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Pullout of a lumbar plate with varying screw lengths

Daniel Kyle Palmer, BS, David Rios, BS, Wyzscx Merfil Patacxil, MS, Paul A. Williams, MS, Wayne K. Cheng, MD, Serkan İnceoğlu, PhD *

Orthopaedic Biomechanics Laboratory, Department of Orthopaedic Surgery, Loma Linda University, Loma Linda, CA

Abstract

Background: Screw length pertains to stability in various orthopedic fixation devices. There is little or no information on the relationship between plate pullout strength and screw length in anterior lumbar interbody fusion (ALIF) plate constructs in the literature. Such a description may prove useful, especially in the treatment of osteoporotic patients where maximizing construct stability is of utmost importance. Our purpose is to describe the influence of screw length on ALIF plate stability in severely and mildly osteoporotic bone foam models.

Methods: Testing was performed on polyurethane foam blocks with densities of 0.08 g/cm^3 and 0.16 g/cm^3. Four-screw, single-level ALIF plate constructs were secured to the polyurethane foam blocks by use of sets of self-tapping cancellous bone screws that were 20, 24, 28, 32, and 36 mm in length and 6.0 mm in diameter. Plates were pulled out at 1 mm/min to failure, as defined by consistently decreasing load despite increasing displacement.

Results: Pullout loads in 0.08-g/cm^3 foam for 20-, 24-, 28-, 32-, and 36-mm screws averaged 303, 388, 479, 586, and 708 N, respectively, increasing at a mean of 25.2 N/mm. In 0.16-g/cm^3 foam, pullout loads for 20-, 24-, 28-, 32-, and 36-mm screws averaged 1004, 1335, 1569, 1907, and 2162 N, respectively, increasing at a mean of 72.2 N/mm.

Conclusions: The use of longer screws in ALIF plate installation is expected to increase construct stability. Stabilization from screw length in osteoporotic patients, however, is limited.

Keywords: ALIF; Lumbar spine; Anterior plate; Pullout; Polyurethane foam; Screw length

Anterior lumbar interbody fusion (ALIF) is commonly applied in the surgical treatment of degenerative spinal conditions, such as discogenic pain, instability, and spondylolisthesis.[1,2] Important to the successful application of this technique is the maintenance of construct stability until fusion. Stability of an anterior interbody fusion may be enhanced with an anterior plate or with transpedicular fixation, although the latter necessitates altering patient position for an additional approach. Numerous biomechanical studies have shown the stabilizing efficacy of anterior plates to approximate that of posterior fixation.[3,4] When stability supplementation comes from an anterior plate, the holding power of screws securing the anterior plate in place relates to procedural success. Many authors have studied factors pertaining to screw stability, such as bone density, outer screw diameter, outer screw diameter–to–inner screw diameter ratio, thread pitch, cannulation, and screw length.[5–9] Accordingly, osteoporosis may contraindicate ALIF depending on severity because of lowered construct stability. It is particularly important to consider means of increasing construct stability in osteoporotic patients with borderline ALIF eligibility to ensure that appropriate treatment is pursued.

Biomechanical analyses of construct stability often entail pullout testing; although different from the in vivo mode of failure, this easily provides standardized values for comparisons of construct stability. Polyurethane (PU) foam has been used in many pullout studies because it replicates biomechanical properties of cancellous bone while also providing increased intra- and inter-specimen homogeneity compared with cadaveric vertebrae.[10–18] Using single screws inserted into PU foam, DeCoster et al.[9] showed relationships between pullout strength and major screw diameter, major screw diameter–to–minor screw diameter ratio, and thread pitch. More recently, DiPaola et al.[16] used PU foam to show that variable-angle anterior cervical

* Corresponding author: Serkan İnceoğlu, PhD, Orthopaedic Biomechanics Laboratory, Department of Orthopaedic Surgery, Loma Linda University, 11406 Loma Linda Dr, Ste 218, Loma Linda, CA 92354; Tel: 909-558-6490; Fax: 909-558-6118.

E-mail address: sinceoglu@llu.edu

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screw-plate constructs produce higher pullout loads than equivalent fixed-angle constructs. In addition, they showed that pullout strength was highest when the screws were inserted straight into the foam rather than at an angle.[16] Conrad et al.[19] found that increasing cervical screw length increases screw pullout strength by 16 N/mm.

