Anterior Cervical Plating – A Historical Perspective

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ABSTRACT

In the 1950s Bailey and Badgley, Smith and Robinson, and Cloward were the first who independently reported the results of their new surgical technique for the treatment of cervical disc disease. 1-3 For the first time, these pioneers performed an anterior approach to the cervical spine and performed a discectomy to fuse the segment. Hence, the ever popular procedure anterior cervical discectomy and fusion (ACDF) was born.

KEY WORDS: Anterior cervical plating, craniovertebral junction, spine biomechanics

INTRODUCTION

In the 1950s Bailey and Badgley, Smith and Robinson, and Cloward were the first to independently report the results of their new surgical technique for the treatment of cervical disc disease (1-3). For the first time, these pioneers used an anterior approach to the cervical spine and performed discectomy to fuse the segment. Hence, the ever-popular procedure anterior cervical discectomy and fusion (ACDF) was born.

Since then, the ACDF has gained popularity and is considered to be the "gold standard" for the treatment of degenerative cervical disc disease. In long-term follow-up studies, good clinical outcomes were reported by several authors. [4 5] Since its introduction, the ACDF procedure has been associated with several (short- and long-term) negative findings. Most of these involved graft-related complications including graft settling, graft compression fractures, graft dislocation, and pseudoarthrosis with subsequent kyphotic deformation (6-8). To overcome these problems and enhance the fusion rate, the anterior cervical plating system was developed and recommended by several authors (9-12). An excellent clinical outcome has been reported in the long-term follow-up with ACDF and cervical plating (13).

Several retrospective studies have reported increased fusion rates with anterior cervical plating.[14-16] However, the addition of a cervical plate is often criticized due to implant-related complications including plate migration, risk of adjacent disc screw penetration, deep mediastinal infections, dysphagia, or esophageal perforation (17). The rate of implant failure including loosening and/or breakage of the screws or the plate has been reported to vary from 22% to 44% (18). Therefore, cervical plates were refined to reduce the complication rate, increase the fusion rate, and to restore cervical alignment. As new cervical plating systems were developed, a new classification system was developed based on the unique biomechanical features of each plating system (19). The classification of cervical plating can be divided into two categories: restricted and unrestricted backout systems. Restricted backout systems were further subdivided into constrained and semi-constrained plates. In this paper, the evolution of the anterior cervical plating system will be reviewed.

Biomechanics of Anterior Cervical Plating

The process of fusion is very complex and must be understood for proper selection of the anterior cervical plate. According to Wolfe`s law, the remodeling of bone in response to loading is achieved via mechanotransduction. [20] In other words, bone heals best under compression. It is well known that periodic micromovements in a fractured tibia enhances union of the bone in form of a callus (21). If the movement becomes too great or too little, the result may lead to nonunion of the bone.

The removal of a cervical disc is not tantamount to a fractured tibia, but the same biomechanical principles apply.

In an unplated ACDF, the load is borne by the graft and the posterior elements of the cervical spine. In an ACDF with anterior cervical plating, the load is borne partially by the plate, the graft and the posterior elements. The load on the cervical plate may be affected by several factors such as the length of the plate, the screw design and screw purchase, and position of the spine (flexion vs. extension). Biomechanical studies have reported that the distribution of the axial load is more on the rigid plate and less on the graft, which results in stress reduction on the graft followed by nonunion and subsequent pseudarthrosis. Reidy et al. reported significant differences in the load borne by rigid plates (23%) versus dynamic plates (9%) in an *in vitro* C5 corpectomy model. Brodke et al. further reported that rigid plates lost about 70% of their load sharing capability in cases of graft shortening by 10%. Significantly more flexion and extension of the cervical spine were simulated by shortening the graft 10% in a cadaver study (22-24). It has been reported that the optimal ratio of load transmitted through the spine should be 70% to enhance fusion (25,26).

