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Short communication

Fracture mechanics of the femoral neck in a composite bone model: Effects of platen geometry

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ABSTRACT

Load applicator (platen) geometry used for axial load to failure testing of the femoral neck varies between studies and the biomechanical consequences are unknown. The purpose of this study was to determine if load application with a flat versus a conical platen results in differing fracture mechanics. Femurs were aligned in 25° of adduction and an axial compressive force was applied to the femoral heads at a rate of 6 mm/min until failure. Load application with the conical platen resulted in an average ultimate failure load, stiffness, and energy to failure of 9067 N, 4033 N/mm, and 12.12 J, respectively. Load application with the flat platen resulted in a significant ($p < 0.05$) reduction in ultimate failure load (7620 N) and stiffness (2924 N/mm). Energy to failure (12.30 J) was not significantly different ($p = 0.893$). Different fracture patterns were observed for the two platens and the conical platen produced fractures more similar to clinical observations. Use of a flat platen underestimates the strength and stiffness of the femoral neck and inaccurately predicts the associated fracture pattern. These findings must be considered when interpreting the results of prior biomechanical studies on femoral neck fracture and for the development of future femoral neck fracture models.

1. Introduction

Femoral neck fractures are most common in elderly populations (Dzupa et al., 2002; Kurtinaitis et al., 2012) and are frequently a product of low energy impacts such as a fall (Al-Ani et al., 2013; Basso et al., 2012; Robinson et al., 1995). Low bone density conditions such as osteopenia and osteoporosis, as well as overly aggressive cam resection to treat femoral acetabular impingement, have been demonstrated to increase the risk of fracture (Basso et al., 2012; Kukla et al., 2002; Mardones et al., 2005; Wijdicks et al., 2013; Zingg et al., 2012). Additionally, high mortality rates have been associated with these injuries (Barnes et al., 1976; Dzupa et al., 2002; Kurtinaitis et al., 2012; Sebestyen et al., 2008). The biomechanical strength of the femoral neck is therefore of great interest to clinicians and orthopaedic researchers.

Challenges exist biomechanically in mimicking the in vivo loading conditions of the hip and subsequent variability exists in the reported in vitro testing methodologies (Basso et al., 2012). Factors such as loading rate, distal fixation, adduction angle, specimen geometry, and specimen material properties reportedly vary between studies (Blair et al., 1994; Holzer et al., 2009; Kukla et al., 2002; Mardones et al., 2005; Nicayenzi et al., 2011; Wijdicks et al., 2013). Consequently, variability in the reported mechanical parameters associated with axial testing exists. Additionally, the use of flat (Blair et al., 1994; Mardones et al., 2005) and concave (Kukla et al., 2002; Kuzyk et al., 2012; Nicayenzi et al., 2011; Wijdicks et al., 2013; Zdero et al., 2010) contacting surfaces (platen) for load application have been reported. The effects of platen geometry on fracture mechanics of the femoral neck during axial testing are unknown.

Therefore, the purpose of this study was to determine if load application with a flat versus a conical platen during axial load to failure testing of the femoral neck results in differing fracture mechanics. We hypothesized that load application with the flat platen would result in a significant decrease of the ultimate failure load, stiffness, and energy to failure relative to the conical platen. Additionally, we hypothesized that different fracture patterns would be observed for the two platen geometries.

2. Material and methods

2.1. Specimens

Testing was performed on two groups of 6 large-sized, fourth-generation composite femurs with a solid cancellous bone density of 0.12 g/cm^3 (Sawbones,

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Pacific Research Laboratories, Inc., Vashon, WA). Composite femurs have been reported to have similar failure modes, stiffness, and strength of cadaveric femurs without the anatomic variability present in cadaveric bone (Gardner et al., 2010; Heiner, 2008). This model allowed for all test variables, with the exception of platen geometry, to be held constant and the mechanical effects of platen geometry to be isolated. Femurs were cut 105 mm distal to the inferior margin of the lesser trochanter, leaving a total length 200 mm, and the distal most 90 mm of the femurs were potted in polymethylmethacrylate (PMMA, Fricke Dental, Streamwood, IL) in a cylindrical mold with the long axis of the femur in line with the cylindrical axis of the mold. Therefore, the working length of the femurs from the top of the femoral head to the shaft insertion in the PMMA was 110 mm.

2.2. Platen geometry

Specimens were compressed with one of the two platen geometries attached to the load actuator (Fig. 1). One platen was a smooth flat surface and the second platen was a smooth conical surface with a 25° recess angle and a depth of 9.5 mm. Both platens were made from 6061 aluminum with similar surface finishes and lithium grease was applied to the platens prior to testing to minimize frictional effects. Load application with the conical platen was considered to be more physiologic due to increased load distribution across the femoral head, relative to the flat platen.

