is critical to prevent injury to the vertebral artery. Dissection of the cephalad aspect of the posterior arch of C1 should not extend more than 15 mm lateral to the midline. Once cervical spine anchors are in place, the rods are contoured anatomically. Then, three paired bicortical paramedian occipital screws are driven through offset connectors positioned on the medial aspect of the rods (Fig. 35-6).

In addition, an important step in any fusion is to prepare a bleeding host bone graft bed. Many options exist for the type of bone graft. Autograft remains the benchmark in most cervical fusions despite the associated morbidity of harvest sites, including the iliac crest. 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.

POSTOPERATIVE CARE

Increased rigidity provided by universal screw–rod constructs has decreased the amount of external immobilization required after surgery. Halo immobilization is not required with rigid internal fixation; therefore the potential morbidity, including pin tract infections, osteomyelitis, and nerve injury associated with halo immobilization, is avoided. This rigid fixation also allows earlier ambulation. A Miami J (Össur, Foothill Ranch, CA) or Philadelphia collar (Philadelphia Cervical Collar Company, Thorofare, NJ) can be worn for 12 weeks postoperatively. These patients should be followed closely for progressive deformities or neurologic deficits that may develop.

{AUTHOR: Confirm or revise manufacturer names/locations.}

COMPLICATIONS AND OUTCOMES

Complications of occipitocervical fusion can be serious (Box 35-1). Many of the early adverse events were associated with placement of sublaminar wires. Complications from loss of fixation and risks of halo immobilization, specifically pulmonary complications and death, have been described.[17,18] Nonrigid fixation lacks rotational stability and has been shown to have higher complication rates compared with rigid fixation.[19] In addition, reports of acute and chronic spinal cord and brainstem injury have been described with sublaminar wire placement.[2] Biomechanical studies have also shown superior stability with rigid screw fixation.[8]

Box 35-1 Minor and Major Complications of Occipitocervical Fusion

Minor Complications

- Halo vest–related pulmonary
- C2 nerve root injury
- Transverse venous sinus penetration
- Venous plexus bleeding
- Inadequate bony purchase
- Loss of fixation
- Pseudarthrosis

{AUTHOR: Halo vest–related pulmonary what?}

Major Complications

- Vertebral artery injury
- Spinal cord injury
- Brainstem injury
- Neurologic deficit
- Death

Occipital screw misplacement can also lead to problems. If they are not positioned close to the superior nuchal line, occipital thickness may be inadequate and poor purchase may result. Also, if the far cortex of the occipital bone is not drilled or tapped, the screw can strip its 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 nuchal line may be very difficult. If screws are then applied cephalad to the superior nuchal line, the transverse venous sinus may be encountered. An attempt to repair this sinus is problematic, and the best option is to 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 biplane fluoroscopic imaging or with a navigation system. These are potentially the most dangerous screws because of the potential for vertebral artery injury. They may be contraindicated in patients with anomalous vertebral artery anatomy. This technique is technically demanding and has had variable vertebral artery injury rates reported in the literature. Wright and Lauryssen[20] have reported a 4% risk of injury. If vertebral artery injury does occur, it is best to place the screw across the joint and obtain an angiogram postoperatively. One should not drill across the contralateral joint if one vertebral artery is contacted.

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. Dissection of the cephalad portion of the posterior arch of C1 should not extend beyond 15 mm lateral from the midline; further dissection should be on the middle to caudal aspect of the arch to avoid vertebral artery injury. Dissection to the lateral mass of C1 at the C1-2 joint requires a significant anterior course from the lateral posterior C1 arch (Fig. 35-7). During this exposure, an extensive venous plexus surrounding the C2 nerve root can be a significant source of bleeding. Subperiosteal dissection to this anterior lateral mass is critical to mobilize the C2 nerve and its venous plexus. The screw entry point is at the cephalad aspect of the lateral mass; exposure is facilitated by caudal C2 nerve root displacement.[21]

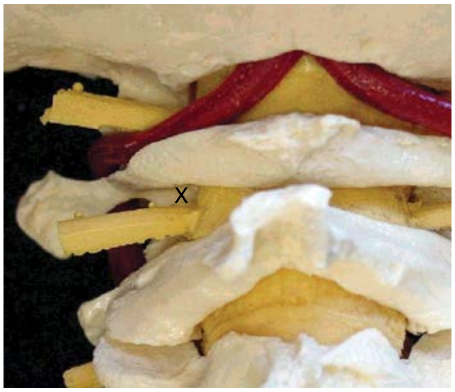

Fig. 35-7 The proper entry point *(X)* for a C1 lateral mass screw.

