History of instrumentation for stabilization of the subaxial cervical spine

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In the past several decades, numerous methods have been developed to stabilize the subaxial cervical spine both posteriorly and anteriorly. Methods of posterior stabilization have progressed from interspinous wiring, through facet wiring and sublaminar wiring, to the lateral mass screws with plates and rods that are in use today. Plates for anterior stabilization have evolved from rigid plates requiring bicortical screws through those used with unicortical locking screws, to dynamic load-sharing plates used with variable angle screws. The original description of spinous process wiring was published by Hadra in 1891. In 1942 Rogers described the interspinous wiring method used for trauma-induced cervical instability, which was modified by Bohlman in 1985 (triple wiring technique). Luque rods with sublaminar wires were introduced in the late 1970s to address multilevel and occipitocervical instability. Facet wiring was developed in 1977 by Callahan to address the problem of stabilization when laminae are not present. Wiring remained the method used until Roy-Camille introduced the lateral mass screw–plate construct in the 1980s. The first plate for anterior stabilization was designed by Orozco and Llovet in 1970 and was later refined by Caspar; this was a rigid plate with unicortical screws. Morscher devised unicortical locking screws in the 1980s. The latest concept of dynamic load-sharing plates with variable angle screws was developed in 2000. In this article historical landmarks in surgical methods for the stabilization of the subaxial cervical spine are reviewed.

KEY WORDS • cervical instrumentation • historical review • spinal fixation

POSTERIOR CERVICAL INSTRUMENTATION

The first recorded surgical instrumentation of the cervical spine dates back to 1891 when Dr. Berthold Earnest Hadra (Fig. 1) performed an internal operative spine immobilization by wiring together the spinous processes of the sixth and seventh cervical vertebrae. Later Hadra applied this technique to correct the deformity associated with Pott disease. This surgical procedure came to the attention of European orthopedists who made modifications and continued its use. Over the past several decades, numerous methods have been developed to stabilize the spinous processes, laminae, and pedicles of the cervical spine. These methods include wiring (interspinous, facet, and interlaminar clamping) and application of lateral mass screws and plates, lateral mass screws and rods, and cervical pedicle screws.

Interspinous Wiring

Rogers initially described the interspinous wiring technique for the treatment of trauma-induced cervical instability in 1942. This technique involves drilling holes into the spinous processes and passing wires through them (Fig. 2). Whitehill, et al., and Benzel and Kesterson have described modifications of this technique, but the fundamentals remain unchanged.

The Bohlman triple-wire fixation technique was a modification of the Rogers technique to stabilize a single or multilevel site of segmental instability. The interspinous wiring method is similar to that of the Rogers technique in that wires are passed through drilled-out holes in the spinous processes. Additional wires are then passed through the holes and are threaded through corticocancellous iliac crest bone grafts. The two wires are tightened to secure the bone grafts against the decorticated spinous processes and laminae on each side.
When spinous processes and laminae cannot be used for fixation, facet wiring provides an additional alternative for cervical spine fusion. This method was introduced in 1977 by Callahan, et al.9 Using this method (Fig. 3) the facet capsular ligaments are removed and the facet joints are opened. Holes are drilled at each level. A wire or cable is passed through each hole in a superior-to-inferior direction and exits through the joint space. The wires are wrapped around autologous strut grafts and fastened to decorticated articular masses. The inferior end of the bone graft is secured to the spinous process. Alternatively, Steinmann pins or Luque rectangles can replace the bone grafts to allow fixation over multiple levels as described by Garfin and associates15 and also by Maurer, et al.21

In 1983, Cahill and colleagues8 described an alternative technique in which the spinous process and facets are wired together (Fig. 4). This procedure is used to stabilize facet fracture dislocations or subaxial flexion–compression injuries. Usually a hole is drilled in the middle of the superior articular facet. A cable or wire is passed through the hole in the facet and looped beneath the caudal spinous process. The procedure is then repeated on the contralateral side to achieve full stabilization.

The placement of sublaminar wires made of stainless steel was associated with a significant incidence of complications, including dural tears and neurological deficits.
A major technical improvement in wiring techniques was the introduction of braided cables, which are flexible and stronger than stainless steel wires. In 1991 Songer, et al., introduced a cable system that consists of two 49-strand stainless steel cables connected to one malleable leader portion. The flexibility of the cables makes it easier and safer to pass them under the laminae.

