INTRODUCTION
Joint replacement surgeries are a common treatment for diseased or damaged joints. The procedure typically involves the insertion of a metal stemmed component into the bone canal, either with or without bone cement, to achieve fixation to the host bone. Although this procedure has proven effective, implant loosening remains a relatively common complication, leading to pain and the eventual need for revision surgery.

Previous work evaluating cemented implant design demonstrated that once the stem-cement interface had de-bonded, the stability was dependent on the implant geometry [1]. Studies have compared stem cross-sectional shape as a geometrical factor in implant stability [2], but few have specifically investigated the effect of stem curvature on the stability of cemented implant systems. Therefore, the purpose of this study was to investigate the role of longitudinal stem curvature to resist torsional loading in an in-vitro model.

MATERIALS AND METHODS
Four circular cross-section (8 mm diameter) stainless steel stems were custom machined to represent generic intramedullary stem components. All stem surfaces consisted of a smooth finish and were machined to achieve four different angles of longitudinal stem curvature: 0, 2, 4, and 6 degrees, with a consistent 100 mm radius of curvature (Figure 1). These angles of stem curvature were chosen based upon a review of commercially-available stems.

Figure 1. Circular cross section stainless steel stems with four angles of curvature: (A) 0, (B) 2, (C) 4, and (D) 6 degrees. All stems consisted of fixed 100 mm radius of curvature.

Polymethylmethacrylate (PMMA) bone cement (Surgical Simplex P®, Stryker Howmedica Osteonics, Allendale, NJ) was used to fixate the stems to a consistent depth of 2 cm within square aluminum tubes, which acted as a surrogate to the host bone canal. Following a 24 hour cure time, potted stems were secured in a custom jig attached to a uni-axial materials testing machine (Instron®, 8872, Canton, MA) for load application (Figure 2).

Figure 2. Experimental set-up showing custom jig used for securing potted stem into the materials testing machine.

A torque arm, with fixed length of 45 mm, was attached to the stem head to allow for conversion of the axial load into a torsional load. Seven samples (n = 7) of each stem curvature were tested under monotonic loading at a rate of 2.5 degrees/minute (corresponding to a vertical displacement of 2 mm/min) to a maximum of 5 degrees. Displacement and load data were collected at a rate of 10 Hz and converted to measures of rotation and torque, using the known length of the torque arm. Failure of the stem-cement interface was defined as a sudden decrease in the slope of the torque-rotation curve (Figure 3). Statistical analysis was performed using one-way analyses of variance (ANOVA), with post-hoc Student-Newman-Keuls tests (α = 0.05) to examine the role of stem curvature on the rotation to failure, torque at failure and work required to reach a stem rotation of 5 degrees.

RESULTS
Failure at the stem-cement interface was detected for all four stem curvature designs. There was no differences in the rotation to failure (p = 0.416), torque at failure (p = 0.730), and work required to reach 5 degrees of rotation (p = 0.648) (Figure 3), among the four stem curvatures (Table 1).

DISCUSSION
Stem surface geometry plays an important role in the interfacial stability between the stem and cement, since bone cement is not an adhesive but instead matches itself to all the surface of the stem. Previous research showed that straight circular cross-section stems have the least resistance to failure under torsional loading when compared to other cross sectional shapes [3], allowing the stem to rotate freely once debonding has occurred. As an extension to this, it was hypothesized that increasing the angle of longitudinal curvature of the circular stem would increase its torsional resistance, thereby improving stability.

Statistically, there was no difference in the values of rotation to failure, torque at failure and work required to reach a fixed rotation of 5 degrees, for the four angles of stem curvature tested in this study. There was a trend towards increases in these values with increasing angles, and it is likely that stem curvature may begin to affect torsional stability at larger angles coupled with longer stem lengths. Furthermore, a fixed 100mm radius of curvature was used for all stem angles in this study, as such, additional radii of curvature may need to be compared in order to fully assess the effect of stem curvature on torsional stability.

The findings from this study demonstrate that in short stems, stem curvature angles up to 6 degrees does not improve torsional stability when compared to the straight stem design.

REFERENCES