62 Anterior Subaxial Cervical Fixation Techniques

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SUMMARY OF KEY POINTS

- Anterior subaxial cervical fixation is still relatively new.
- Current fixation techniques involve the use of titanium plates and screws.
- Polyetheretherketone and carbon fiber interbody devices can be used in lieu of structural autograft of allograft in ventral spine reconstruction.
- Multiple plate options are available, allowing for constrained or semiconstrained constructs.
- Prior to implant placement, appropriate preparation of the spine including proper decompression and gardening of the spine must be completed to allow for a better fit of the implants.
- Ventral fixation is used as an adjunct to promote fusion.
- Proper and adequate review of preoperative imaging allows for anticipation of the implants necessary for ventral cervical fixation.

HISTORY

Historically, cervical spine surgery was mostly done posteriorly. In the 1950s, anterior cervical surgery was pioneered and popularized by Smith, Robinson, Cloward, Bailey, and Badgley. Cloward used a cylindrical graft for an anterior fusion after a discectomy, whereas Smith and Robinson used a tricortical bone graft. At this time, anterior surgeries were being performed without the plating. However, in the 1970s Orozco and Senegas released the first reports on anterior cervical plating. The addition of a ventral cervical plate prevents the anterior migration of the bone graft used after a discectomy. The plates also decrease the compression and shear forces that the spine is exposed to. Some of the earlier plates included the Caspar plate in the 1980s and the Morscher plate, also known as the cervical spine locking plate (CSLP).

CERVICAL SPINE ANATOMY

The cervical spine has two main regions: the upper (C1 and C2) and the lower (C3 through C7) cervical regions. The upper cervical spine is unique because of its distinct anatomic arrangements, compared with the rest of the cervical spine. C1 is a bony ring without an actual body and as a result, it allows for the intrusion for the dens of C2 between the lateral masses of C1. It is held in place by a ligamentous complex. The dens articulates with the dorsal aspect of the ventral portion of the ring of C1. The lateral masses of C1 join with the occipital condyles and C2 by kidney-shaped articulations. The C2 vertebral body is more closely related to the rest of the subaxial spine than the C1 vertebra. It has a rostral extension knows as the dens or the odontoid process. The pars interarticularis of C2 connects the posterior bony elements of C2 to the anterior bony element. It projects from the lamina to attach to the lateral masses and is the part of C2 that is compromised in a hangman's fracture. The atlanto-occipital joint allows flexion-extension (25 degrees), as well as a minimal degree of lateral flexion (5 degrees) and minimal rotation (5 degrees). The atlantoaxial joint allows 20 degrees of flexion-extension, 5 degrees of lateral bending, and 40 degrees of axial rotation. The failure strength of the alar ligament is about 200 N, whereas that of the transverse ligament is 350 N. The vertebrae of the middle and lower cervical spine are fairly uniform and the overall alignment allows for a lordotic curve to the cervical spine, which helps to prevent spinal cord injury because most axial loads are imparted symmetrically to the spine rather than with a significant flexion component. Because the addition of a flexion component to an axial load greatly increases the chance of vertebral body failure and the retropulsion of bone and disc fragments into the spinal canal, the lordotic posture thereby helps to prevent catastrophic injury.

ANTERIOR INSTRUMENTATION

Anterior cervical instrumentation is used to treat a variety of abnormalities of the cervical spine, including traumatic injuries, neoplastic processes, infectious processes, and degenerative disorders of the cervical spine. These techniques involve placing a ventral cervical plate to the spine to promote fusion, maintain alignment, and prevent graft or cage dislodgment after a cervical discectomy or corpectomy. As previously stated, Caspar developed a semiconstrained (semirigid or dynamic) plate that uses a bicortical screw purchase in the vertebral body. Today the options for ventral cervical fixation are almost limitless, but in order to use the appropriate system, an in-depth understanding of biomechanics is required. It is important to determine what type of construct is required to achieve a particular goal. For example, in trauma, a rigid construct or implant is preferred to a dynamic construct or implant.