2.3. Biomechanical testing

Specimens were fixed in a tensile testing machine (ElectoPuls E10000, Instron Systems, Norwood, MA) with a custom steel jig and aligned in 25° of adduction in the coronal plane (Fig. 1), as previously reported (Mardones et al., 2005; Wijdicks et al., 2013). This alignment replicated loading conditions during single leg stance phase of gait (Bergmann et al., 2001). A compressive pre-load of 10 N was applied with the flat or conical platen to the femoral head of each specimen and held for 10 s to establish the time-zero position (Wijdicks et al., 2013). The specimens were then loaded to failure at a displacement controlled rate of 6 mm/min (Wijdicks et al., 2013). Load and position data were recorded using the testing system software (Instron WaveMatrix Version 1.5, Norwood, MA). Ultimate failure load was identified and stiffness and energy to failure were calculated. The conical platen data was previously reported by Wijdicks et al. (2013) as a control group in comparison to differing levels of cam resection and cortical notching.

2.4. Statistical analysis

Statistical analysis was performed with the use of predictive analytics software (SPSS; Statistics Version 20, IBM Corporation, Armonk, NY). The study compared data for each group using an independent *t*-test. Significant difference was determined to be present for $p < 0.05$.

3. Results

3.1. Ultimate failure load, stiffness, and energy

Load application with the conical platen resulted in an ultimate failure load, stiffness, and energy to failure (mean ± SD) of

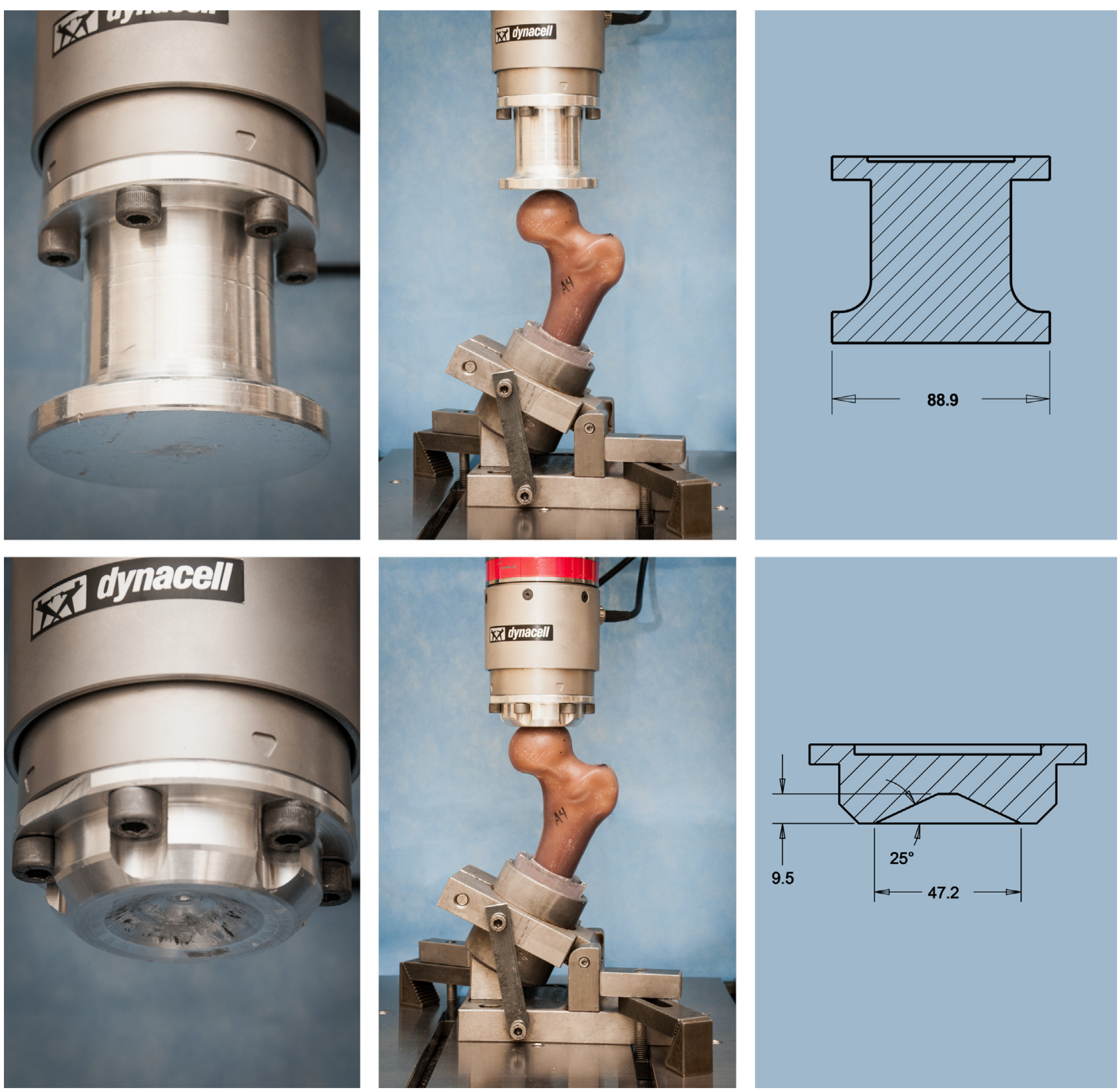

Fig. 1. Comparison of the biomechanical test setups with the flat platen (top) and conical platen (bottom) in the tensile testing machine. Dimensions for cross sectional views are in millimeters.