The initial process of bony fusion involves graft resorption before it can be replaced with new bone. Subsidence and settling of the bone graft is a natural consequence in this process. In single and two-level ACDF with the use of autologous graft, the amount of subsidence varies from 1.4 to 1.8mm, respectively (27). Depending on the number of operated levels and the material of the graft, subsidence might be even greater. As the amount of subsidence increases, more of the load is placed on the rigid plate. This may result in implant failure resulting in plate or screw breakage. Interestingly, in some cases, fusion was seen after breakage of the plate as the load on the graft increased (28). Based on these findings, the development of dynamic plates was introduced to allow subsidence to occur in a "controlled fashion". Depending on the biomechanical characteristics of each plate, axial subsidence is either permitted by screw toggling, slotting of the screw longitudinally within the plate or by internal shortening of the plate. This should subsequently result in a consistent load on the bone graft.

Unrestricted Backout Plates

In the 1970s, Orozco and Llovet first implanted unrestricted plates for fixation of an unstable spine induced by trauma. The H-shaped plate was produced by ASIF (Figure 1) (29). In the early 1980s, Caspar invented a trapezoidal osteosynthetic cervical plating system in collaboration with Aesculap Inc. (Tuttlingen, Germany) (Figure 2). Caspar plating was popularized due to the enhanced fusion rate and recommended for the treatment of cervical degenerative disc disease, as well as trauma.

During this time, anterior cervical plating became widely commercially available.

The Caspar Plate and the H-shaped Plate used by Orozco are unrestricted backout plates. Screw angulation was determined entirely by the patients` needs and surgeon`s preference (7,9). The Caspar plate itself does not allow for motion, but the screws can toggle between 0-17° from the perpendicular plane. Both plates did not have a fixed-moment arm and had limited fixation at the screw plate interface which led to a higher chance of fusion due to a greater exposure of the graft to compressive forces (30,31).

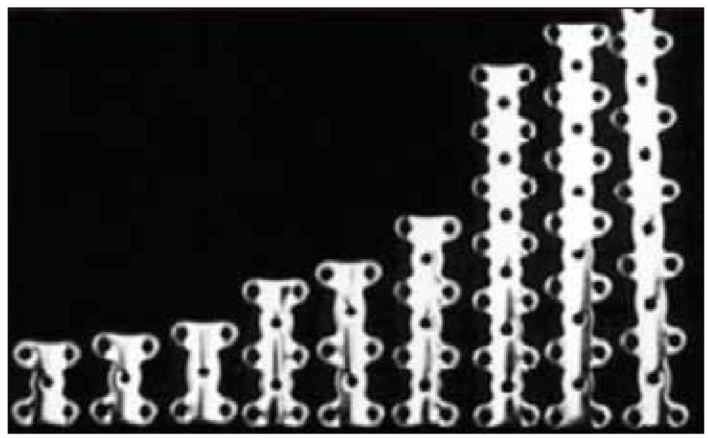

Figure 1: *H-shaped ASIF plates, which were one of the earliest cervical plates (source: http://images.google.de).*

Figure 2: *Latest model of Caspar plate with monocortical (green), bicortical (blue) and rescue screw (purple), (with permission from ® B. Braun Melsungen AG).*

The Caspar and Orozco plate are both unconstrained, non-rigid plates that allow motion at plate-screw interface. Motion at the plate-screw interface led to screw loosening and screw breakage (18,31-33). Bicortical screw purchase was required but was technically demanding. Increased screw length could result in cerebrospinal fluid leak or spinal cord injury and a shorter screw length could result in implant failure and screw loosening and/or pullout. Caspar et al. reported a repeat surgery rate of 9% in 210 patients with non-plated one- and two-level ACDF and a repeat surgery rate of 2% in 146 patients who underwent ACDF with a Caspar plate with a fusion rate of 97.9% (7,17).