BIOMECHANICS OF VENTRAL ANTERIOR SPINE CONSTRUCTS

During ventral cervical spine fixation, the biomechanical principles employed in creating a sound construct include ventral distraction, central compression (tension band), and ventral cantilever beam fixation. In addition to the cervical plates helping to achieve these biomechanical principles, they are also attained through the use of Caspar posts/pins.

Ventral Distraction

Ventral distraction can be achieved by placing a Caspar post in the most cephalad and caudad vertebral bodies in the construct with a distractor placed over the posts with a craniocaudal distraction force applied. Ventral distraction may also occur from the placement of a neutral construct with the expectation that the construct will bear the axial load and thereby distract the spine by resisting compression. Ventral distraction implants come in two fundamental types: interbody struts and cantilever beams. They both use screws in a fixed-moment arm, nonfixed moment arm, applied-moment arm, or dynamic mode. The interbody struts may be composed of bone, polymer (polyetheretherketone or carbon fiber), or metal implants; the cantilever beams are generally of a screw-plate construct type.

Ventral Compression (Tension Band) Fixation

Unlike ventral distraction techniques, ventral compression techniques do not employ interbody struts that apply compression forces to the spine. In general, it is difficult to use rods to provide significant compression or distraction in the ventral cervical spine, as can be easily achieved in the thoracic and lumbar spine. However, with the development of implants such as the DOC VSS (DePuy Spine, Raynham, MA: discussed later in this chapter), such use has been facilitated. This device allows the application of a compression force on the bone graft by preloading it, which is consistent with Wolf's law. This compression and preloading is achieved using a cantilevered screw-rod system.

Ventral Cantilever Beam Fixation

There are three types of cantilever beam fixation constructs: fixed-, nonfixed-, and applied-moment arm constructs. The fixed- and applied-moment arm constructs provide what has been termed constrained or rigid spinal fixation. The nonfixed moment arm fixation provided what is termed as semiconstrained, semirigid, or dynamic fixation.

Dynamic Versus Constrained Plates

Lowery and McDonough, retrospectively, compared nonconstrained (dynamic) and constrained plates, and they reported fewer complications with the constrained system. Dynamic plates are now in use to compensate for graft subsidence, and more recent biomechanical studies have reported the improved outcomes with these translational plates over the constrained devices. Brodke and colleagues compared two dynamic plate designs and two constrained designs in a corpectomy model. They discovered that locked constrained plates provided excellent load-sharing fixation in the absence of graft resorption and subsidence, whereas dynamic plates provided superior load sharing with 10% graft subsidence. DiAngelo and coworkers noted significant loading of the graft in extension with constrained plates. This was not observed in translational plates. It is up to the surgeon to determine what type of construct is required. In the case of trauma, for example, most surgeons agree that a more rigid nonconstrained construct is required.

FIRST-GENERATION PLATES

The first-generation plates allowed motion at the screw-plate interface and as such were considered nonrigid implants. They also had limited fixation at the screw-plate interface, allowing the graft to be exposed to greater compressive forces thereby promoting fusion. Examples of the first-generation plates include the Caspar plate (Aesculap, Center Valley, PA) and the Orozco plating system (Synthes, Paoli, PA). These plates had poor screw backout prevention mechanisms and were abandoned due to a high rate of screw backout and breakage. These plates also required fixation with bicortical screw purchase, which can sometimes be challenging as overpenetration of the vertebral body can lead to spinal cord injury and underpenetration can lead to a weaker construct causing failure of the construct or screw pullout before a fusion is achieved.

Figure 62-1. Caspar plate.

