Engineering Failure Analysis 95 (2019) 96–106

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Comparison of the mechanical properties of two designs of polyaxial pedicle screw

Alicja J. Kubiak, Katherine Lindqvist-Jones, Karl D. Dearn, Duncan E.T. Shepherd*

Department of Mechanical Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

ARTICLE INFO

Keywords:
Pedicle screw
Pullout
Design
Quasi-static test
Dynamic test

ABSTRACT

In this study, the mechanical properties of a novel dual-core pedicle screw were compared with a commercially available cylindrical screw. In order to evaluate and compare their mechanical performance, a series of axial pullout, quasi-static and dynamic bend tests were conducted. In the pullout tests, three polyurethane (PU) foams (density: 0.16, 0.32 and 0.64 g/cm^3) were used to compare the pullout strength between both screw types. The ultimate static strength of each screw was determined by a series of quasi-static cantilever bend tests. Dynamic tests were performed with a peak forces corresponding to 10%, 30%, 40%, 50%, 65% and 75% of the ultimate static strength of each screw type. Each specimen was subjected to a sinusoidally varying load which continued until the specimen fractured or reached 2.5 million cycles. The results of the pullout force indicated that the dual-core screws had higher pullout strength, in each PU foam, compared to cylindrical screws, however, the differences were not statistically significant. The average stiffness of dual-core screw during pullout from the 0.16 and 0.32 g/cm^3 PU foams was significantly higher ($p < .05$). In quasi-static tests, results of ultimate bending load; bending stiffness and structural stiffness were significantly higher for dual-core screws ($p < .05$). During the dynamic bending tests, the dual-core screws had longer fatigue lives for all loading levels. It was observed that the fatigue failures for both screw types occurred either at the head-shank junction or between third and fourth thread. In conclusion, the findings of this study indicated that the dual-core screw design has improved mechanical performance compared to the cylindrical design, with the exception of pullout resistance, which showed no significant difference.

1. Introduction

Pedicle screws are used as fixation for posterior stabilisation systems for the lumbar spine [1–3]. They are inserted into the isthmus of the pedicle and used for connecting vertebrae to rods. Currently, there are many different designs of pedicle screws available on the market, which differ both in the thread, the geometry of the core and the outer diameter. The thread of the pedicle screw can be square, buttress or V-shaped, while the core and outer diameter geometry can be conical, cylindrical and dual-core.

Although pedicle screws are widely used in the treatment and stabilisation of the spine, cases of screw failures, in particular breakage and loosening, are still being reported. The incidence of screw breakage has been reported to range between 3% and 7.1% of procedures and often occurs around the thread-shank junction of the screw [4–6]. Fracture is likely to occur due to bending fatigue or due to a loading situation that exceeds the load-bearing capacity of the screw. Screw loosening leading to pullout is the next common complication associated with pedicle screws, which is reported to range between 0.6% and 11% [7]. Loosening is more likely to occur

* Corresponding author.
E-mail address: d.e.shepherd@bham.ac.uk (D.E.T. Shepherd).

https://doi.org/10.1016/j.engfailanal.2018.08.023
Received 24 April 2018; Received in revised form 4 July 2018; Accepted 20 August 2018
Available online 23 August 2018
1350-6307/

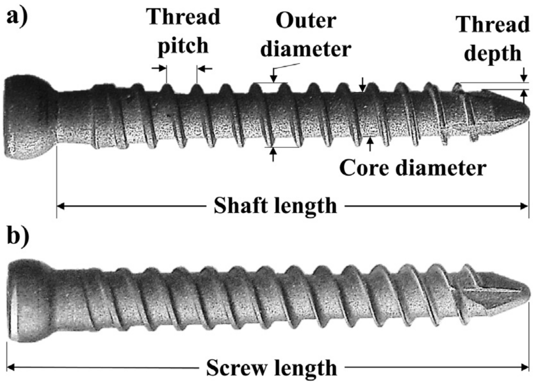

Fig. 1. Pedicle screws: a) 5.5 mm cylindrical screw; b) 5.5 mm dual-core screw.

due to a weak screw-bone interface and continuous bending forces applied to the head of the screw, which are causing micro-movements of the distal part of the screw. Pedicle screw failures are dangerous for the patients, as they can result in instability of fixation and may lead to more complicated problems, resulting in corrective surgery [8].

Previous work has shown that factors, such as the geometry of the thread and screw shaft, have a great impact on both bending and pullout strength [9]. Cho et al., [10] stated in their study that the outer diameter of the pedicle screw determines the pullout strength, while the core diameter determines the fatigue strength. Lill et al. [11] evaluated the pullout resistance of a dual-core screw and showed that it had a higher pullout strength compared to a cylindrical screw. Other studies have shown that the screws with a more conical core are more resistant to breakage and loosening, compared with cylindrical screws [12,13].

The aim of this study was to evaluate and compare the mechanical performance of a completely new design of the dual-core screw with a commercially available cylindrical screw, particularly their response to pullout and bending forces. For this purpose axial pullout, quasi-static and dynamic bend tests were conducted.

2. Materials and methods

2.1. Pedicle screws

Two different pedicle screw designs, made by S14 Implants (Pessac, France), were investigated: a commercially available cylindrical screw - BFus 2; and a novel dual-core screw BFus 2+, both with a major diameter of 5.5 mm and different lengths of 45 mm and 45.7 mm, respectively (Fig. 1). The geometry of the screws differs mainly in the size of the core diameter, the geometry of the neck, thread profile and the flank overlap area (FOA) (Fig. 2). The FOA is the projected area of the bone that is covered by the threads of the screw [14]. It is defined as follows:

$$FOA = [\pi/4 \times (D^2_{outer} - D^2_{inner})] \times l/p$$

where D_{outer} and D_{inner} are the projected areas of the outer and inner screw diameter, respectively, *1* is the length of the threads, and *p* is the thread pitch.

The first screw type has a V-shaped thread and a cylindrical core up to 3/4 of its thread length. The second screw type is characterized by a double lead (Fig. 3a), buttress thread and dual-core connected by a conical transition. Geometrically, the thread of the dual-core screw varies down the shank. At the proximal end, it is characterized by a larger core diameter (4.5 mm) with low and

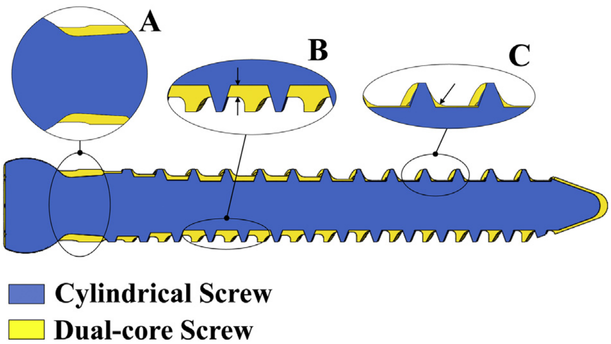

Fig. 2. Illustration of the geometric changes made to the screw design. The letters in the photo indicate: A - The geometry of the neck; B - Core diameter; C - Thread profile.