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Cervical plates: comparison of physical characteristics and in vitro pushout strength

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Abstract

Background context: There are many cervical plates available to the spine surgeon today. A single plate design may not be appropriate for every clinical situation. It is important for the surgeon to understand the differences of these plating systems. Plate systems are known to fail by screw pullout from the bone, screw and plate breakage and a less frequent but clinically observed screw pushout from the plate. Pushout testing of the screws from the plate have not previously been subjected to study.

Purpose: This compares the features of cervical plating systems and the strength of the locking mechanisms to allow the surgeon to make a knowledgeable choice of plating system.

Study design: This is a review of descriptive geometric characteristics of cervical plate systems and a biomechanical evaluation of locking mechanism screw pushout strength.

Methods: Physical characteristics of each plate were determined. Features of plates and screws were cataloged. Each of the test plate systems had a different locking mechanism. Biomechanical testing of the locking mechanism–screw-plate constructs was performed to determine the pushout strength of the fixation screw from the plate-locking mechanism.

Results: Physical characteristics of the plating systems, including lengths, widths, shortest screw lengths and distance from edge of plate to nearest screw, were determined. Biomechanical testing showed significant differences in pushout strength, in part explained by the type of locking mechanism.

Conclusions: Biomechanical screw pushout data demonstrate that a significant range of pushout strengths exist across the available cervical plate systems today. Knowing the physical characteristics of the cervical plating systems available may allow the selection of a plate best suited for a given clinical situation.

Keywords: Biomechanics; Bone plates; Bone screws; Cervical vertebrae; Surgery; Equipment design; Spinal fusion/instrumentation

Introduction

Anterior plating systems have become increasingly popular for fixation of the subaxial cervical spine. Internal fixation of the anterior cervical spine using instrumentation in patients with fracture instability is well recognized [1,2]. The role of instrumentation for cervical degenerative disorders has been more controversial but recent studies support the use of plating, especially for multiple-level fusions [3–8]. The plate systems have been recommended to decrease the pseudarthrosis rate in cervical surgery [9–15]. Other advantages of the plate include prevention of graft extrusion and decreased need for external postoperative immobilization [7,8,14–19]. The disadvantages may include the cost, stress shielding of a bone graft, fixation failure from the bone with loosening of the screws and the risk of neurological or vascular injury [12,15,17,18,20–24]. Currently, cervical plating systems incorporate a bone fixation screw secured by a locking mechanism. The locking mechanism makes the screw-plate construct more rigid without using bicortical fixation [25,26] and prevents pushout of the bone screw.

FDA device/drug status: not applicable.

Nothing of value received from a commercial entity related to this research.

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This screw-plate construct thus acts mechanically as a single-piece implant. Without the need for posterior cortical penetration in the vertebral body, there is a decreased risk of screw misplacement and resultant spinal cord injury [27]. These plating systems are subject to failure. These are not common complications but may include screw pullout from the bone or from the plate and hardware breakage.

There has been a proliferation of plating systems with variable locking mechanisms in recent years, all with their own purported advantages. No information exists in the spine surgery literature about the physical characteristics of these plating systems. The first purpose of this study was to consolidate physical information for 10 commonly used plates. Secondly, six of the systems were evaluated for screw pushout strength. The goal was to expand the spine surgeon's understanding of the versatility of each plating system.

Materials and methods

Test systems included cervical spine locking plate (CSLP) (Synthes, Paoli, PA); Orion, Premier, Zephr and Atlantis (Sofamor-Danek, Memphis, TN); Vuelock (EBI, Parsippany, NJ); PEAK and DOC (Depuy-AcroMed, Cleveland, OH); Aline (Surgical Dynamics, Memphis, TN) and the Blackstone (Blackstone Medical, Inc., Springfield, MA). These 10 plate systems are not inclusive of all plating systems available today. Additionally, only six of the systems were made available for the biomechanical pushout testing. These systems were CSLP, Orion, Vuelock, PEAK, Aline and the Blackstone.

Using a caliper accurate to 0.1 mm, repeated physical measurements were made for each plate variable. Characteristics studied for each system included the height or profile, the maximal width, the distance between the nearest screw hole to the end of the plate and the shortest normal-sized and rescue screw. Details were obtained to demonstrate the range of lengths for plates designed for one, two, three and four levels of fusion, as well as the incremental length increases for each of these plate designs.