To our knowledge, however, the relationship between screw length in a lumbar anterior plate construct and plate pullout strength has yet to be determined. We analyzed ALIF plate pullout strength in both mildly osteoporotic and severely osteoporotic cancellous bone foam models using 5 different screw lengths. We hypothesized that pullout load would increase with screw length and that it would do so similarly in both foam densities.

Methods

Testing was performed on PU foam blocks (Sawbones, Vashon, Washington) with densities of 0.16 g/cm^3 and 0.08 g/cm^3, replicating mildly osteoporotic and severely osteoporotic cancellous bone, respectively. Block dimensions of $130 \times 40 \times 60$ mm were selected to enable secure gripping and 2-sided use. Four-screw, single-level, variable-angle ALIF plates (Lanx, Broomfield, Colorado) were secured to the PU foam blocks by use of sets of self-tapping cancellous bone screws that were 20, 24, 28, 32, and 36 mm in length and 6.0 mm in diameter (Fig. 1). Pilot holes were drilled into the foam block perpendicular to its axis with a 1/8-in drill bit, into which screws were placed and appropriately tightened by a single investigator to reduce variations in insertion torque.

Biomechanical testing was performed with a materials testing machine (Instron, Norwood, Massachusetts). Two clamps, placed 1 cm away from opposite edges of the plate, were used to secure the foam blocks in place and prevent bending. Plates were then connected to the load cell by securing a threaded rod into a central threaded hole in the plate (Fig. 2). A preload of 50 N was applied to the plate. Plates were pulled out at 1 mm/min to failure. Pullout load was defined as the maximum load encountered before failure, which was defined by consistently decreasing load despite increasing displacement (Fig. 3). Load-displacement data were recorded. Stiffness was calculated as the slope of the linear region of the load-displacement curve before yield. Five pullout tests were performed in each group. Regression analysis (SPSS software, version 18; SPSS, Chicago, Illinois) was used to determine the relationship between screw length and either pullout load or stiffness.

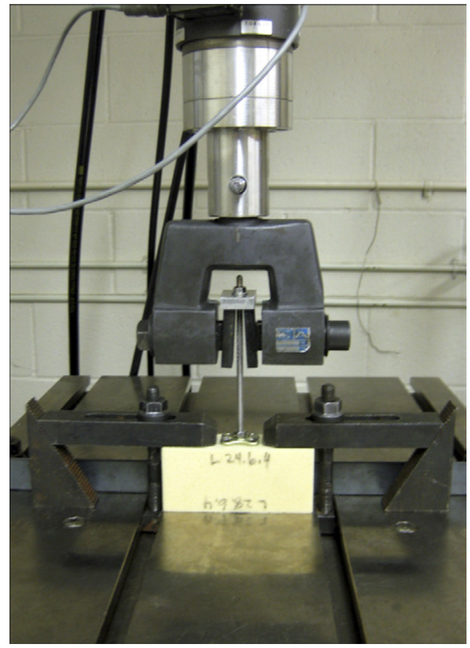

Fig. 2. Pullout testing setup.

Results

Pullout loads in 0.08-g/cm^3 foam for 20-, 24-, 28-, 32-, and 36-mm screws averaged 303, 388, 479, 586, and 708

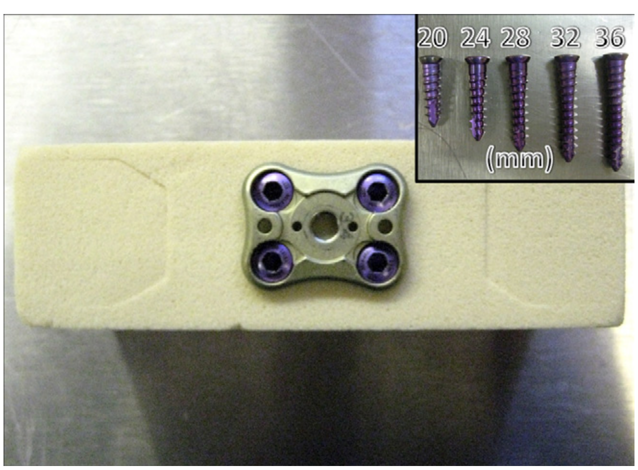

Fig. 1. ALIF plate attached to foam block and screw lengths tested (inset).