Mayr et al. noted fusion rate of 83% after one- and two-level anterior cervical corpectomy and fusion and rate of 20% for screw breakage (34). Similar results for implant failure (22.4%) have been reported by Paramore et al. (35) Lowery et al. described a hardware failure rate of 4% with screw loosening and breakage and 14% plate breakage for the Orozco plate (18).

In the series conducted by Caspar et al., the rate for repeat surgery was 2% (3 patients). In two out of these three patients, screw breakage or screw backout was the indication for repeat surgery. Bose et al. reported an implant failure rate of 19.6% after ACDF with Caspar plating. As in Casper`s report, all implant failure occurred in multilevel ACDF. The most common reason was inferior screw fractures or inferior screw backout. To overcome screw pullout, Bose et al. recommended the use of a bigger "rescue" screw. However, the incidence of these implant-related complications forced engineers to develop new anterior cervical plates with other biomechanical characteristics to overcome these problems.

RESTRICTED BACKOUT PLATES

Constrained Systems

Contemporaneous to Caspar, several groups developed a titanium coated hollow-screw locking plate system. Morscher et al. modified the Orozco plate for the use of a titanium expansion screw that was rigidly affixed to the plate (36,37).

This construct allowed a more direct transfer of applied forces from the cervical spine to the plate which increased the stiffness. Thereby bicortical screw purchase could be avoided (31,38).

The locking plate was produced by Synthes (West Chester, PA, USA) and introduced in the USA in the 1990s (Figure 3). The major biomechanical difference to the Caspar plate was the rigid screw trajectory and the monocortical screw purchase. The advantage of the Synthes locking plate was the reduced incidence of screw backout and the shorter operative times due to no intraoperative fluoroscopy during screw purchase (38,39).

Typically the cranial screw had a 12° cephalad trajectory, whereas the caudal screw was placed perpendicular. Due to the monocortical technique, penetrating past the posterior aspect of the vertebral body was extremely rare.

However, due to the high rigidity of the Synthes plate, screw fractures were observed (18,34) Moreover the plate was wide and not precontoured for lordosis which made it difficult to bend. This increased the risk for a loss of sagittal alignment in multilevel procedures (34). To overcome these disadvantages, the curvature radius of the Synthes plate was reduced to from 25 mm to 15 mm. A fusion rate of 86% has been reported after one- to three-level anterior cervical corpectomy with a rate of 6.4% in screw breakage or screw backout failure (34).

Lowery et al. reported a rate of 9% for plate breakage and plate loosening, but only 1% with screw loosening (18). The Orion plate by Medtronic Sofamor Danek (Memphis, TN, USA) was introduced shortly after the Synthes plate, which came with a variable screw length from 10 mm to 26 mm to allow the surgeon to choose between monocortical and bicortical screw purchase (Figure 4). Furthermore the plate was manufactured with a precontoured lordosis to provide a better bone-plate interface and better restoration of the sagittal alignment. The length of the plate was shorter than its predecessors to prevent screw purchase in the endplate of the cranial and caudal vertebral body. The screw angle was 15° cranial and caudal, respectively and 6° medial. A drill guide which locked the plate ensured that the screws had a

__Figure 3:__ Synthes Cervical Spine Locking Plate (CSLP). Lateral view on a three models with different size and different screw shape (With permission from ® Depuy Synthes GmbH).

fixed angle. In theory, this plate should prevent caudal screw pullout. The 4 mm tapered screws of this system provided a redistribution of stress from the crew-plate interface to the full length of screw which diminished the risk of screw breakage (19). Kaiser et al. reported fusion rate after one-, two-level ACDF varying from 93% - 96%, respectively. In this series with a mean follow-up of 15.4 months, there were no recorded complications related to the cervical plate and no complications related to collapse, kyphosis, or subsidence secondary to the graft (40).

