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Biomechanical study of expandable pedicle screw fixation in severe osteoporotic bone comparing with conventional and cement-augmented pedicle screws

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ABSTRACT

Pedicle screws are widely utilized to treat the unstable thoracolumbar spine. The superior biomechanical strength of pedicle screws could increase fusion rates and provide accurate corrections of complex deformities. However, osteoporosis and revision cases of pedicle screw substantially reduce screw holding strength and cause loosening. Pedicle screw fixation becomes a challenge for spine surgeons in those scenarios. The purpose of this study was to determine if an expandable pedicle screw design could be used to improve biomechanical fixation in osteoporotic bone. Axial mechanical pull-out test was performed on the expandable, conventional and augmented pedicle screws placed in a commercial synthetic bone block which mimicked a human bone with severe osteoporosis. Results revealed that the pull-out strength and failure energy of expandable pedicle screws were similar with conventional pedicle screws augmented with bone cement by 2 ml. The pull-out strength was 5-fold greater than conventional pedicle screws and the failure energy was about 2-fold greater. Besides, the pull-out strength of expandable screw was reinforced by the expandable mechanism without cement augmentation, indicated that the risks of cement leakage from vertebral body would potentially be avoided. Comparing with the biomechanical performances of conventional screw with or without cement augmentation, the expandable screws are recommended to be applied for the osteoporotic vertebrae.

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1. Introduction

Use of pedicle screw systems for spinal stabilization has become increasingly common in reconstruction, fixation, and other spinal disorder surgeries [1–3]. However, osteoporosis has been considered as a contraindication for pedicle screw fixation. The fact that the pullout strength of pedicle screw is highly correlated with bone mineral density (BMD) has been demonstrated in previous study [4]. With poor BMD, the pull-out strength of the pedicle screw in osteoporotic bone shall be decreased and lead to screw loosening [5,6]. The insufficient fixation strength at the pedicle screw-bone interface will also cause high risks in spine curve progression, implant failure, and pseudarthrosis.

To improve the pull-out strength of pedicle screws for osteoporotic bone, surgeons have paid attention to the technique of cement-augmented pedicle screws. It has been agreed that, in clinical practice, a cement-augmented screw can increase the pull-out strength of screws in osteoporotic bone [7–9]. Although the advantages of cement-augmented screws are quite obvious, the related clinical reports of their practical usage were limited.