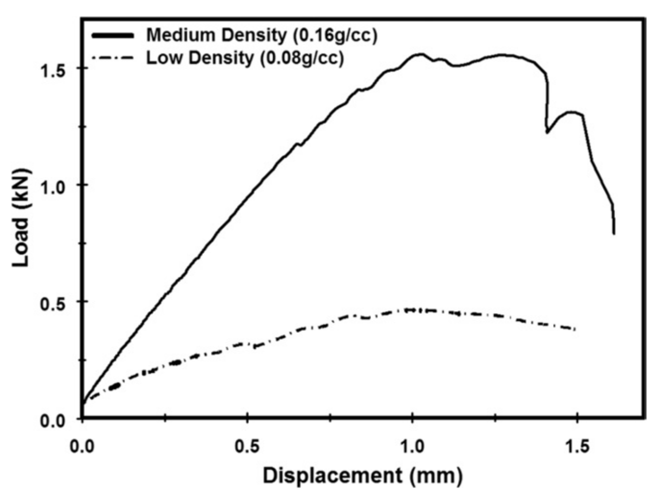

Fig. 3. Load-displacement curves for both foam densities.

Table 1
Summary of maximum load to failure for each screw length and foam density

Screw length	Low density (0.08 g/cm³) Mean (N)	SD (N)	Medium density (0.16 g/cm³) Mean (N)	SD (N)	Low density–medium density ratio
20 mm	302.8	11.0	1004	86.1	0.302
24 mm	388.2	35.6	1335	30.7	0.291
28 mm	479.4	43.5	1569	41.5	0.306
32 mm	585.9	12.5	1907	214.3	0.307
36 mm	707.8	33.9	2162	106.7	0.327

N, respectively. In 0.16-g/cm^3 foam, pullout loads for 20-, 24-, 28-, 32-, and 36-mm screws averaged 1004, 1335, 1569, 1907, and 2162 N, respectively (Table 1). At each screw length, the pullout load in the lower-density foam was approximately 30% that of the higher-density foam.

Pullout load was observed to increase with screw length in both foam densities. In the lower-density foam (0.08 g/cm^3), a mean of 25.2 N was gained for each millimeter increase in screw length (Table 2). In the higher-density foam (0.16 g/cm^3), a mean of 72.2 N was gained for each millimeter increase in screw length (Table 2). Pullout load was linearly associated with screw length in both foam densities (Fig. 4) and showed strong regression with screw length ($r = 0.97$, $P < .001$ for 0.16 g/cm^3; $r = 0.98$, $P < .001$ for 0.08 g/cm^3). Stiffness also showed strong regression with screw length ($r = 0.82$, $P < .001$ for 0.16 g/cm^3; $r = 0.87$, $P < .001$ for 0.08 g/cm^3) (Fig. 5).

Discussion

There are many factors to consider when one is attempting to maximize the stability of an ALIF screw-plate construct. Variables observed to be of particular importance to screw pullout strength include bone density, outer screw diameter, screw length, and screw type.[5–9] There is often a

Table 2
Regression results for low-density (0.08-g/cm^3) and medium-density (0.16-g/cm^3) foam block specimens

Parameter	Slope (95% CI)	r Value	P value	Ratio
0.08 g/cm³				
Maximum load	25.2 N (8.8%)	0.980	<.001	
Displacement	0.03 mm (30.3%)	0.821	<.001	
Stiffness	24.6 N/mm (24.2%)	0.872	<.001	
0.16 g/cm³				
Maximum load	72.2 N (11.2%)	0.968	<.001	2.87
Displacement	0.02 mm (60.9%)	0.584	.002	0.67
Stiffness	51.6 N/mm (30.5%)	0.816	<.001	2.10

NOTE. The 95% CI for the slope is given as the percentage of the slope. The slope is expressed as change per millimeter of screw length. The ratio is the medium-density slope divided by the low-density slope.

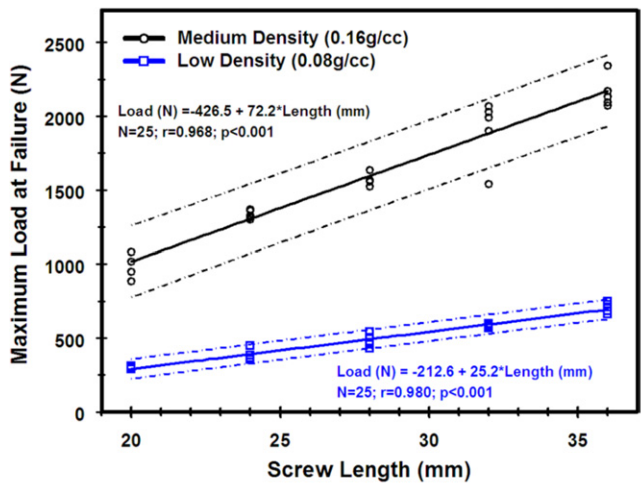

Fig. 4. Maximum pullout load plotted against screw length.

range of feasible screw lengths available for the surgeon's selection; however, outer screw diameter and screw shaft type are more or less fixed, and bone density is highly patient specific. In this study we have analyzed the influence of screw length on ALIF screw-plate construct stability in mildly and severely osteoporotic cancellous bone foam models.