C2 pedicle screws can also be a potential hazard to the vertebral artery if the incorrect entry point is confused for that of the pars screw. The anatomic location of the C2 pedicle must be clearly differentiated from the pars (Fig. 35-8). The C2 pedicle entry point is more cephalad and lateral than the pars screw entry point.[21] Most important, the greater medial trajectory of the pedicle screw at C2 makes it less likely to injure the vertebral artery. The vertebral artery runs from medial to lateral at the C2-3 facet and thus is lateral to the more cephalad pedicle screw starting point, but the pars screw does not have such a medial trajectory and is closer to the vertebral artery.

{AUTHOR: Insert "screw" so that the sentence reads, "The C2 pedicle screw entry point….?"}

A significant degree of flexion-extension and virtually all rotation occurs in these spinal segments; therefore proper intraoperative positioning is critical, because patients will likely remain fixed in this position for life if fusion is successful. Care must be taken to ensure that patients are not positioned with the head rotated. In addition, hyperextension can result in problems with horizontal gaze and frequent falls, whereas hyperflexion can result in swallowing difficulties. Some surgeons have advocated preoperative halo vest fixation to ensure that patients are comfortable with the stature and position of the head before surgical intervention.

Lastly, our goal is to provide the best environment for fusion. Autograft bone is the benchmark and should be placed into a bleeding cancellous bed. Decortication must be performed with a high-speed bur and graft 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.

Despite the potential risks with the current rigid fixation techniques, complication rates have decreased substantially compared with nonrigid methods.

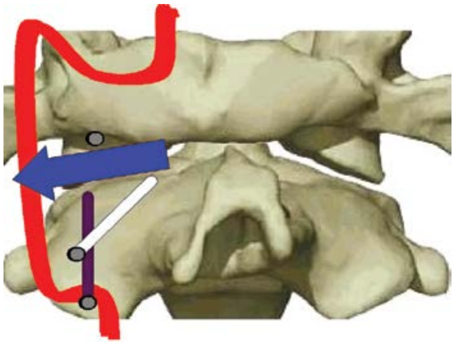

Fig. 35-8 The starting points and trajectory for C2 pars *(purple line)* and pedicle *(white line)* screws. The vertebral artery is *red*. The *blue arrow* is the C2 nerve root. The *gray dot* above the arrow is the starting point for the C1 lateral mass screw.

RESULTS

This 71-year-old man with previous C2-T2 fusion presented with a chin-on-chest deformity, was myelopathic, and had developed kyphosis over the top of the construct (Fig. 35-9, *A*). Lateral cervical spine radiographs demonstrated his kyphosis (Fig. 35-9, *B*).

Occipitocervical fusion was performed. Postoperative lateral cervical spine radiography shows improved sagittal alignment (Fig. 35-9, *C*).

