Biomechanical Comparisons of Pull Out Strengths After Pedicle Screw Augmentation with Hydroxyapatite, Calcium Phosphate, or Polymethylmethacrylate in the Cadaveric Spine

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OBJECTIVE: **In vertebrae with low bone mineral densities pull out strength is often poor, thus various substances have been used to fill screw holes before screw placement for corrective spine surgery. We performed biomechanical cadaveric studies to compare non-augmented pedicle screws versus hydroxyapatite, calcium phosphate, or polymethylmethacrylate augmented pedicle screws for screw tightening torques and pull out strengths in spine procedures requiring bone screw insertion.**

METHODS: **Seven human cadaveric T10–L1 spines with 28 vertebral bodies were examined by x-ray to exclude bony abnormalities. Dual-energy x-ray absorptiometry scans evaluated bone mineral densities. Twenty of 28 vertebrae underwent ipsilateral fluoroscopic placement of 6-mm holes augmented with hydroxyapatite, calcium phosphate, or polymethylmethacrylate, followed by transpedicular screw placements. Controls were pedicle screw placements in the contralateral hemivertebrae without augmentation. All groups were evaluated for axial pull out strength using a biomechanical loading frame.**

RESULTS: **Mean pedicle screw axial pull out strength compared with controls increased by 12.5% in hydroxyapatite augmented hemivertebrae ($P = 0.600$) and by 14.9% in calcium phosphate augmented hemivertebrae ($P = 0.234$), but the increase was not significant for either method. Pull out strength of polymethylmethacrylate versus hydroxyapatite augmented pedicle screws was 60.8% higher ($P = 0.028$).**

CONCLUSIONS: **Hydroxyapatite and calcium phosphate augmentation in osteoporotic vertebrae showed a trend toward increased pedicle screw pull out strength versus controls. Pedicle screw pull out force of polymethylmethacrylate in the insertion stage was higher than that of hydroxyapatite. However, hydroxyapatite is likely a better clinical alternative to polymethylmethacrylate, as hydroxyapatite augmentation, unlike polymethylmethacrylate augmentation, stimulates bone growth and can be revised.**

INTRODUCTION

With the dramatic increase of complex spinal surgery and other osteoporotic vertebral fracture interventions, implant enrichment with coatings and fillings of biocompatible materials has become popular (4, 13, 14, 16). Implant stability is the ability of the polyaxial pedicle screws to maintain vertebral positioning (1, 16). Screw fixation or loosening is an important characteristic of implant materials that can affect the bone healing process (3-8). Calcium phosphate (CaP) and derivatives represent potential clinically applicable biomaterials for implant fixation (5, 15).

To provide a solid fixation and thus reduce the risk of loosening, coating orthopedic implants with biocompatible materials can be a useful approach. In the vertebral fixation of polyaxial pedicular screws, because hydroxyapatite (HA) possesses the biomaterial properties of biocompatibility, bioactivity, osteoconductivity, and

Key words
- Biomechanics
- Calcium phosphate
- Human cadaver
- Hydroxyapatite
- Osteoporosis
- Pedicle screw
- Polymethylmethacrylate
- Pull out strength
- Spine

Abbreviations and Acronyms
BMD: Bone mineral density
CaP: Calcium phosphate
HA: Hydroxyapatite
PMMA: Polymethylmethacrylate

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Citation: World Neurosurg. (2015) 83, 6:976-981.
http://dx.doi.org/10.1016/j.wneu.2015.01.056

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

direct bonding to bone, its use as a coating material may improve biomechanical efficiency. The most important issue, however, is the coating method and its quality, as these factors have a crucial impact on implant fixation and bone ingrowth. In addition, coating screws with HA may be more economical and easier to apply compared with other coating methods, such as plasma spray coating (3, 6, 8, 19) and electrophoretic deposition (22).

Many researchers have used animal models to investigate osteointegration of implant materials with pedicle and cortical screws, plates, and rods (11, 12, 20). Three studies showed that HA coating improves the fixation of stainless steel pedicle screws, resulting in increased pull out resistance and reduced loosening risk (4-6). Using the plasma spraying method, Sanden et al. (13-15) performed a series of experimental and clinical studies involving sheep and humans to determine the feasibility of HA-coated stainless steel screws and reported a significant difference in insertion-extraction torques between coated and uncoated pedicle screws.