Results show that the pullout strength of an ALIF screw-plate construct directly correlates with screw length. This was observed in both mildly and severely osteoporotic bone foam models. Whereas roughly doubling screw length yielded roughly doubled pullout strength in both foam densities, the absolute increase in load per added millimeter was substantially more in the higher-density foam (72.2 N/mm compared with 25.2 N/mm). Conrad et al.[19] observed similar increases in load per added millimeter in 0.16-g/cm^3 foam (16 N/mm) considering that their pullout tests were on single screws. Therefore one can expect that increasing ALIF screw length will increase construct stability in osteoporotic patients, though not to the same extent as it

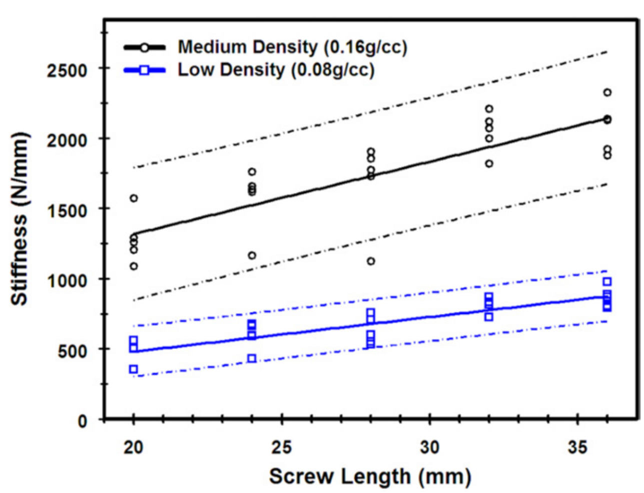

Fig. 5. Stiffness plotted against screw length.

would in non-osteoporotic patients. This is pertinent because the patient's anatomy limits the length a surgeon can increase the screw by without risking serious complications. Athiviraham et al.[20] observed a mean lumbar vertebral body anterior-posterior diameter of 34.8 $\pm$ 4.3 mm in their study of 123 male and female adults. Careful assessment of patient-specific anatomy may aid the surgeon in determining the maximum safe screw length. The most common screw lengths for ALIF plate installation have been, in our experience, 24 to 32 mm.

These results are consistent with those of Dvorak et al.[6] in showing bone density to be of great importance to the stability of anterior screw-plate constructs. The data show that doubling screw length roughly doubles pullout load, whereas doubling density roughly triples pullout load. Even the set of 36-mm screws used in 0.08-g/cm^3 PU foam did not yield the pullout strength obtained by 20-mm screws in 0.16-g/cm^3 foam. This suggests bone density to be more pertinent to construct stability than screw length. Methods of increasing vertebral body density may therefore be considered to qualify osteoporotic patients for ALIF. Cement augmentation is commonly used to increase density.[21,22] Alternatively, because bone density varies within the vertebral body, screw placement in different locations within the vertebra may also provide a means of increasing construct stability. Cadaveric studies have shown that bicortical screws placed near the endplate are more resistant to toggle than bicortical screws placed in the center of the vertebral body.[23,24] This may be a result of the increased density of the cortical shell, as well as trabecular disruption with age, beginning in the center of the vertebral body and progressing outward.[25] Other means of stabilization include the addition of posterior instrumentation, such as pedicle-based fusion devices and interspinous spacers.[3,4,26]

The limitations of this study are similar to those of many in vitro biomechanical studies. First, construct failure through pullout differs from in vivo construct failure, which involves cyclic loading mechanisms. Second, only 1 ALIF screw-plate construct was used in this study, and plate construct strength may vary with design.[6] Lastly, although PU foam allows for increased intra- and inter-specimen homogeneity, it is not perfectly representative of vertebra. Subsequent pullout tests using cadavers could strengthen findings initially observed in PU foam.

In conclusion, the use of longer screws in the installation of an ALIF plate is expected to increase construct stability. Stabilization from screw length in osteoporotic patients, however, is limited.

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