Medical Engineering & Physics 32 (2010) 822–828

Contents lists available at ScienceDirect

Medical Engineering & Physics

journal homepage: www.elsevier.com/locate/medengphy

# The effect of screw insertion angle and thread type on the pullout strength of bone screws in normal and osteoporotic cancellous bone models

Purvi S.D. Patel*, Duncan E.T. Shepherd, David W.L. Hukins

*School of Mechanical Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, West Midlands, UK*

ARTICLE INFO

*Article history:*
Received 21 November 2009
Received in revised form 10 May 2010
Accepted 12 May 2010

*Keywords:*
Bone screws
Osteoporosis
Pullout strength
Screw insertion angle

ABSTRACT

Screw fixation can be extremely difficult to achieve in osteoporotic (OP) bone because of its low strength. This study determined how pullout strength is affected by placing different bone screws at varying angles in normal and OP bone models. Pullout tests of screws placed axially, and at angles to the pullout axis (ranging from 10° to 40°), were performed in $0.09\,g\,cm^{-3}$, $0.16\,g\,cm^{-3}$ and $0.32\,g\,cm^{-3}$ polyurethane (PU) foam. Two different titanium alloy bone screws were used to test for any effect of thread type (i.e. cancellous or cortical) on the screw pullout strength. The cancellous screw required a significantly higher pullout force than the cortical screw ($p < 0.05$). For both screws, pullout strength significantly increased with increasing PU foam density ($p < 0.05$). For screws placed axially, and sometimes at 10°, the observed mechanism of failure was stripping of the internal screw threads generated within the PU foam by screw insertion. For screws inserted at 10°, 20°, 30° and 40°, the resistance to pullout force was observed to be by compression of the PU foam material above the angled screw; clinically, this suggests that compressed OP bone is stronger than unloaded OP bone.



## 1. Introduction

This paper compares the fixation of screws in normal and osteoporotic (OP) bone models. Osteoporosis is a disease in which bone is weakened because resorption exceeds deposition [1]. The resulting loss of bone often leads to fractures, which in turn leads to the need for fixation of implants to aid repair. Bone screws are commonly used for fixing orthopaedic implants [2]. Pullout strength can be used to measure screw fixation strength [3]. To date, work on screw pullouts has focused mainly on axial pullouts in cadaveric [4–6] and animal [7–9] bone and synthetic materials mimicking the properties of human bone [7,9,10]. Several studies report on the pullout of screws augmented with polymethylmethacrylate, various bone cements, calcium phosphate products and laminar hooks in OP bone [4–6,11–15]. This is because, without augmentation, axial screw pullout strength from non-augmented/untreated OP bone has been reported to decrease with decreasing bone mineral density [16–20]. For this reason, OP is sometimes considered a contra-indication for screw fixation, particularly in the spine [17,18,21–23]. However, screw fixation to OP bone has been performed in the spine for cases of instability (after fracture), deformity, tumours, multi-segmental spinal stenosis and neurological deficits that require decompression and stabilisation [13,24–26].

The work described in this study uses polyurethane (PU) foam to overcome the main problem in determining screw fixation strength in OP bone. The widespread variability in the mechanical properties of OP bone [27] make it difficult to distinguish effects caused by differences in screw fixation from those caused by bone specimen variability. In this study, the problem of variability was overcome by using PU foams of different densities that are suitable as models for representing the mechanical properties of normal and OP bone [28].

For OP bone, multiple sites of screw fixation are often used [24], which means that screws can be placed at various angles [29]. Only a small number of studies have investigated angled screws [29–37] and most are specific to a single anatomical site [30–35]. There has been a previous study of the pullout resistance of individual screws inserted at varying angles to the axis of pullout in PU foam [29] but it was restricted to foams of a single density ($0.32\,g\,cm^{-3}$). In addition, a recent study has investigated the effects of screw orientation and load to failure of a plate–bone construct that was attached to $0.09\,g\,cm^{-3}$ PU foam (used to model severely OP bone); these authors noted that further study is required in bone of varying density to determine where the benefit of angled screws, to increase fixation strength, is lost [37]. No previous study has reported any general relationship between bone screw insertion angle and screw pullout strength with reference to OP bone.

The objective of this study was to determine how the pullout strength of a bone screw is affected by the following factors: (i) screw insertion angle, (ii) screw thread type (cortical or cancellous) and (iii) the density of PU foam, representing different densities of

* Corresponding author. Tel.: +44 121 414 4266; fax: +44 121 414 3958.
*E-mail address:* purvi.patel83@yahoo.co.uk (P.S.D. Patel).

1350-4533/$ – see front matter 
doi:10.1016/j.medengphy.2010.05.005

bone. The findings are intended to determine the effect of screw insertion angles to achieve enhanced screw fixation in OP bone. This is the first study to use a set of pre-defined screw insertion angles and investigate their effect in several models of bone with varying density.

## 2. Materials and methods

### 2.1. PU foam samples

Three different PU foams were used: (1) closed-cell foam of density 0.32 g cm$^{-3}$, (2) closed-cell foam of density 0.16 g cm$^{-3}$ (ASTM Grades 20 and 10, respectively [38]) and (3) open-cell PU foam of density 0.09 g cm$^{-3}$. All foams were supplied as blocks (130 mm × 180 mm × 40 mm) from Sawbones® Europe AB (Malmö, Sweden). A smaller block (45 mm × 60 mm × 40 mm) was sawn from these blocks for each test. The fracture stresses of these foams enable them to be used as models for: (1) normal, (2) OP and (3) very low density OP cancellous bone [28].