Biomechanical testing was carried out with six different plate styles. Each plating system tested was prepared for screw pushout testing by potting the plate in a polyvinyl chloride cup with lead epoxy with a pit beneath the screw to allow the pushout of the single screw being tested (Fig. 1). The plate was stabilized with additional screws to the potted surface to prevent motion of the plate. Each plate was tested with the locking mechanism in place at the manufacturers' recommendations, including appropriate torque settings for the locking mechanism screws. The fixation screw was tested at manufacturers' optimal position to the plate, either 90 degrees or slight angulation away from the center of the plate. All constructs were maintained at body temperature (37 degrees Centigrade) for the testing. Testing was performed with a materials testing system (model 1321; Instron Corporation, Canton, MA). The pushout strength value was the force at which the screw uncoupled from the plate.

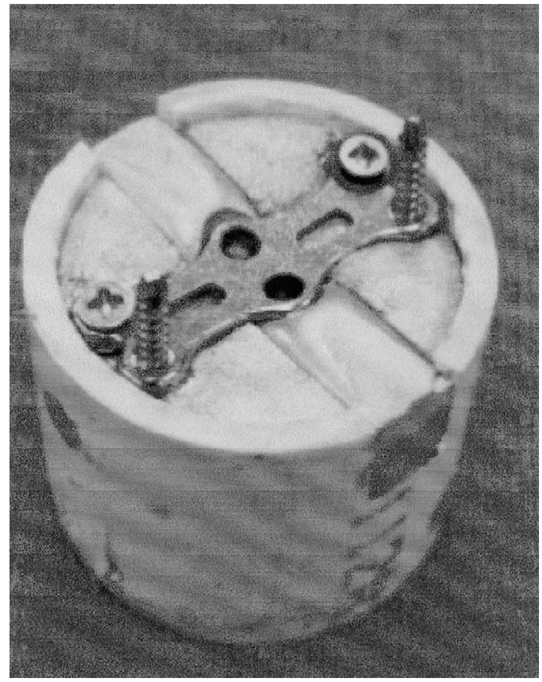

Fig. 1. Potting technique used for each plate. PEAK plate demonstrated. Pit beneath each of the upside down screws allows pushout of the individual screw.

Statistical analysis

A single-factor analysis of variance (ANOVA) was performed to compare the pushout strengths of the screw-plate constructs for the different plate systems

Results

Table 1 summarizes height, width, screw length and distance from the end of the plate to the nearest screw hole. Heights ranged from 1.8 to 3.2 mm, widths form 14.9 to 20.7 mm, and end of the plate to near screw measurement ranged from 1.4 to 3.2 mm. Of note also, four systems had rescue screws for which the minimum length was longer than the minimum length standard screw. Table 2 summarizes the locking mechanism and angulation position of the screw to the plate. Some are fixed angle and some are variable.

Table 3 details the variation in plate length. The Orion has a continuous slot and therefore has a non–level-specific design for any number of fusion levels. A single screw may be placed at any point between the two ends of the plate, as the surgeon desires. The multilevel style of plate assumes that the surgeon is trying to place screws in separate vertebral bodies after individual anterior discectomies. These designs are specific for a given number of fusion levels depending on the number of levels of screw holes between the ends of the plate. The variability is in the overall length of the plate, the increment in plate length, and the number of intermediate holes.

Table 1
Physical measurements of cervical plates

Name of plate	Height (profile)	Width	Distance edge of plate to near screw	Shortest normal	Screw rescue
Aline*	2.4	19.0	1.7	10	12
Blackstone[†]	2.6	17.8	1.4	12	12
Premier[‡]	2.6	17.9	3.1	10	13
Orion[‡]	2.6	17.9	3.2	10	11
Atlantis[‡]	2.7	17.8	2.6	10	13
Zephyr[‡]	1.8	14.9	1.7	13	13
PEAK[§]	3.2	18.1	2.9	10	10
DOC[§]	2.4	17.7	2.0	12	12
CSLP[‖]	2.0	20.7	2.2	12	12
CSLP SS[‖]	2.1	16.4	2.1	12	12
CSLP VA[‖]	2.6	18.1	2.3	12	12
Vuelock[¶]	2.4	18.0	1.8	12	12

SS = short stature; VA = variable angle.
*Surgical Dynamics, Memphis, TN.
[†]Blackstone Medical, Inc., Springfield, MA.
[‡]Sofamor-Danek, Memphis, TN.
[§]Depuy-AcroMed, Cleveland, OH.
[‖]Synthes, Paoli, PA.
[¶]EBI, Parsippany, NJ.