Caspar Plate System

This is a nonconstrained titanium plate where the screws are not locked to the plate (Fig. 62-1). It can be affixed to the spine using both unicortical and bicortical screws. The unicortical screws come in a variety of lengths ranging from 10 to 28 mm. Screws have a constant outer diameter of 3.5 mm and an inner diameter of 2.2 mm. The bicortical screws are self-tapping and come in lengths from 14 to 19 mm. The outer diameter is 4 mm and the inner diameter is 2.2 mm at the tip and 2.7 mm at the head; creating a tapered configuration. The screws are made of a titanium alloy with a corundum-blasted surface over a third of the length of the tip.

Techniques for Placing Caspar Ventral Cervical Plates

Once the spine is exposed, distracting pins are placed into the rostral and caudal vertebral bodies. This allows for the discectomy or corpectomy to be performed with relative ease. The distracting pins are placed using a mallet and a screwdriver. The length of the plate to be used may be measured intraoperatively or it could be measured on preoperative radiographs. Once the plate is placed, it is important to make sure that the screw holes are not over holes caused by the distracting pins or over soft tissue. Prior to plate placement, ventral osteophytes should be drilled off to allow the plate to sit flush on the ventral aspect of the spine. The plate should also be placed in the midline. If the contour of the spine does not allow for a perfect fit, one may consider contouring the plate as a last resort option. It is important to avoid multiple bends, as this may weaken the plate. It is also important to place the plate greater than 5 mm from the adjacent disc space to decrease the incidence of adjacent segment disease. To determine screw length, intraoperative imaging may be used, or this could have been measured out on preoperative imaging. The distance between the ventral cortical margin and the back end of the vertebral body will guide screw length selection. The drill guide should be set to 3 mm less than the distance from the ventral to the dorsal aspect of the vertebral bodies to prevent spinal cord injury. The plate is held in place with a temporary plate holding pin and the drill guide is used to drill the screw holes to the preset depth. Next the screw holes are tapped and the first screw is placed. It is not completely tightened. Next the screw that is diagonal to the first screw is placed and once the final screw is placed, they are all tightened, as initially tightening a screw prior to placement of the other screws may cause the plate to move.

SECOND-GENERATION PLATES

The second-generation plates were rigid implants that were best utilized in trauma. They have the benefits of providing rigid stabilization and maintaining alignment. They also reduce the need for postoperative immobilization leading to earlier return to function and potentially leading to enhanced fusion. These implants are described as restricted and constrained. However, they may stress shield the bone graft and result in either implant failure or a pseudoarthrosis. Stress shielding occurs when the implant reduces fusion-promoting stresses on the bone graft, leading to a nonunion or pseudoarthrosis.

Cervical Spine Locking Plate

The Synthes Cervical Spine Locking Plate (Synthes CSLP, West Chester, PA) was developed and designed as a prelordosed plate. The bushings in the plate holes allow for screw angulation and locking and come with a wide variety of screws, including self-drilling and self-tapping as well as unicortical and bicortical screws. The screws vary in length from 12 to 20 mm (Fig. 62-2).

Techniques for Insertion of Cervical Spine Locking Plate

Once the discectomy is completed, the distraction pins are removed and the holes are sealed with wax. Calipers that come in the set are used facilitate plate selection. Plate selection is very important because in order to decrease the incidence of adjacent segment disease, the plate should be sized in a manner that leaves it greater than 5 mm from the adjacent cephalad and caudad disc space. Next, a Kirschner (K-wire) may be placed approximately 1 cm into the vertebral body, and then the chosen plate is placed over the K-wire. A temporary plate holding pin is then placed in the hole diagonal to the K-wire. Next, the screws are inserted. One can also substitute the K-wire for another temporary plate holding pin. The screw holes are placed using a drill guide and drilled at the desired angle. In the cephalad vertebral body, the screws are angled superiorly and medially. In the lower vertebral body, the screws are angled inferiorly and medially. Once all the screws are tightened to engage the bushing, locking screws are then inserted into the permanent fixation screws.