The objective of this study was to compare biomechanical responses to unfilled and filled titanium polyaxial pedicle screws with HA, CaP, or polymethylmethacrylate (PMMA) bone cement as implant materials in human cadaveric vertebrae. To our knowledge, this study, which correlates the pull out strength and bone density, has never before been reported.

METHODS

Seven human cadaveric T10—L1 spine specimens with 28 vertebral bodies were examined with x-ray to exclude bony abnormalities and a dual-energy x-ray absorptiometry scan to evaluate bone mineral density (BMD). Specimens were stripped of soft tissue and posterior elements (i.e., structures posterior to bodies including pedicles). Anterior vertebral bodies were mounted with PMMA and polyester resins in the potting fixtures of a material testing machine (MTS 858 Bionix test system, Eden Prairie, Minnesota, USA). The left sides of the vertebral bodies were exposed for screw insertion (Figure 1). Specimens were divided into 4 groups with the average BMD in each group as close as possible to the average BMD of all specimens (Table 1). The exposed left sides of the vertebral bodies were tapped and pedicle screws were inserted without augmentation as the control group (group 1), consisting of 20 of 28 vertebrae that underwent ipsilateral fluoroscopic placement of a 6-mm diameter hole (Table 2). Augmentation with HA (group 2) or CaP (group 3) was followed by transpedicular screw placement. The remaining 8 ipsilateral hemivertebrae were tested for HA augmentation versus contralateral PMMA augmentation (group 4). Pedicle screws were then evaluated for axial pull out strength using a biomechanical loading frame.

In summary, before screw insertion, the tapped hole was left unfilled (group 1) or filled with HA, CaP, or PMMA (groups 2—4, respectively). For specimens in groups 2—4, screw insertion was performed within 5 minutes of applying the bone filling material to the screw holes.

Biomechanical Testing

Pedicle screws were then evaluated for axial pull out strength using a biomechanical loading frame. The potted specimens were fixed onto the lower spine fixture of the testing machine with the screw head facing upward (Figure 2). The screw head was fixed onto the axial rotary actuator of the testing machine. The rotational screwing action of the final 180 degrees of the screw was applied by the rotary actuator and the torque measured by the load/torque cell of the MTS machine. Specimens in groups 3 and 4 were removed from the testing machine, and the bone filling substances were allowed to cure for 24 hours before conducting the bone screw pull out strength test. To measure bone screw pull out strength, specimens were fixed onto the lower spine fixture of the MTS machine. The axial actuator of

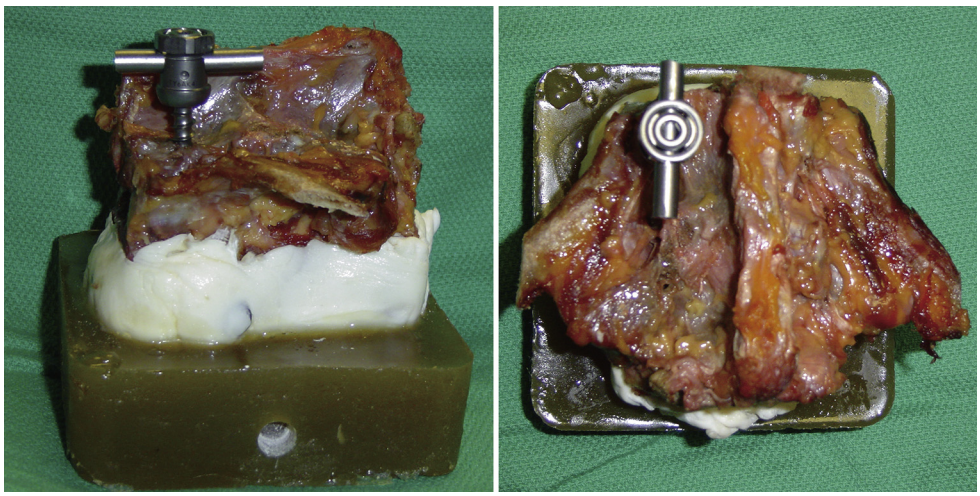

Figure 1. Anterior vertebral bodies were mounted with polymethylmethacrylate and polyester resins in the potting fixtures of a material testing machine.