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Influence of plate material and screw design on stiffness and ultimate load of locked plating in osteoporotic proximal humeral fractures

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ABSTRACT

Introduction: The main purpose was to compare the biomechanical properties of a carbon-fibre reinforced polyetheretherketone (CF-PEEK) composite locking platewith pre-existing data of a titanium-alloy plate when used for fixation of an unstable 2-part fracture of the surgical neck of the humerus. The secondary purpose was to compare the mechanical behaviour of locking bolts and conventional locking cancellous screws.
Methods: 7 pairs of fresh frozen human humeri were allocated to two equal groups. All specimens were fixed with the CF-PEEK plate. Cancellous screws (PEEK/screw) were compared to locking bolts (PEEK/bolt) for humeral head fixation. Stiffness, fracture gap deflection and ultimate load as well as load before screw perforation of the articular surface were assessed. Results were compared between groups and with pre-existing biomechanical data of a titanium-alloy plate.
Results: The CF-PEEK plate featured significantly lower stiffness compared to the titanium-alloy plate ($P < 0.001$). In ultimate load testing, 6 out of 14 CF-PEEK plates failed due to irreversible deformation and cracking. No significant difference was observed between results of groups PEEK/screw and PEEK/bolt ($P > 0.05$).
Discussion: The CF-PEEK plate has more elastic properties and significantly increases movement at the fracture site of an unstable proximal humeral fracture model compared to the commonly used titanium-alloy plate. The screw design however does neither affect the constructs primary mechanical behaviour in the constellation tested nor the load before screw perforation.

Introduction

Locking-screw plating is an established and commonly used treatment for dislocated proximal humeral fractures [1–4]. Despite advancement of implants and a better understanding of failure mechanisms, complication rates for proximal humeral locked plate fixation remain high at up to 30% of cases being reported [1–3,5]. A large number of complications and unsatisfactory treatment results can be attributed to varus loss of reduction and articular screw perforation [1–3,6–8]. Although locked plating has improved the functional outcome, complications are partially ascribed to the rigidity of locked plating in osteoporotic bone [2,3]. Newly developed implants are regularly introduced to the market which attempt to address these issues with the objective of reducing complications and improving treatment results.

Locking plates made of carbon fibre (CF) reinforced polyetheretherketone (PEEK) composite are one example of these innovations. CF-PEEK composite plates are less stiff than stainless steel and titanium plates, with an elastic modulus similar to bone as well as the ability to withstand prolonged fatigue strain [9–11]. Reduced implant stiffness in proximal humeral fracture treatment was proven to unload the bone-screw tip interface which might lead to a reduction of implant associated complications [12–14]. The development of CF-PEEK plates for fixation of proximal humeral fractures derived from the idea to combine the advantages of locked plating with the potential advantages of reduced implant rigidity. A further benefit of CF-PEEK is that the radiolucency of polymer composites allows for good imaging of fracture healing and early evaluation of possible complications [15].

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New designs of locking screws are another innovative development. Stable screw anchorage within the osteoporotic cancellous bone of the proximal humerus is a major challenge of successful fracture treatment in the typical patient population [16]. Screws with a thicker diameter and a lower thread depth compared to conventional screws are intended to provide a larger loading surface within the cancellous bone [17]. Furthermore, a rounded rather than a pointed screw tip is intended to better underpin the far cortex with lower rate of articular screw perforation when used for proximal humeral fracture fixation [17]. At this point, it is unknown whether the differences in screw design affect overall mechanical behaviour of a proximal humeral fracture model.

The purpose of this study was to compare the biomechanical properties of a CF-PEEK composite proximal humeral locking plate with pre-existing data of a titanium-alloy plate when used for fixation of an unstable 2-part fracture of the surgical neck of the humerus. The secondary purpose was to investigate the mechanical performance and screw perforation behaviour of newly developed locking bolts in comparison to conventional locking humeral head cancellous screws. We hypothesised that the CF-PEEK plate would feature less stiffness compared to the titanium-alloy plate. Concerning the new locking bolts, we expected reduced fracture gap motion when compared to conventional locking humeral head cancellous screws. Additionally, we hypothesised an increased load bearing for the locking bolts before cut out through the articular surface.