Orion Cervical Plate System

The Orion plate (Medtronic, Sofamor-Danek, Memphis, TN) is highly constrained, and the screws are locked into the plate at a fixed angle. The plate has a predetermined lordotic curvature. The fact that the cephalad and caudad screws are locked in place prevents screw migration if the screws were to break. The plate design also allows for convergent screw placement, thereby reducing the risk of injury to the vertebral artery. The superior screws are directed 15 degrees cephalad and 6 degrees medially. Variable-length 4-mm cancellous screws are available ranging from 10 to 26 mm. The plates vary in size from 25 to 90 mm. The Orion plate is made of titanium alloy with a titanium-anodized (Tiodized) surface coating, which increases the surface's resistance to wear and improves fatigue life (Fig. 62-3).

THIRD-GENERATION PLATES

Due to the problem of stress shielding that was evident with second-generation plates, dynamic plates were again revisited. The third-generation plates improved on the original Caspar plate design by preventing screw backout while allowing for some motion at the screw-plate interface, thereby enabling load sharing between the bone graft and the implant. These third-generation plates are described as dynamic plates with two subtypes: (1) rotational and (2) translational. The rotational dynamic plates allow screws to rotate or toggle at the screw-plate interface and include the Atlantis (Medtronic, Sofamor-Danek, Memphis, TN), Blackstone (Blackstone Medical Inc., Springfield, MA), Aline (Surgical Dynamics Inc., Norwalk, CT), Zephir (Medtronic, Sofamor-Danek, Memphis, TN), Slim-Loc (DePuy Spine, Raynham, MA), Acufix (Austin, TX), and Deltaloc (Alphatec Spine,

Figure 62-2. CSLP. *(© DePuy Synthes 2016. All rights reserved.)*

Figure 62-3. The Orion Plate. *(Photo courtesy of Medtronic Sofamor-Danek, Memphis, TN.)*

Carlsbad, CA). Translational dynamic plates allow for axial translation and rotation of the plate and include the Premier (Medtronic, Sofamor-Danek, Memphis, TN), Translational Atlantis (Medtronic, Sofamor-Danek, Memphis, TN), ABC (Aesculap, Tuttlingen, Germany), DOC (DePuy Sine, Raynham, MA) plates and most recently the Zevo plate (Medtronic, Sofamor-Danek, Memphis, TN). Movement at the screw-plate interface helps to avoid stress shielding, thereby increasing fusion rates and decreasing time to fusion.

Atlantis Anterior Cervical Fixation System

The Atlantis cervical plate (Medtronic, Sofamor-Danek, Memphis, TN) is made of titanium and has an integral locking mechanism that helps reduce screw pullout. There is also a translational version of the plate. These plates were designed with the concepts of load bearing and load sharing in mind. The plate design allows for different levels of rigidity as a result of having both fixed and variable angle screws that can be used to affix the plate to the spine. An Atlantis plate that is secured with fixed angle screws is a relatively rigid load-bearing construct with maximum stability at the graft site. When variable angle screws are used with the Atlantis plate, axial load forces are transferred to the graft. Finally, a hybrid construct can be created with fixed angle screws at one end of the plate and variable angle screws at another end. This creates a semiconstrained construct that provides a moderate degree of rigidity while still allowing for some transfer of axial load to the bone graft. The plates vary in size from 19 to 110 mm (Fig. 62-4).

Insertion Technique for the Atlantis Cervical Plate

The Atlantis plate can be secured with fixed angle screws, variable angle screws, or a combination of fixed angle screws at one end and variable angle screws at the other end. In placing the fixed angle screws, the fixed angle drill guide must be used. Screw holes are drilled using the adjustable drill bit and drill stop. There is also a fixed 13-mm drill bit. The screw holes are tapped, and the fixed angle screws, which are usually 4 or 4.5 mm, are placed. There are also self-tapping screws that improve efficiency. Once all screws are placed, final tightening seats the plate firmly on the ventral aspect of the vertebral body. The steps for placement of the variable angle screws is similar except that a variable angle drill guide is used and the screw has a range of 22 degrees in the sagittal plane and 17 degrees in the axial plane.

