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Lecture

Biomechanical arrangement of threaded and unthreaded portions providing holding power of transpedicular screw fixation

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ABSTRACT

Background: Failure of pedicle screw is a major concern in spinal surgery. The threaded and unthreaded portions of the pedicle screw provide the ability to anchor and squeeze the surrounding bone, respectively. This study aimed to investigate the anchoring and squeezing effects of different design of the threaded/unthreaded portions of a pedicle screw to vertebrae.

Methods: Four variations (one fully and three partially threaded, with a 1/3, 1/2, and 2/3 unthreaded designs at the proximal portion) of screws were used to measure pullout strength and withdrawn energy using synthetic and porcine specimens. The tests were conducted in static and dynamic fashions, in that the screws were axially extracted directly and after 150,000 cycles of lateral bending. The load-displacement curves were recorded to gain insight into the peak load (pullout strength) and cumulative work (withdrawn energy).

Findings: The two testing results of the synthetic and porcine specimens consistently showed that the 1/3 unthreaded screw provides significantly higher pullout strength and withdrawn energy than the fully threaded screw. The withdrawn energy of the three unthreaded screws was significantly higher than that of the threaded counterpart.

Interpretation: The holding power of a pedicle screw was the integration of the anchoring (cancellous core) and squeezing (compact pedicle) effects within the threaded and unthreaded portions. The current study recommends the 1/3 unthreaded screw as an optimal alternative for use as a shank-sliding mechanism to preserve the holding power within the pedicle isthmus.

1. Introduction

Transpedicular fixation has been widely used in spinal surgery to correct deformity and stabilize the spine. However, loosening at the bone-screw interfaces and breakage at the screw threads are common failure modes (Pihlajämaki et al., 1997; Davne and Myers, 1992; Lonstein et al., 1999; Okuyama et al., 2000; Kwok et al., 1996; Hsu et al., 2005). Failure of pedicle screws often leads to loss of fixation, symptomatic pseudarthrosis, and possible reoperation. To eliminate these complications, several concepts have been investigated, including shape modification of the threads, surface coating of the screws, and polymethylmethacrylate (PMMA) augmentation within screw holes (Krenn et al., 2008; Choma et al., 2011; Hashemi et al., 2009; Hasegawa et al., 2005; Sandén et al., 2001). These aim to enhance holding power at the bone-screw interfaces and fatigue resistance at the thread-shank junction, which have been reported to be stress-concentrated sites that jeopardize screw strength (Chao et al., 2008).

The pedicle screw is inserted to hold the bone through a pedicle isthmus and vertebral core (Fig. 1). The anchoring ability of the threaded shank comes from the shearing cut of the sandwiched bone chips along the cylindrical surface, formed by the thread tips (Tsai et al., 2009). However, slipping resistance at the unthreaded shank-bone interfaces results from the increased friction of the bone chips that were squeezed onto the surrounding zone (Chapman et al., 1996). The current study proposes two hypothetical, optimal arrangements of screw threads within two bony regions. The first uses the unthreaded shank to suppress the stress-concentrated effect, thus reducing the breakage risk within the pedicle isthmus (Chao et al., 2008). Furthermore, the greater diameter of the unthreaded shank can squeeze the surrounding

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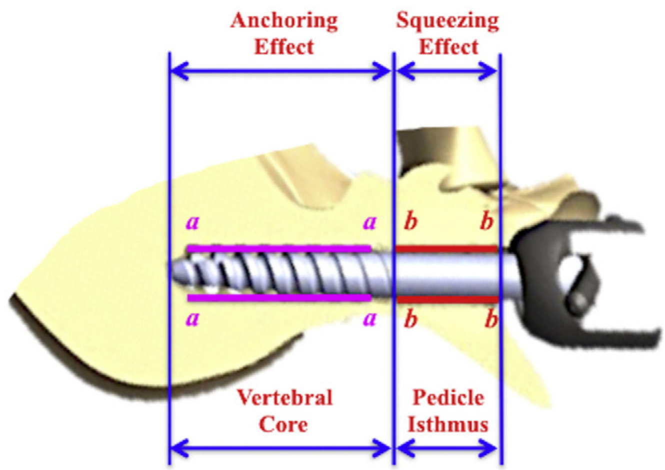


Fig. 1. Schematic diagram showing the insertion pathway of a pedicle screw. The anchoring and squeezing ability of the threaded and unthreaded shanks were assumed to occur within the vertebral core (lines *aa*) and pedicle isthmus (lines *bb*).

bone onto the peripheral wall of the predrilled hole, thus increasing the frictional resistance and the holding power of the inserted screw. The second is to preserve the deeper threads near the screw tip to anchor the cancellous bone of the vertebral core. Static and dynamic tests were used to evaluate the outcome of the different threaded strategies within the two bony regions.

