INTRODUCTION

Image-guided failure assessment (IGFA) is a technique in which stepwise mechanical testing is combined with high-resolution computed tomography (CT) [1]. Using this novel modality, the deformations of bone under load can be visualized and quantified at the micro-structural level. Recently, we introduced IGFA to study the mechanical behavior of clinically used implants in human bone [2]. In order to avoid imaging artifacts during CT scanning, replicas of the original implants were used, made from a high-performance polymer. The elastic modulus of such implants is around one order of magnitude smaller than for the original steel implants. The goal of this experimental study was to investigate the influence of implant elastic modulus on the stability of the bone-implant construct, on its failure loads and its failure modes. This knowledge is required to determine whether the use of polymer implants in IGFA studies is justified. Furthermore, the question was addressed whether the stepwise mode of testing used in IGFA alters the mechanical response in comparison with a standard continuous test.

METHODS

Bone surrogate specimens were used instead of biological specimens to improve the reproducibility of the measurements. Specifically, solid rigid polyurethane foams (Sawbones, Malmö, Sweden) of the following densities were used: 160 kg/m³, 240 kg/m³ and 320 kg/m³. The blocks had a dimension of 60 x 60 x 40 mm³. Prior to implant insertion, pre-drilling and tapping was carried out according to the surgical guidelines of the manufacturer. Dynamic Hip Screws (DHS) made from steel (original) and the high-performance polymer Torlon (replica) were inserted into the surrogate blocks, leaving approximately 10 mm of material in front and behind the screw thread. Push-through experiments until failure were carried out on a standard mechanical testing machine. In the first test series, the specimens were loaded at a constant crosshead speed of 1 mm/min until failure of the bone-implant construct. The second test series was run in stepwise mode, with displacement steps of 400 µm separated by relaxation times of 10 min. For the continuous test series, 10 specimens of each bone surrogate density were prepared for mechanical testing. In the data analysis, strength was defined as the maximum measured resistance to failure. Only for the metal implants were significantly higher strengths measured in stepwise rather than in continuous mode. This may be explained by relaxation of the polyurethane foam during stepwise testing. In contrast, for the metal implants a small but significant difference in strength was found for the two testing modes.

RESULTS

No significant differences (p > 0.01) were found between the strength of the metal and polymer implants. For the polymer implants, there was also no significant difference between the strength in continuous and stepwise testing. In contrast, for the metal implants a small but significant difference in strength was found for the two testing modes. During stepwise testing all bone-implant constructs behaved slightly less stiffer than during continuous testing (Fig. 1, Tab. 1). Failure of the constructs consistently occurred at the outer thread diameter of the DHS (Fig. 2).

Table 1: Measured stiffness and strength of the bone-implant constructs

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel</th>
<th>Torlon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>low</td>
<td>mod.</td>
</tr>
<tr>
<td></td>
<td>cont.</td>
<td>cont.</td>
</tr>
<tr>
<td>Strength</td>
<td>N/mm²</td>
<td></td>
</tr>
<tr>
<td>Mode of testing</td>
<td>stepw</td>
<td></td>
</tr>
<tr>
<td>1972 ± 965</td>
<td>2371 ± 870</td>
<td>3477 ± 900</td>
</tr>
<tr>
<td>585 ± 110</td>
<td>1484 ± 45</td>
<td>2342 ± 52</td>
</tr>
</tbody>
</table>

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