Figure 62-4. Atlantis plate. *(Photo courtesy of Medtronic Sofamor-Danek, Memphis, TN.)*

Premier Anterior Cervical Plate

The Premier plate is a dynamic plate designed by Medtronic that permits axial load sharing via translational movement of the screws at all levels except the caudal end. The plate is currently being phased out. The Premier plating system has screws that are either 4 or 4.5 mm in diameter. The 4-mm screws vary in length from 10 to 20 mm. The 4.5-mm screws come in 13-, 15-, and 17-mm lengths and serve as rescue screws. The plate has fixed holes and slots, which can accept either diameter screw. The caveat is that the 4.5-mm diameter screws have less angle variability when placed in the slots. The plate comes in 32 sizes ranging from 23 to 110 mm (Fig. 62-5).

DOC Ventral Cervical Spine System

The dynamic osteosynthesis cervical (DOC) ventral cervical spine system (VCSS) is mainly composed of rods and platforms. The platforms utilize fins that are placed above and below the respective rostral and caudal vertebral bodies of the proposed construct. The fins add to the stability of the implant. The platforms are rigidly fixed to the vertebral body via screws that have nonvariable angles. The platforms, however, come in three different choices that allow a 0-, 20-, or 30-degree screw angle. The screw length options are 12, 14, and 16 mm. Rods are situated on either side of the platform, and the rostral platform is not firmly fixed to rods whereas the caudal platform is secured via set screws. Intermediate platforms may be placed along the rods between the rostral and caudal ends of the implant and are rigidly fixed to the intermediate vertebral bodies. As the spine subsides, the platforms are able to slide or settle along the rods. A cross-fixator is firmly attached to the rods at the cranial extent of the implant and limits the amount of subsidence. The DOC VSS was the first truly axially

Figure 62-5. Premier anterior cervical plate. *(Photo courtesy of Medtronic Sofamor-Danek, Memphis, TN.)*

Figure 62-6. DOC ventral cervical spine system.

dynamic implant available for the cervical spine. It permits controlled axial deformation and prevents kyphosis. It results in load sharing with the bone graft while off loading stresses on the implant itself, resulting in an improved rate of fusion and less chance of construct failure (Fig. 62-6).

SLIM-LOC Anterior Cervical System

In 2002, DePuy Spine released the semiconstrained SLIM-LOC anterior cervical plate. The template for this plate was the original Codman plate. The changes to the Codman plate that resulted in the development of the SLIM-LOC plate included reducing the plate's thickness to 2.1 mm and increasing the plate-screw bending rigidity by 40%. This was achieved by increasing the inner diameter of the screw in the direction of the screw head. The SLIM-LOC plate is a dynamic system that prevents screw backout using the cam-lock mechanism. The plate has a precontoured curvature, which is appropriate for the majority of cases. There is a plate bender in the set if more of a curvature is required (Fig. 62-7).

Zevo Anterior Cervical Plate

Medtronic released this plate in 2015. It comes in a variety of lengths. For a one-level construct, the length ranges from 17 to 29 mm, for a two-level construct it ranges from 27 to 51 mm, 43 to 71 mm for a three-level construct, and 65 to 89 mm for a four-level construct. There is also a five-level option that ranges from 77 to 108 mm. The one-, two-, and three-level plates are 1.9 mm thick and the four- and five-level plates are 2.1 mm thick. The bone screws are 3.5 and 4 mm in diameters and come in 13-, 15-, and 17-mm lengths. The screws also come in a self-drilling and self-tapping option. This system does come with an intradiscal drill guide that allows for proper angulation and proper trajectory during screw placement. The plate also has a fixation pin feature at the cephalad and cauda aspect of the plate that obviates the need to use an actual screw hole for temporary fixation pin placement (Fig. 62-8).

