Introduction: Grit blasted stem-cement interfaces have been advocated as a means of increasing the bond strength of the stem-cement interface in cemented total hip arthroplasty. Recent work has suggested that early cementing of rough stem surfaces can increase the bond strength of the interface when compared to the same interface cemented using very doughy cement [1]. Based on these findings, suggestions have been made to encourage early cementing of stems with a rough or textured surface. However, these studies were performed using ideal test specimen geometries and testing was performed in air at room temperature. Tests of stem-cement interfaces have shown that exposure to a physiological environment at 37 degC can substantially reduce the fracture toughness of the stem-cement interface when compared to testing dry at room temperature [2]. The purpose of this study was to determine if the fracture toughness of grit blasted stem-cement interfaces are affected by the time of cementation using a realistic model of the cemented stem construct. We hypothesized that the fracture toughness of constructs cemented early would be stronger than constructs cemented late.

Methods: A new stem/mould construct was developed to achieve two main goals: 1) provide boundary conditions similar to the in vivo condition and 2) produce specimens for clamped cantilever beam fracture toughness tests (Fig 1). The CoCr 'stems' consisted of a central square bar to which two half-rounds were bonded (see inset Fig1). The stems were grit blasted (Ra = 5.7 µm) over a 75mm length using 160 grit aluminium oxide. An aluminium mould was created to simulate the proximal femur with a consistent 6.3mm mantle thickness. One hundred NF10-32 screws were used to create a rough trabecular surface in the mould. PMMA cement was vacuum mixed for 1 minute followed by filling of the mould in a retrograde fashion at either 2 minutes (early) or 6 minutes (late) from start of mix. Stem and cement temperature was 21 deg C while mould was warmed to 37 deg C before cementation. The mantle construct was removed from the mould after 24 hours and then stored for two weeks in saline at 37 deg C. Cement in the half-round regions was then carefully machined, the half rounds were removed, resulting in a clamped cantilever beam specimen.

Fracture toughness testing was conducted using multiple loading-unloading steps in displacement control [3]. Testing was performed in a 37 degC deionized water bath. The crack length at the stem-cement interface was monitored with a 45x traveling scope attached to a linear micrometer stage. Using an elasticity solution for the compliance of a clamped cantilever beam we develop an equation for the debond energy:

\[ G_c = \frac{6P_a^2}{EFH^2} \left( a^2 + \frac{H^2 + H(1+v)}{4} \right) \]

where \( P_a \) is the applied load, \( a \) is the crack length, \( H \) (6.3mm) is the cement bar height, \( B \) (12.3mm) is specimen depth, \( E \) (2200MPa) is the cement modulus, and \( v \) (0.3) is Poisson’s ratio. Average values were determined for each cement bar. A total of 20 specimens were tested for both early (n=10) and late (n=10) cement times.

Results: The debond energy of the stem-cement interface was not significantly different (p=0.4) for the early (137 +/- 66 J/m²) versus the late (157 +/- 35 J/m²) cement insertion times. For the twenty cement bars tested, eleven fractured through the cement bar before complete debonding of the stem-cement interface. The fractures were always associated with voids in the cement layer but were also associated with higher stem-cement debond energies (bar fx = 175 +/- 50 J/m²; no bar fx = 113 +/- 34 J/m²; p < 0.006). Five of the early cemented and six of the late cemented specimens failed through the bars; thus time of cementation did not affect propensity to fracture through cement (p=0.65).

Discussion: Our initial hypothesis was found to be false; there was no difference in the debond energy (or fracture toughness) of the stem-cement interface when cemented early or late using our simulated stem-cement-bone structure. These findings appear to be inconsistent with push-out pin tests using a grit-blasted surface (Ra =4.3 µm) [1]. In that study, the peak push-out force dropped by over 30% when cementation time was increased from 2 to 6 minutes. However, in that study, specimens were cured and tested in air and the polymerization process may have been affected by the use of a smooth sided mould at room temperature. Further work of stem and mould temperature and boundary conditions is warranted to help explain these differences.

Debond energies found here were similar to grit blasted stem/cement specimens that were prepared by hand [3] and tested at room temperature (\( G_c=179J/m^2; \) Ra=6,19µm). This suggests that the previously reported [2] loss in toughness associated with modifying the test environment from air at room temp to testing in Ringer’s solution at 37 deg C may be very dependent on specimen geometry or preparation techniques [2].

Gap formation at the stem-cement interface is very worrisome in clinical practice because gaps could serve as both failure initiation sites and conduits for debris transfer. In this study, more gaps were found for late cementation times, from which one could argue that early cementing may be preferable with rough surfaces to minimize gap formation.