Each of the plate systems reviewed had some differences in locking mechanism. However, the plates could be loosely grouped into general categories by type of locking mechanism (Table 4). The types were 1) expansion screw; 2) locking ring; 3) blocking plate, set screw or flange and 4) a separate threaded bushing within the plate. The expansion screw locking mechanism (Type 1) is characterized by a hollow head of the bone fixation screw head, with longitudi-

Table 2
Locking mechanisms and screw angulation to plate

Name	Locking mechanism	Allowable angulation of screws to plate
Aline*	Inner expansion screw compresses head of screw to plate.	Screw to plate variation
Blackstone[†]	Top-locking cover plate	Variable screw alignment 0–30 degrees
Premier[‡]		Fixed angle screw
Orion[‡]	Locking screw covers head of plate screws.	Fixed at one end but may angle 0–12 degrees away. A variable slot at other end, ideal 12 degrees up to 20 degrees away
Atlantis[‡]	Locking screw covers head of plate screws.	Variable angulation middle screws. Single screw placed through a slot that allows placement anywhere top to bottom of plate. End screws fixed at 15 degrees away from middle of plate
Zephyr[‡]	Locking flange blocks screw from backing out.	Fixed 12 degrees away, variable 2 degrees to center, 0–22 degrees away
PEAK[§]	Plate bushing with separate threads locks screw to plate.	Cephalic and caudal screws 0–16 degrees. Middle screws 0–7 degrees arc. Two screws at each end, but only one for middle segment
DOC[§]		Up to 25 degrees angulation in a conical arc
CSLP[‖]	Inner expansion screw compresses head of screw to plate.	Fixed at 0 degrees
CSLP SS[‖]	Inner expansion screw compresses head of screw to plate.	Fixed 0 degrees caudal and 12 degrees cephalic
CSLP VA[‖]	Inner expansion screw compresses head of screw to plate.	Fixed 0 degrees caudal and 6 degrees cephalic
Vuelock[¶]	Preattached expansive ring design locks screw below the ring.	20 degrees variable in conical arc

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[‖]Synthes, Paoli, PA.
[¶]EBI, Parsippany, NJ.

Table 3
Length of plates designed for one- to four-segment coverage

	One-segment		Two-segment		Three-segment		Four-segment	
Name of plate	Length	Increment	Length	Increment	Length	Increment	Length	Increment
Aline*	22–28	2	28–48	4	48–108	6		
Blackstone†	23–36	2	38–54	2	56–70	2		
					70–90	2.5		
Premier‡	23–25	2	25–90	2.5	90–110	5		
Orion‡	21.5–23	1.5	23–25	2	25–90	2.5	90–110	5
Atlantis‡	14–25	2	35–47.5	2.5	50–72.5	2.5	62.5–90	2.5
	25–32.5	2.5					90–110	5.0
Zephyr‡	22.5–25	2	27.5–47.5	2.5	50–55	2.5	98–110	4
PEAK§	24–30	2	39–63	3	57–90	3	59–87	4
	30–36	3			90–94	4	74–109	5
DOC§	16–28	2	30–42	3	44–64	4	68–92	4
CSLP‖	22–34	2	39–54	3	53–77	3		
CSLP SS‖	20–34	2	34–54	3	47–77	3		
CSLP VA‖	23–35	2	37–55	3	54–78	3		
Vuelock¶	12–24	2	26–42	2	44–66	2	60–92	4