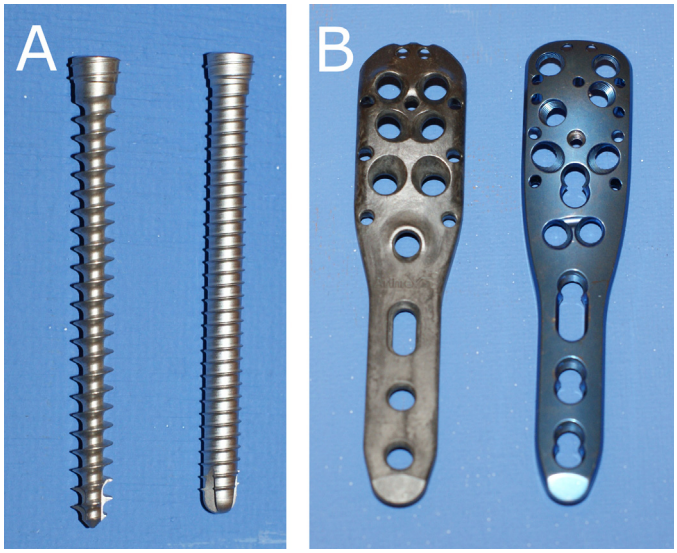

Fig. 1. Material used in the tests: A: Left – 4.0 mm cancellous locking screw; Right – 4.0 mm locking bolt with low thread depth and rounded screw tip (Arthrex®, Karlsfeld, Germany); B: Left - CF-PEEK proximal humeral plate (PEEK Power Humeral Fracture Plate; Arthrex®, Karlsfeld, Germany); Right: titanium-alloy plate (PHILOS; DePuy Synthes®, Umkirch, Germany).

Material and methods

Specimens

Seven matched pairs of fresh-frozen humeri ($n = 14$) attained from female human donors (mean age 59 years; range, 46–75 years) were randomised into two groups. Bony pathologies were ruled out by means of radiographs taken in two planes (anteroposterior and axial). The bone mineral density (BMD) of each humeral head was assessed with dual X-ray absorptiometry (Discovery QDR Series; Hologic®, Bedford, MA, USA).

Implants and groups

The carbon-fibre reinforced PEEK proximal humeral locking plate (PEEK Power Humeral Fracture Plate; Arthrex®, Karlsfeld, Germany) was used in 90 mm length (Fig. 1). This plate is manufactured from continuous carbon fibres (55–60%) and injection-moulded PEEK and is 2.6 mm thick. The assembly of the carbon fibres is multidirectional and randomly oriented.

In the PEEK/screw group, seven conventional 4.0 mm cancellous locking screws (Figs. 1 and 2; Cancellous Screw, Arthrex®, Karlsfeld, Germany) were used to fix the humeral head. In the second group (PEEK/bolt), seven newly developed 4.0 mm locking bolts (Locking bolt, Arthrex®, Karlsfeld, Germany) with low thread depth and rounded screw tip (Figs. 1 and 2) were used to stabilise the proximal humerus. In both groups three cortical screws were used to stabilise the shaft. All screws were made of titanium alloy (ASTM F136; Ti6Al4V; Arthrex®, Karlsfeld, Germany). The lengths of all screws were not predefined but selected such that their tips extended to the subchondral surface of the humeral head without penetration of the articular surface. Locking screw fixation was achieved by threading the screw heads into the CF-PEEK-plate. A

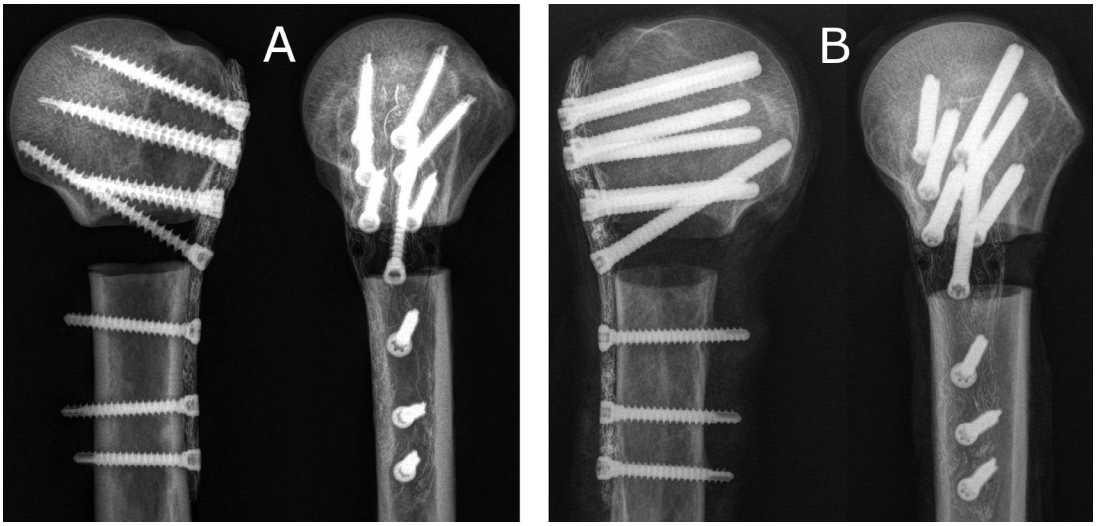

Fig. 2. X-rays in two planes of a left humerus after osteotomy and fixation with the CF-PEEK plate and seven conventional. A: 4.0 mm cancellous locking screws in the humeral head. B: Newly developed 4.0 mm locking bolts in the humeral head.