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Original article

Biomechanical comparison between stainless steel, titanium and carbon-fiber reinforced polyetheretherketone volar locking plates for distal radius fractures

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ABSTRACT

Introduction: As the popularity of volar locked plate fixation for distal radius fractures has increased, so have the number and variety of implants, including variations in plate design, the size and angle of the screws, the locking screw mechanism, and the material of the plates.
Hypothesis: Carbon-fiber reinforced polyetheretherketone (CFR-PEEK) plate features similar biomechanical properties to metallic plates, representing, therefore, an optimal alternative for the treatment of distal radius fractures.
Materials and Methods: Three different materials-composed plates were evaluated: stainless steel volar lateral column (Zimmer); titanium DVR (Hand Innovations); CFR-PEEK DiPHOS-RM (Lima Corporate). Six plates for each type were implanted in sawbones and an extra-articular rectangular osteotomy was created. Three plates for each material were tested for load to failure and bending stiffness in axial compression. Moreover, 3 constructs for each plate were evaluated after dynamically loading for 6000 cycles of fatigue.
Results: The mean bending stiffness pre-fatigue was significantly higher for the stainless steel plate. The titanium plate yielded the higher load to failure both pre and post fatigue. After cyclic loading, the bending stiffness increased by a mean of 24% for the stainless steel plate; 33% for the titanium; and 17% for the CFR-PEEK plate. The mean load to failure post-fatigue increased by a mean of 10% for the stainless steel and 14% for CFR-PEEK plates, whereas it decreased (−16%) for the titanium plate. Statistical analysis between groups reported significant values (p < 001) for all comparisons except for Hand Innovations vs. Zimmer bending stiffness post fatigue (p = .197).
Discussion: The significant higher load to failure of the titanium plate, makes it indicated for patients with higher functional requirements or at higher risk of trauma in the post-operative period. The CFR-PEEK plate showed material-specific disadvantages, represented by little tolerance to plastic deformation, and lower load to failure.
Level of evidence: N/A.

1. Introduction

As the popularity of volar locked plate fixation for distal radius fractures has increased, so have the number and variety of implants, including variations in plate design [1–4], the size and angle of the screws [1], the locking screw mechanism [5], and the material of the plates [6].

In the past few decades, the use of titanium alloys has gained popularity, because of its excellent biocompatibility, high mechanical strength and corrosion resistance [7]. A potential advantage of titanium alloy plates (e.g. Ti–6Al–4 V) is represented by the less stress-shielding to bone, because its stiffness is 110 ± 10 GPa [8,9], compared to 200 ± 20 GPa of stainless steel (e.g. 316 L) [10], but much higher, however, than that of human cortical bone (around 20 GPa) [11]. Disadvantages of metal implants include limited fatigue life, mismatch of modulus of elasticity, cold-welding seen with titanium locking screw constructs, corrosion, osseo-integration, and radiodensity that can preclude accurate

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radiographic visualization of fracture reduction, healing, and tumor or infection progression or resolution [12,13].

“Semi-rigid” Carbon-Fiber Reinforced (CFR) polymers fracture fixation plates were developed starting in the 1980s as an alternative to comparatively “rigid” metallic bone plates [14,15].

In literature, several studies reported the biomechanical properties of CFR implants [16–19]; however, only few recent studies directly compared the biomechanical characteristics of metallic and CFR polymer bone plates [19–21].

Thus, the aim of the present research was to compare the load to failure and bending stiffness with a single axial load and after cyclical loading of three different materials-composed plates currently available for distal radius fractures. It was our hypothesis that the Carbon-Fiber Reinforced polyetheretherketone (CFR-PEEK) plate would feature similar biomechanical properties in terms of load to failure with reduced stiffness, compared with titanium and stainless steel plates, therefore representing an optimal choice for the treatment of distal radius fractures.

2. Materials and Methods

2.1. Specimens preparation

The fixed-angle volar plating systems tested were: stainless steel volar lateral column (Zimmer, Warsaw, IN); titanium DVR (Hand Innovations, Miami, FL); CFR-PEEK DiPHOS-RM (Lima Corporate, San Daniele Del Friuli, Udine, Italy). Six plates were obtained from each individual manufacturer through research donation. For each type of plate, 6 right synthetic composite bone radii with a cancellous inner core and a foam cortical shell (25 cm long, 5.5 mm canal diameter; model #1027-20, Pacific Research Laboratories, Inc., Vashon, WA, USA) were used. Plates were implanted using all the distal and proximal fixation holes (Fig. 1). The CFR-PEEK plate featured the possibility of minimal variable axis for the distal screws. However, in our research neutral orientation of the distal screws was assured by inserting the guide sleeve in the specfic alignment mask. The remaining two plates (stainless steel volar lateral column and titanium DVR) incorporated a fixed screw axis.

Fig. 1. Plates tested. From left to right: titanium DVR (Hand Innovations, Miami, FL); CFR-PEEK DiPHOS-RM (Lima Corporate, San Daniele Del Friuli, Udine, Italy); stainless steel volar lateral column (Zimmer, Warsaw, IN).

An unstable, extraarticular fracture was simulated by making an 8 mm gap with a saw starting 12 mm proximal to the articular surface of the radius on the distal radio-ulnar joint side. The osteotomies were made perpendicular to the long axis of the bone to allow for a consistent fracture gap on the dorsal and volar sides of the radius. We decided to perform a rectangular osteotomy, allowing to focus on the loads transmitted to the plate, since we hypothesized that a wedge osteotomy with partial bone contact on the dorsal side could influence the resistance of the fracture gap motion [22,23]. A single investigator (L.T.) created the fractures and applied all the plates to minimize variability. The proximal 15 cm of each synthetic radius model were potted in methylmethacrylate. In order to ensure standardised axial load transfer, each radius was fixed in line with its long axis from the radial part of the lunate fossa to the centre of the head of the radius, to provide for linear load transfer; then the potting cup was secured in the testing machine.

2.2. Tests description

Three plates for each type were tested for load to failure and bending stiffness pre-fatigue using a bi-axial servo-hydraulic test frame (MTS Minibionix 858, universal testing machine) by advancing a ceramic sphere, centered at the radial side of the lunate fossa, at a constant rate of displacement of 5 mm/min [22] (Fig. 2). The failure load was defined as the first local maximum of the

Fig. 2. Axial loading test performed by advancing a ceramic sphere centered over the lunate fossa at a constant rate of displacement of 5 mm/min.

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