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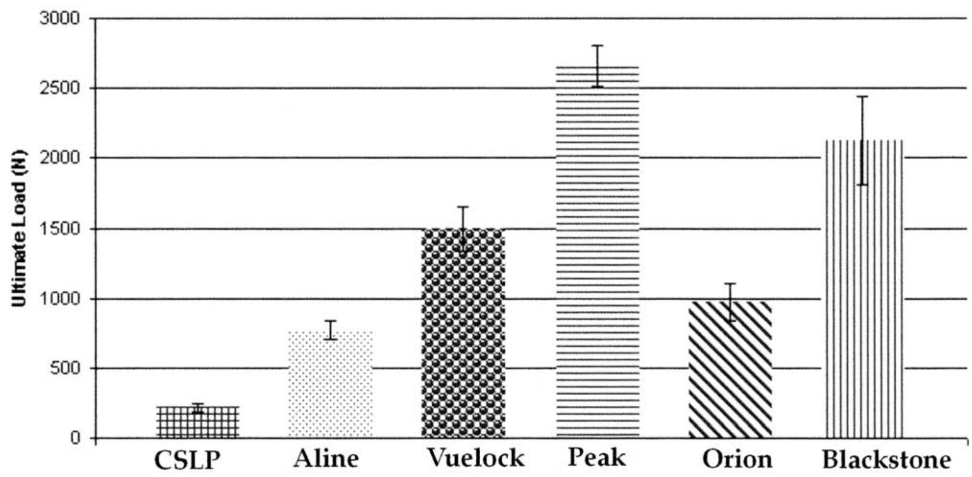
nal slots in the head to allow expansion of the head of the screw. There is an inner screw applied to expand the head of the fixation screw, which increases the rigidity of the coupling of the fixation screw to the plate. The CSLP was the initial design of the expansion screw locking design, and the Aline plate has a modification on the expansion screw mechanism with a more bulbar head and a longer inner screw. The inner screw can apply more torque slowly through its longer threaded length. The DOC has a similar expansion screw locking mechanism. The locking ring type of locking mechanism (Type 2) is characterized by a ring device pressed into the plate. The Vuelock has a snap-ring that the fixation screw passes through and is locked beneath. This ring locks the screw beneath the ring and the surface of the plate but does allow a degree of conical screw positioning for optimal screw placement, without locking the screw rigidly to the plate. The blocking type of mechanism (Type 3) is characterized by a second screw, flange or blocking cover that is screwed down onto the heads of the fixation screws to block the fixation screw from pushing out. The blocking type includes the plates of Sofamor-Danek (Atlantis, Orion, Prestige and the Zephyr) and the Blackstone plate. Type 4, the PEAK, has a movable polyaxial bushing, which secures the screw to the plate by a separate threaded area mating the screw to the plate.

Pushout strengths were tested for six systems and ranged from 215 neutons (N) to 2662 N. Fig. 2 tabulates the pushout strengths of the six plate systems with statistical comparison (ANOVA). The CSLP and the Aline failed with a pushout of the screw from the plate The Vuelock failed by a pushout of the locking ring from the plate, carrying the screw with it. The Orion failed by pushing out the central locking screw. The Blackstone failed by the screw pushing the cover plate up and away from the main plate. The PEAK failed by pushing out the bushing from the plate carrying the screw with it. Comparison of pushout strengths showed a significant difference between all the plates, with p values ranging from 1.5×10^{-9} to .007. Of the six systems, the expansion screw locking mechanism demonstrated the weakest pushout values.

Discussion

As the usage of cervical plates has increased, so too has the number of cervical plating systems. There is variability in these plates. Technical problems arise during surgery, and certain features within the plating systems more easily address these. For example, some patients have a smaller bone surface area of the anterior cervical spine and do not accommodate wide plates and longer screws. Lordosis is variable also. Therefore, optimal screw to plate angles vary as well. There is generally an optimal plate length, one that clearly spans the fusion levels but does not abut or overhang adjacent levels. Sometimes there is a wide range of acceptable lengths, but other times, particularly in the presence of a partial corpectomy, there is a narrow range of optimal lengths. Features of the optimal plate include not only the incremental distance between holes, but also the distance from the end of the plate to the near hole. Lastly, particularly with three- or four-level fusions, it has been our expe-



Statistical Analysis (p value)

	Aline	Vuelock	Peak	Orion	Blackstone
CSLP	p=4.3E-09	p=2.9E-09	p=2.7E-12	p=9.5E-08	p=3.6E-07
Aline		p=1.1E-06	p=6.5E-11	p=0.007	p=6.1E-06
Vuelock			p=1.1E-07	p=0.0001	p=0.002
Peak				p=1.5E-09	p=0.006
Orion					p=4.1E-05

Fig. 2. Pushout strengths of six plate systems with statistical comparison (analysis of variance).

rience that there is a much greater variation in usual length of plates. Sometimes, the ideal length plate does not correspond to the number of fusion levels for which it is intended. In this situation the surgeon is unable to use most if not all of the intermediate fixation screws. Overlap in lengths of plates designed for three- and four-level fusions helps prevent this problem.

Familiarity with plating system features should allow the surgeon to individualize and optimize plate selection. Ideally, plates should have narrow and wider choices, small increments in plate length, with short end of plate to near hole distances, overlap in lengths from two- to three- and from three- to four-level implants, low profiles and good visibility of the grafted levels. Screws should ideally come in variable lengths starting at 10 mm, have variable placement angulation capability, have rescue screws of the same length as the corresponding standard screw and be easily placed with a reliable locking mechanism.

The contemporary cervical plating system is designed for unicortical placement to prevent posterior bicortical penetration of the cervical vertebra and injury to neurologic structures. The locking mechanism has evolved for two functions; one is to increase plate -screw rigidity while allowing unicortical fixation of the plate to the vertebra [25]. The second is to prevent pushout failure of the screw from the plate [25].