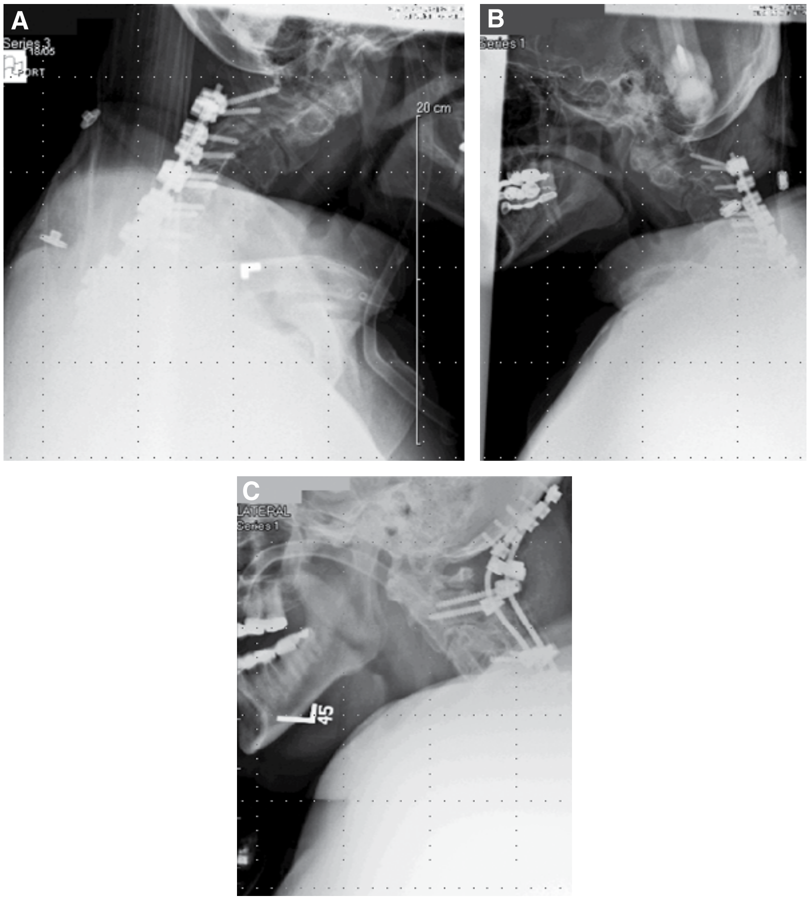

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Fig. 35-9 This patient presented with chin-on-chest deformity and myelopathy, and had developed kyphosis over the top of the construct. **A** and **B,** Preoperative lateral cervical spine radiographs demonstrated kyphosis. **C,** A postoperative lateral radiograph after occipitocervical fusion shows improved sagittal alignment.

This 51-year-old woman with Down syndrome ambulated independently. She presented with progressive cervical myelopathy and difficulty using her upper extremities and walking. A preoperative lateral cervical spine radiograph demonstrated atlantoaxial subluxation and associated cranial cervical instability (Fig. 35-10, *A*). Preoperative sagittal T2 MRI showed C1-2 instability with cranial migration of the odontoid. Intrinsic cord change was evident at the occipital cervical junction (Fig. 35-10, *B*).

Occipitocervical fusion with C1 laminectomy was performed. The six occipital midline screws with C2 pedicle and translaminar cervical fixation are shown in Fig. 35-10, *C*. A postoperative AP radiograph of the occipitocervical junction shows fixation of occipital screws at midline, the C2 pedicle screw, C2 translaminar screw construct, and C1 laminectomy (Fig. 35-10, *D*). Postoperative axial MRI confirms C2 pedicle screw and translaminar screw anchorage (Fig. 35-10, *E*).

{AUTHOR: Please provide long-term follow information for the patient in Fig. 35-10, with images and legends.}