Similar results were reported by Mayr et al. after 1 – 4 level corpectomy. The fusion rate was 88% and no implant related complications occurred in this series (34). In contrast Lowery et al. reported a pseudarthrosis rate of 12% caused by screw breakage after one-level ACDF which made some surgeons believe that this plate is too rigid. The high rigidity of the Orion plate construct is believed to result in a large amount of stress on the plate, which decreases the amount of compressive force on the graft and hence reduces fusion. Experimental studies have reported that the Orion plate diminishes motion after corpectomy and results in extension of the segmental fusion, which increases the risk for construct failure (41). The high rigidity of the Orion plate or any other rigid fixed system seems to be more suitable in the setting of trauma in which intermediate fixation is desired (42).

Semiconstrained System

With the knowledge that constrained plates do not allow settling of the graft, the next generation of cervical plates, which are also referred to as semiconstrained plates, were dynamic. Semiconstrained plates can be divided into rotational and translational plating systems. Rotational plates provide rotation at the plate–screw interface and translational plates provide a mechanism to allow each screw to longitudinally slide within the slotted hole of the plate. If a variable screw is used, the screw might also rotate. Additionally, transitional plates allow the cranial and caudal ends of the plate to move toward each other while the graft settles like a telescope.

Semiconstrained - Rotational Systems

The Codman (Raynham, MA, USA) plate system was developed to allow for variability in the trajectory for cranial and caudal screws. The screws had a cam locking to prevent screw back-out (Figure 5). The tapered screws in this construct could not back out of the plate, but could toggle, which allowed motion of the construct and spread the stress along the screw. Therefore, the load on the graft increases which in theory should allow providing controlled "rotational" subsidence. Failure of the Codman plate has been identified in multilevel corpectomies and in unstable spines without posterior instrumentation (19,34).

Casha et al. described 93.8% fusion rate after 24 months of follow-up. In this study the Codman ACP plate was used for degenerative cervical disc disease, trauma, tumor, and failed previous surgery. The rate of hardware failure such as screw breakage and screw pullout was 8.2% (43). Kaiser reported similar finding with 92% fusion rate. Mayr et al. stated a fusion rate of 88% and screw breakage of 4.2% after cervical corpectomy (34).

The amount of screw rotation has an influence on graft dislodgment (43,44). Radiological data showed statistically significant changes in the screw–plate angle after surgery. The angle changed toward the midline of the plate, compatible with settling of the graft. These changes

Figure 4: *Anterior (left) and lateral (right below) view of the Orion constrained restricted backout plate (source: http://images.google.de).*

Figure 5: *Anterior (above) and lateral (below) view on the Codman semiconstrained, rotational plate. Screw with variable angle and backout cam locking device (With permission from ® Depuy Synthes GmbH).*

were most pronounced within the first 4 weeks, but still occurred at the caudal screw after 6 months. The changes were greater at the caudal screw (6.4°) compared to the cranial screw (2.4°). Since then, a multitude of different semiconstrained plates have been introduced. The Atlantis plate by Medtronic Sofamor Danek (Memphis, TN, USA) may be used as a restricted plate in which all the screws are fixed and rigid (Figure 6). It can be configured into a semiconstrained rotational plate in cases in which all the screws are variable. Oh et al. reported a fusion rate of 100% by using fixed type screws (8° - 12°) in combination with the Atlantis plate. Kaiser et al. described a fusion rate of 92% – 98% after one- and two-level ACDF with the Atlantis plate. Kaiser though did not particularly explain the technique of screw selection (40). Barnes et al. reported an overall fusion rate of 93.5% in a group of 77 patients who underwent a multitude of different anterior cervical procedures (single-multilevel ACDF, single-multilevel corpectomies with and without posterior instrumentation). During the 12 months follow-up, two patients had screw backout (45). Over time, the profile of several cervical plates became thinner to decrease irritation of the esophogus, and the surgeon could choose either self-tapping or self-drilling screws. Semiconstrained rotational systems are most likely suitable for cases requiring one- and two-level ACDF.