Figure 62-7. Slim-Loc anterior cervical plate. *(Photo courtesy of DePuy-Synthes.)*

Figure 62-8. Zevo anterior cervical plating system. *(Photo courtesy of Medtronic Sofamor-Danek, Memphis TN.)*

BONE GRAFT OPTIONS IN VENTRAL SUBAXIAL CERVICAL FIXATION

Once a discectomy or corpectomy is completed, the integrity of the ventral subaxial spine has to be restored. The options for this restoration/reconstruction is usually some kind of bone graft that is either tailored to fit the space or bone that is placed within a carrier device that will fill the space. There are two main types of bone graft options: (1) autograft and (2) allograft. The autograft options may be harvested from the iliac crest and could consist of both cortical and cancellous bone graft. Allograft can be in the form of structural allograft, cancellous bone chips, crushed cancellous, or putty. There are also demineralized bone matrix options (DBM) and ceramics. In addition to placing bone directly in discectomy and corpectomy sites, carrier devices packed with bone graft can also be used. The options for carrier devices include titanium cages, carbon fiber cages, and polyetheretherketone (PEEK) cages. The carrier devices only provide structural support and do not promote fusion.

BAK/C Interbody Fusion System

The BAK/C interbody system (Zimmer Spine, Minneapolis, MN) provides an alternative to either a tricortical structural autograft, which is associated with donor site morbidity, or allograft, which may be associated with a small risk of disease transmission. The BAK/C is a threaded, hollow device that is made of a titanium alloy (Ti-6Al-4V) and as such cannot collapse and is highly resistant to migration. It has a porous design that allows bone growth through all sides. In comparison to anterior cervical plates, the BAK/C has a zero profile, and if adjacent segments need to be fused, it does not have to be removed. The device comes in five diameters (6, 7, 8, 10, and 12 mm) without factoring in the threads. The threads add an additional 2.5 mm to the outer diameter of the device. The BAK/C device allows for both unilateral and bilateral placement. It is imperative to understand that best results for fusion are obtained when the BAK/C device is packed with either locally harvested autograft, allograft, or bone graft extenders (Fig. 62-9).

Bengal Carbon Fiber Interbody Cage

The Bengal (DePuy Spine, Raynham, MA) cervical cages are carbon fiber polymer cages that bear the mechanical forces of the spine to promote fusion. The modulus of elasticity of these carbon fiber cages is similar to that of cortical bone. The cages should be filled with cancellous autograft, which does not require as extensive a harvesting process as tricortical graft. The cage is resistant to collapse and, as a result, the height restoration that occurs with placement leads to indirect foraminal decompression. These cages come in three sizes: standard (12 mm × 14.5 mm), large (14 mm × 17 mm), and extra large (16 mm × 20 mm) (Fig. 62-10).

Polyetheretherketone Spacer

Polyetheretherketone (PEEK) is a polymer with a modulus of elasticity within the range for cancellous bone. The modulus of elasticity is defined as stress divided by strain. The modulus of elasticity of cancellous bone ranges from 0.5 to 5, whereas the modulus of elasticity of PEEK is 3.7. PEEK implants do not cause any radiographic artifact on plain radiographs, computed tomography, or magnetic resonance imaging. The PEEK implants also have radiographic markers consisting of titanium wires that are inserted into the wall of the PEEK implant. PEEK elicits a minimal inflammatory response and reduces graft subsidence that might be seen with titanium cages. The PEEK space should be filled with local autograft or other bone

Figure 62-10. Bengal carbon fiber cage. *(Photo courtesy of DePuy-Synthes.)*

Figure 62-9. BAK/C interbody cage. *(Courtesy of Zimmer Spine, Minneapolis, MN.)*

