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Review Article

The biomechanics of pedicle screw augmentation with cement

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Abstract

BACKGROUND CONTEXT: A persistent challenge in spine surgery is improving screw fixation in patients with poor bone quality. Augmenting pedicle screw fixation with cement appears to be a promising approach.

PURPOSE: The purpose of this study was to survey the literature and assess the previous biomechanical studies on pedicle screw augmentation with cement to provide in-depth discussions of the biomechanical benefits of multiple parameters in screw augmentation.

STUDY DESIGN/SETTING: This is a systematic literature review.

METHODS: A search of Medline was performed, combining search terms of pedicle screw, augmentation, vertebroplasty, kyphoplasty, polymethylmethacrylate, calcium phosphate, or calcium sulfate. The retrieved articles and their references were reviewed, and articles dealing with biomechanical testing were included in this article.

RESULTS: Polymethylmethacrylate is an effective material for enhancing pedicle screw fixation in both osteoporosis and revision spine surgery models. Several other calcium ceramics also appear promising, although further work is needed in material development. Although fenestrated screw delivery appears to have some benefits, it results in similar screw fixation to prefilling the cement with a solid screw. Some differences in screw biomechanics were noted with varying cement volume and curing time, and some benefits from a kyphoplasty approach over a vertebroplasty approach have been noted. Additionally, in cadaveric models, cemented-augmented screws were able to be removed, albeit at higher extraction torques, without catastrophic damage to the vertebral body. However, there is a risk of cement extravasation leading to potentially neurological or cardiovascular complications with cement use. A major limitation of these reviewed studies is that biomechanical tests were generally performed at screw implantation or after a limited cyclic loading cycle; thus, the results may not be entirely clinically applicable. This is particularly true in the case of the bioactive calcium ceramics, as these biomechanical studies would not have measured the effects of osseointegration.

CONCLUSIONS: Polymethylmethacrylate and various calcium ceramics appear promising for the augmentation of pedicle screw fixation biomechanically in both osteoporosis and revision spine surgery models. Further translational studies should be performed, and the results summarized in this review will need to be correlated with the clinical outcomes. Published by Elsevier Inc.

Keywords: Pedicle screw augmentation; Cement; Polymethylmethacrylate; Vertebroplasty; Kyphoplasty; Proximal junction kyphosis; Biomechanics

FDA device/drug status: Not approved for this indication: pedicle screw augmentation with polymethylmethacrylate or other cements.

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The disclosure key can be found on the Table of Contents and at www.TheSpineJournalOnline.com.

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Introduction

An increasing challenge in spinal surgery has been the need to achieve optimal fixation of the pedicle screws in cases with poor bone quality such as in osteoporosis and previously radiated spinal levels. Additionally, revision surgeries to correct previously failed instrumentation are progressively more common. Therefore, techniques to enhance the fixation of pedicle screws are required, and a primary method for this has been to augment the screw fixation with cement. Although polymethylmethacrylate (PMMA) has been approved by the US Food and Drug Administration for the treatment of osteoporotic and tumor-related compression fractures, it has not been approved for pedicle screw augmentation, and this technique is currently used off-label.

The objective of this article was to review the studies assessing the biomechanical properties of pedicle screw cement augmentation in humans, with a specific focus on use in osteoporosis and revision spine cases. In-depth discussions of biomechanical testing methods, fenestrated screws, cement volume, cement curing time, cement material, augmented screw failure modalities, cementing technique, cementing complications, and the biomechanical effects on the vertebral bodies are also provided.

Materials and methods

A comprehensive search was conducted using Medline with an attempt to identify all the relevant studies documenting biomechanical testing in human tissues on cement augmentation of pedicle screws. A Medline search was conducted using the search terms ''pedicle screw'' combined with ''augmentation,'' OR ''vertebroplasty,'' OR ''kyphoplasty,'' OR ''PMMA,'' OR ''polymethylmethacrylate,'' OR ''Calcium phosphate,'' or ''Calcium sulfate'' from January 1, 1970 to September 30, 2014 as cement augmentation of pedicle screws was not documented before this time. Studies describing biomechanical testing of cement-augmented pedicle screws in human cadaveric or synthetic cadaveric bone were included. Articles not including pedicle screws or sacropelvic fixation; articles with only clinical data, technical reports, case reports, review articles, letters to the editor, and not in English; articles only with animal bone tissue; and studies only with modeling data were excluded.

Results

Using the search strategy described previously, 306 articles were identified. As this systematic review targeted studies on cement augmentation biomechanics in human spines, studies with only clinical data and biomechanical studies performed in animals with different vertebral anatomy were excluded. Additionally, studies only providing modeling data were not included in the analysis as they were based on previous biomechanical work and would therefore be redundant. Following this search strategy, and after reviewing the citations of the isolated articles, 33 relevant studies were identified and included in this systematic review.

Biomechanics of cement-augmented screws in osteoporosis

Studies describing the use of PMMA for screw augmentation in normal and osteoporotic spines are summarized in Table 1. Liu et al. [1] compared PMMA-augmented and nonaugmented screws in osteoporotic L1–L4 cadaveric vertebrae and found a two-fold increase in pullout strength and energy to failure. A similar 1.8- to 2.1-fold increase in axial pullout strength with augmentation was noted in a separate study on osteoporotic T12–L5 vertebrae, although they also noted a linear correlation between bone density and axial pullout force [2]. Additionally, after cyclic compressive loading, Sven et al. [7] found no difference in screw migration in normal bone but less displacement with cement in osteoporotic bone.

Other studies have assessed the use of PMMA screw augmentation in sacropelvic fixation. For example, Yu et al. [4] studied cement augmentation of iliac screws in osteopenic cadaveric pelvises, and noted a 1.2- to 1.5-fold increase in axial pullout strength with PMMA augmentation. When examining sacral fixation in osteoporotic bone, tricortical PMMA-augmented pedicle screws had the least subsidence displacement after cyclic compressive loading [5]. In contrasts, Zhuang et al. [8] tested sacral fixation in osteoporotic bone and noted similar subsidence and pullout strength between bicortical nonaugmented screws and unicortical PMMA-augmented screws, with less severe degrees of osteoporosis. However, these results may be less clinically applicable as S1 pedicle screws are typically placed in a bicortical or tricortical fashion.

Biomechanics of cement-augmented screws in revision spine surgery

Kiner et al. [3] compared 8-mm-diameter screws with 6 mm screws augmented with PMMA in previously instrumented vertebra and found increased initial and final stiffness for the large diameter screws after cyclic compressive loading. However, 8-mm-diameter screws would potentially be challenging to place at all lumbar levels.

On the other hand, in previously instrumented osteoporotic lumbosacral vertebrae, a nonpressurized cement injection for pedicle screw augmentation restored the pullout strength to baseline, whereas a pressurized injection of cement led to a two-fold increase in pullout strength [6]. Similarly, Frankel et al. [9] tested reinstrumented thoracolumbar osteoporotic vertebrae and found that cement augmentation resulted in a 1.6-fold increase in axial pullout strength. Additionally, Moore et al. [10] found that PMMA screw augmentation restored axial pullout strength