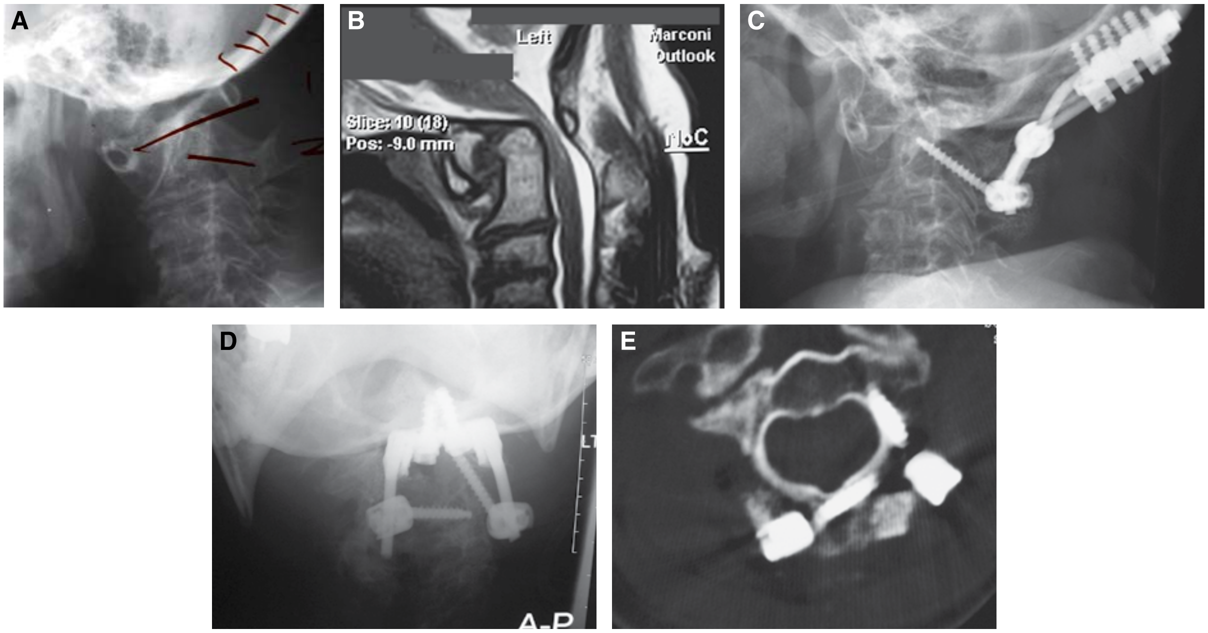

Fig. 35-10 **A,** A preoperative lateral cervical spine radiograph showed atlantoaxial subluxation and associated cranial cervical instability. **B,** A preoperative sagittal T2 MRI showed C1-2 instability with cranial migration of the odontoid and intrinsic cord change at the occipitocervical junction. **C,** A postoperative lateral view of the occipitocervical junction after fusion and C1 laminectomy shows six occipital midline screws, the C2 pedicle, and translaminar cervical fixation. **D,** An AP radiograph demonstrates the occipitocervical junction with occipital screws in midline fixation, C2 pedicle screw, C2 translaminar screw construct, and C1 laminectomy. **E,** Axial MRI shows the C2 pedicle screw and translaminar screw anchorage.

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CONCLUSION

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. With this advancement we have achieved higher fusion rates and less postoperative immobilization–associated complications. Outcomes have improved compared with former sublaminar wiring and nonrigid instrumentation techniques.

With the advances of this rigid occipitocervical stabilization have come 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. As occipitocervical fixation continues to evolve, we must further investigate long-term outcomes in the hopes of improving fusion rates and patient functional status.

{AUTHOR: Please provide updated references and indicate where to cite them in text. Also indicate any that should be deleted.}

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    This study investigated outcomes of 32 patients who had occipitocervical fusions with posterior plate and screw instrumentation. The average follow-up was 50 months. Exclusion criteria resulted in 23 patients who all had solid fusions. No pseudarthrosis occurred. Halos or traction immobilization was not used postoperatively. A detailed analysis was performed of intraoperative findings and the postoperative course, including activity level, follow-up, and radiographic findings. Posterior occipitocervical fusion can be performed very safely with plate and screw instrumentation. An extremely high fusion rate can be expected with minimal complications and minimal postoperative immobilization. This technique, however, is technically demanding.

5. Smith MD, Anderson P, Grady MS. Occipitocervical arthrodesis using contoured plate fixation. An early report on a versatile fixation. Spine 18:1984-1990, 1993.

    This study reported on a rigid fixation technique for occipitocervical fusion performed in 14 patients with occipitocervical instability. A simple, inexpensive yet rigid construct with pelvic reconstruction plates and screws was used for posterior arthrodesis of the occipitocervical region. The average follow-up time was 11.7 months. All patients had fused with minimal complications. This versatile technique is readily adapted to complex deformities and is extensible for subaxial fixation.

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7. Stock GH, Vaccaro AR, Brown AK, et al. Contemporary posterior occipital fixation. J Bone Joint Surg Am 88:1642-1649, 2006.

    This was an excellent review of occipitocervical fixation and its historical evolution from nonrigid fixation to more rigid fixation constructs, as well as their technical challenges and demands. These contemporary modular systems now allow the surgeon to place occipital and spinal anchors in optimal anatomic locations. The authors discussed causes of junctional occiptocervical instability, the nature of the injury, the patient's anatomy, and the quality of the host bone, which ultimately determines the best form of fixation. An overview of the ever-growing number of stabilization techniques and implants was provided.

8. Hurlbert RJ, Crawford NR, Choi, et al. A bioechanical evaluation of occipitocervical instrumentation: screw compared with wire fixation. J Neurosurg 90(1 Suppl):84–90, 1999.
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   This study evaluated construct stability provided by five different occipitocervical fixation techniques. A total of 21 human cadaveric spines were tested, initially as intact specimens and then with created dens fractures. Five different reconstructions were performed, and models were subjected to axial rotation, flexion-extension, lateral bending, and anteroposterior translation. Significant stabilizing effects were provided with C2 transpedicular and C1-2 transarticular screws, compared with sublaminar wiring and lamina hooks. The improved stability may offer many potential advantages, including a high rate of bony union, early ambulation, and easy nursing care.

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{AUTHOR: Update reference 12 to the sixth edition, published in 2011?}

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{AUTHOR: Update reference 19 to the third edition, published in 2011?}

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21. Sasso RC. Complications of posterior occipitocervical instrumentation. In Vacarro AR, Regan JJ, Crawford AH, et al, eds. Complications of Pediatric and Adult Spinal Surgery. New York: Marcel Dekker, 2004.

   This chapter provided a thorough and in-depth discussion of advanced techniques in posterior occipitocervical instrumentation. The evolved fixation techniques and newer instrumentation allowed anchorage into every segment of the occipitocervicothoracic spine. A complete anatomic perspective was provided, with a discussion of specific challenges and potential complications associated with these new techniques of screw fixation at every level. The chapter detailed preoperative strategies and surgical techniques to avoid adverse events.

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