In this study, specially manufactured pedicle screws with varying lengths of unthreaded designs at the proximal portion were tested. The peak load (pullout strength) and cumulative work (withdrawn energy) of the load-displacement curve were used as the comparison indices of the four screws. The measured pullout strength and withdrawn energy are discussed to investigate the holding characteristics of the threaded and unthreaded designs. The results of the testing were aimed to provide insight into the bone-screw interaction at the vertebral core and pedicle isthmus.

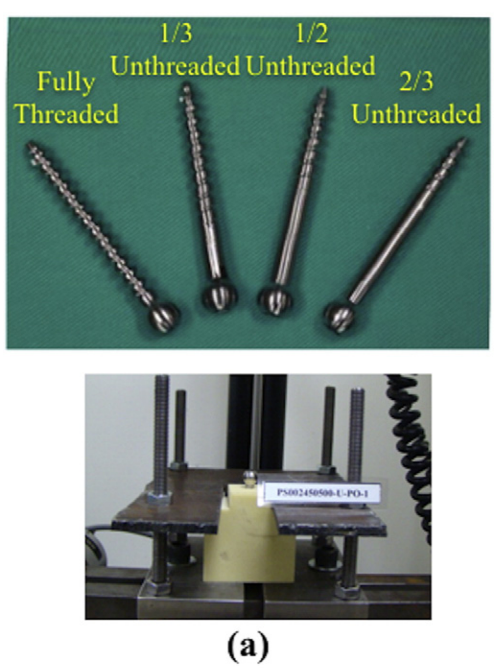
2. Methods

2.1. Pedicle screws

There were four variations of the threaded and unthreaded screws in this study: (1) threaded design along the full shank, (2) unthreaded design in the proximal one-third of the shank: 1/3 unthreaded, (3) unthreaded design in the proximal half of the shank: 1/2 unthreaded, and (4) unthreaded design in the proximal two-thirds of the shank: 2/3 unthreaded (Fig. 2a). The fully threaded screw was used as a control. The specifications of the four screws were the same, including outer and core diameters, pitch, depth, and profile of the threads, and screw length. All screws were 5.5-mm in diameter and 45-mm in length, and were made of titanium alloy (Ti6Al4V). The sample size was six for each of the groups in each test.

2.2. Biomechanical tests

The testing protocol used for pullout strength and withdrawn energy of the pedicle screws was based on the ASTM F543 standard and previous studies (Tsai et al., 2009). Two types of synthetic and porcine specimens were used to measure the biomechanical behaviors of holding power for the bone-screw constructs. The synthetic specimen served as the representative to avoid individual variation of the mechanical properties while using cadaveric bones. The adapted bricks had porosity of 0.16 g/cc which were made of cellular polyurethane foam (Sawbones, Pacific Research Corporation, Vashon, Washington, USA). Each brick of polyurethane foam was equally segmented into cubic blocks, $6 \times 6 \times 6$ cm in size. The testing blocks were prepared by pre-drilling pilot holes, and followed by pedicle screw insertion perpendicularly into the center of the testing block without pre-tapping. The porcine specimens were used as a control group that could mimic the bony properties of the vertebral core and pedicle isthmus. Porcine specimens were isolated from porcine lumbar spine obtained from a local slaughterhouse. Before experimentation, all intervertebral disc tissues and subjacent soft tissues were cleaned, and bony vertebral structure was isolated individually. Application of the pedicle screw into synthetic and porcine specimen is all performed by a spine surgeon to avoid man-



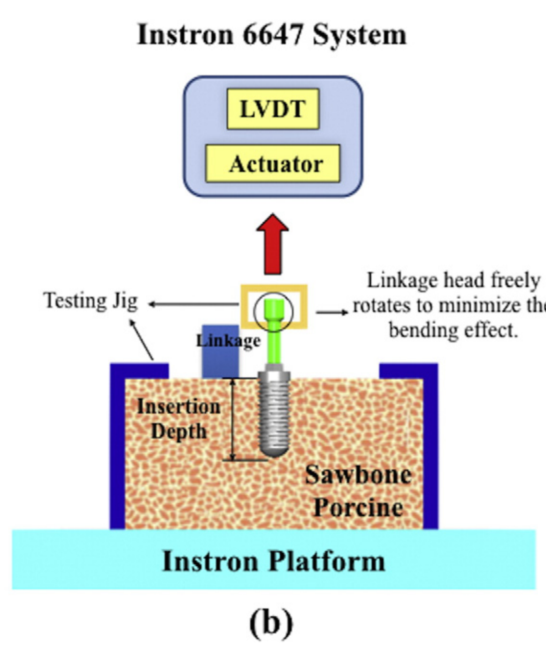


Fig. 2. Experimental Setup. (a) Four pedicle screws used in this study and setup of the pullout tests using the Instron 4467 servohydraulic testing system. (b) The schematic diagram showing the protocol of the testing jigs and screw insertion.