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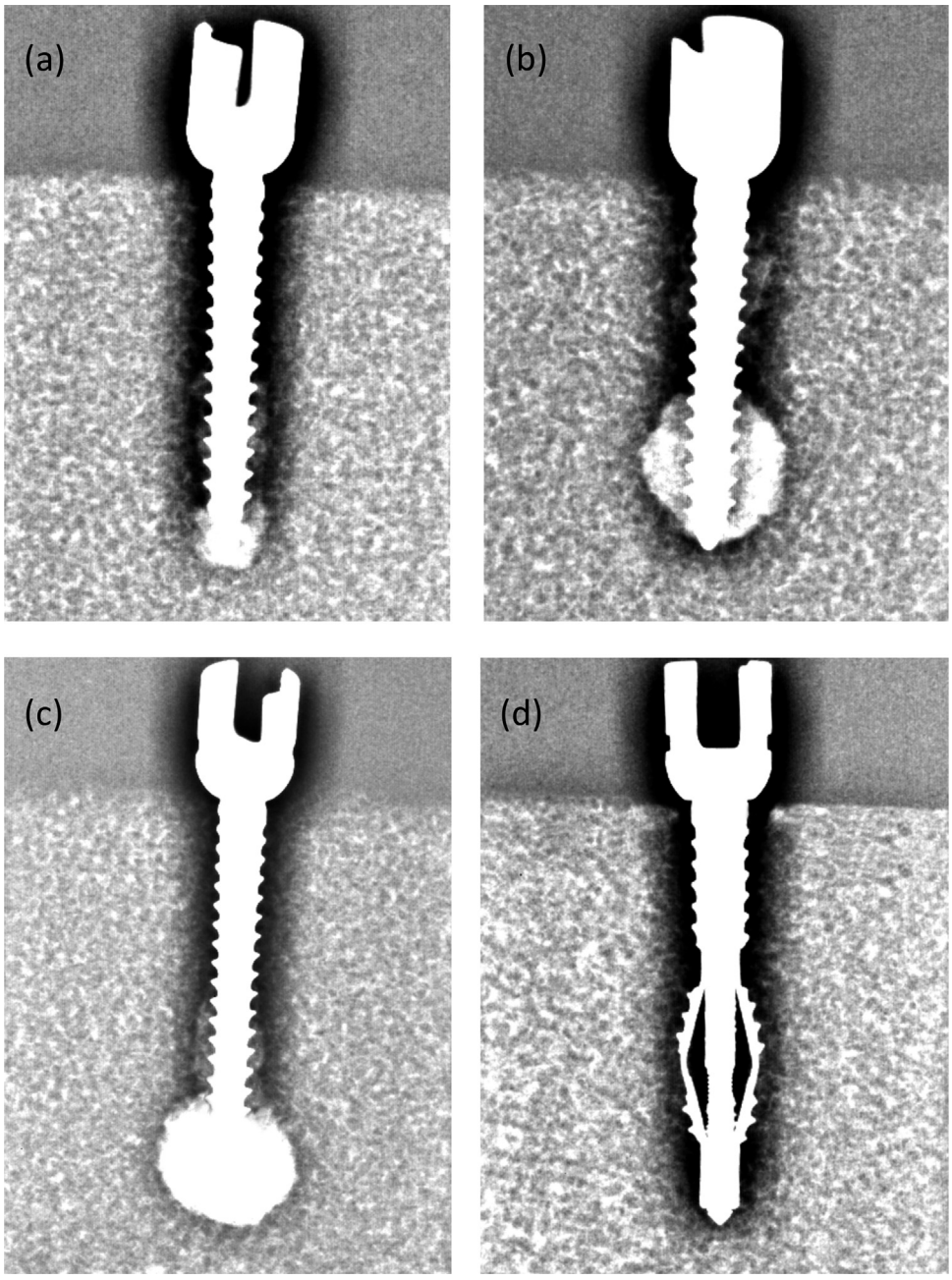

Fig. 1. The radiographic images of conventional pedicle screw augmented with bone cement volume of (a) 1 ml, (b) 2 ml, (c) 3 ml, and the expandable screw (Φ6.5 mm, length 50 mm).

One possible concern would be that the low-viscosity cement utilized for augmentation may be resulted in its leakage and cause neurological complications. Clinical cases of cement leakage into the spinal canal, neural foramina, paravertebral veins, and pulmonary artery cement embolism have been reported [10,11].

Due to this serious limitation of cement-augmented screw, the expandable screw has been developed and validated its efficiency in several biomechanical studies. Lei and Wu [12] reported the expandable screw could increase a mean of 38.3% of the pullout force comparing to conventional pedicle screws with an increase of 2.1 mm in the diameter of the expandable screw. Cook et al. [13] have also evaluated the pull-out strength of an expandable screw, which can be expanded by 1.5 mm at the end distal portion of the screw, and moderate improvements in fixation strength have been observed. According to the previous papers, most of the studies represented the existing design of expandable pedicle screws were capable to enhance their fixation strengths. However, the fixation strength was still lower than that of the conventional pedicle screws with bone cement [14]. On the purpose of fixation strength improvement, we modified the existing design of expandable pedicle screws. The smallest diameter of this expandable pedicle screw was 6.5 mm, and there were four centrosymmetrical fins protruded from the anterior of the screw. A smaller gauge can be inserted into the interior of the expandable pedicle screw and opened the fins concentrically as advanced. This system increased the diameter by approximately 60% of the expandable screw (over 3 mm) while the diameter of the posterior portion of the screw remained constant during its expansion.

The purpose of this study was to evaluate the pull-out strength, and energy required to failure of this expandable pedicle screw

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