**Interlaminar Clamps**

Tucker first described the use of interlaminar clamps in 1975. He used Halifax interlaminar clamps (Fig. 5) for posterior C1–2 arthrodesis. Since that time, these clamps have been applied to stabilize flexion injuries at a single-motion segment. This technique requires the presence of intact laminae at the fusion level and may increase the risk of neurological injury by contributing to canal stenosis due to sublaminar hooks. Usually, bilateral interlaminar clamps are placed to optimize fixation and stability.

Using this technique the posterior elements are exposed. The leading and trailing edges of the laminae are thinned to augment the size of the interlaminar spaces bilaterally. The clamps are hooked over the leading and trailing laminar edges. Then screws are applied and the clamps are tightened together. An autologous graft can be interposed between the two spinous processes to prevent hyperextension and enhance fusion.

**Lateral Mass Screws and Plates**

In the late 1980s, Roy-Camille and colleagues introduced the concept of using a lateral mass screw-and-plate system to stabilize the cervical spine. This procedure was originally the method of choice for stabilizing the cervical spine when posterior elements are compromised or absent. It provides immediate rigid stability, obviates the need for an external halo vest orthosis, and readily promotes fusion.

The original Roy-Camille procedure for managing cervical instability was modified by Magerl, Anderson, and An. These surgeons’ techniques differ in the entrance point for screw insertion and screw trajectory. The screw is usually directed superiorly and laterally to avoid the nerve root and the vertebral artery. In the Magerl procedure, the entrance point for screw insertion is located slightly medial and rostral to the midpoint of the lateral mass. The direction of the screw is 25° lateral in the axial plane and parallel to the facet joint in the sagittal plane. In the Anderson technique, the direction of the screw is 10° lateral in the axial plane and 30 to 40° rostral in the sagittal plane. In the An technique the direction of the screw is 30° lateral in the axial plane and 15° rostral in the sagittal plane.

**Lateral Mass Screws and Rods**

Lateral mass screws and rods (Fig. 6) were introduced because the lateral mass plating system cannot accommodate complex spinal abnormalities such as those occurring in severe degenerative spondylolisthesis or trauma. In an effort to apply precise screw placement and realignment, the screw-and-rod system was developed throughout the late 1980s and the 1990s. Currently, three systems contain this construct: the Cervifix System (Synthes), the Vertex System (Medtronic), and the Summit System (Depuy). These systems allow for placement of the screws in the desired entry point, after which the rod is attached either by a clamp (Cervifix System) or directly onto a polyaxial head. Screw-and-rod systems can accommodate for variations in anatomy and, thereby, allow precise screw placement. They are especially useful when there is multilevel disease or a sagittal or coronal deformity, or when occipitocervical or cervicothoracic stabilization is indicated.
Cervical Pedicle Screws

In 1994, Abumi and colleagues introduced and used cervical pedicle screws in a novel method of posterior cervical instrumentation. They were the first to report the successful use of these screws in stabilizing a subaxial traumatic instability, and have shown that cervical pedicle screws can be used effectively in the reconstruction of the cervical spine. The superior stability, fixation, and resistance to screw pullout provided by this technique, compared with the lateral mass plating system, has been demonstrated in animal models and in human cadavers.

Once the posterior elements have been exposed, the site of the pedicle screw insertion is penetrated with a high-speed drill. The entry point has been determined to be lateral to the center of the facet and close to the posterior margin of the superior articular surface. The angle at which the screw is inserted can vary from 25 to 45 degrees medial to the midline in the transverse plane. In the sagittal plane the angle of insertion should be parallel to the upper endplate of the vertebral body. After the entrance hole has been made, a small pedicle probe is inserted with the guidance of fluoroscopy. The appropriate pedicle is then tapped and the screw is inserted.

Given the anatomical variability in the angularity of cervical pedicles care must be taken to avoid neurovascular complications, such as vertebral artery injury, as well as nerve root injury from screw insertion.

ANTERIOR CERVICAL INSTRUMENTATION

Dr. Leroy Abbott first suggested the anterior surgical approach to the cervical spine in 1952 while he was serving as a visiting professor on the service of Drs. Bailey and Badgley; the approach was used and subsequently described by Bailey and Badgley. In 1958, Robinson and Smith introduced their use of a horseshoe-shaped bone graft for enhanced bone fusion during an anterior cervical reconstruction. Cloward soon followed with his technique of inserting a cylindrical graft for anterior cervical fusion after discectomy. The next major advance was the introduction of anterior cervical instrumentation. The technology for anterior plate fixation of the cervical spine has evolved rapidly over the last three decades.