Lowery and McDonough [28] found hardware failure in the cervical spine is more common the longer the patient is observed after surgery. There was a 35% failure rate overall but only 18% failure of constrained cervical plates [28]. Most hardware failures are inconsequential when the patient is not symptomatic. Long-term observation is suggested, and immediate removal of hardware is rarely necessary. They reported no patient had tracheal-esophageal erosion or neurovascular compromise as a result of the instrumentation failure [28,29].

Although not common, cervical plate bone screws do fail with pushout from the plate. Geyer and Foy [30] described erosion through the esophagus with subsequent oral extrusion of a locked expansion type screw originating from a cervical plate. In this case initial failure was pullout of the screw from the bone, followed by later pushout failure of the screw from the plate [30]. The authors have had two additional cases that required revision because of symptomatic screw pushout (Figs. 3 and 4).

This pushout testing may be criticized because the forces may be higher than are physiologically possible, and clinically, failure may not be purely a pushout mechanism. Each plate was tested to failure of the screw from the plate, and some plates required large pushout forces. In vivo, theoretically one might not require such large forces. Perhaps the failure of a locking mechanism may occur more slowly, first

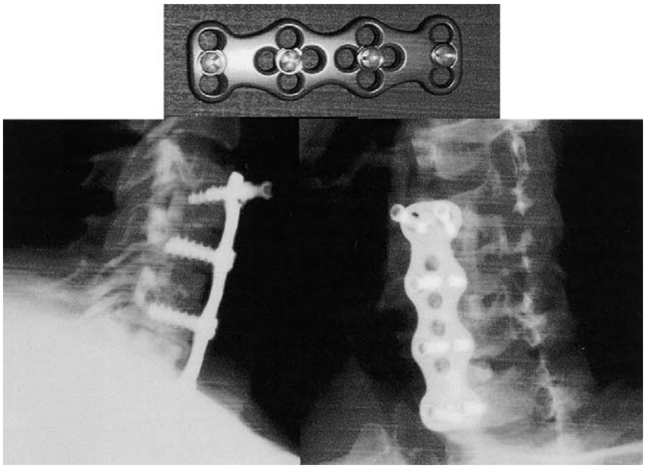


Fig. 3. Proximal screw failure from plate and locking mechanism.

after failure of the fixation to the bone. The authors acknowledge there are differences in failure from a single pushout force and failure from physiological cyclical stress, as might occur from nonunion or after failure of the screw from the bone. This mode of testing of a locking mechanism is a new method to demonstrate differences of characteristics of the cervical plate locking mechanisms. It does not prove that one pushout strength is necessarily better, only that there are differences between the locking mechanisms. The clinical significance of this difference requires further investigation.

Conclusions

All locking mechanisms significantly increased the pushout strength of the tested screw-plate systems. The expansion screw had the lowest pushout values. These data demonstrate a range of pushout strengths exists across the selections of available cervical plate systems today. Further study is needed to understand the optimal or minimal pushout strength to avoid this mode of failure. In addition, each plate has several unique physical characteristics, which permits the knowledgeable surgeon to choose the best plating system for each individual patient.

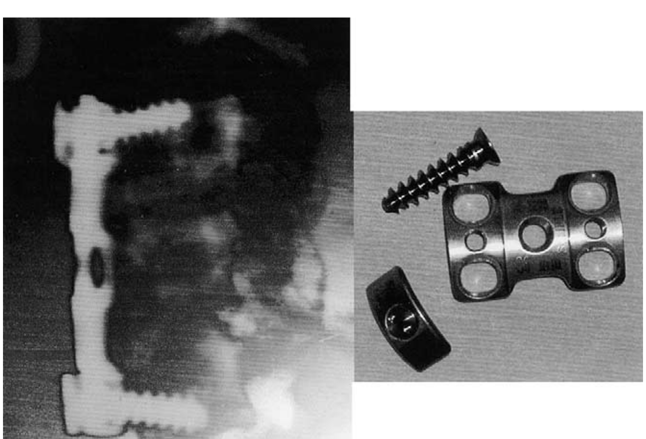


Fig. 4. Loosening of cover plate locking mechanism and bone screw backing out of cervical plate.

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Two Hundred Fifty Years Ago in Spine . . .

The prototype of the controlled therapeutic trial was the experimental work done on scurvy by James Lind, which he reported in 1753. Lind, a native of Scotland, was a physician in the Royal Navy. Various reports of the use of citrus to treat or prevent scurvy among sailors preceded Lind's work, but his organized trial and thorough report convinced the Admiralty and led to measures that eradicated scurvy from the Navy.

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