Semiconstrained - Translational Systems

The first so-called "translational" cervical plate DOC was developed by Depuy-Acromed (Raynham, MA, USA) (Figure 7). The screws in the DOC plate were designed to slide along a rail. The caudal screws are generally rigid at the cranial screws slide. The movement at the screw-plate interface should avoid stress shielding and allow for an increased compressive load which was thought to increase bone integrity and bone healing.

Theoretically, the time to fusion should diminish and the fusion rate should increase. Biomechanical studies have reported the DOC did function as designed but under various loads the plate was less stiff compared to rigid and other translational plates. The DOC plate permitted axial telescoping and lateral bending with much less force compared to the ABC plate and therefore transmitted all the applied forces to the graft (23). Stancic et al. described a lower fusion rate after 6 weeks for the DOC plate compared to a rigid plate. Further they reported new heterotropic ossification in 21.1% of patients and therefore recommended to implant the device upside down to avoid overlapping of the DOC rods with the adjacent segment (46).

The ABC plate by Aesculap (Tuttlingen, Germany) (Figure 8) and the Premier plate by Medtronic Sofamor Danek (Memphis, TN, USA) combine rotational and translational characteristics (Figure 9). Both plates allow the use of bicortical variable angle screws similar to the Caspar plate and have a translational motion at the screw-plate interface. Biomechanically, the screw slides longitudinally in a slotted hole (translation) and then may rotate after maximum translation. Epstein reported a fusion rate of 88% an average of 3.7 month after 1 level ACDF with the ABC-plate. Two out of 42 patients underwent repeat surgery for implant-related complication or pseudarthrosis (47). Pitzen et al. reported a fusion rate of 83.4% after 2 years with no implant complications for the ABC-plate (48).

Figure 6: *Lateral view of the Atlantis plate in three different set-ups. Upper: Rigid set-up with fixed (purple) screws. Middle: hybrid set-up with fixed (purple) and variable (green) screws. Lower: variable set-up with rotation at both ends of the plate (green screws). (source: http://images.google.de).*

Figure 7: *DOC plate which allows for translation at the screw-plate interface. The cross fixator is at the cranial end of the plate (With permission from ® Depuy Synthes GmbH).*

Ragab et al. showed a fusion rate of 92% an average of 7.7±4.8 month after surgery for the Premier plate. The average subsidence of the implant was 2.4±2.6 mm. Adjacent segment overlapping was found to be increased in the Premier plate compared to the static locking and semi-rigid locking plate (49).

Multiconstruct Systems

Multiconstruct systems combine different biomechanical favorable aspects of each plate. These multiconstruct plates allow the surgeon to configure the plate in a way to match the biomechanical requirement of each case.