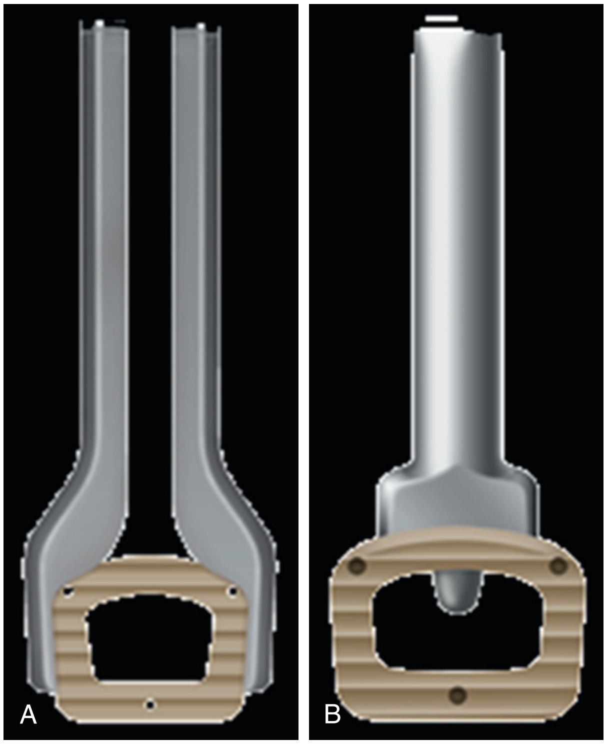

Figure 62-11. Cervical PEEK stackable cage (PSR). *(Photo courtesy of Medtronic Sofamor-Danek, Memphis, TN.)*

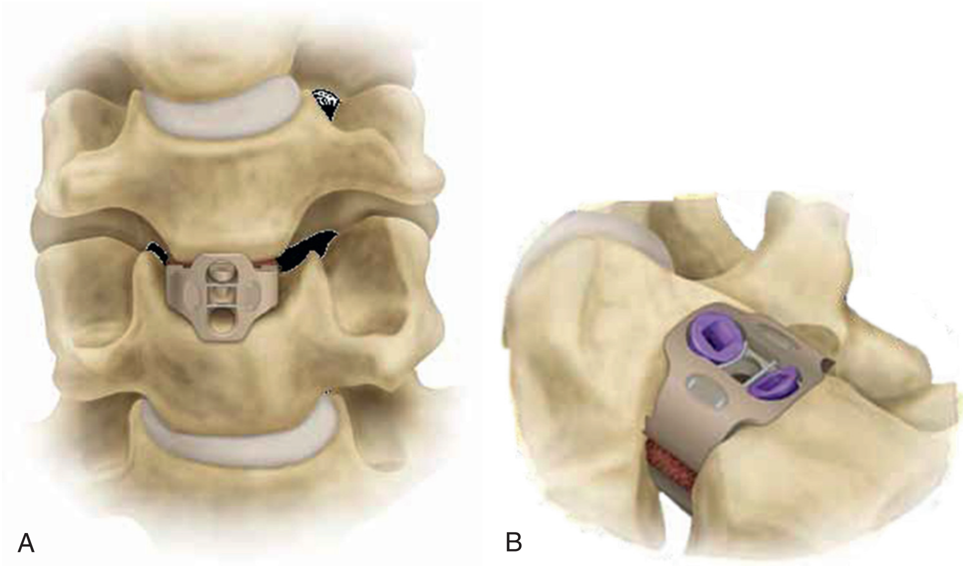

Figure 62-12. Prevail zero profile interbody device. *(Photo courtesy of Medtronic Sofamor Danek, Memphis, TN.)*

graft extenders with osteoinductive properties (Fig. 62-11). Zero profile cage-screw constructs have been designed to eliminate placement of a plate after a discectomy is performed (Fig. 62-12). A few options include the prevail device (Medtronic Sofamor-Danek) and the Synthes zero profile device (DePuy-Synthes). A biomechanical study by Healy and coworkers showed that when treating adjacent segment disease after a single-level anterior cervical discectomy and fusion with a plate, a zero profile implant showed stabilizing potential that was statistically similar to that seen with a standard revision with a two-level plate.

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