### 2.2. Bone screws

Two types of bone screw were investigated: a cortical bone screw (4.5 mm diameter × 30 mm length) and a cancellous bone screw (6.5 mm diameter × 30 mm length) (Fig. 1). The cortical screw was not tapered. The cancellous screw had a 4° core taper angle; this was measured from a shadowgraph (Zeiss MP320 Measuring Projector, Carl Zeiss Ltd., Rugby, Warwickshire, UK). Both screws were manufactured from medical grade titanium alloy, Ti–6Al–4V, in accordance with the British Standard, BS 3531-5.3:1991 [39], and are available commercially (Surgicraft Ltd., Redditch, Worcestershire, UK). Table 1 summarises the bone screw dimensions, which were determined from a series of measurements obtained using a stereo microscope (Leica MZ9.5), digital microscopy camera (UEye 3.1MP) and imaging software (Omnimet Imaging Software version 9.0r3) (all available in the Buehler Centre of Excellence, School of Mechanical Engineering, University of Birmingham, UK); supplied by Buehler, Coventry, West Midlands, UK. The screw lengths were measured using digital Vernier callipers (Fisher Scientific UK Ltd., Loughborough, Leicestershire, UK).

### 2.3. Screw pullout testing

Pilot holes of 3.5 mm diameter, for the cancellous bone screw, and 3 mm diameter, for the cortical bone screw, were drilled into a PU foam test block before screw insertion. A swivel angle plate (Type 5150, J&L Industrial Supply, Wednesbury, West Midlands, UK) and digital protractor (Lucas AngleStar® DP45, Lucas Sensing Systems Inc., Hampton, VA, USA) were used to ensure accurate drilling of the pilot holes. Each screw was inserted into the foam block through a pullout fixture that was tailor-made to the desired screw angle (Figs. 2 and 3) and was hand-tightened by a single investigator using a hexagonal key, until the head of the screw met the surface of the block; this procedure ensured that all screws were inserted under the same conditions. The pullout fixture, engaged with the bone screw head, was then attached to the actuator of an ELF3300 materials testing machine (Bose Corporation, ElectroForce Systems Group, Minnetonka, MN, USA). The bottom part of the test set-up, involving the PU foam block, was placed in a custom-made rig attached to a plate on the machine's load cell (Figs. 2 and 3).

Each screw was pulled from its head and along the axis perpendicular to the top surface of the test block (Fig. 2). Each screw was pulled out of the bone model at a rate of 0.1 mm s$^{-1}$ [40], under displacement control. Load and displacement values were recorded and the maximum load generated during screw pullout

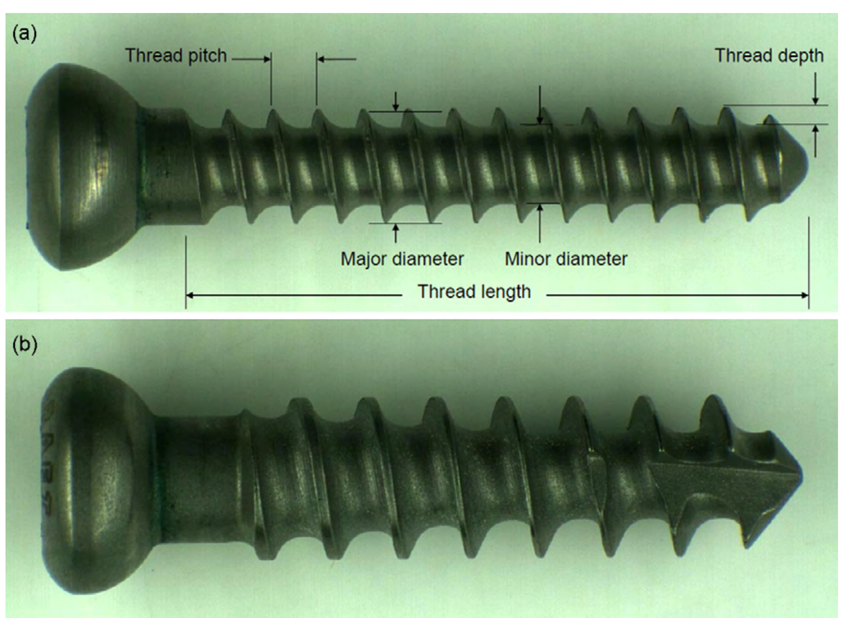


**Fig. 1.** Screw thread terminology and screws used for the pullout tests: (a) 4.5 mm cortical screw; (b) 6.5 mm cancellous screw.

**Table 1**
Cortical and cancellous bone screw measurements expressed as mean ± standard deviation. All measurements are defined in Fig. 1a, except for the thread shape factor ($T$), which is defined by Eq. (3) (see Appendix B). Dimensions are in mm, except for $T$, which is dimensionless.

| Bone screw type | Major diameter, $D_{major}$ | Minor diameter, $D_{minor}$ | Thread length, $L$ | Thread depth, $d$ | Thread pitch, $p$ | Thread shape factor, $T$ |
|---|---|---|---|---|---|---|
| Ø 4.5 mm × 30 mm cortical | 4.67 ± 0.19 | 3.18 ± 0.09 | 23.93 ± 0.51 | 0.74 ± 0.11 | 1.83 ± 0.04 | 0.73 ± 0.11 |
| Ø 6.5 mm × 30 mm cancellous | 6.73 ± 0.12 | 4.09 ± 0.53 | 22.65 ± 0.20 | 1.32 ± 0.27 | 2.60 ± 0.30 | 0.79 ± 0.19 |