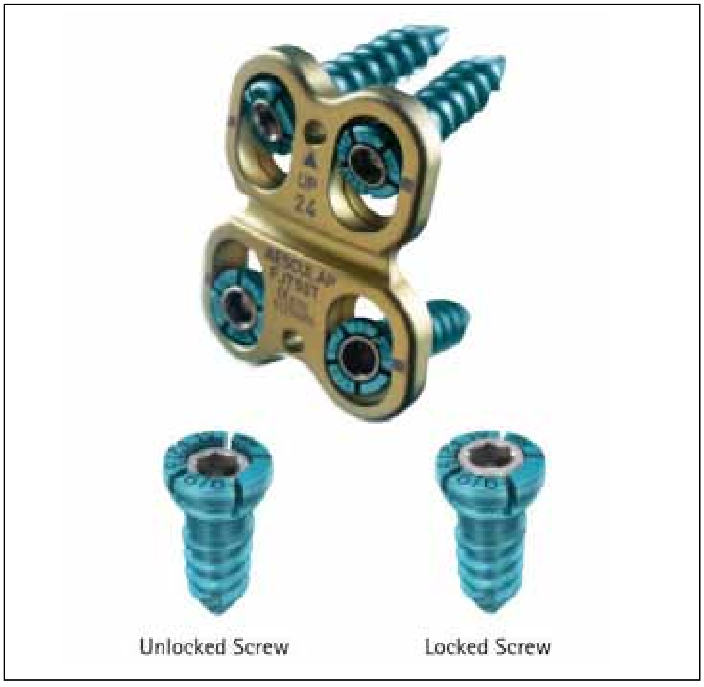

Figure 8: *Anterior view of the second generation of the ABC plate (above). Monocortical locked and unlocked screw (below). The ABC plate allows for rotation and translation at the plate–screw interface (With permission from ® B. Braun Melsungen AG).*

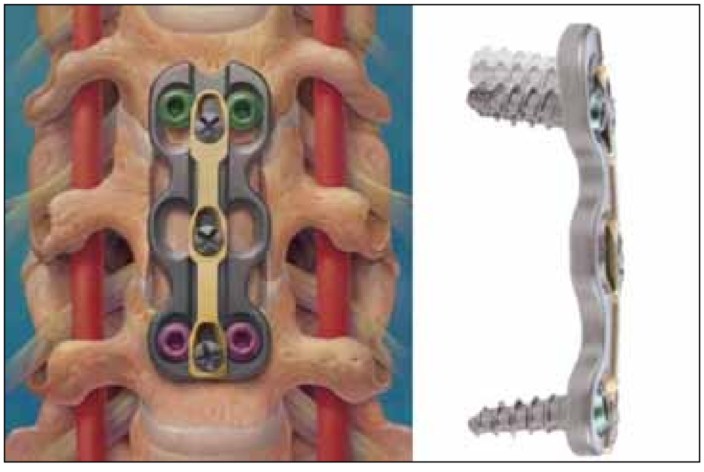

Figure 9: *Anterior (left) and lateral (right) view of the Premiere plate which allows for rotation and translation at the plate–screw interface (source: http://images.google.de).*

The Atlantis plate Medtronic Sofamor Danek (Memphis, TN, USA) was one of the first cervical plates on the market to fulfill all the characteristics to be considered a multiconstruct system. The Atlantis plate provided variable and/or fixed screw angulation. Depending on the underlying pathology of any case, the surgeon had the option to create a rigid or a rotational semiconstrained plate. Each screw can be adjusted and therefore a "hybrid" construct with rigid and rotational elements could be created as well. Furthermore the Atlantis plate has a feature that prevents screw backout. When the Atlantis plate is setup for a rigid system, the screws are angled 12° cranial and caudal respectively and 6° medially.

In a semiconstrained setup, variable screws are used to allow for rotational motion at the cranial and caudal screw-plate interface. In a hybrid set up, the caudal screws are fixed and the cranial screw purchase is variable in angulation. Graft loading can either occur due to rotational or translational motion at the cranial screw-plate interface. The biomechanical advantage of a hybrid setup is controlled subsidence at the cranial end of the cervical plate which provides increased compressive force to promote fusion. The hybrid set up is recommended for the treatment of degenerative cervical disc disease whereas the rigid set seems to be more suitable for trauma (45,50).

CONCLUSION

Over the past 30 years, the fundamental design of the cervical plate has essentially remained the same. Although a multitude of studies have examined fusion rates after rigid and dynamic anterior cervical plating, the fusion rates are not consistent because of a number of variables such as comorbidities, smoking, age, bone quality and numbers of levels of disease influence the process of fusion. Technical developments have been made to increase the fusion rate and to overcome implant-related complications. Companies have released second generation plating systems after refining their initial plates. With new plating systems, the implant failure rate appears to have declined.

Despite minor differences in the design, the majority of these plates can be allocated to one of the aforementioned groups. Understanding the biomechanical properties of each plating system and careful selection of the appropriate cervical plate by the surgeon will provide the stabilization and rigidity desired.

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