Early Cervical Plating—Unrestricted Backout

The earliest anterior cervical plate was developed by Orozco Delclos and Llovet Tapies in 1970. It was first used in the fixation of an unstable spine induced by trauma. The plate was later refined by Caspar (Fig. 7), who developed and used the trapezoidal osteosynthetic plate to stabilize the anterior cervical spine and enhance fusion after trauma. The addition of a plate, in theory, provides immediate stabilization, prevents graft extrusion, and decreases the need for extended external immobilization or supplemental posterior procedures. Furthermore, anterior plate fixation helps maintain the restored sagittal alignment through the prevention of graft collapse and extrusion (Fig. 8).

Both systems are composed of load-sharing plates that require bicortical screws. The Caspar system does not allow for cephalad or caudal motion of the plates themselves, but includes variable screws that can toggle between 0 and 17 degrees cephalad or caudal from the perpendicular plane. Telescoping of the bone–plate construct occurs to some degree, allowed by a combination of slippage and screw angulation in the plate slots in the sagittal plane. There is no mechanism present to prevent the backout of screws from the plate. Excessive telescoping may lead to screw loosening, breakage, or plate pullout; therefore, engaging the posterior vertebral cortex is required to minimize loosening of the screws. The incidence of these complications was not insignificant, and the disadvantages led to the next set of technical improvements in anterior cervical plating.

Constrained Plates

Pioneered by the Association for the Study of Internal Fixation, the constrained plate system contains screws that are firmly locked to the plate, avoiding the need for bicortical screws. Morscher developed an expandable cross-split screw head that locks into the plate after insertion of a small central bolt. Securing the screws to the plate allows for a more direct transfer of applied forces from the spine to the plate and improves the stiffness of
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the construct. Screw perforations for bone ingrowth and a plasma spray coating initially showed promise, but, ultimately, were abandoned after an increased rate of screw breakage had been observed.17

The Orion Anterior Cervical Plate System (Medtronic Sofamor Danek; Fig. 9) is another constrained system that can be used with either unicortical or bicortical screws. The plates come with a lordotic curve. The screw–plate locking mechanism is created by two small lock screws that thread into the plate and overlap the top of the bone screws. The system requires fixed screws which prevent cephalad and caudal motion. Constrained plates are more appropriate in the setting of trauma, in which immediate rigid fixation is desired.

Semiconstrained Plates

The disadvantage of constrained plates is that they do not allow for settling, which is a natural occurrence during fusion. A rigid system may shield the graft from the stress required for arthrodesis to take place. This may lead to pseudarthrosis and hardware failure, especially in multilevel constructs. To address this problem, plates that restrict screw backout but still allow for screw motion within the plate in either a rotational or translation plane were developed.

The anterior dynamic plate13 (ABC; Aesculap; Fig. 10) has a slotted design that allows for up to 10 mm of migration in both cephalad and caudal directions. Expansion and locking of the petals of the screw heads in the 10-mm slots allow for plates to migrate over the screw heads. Variable screws toggle up to 34°, 17° in both cephalad and caudal directions. The Atlantis plate (Medtronic, Inc.) and the Codman plate (Codman, Johnson & Johnson) are examples of plates that allow for rotation of the screws in the plate as settling takes place. Semiconstrained plates are appropriate in the setting of multilevel disease, in which there can be a significant chance of settling.

CONCLUSIONS

The past several decades have witnessed remarkable advances in the structural design of instrumentation for subaxial cervical spine stabilization. Cervical internal fixation provides immediate stability to control an unstable segment, improves bone union, and has decreased the need for bracing. Current methods allow for rigid posterior stabilization and correction of deformity with the use of screw-rod fixation to the lateral masses or pedicles. Both constrained and semiconstrained anterior cervical plates can be used to treat the instability caused by trauma, degenerative disease, neoplasm, or infection. Technical improvements in cervical spine instrumentation are the result of innovations that have evolved from previous instrumentation that produced clinical failures. These improvements have made stabilization of the subaxial cervical spine a safe and effective procedure for patients today.

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Manuscript received November 18, 2003. Accepted in final form December 11, 2003. Dr. Das is the recipient of an Educational Research Grant from Synthes.

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