INTRODUCTION:
Alumina ceramics for total hip arthroplasty (THA) were introduced nearly four decades ago, to address concerns over polyethylene-particle-induced osteolysis and to improve long-term results in younger and more active THA patients. While even more popular abroad, usage of ceramic-on-ceramic (CoC) bearings in the United States is increasing, and currently represents 14% of all THAs performed annually [1]. However, due to the brittle nature of ceramic materials, concerns persist regarding implant failure due to catastrophic fracture. In general, both components of a CoC implant are prone to fracture. Fracture of the ceramic head is a well recognized problem historically, and extensive investigation has led to several design-specific improvements. As a result, fracture rates of ceramic heads have decreased from 13% in 1st generation alumina to less than 0.004% for contemporary ceramics [2]. In contrast, for ceramic liners systematic analysis regarding fracture risk mitigation has been much more limited. Consequently, current fracture rates for alumina liners are approximately 400-fold higher than for ceramic heads. While it is well established clinically that impingement between the femoral neck and liner can predispose to fracture, to date, little quantitative information exists regarding fracture propensity for liners. To help close this knowledge gap, an eXtended Finite Element Methodology was developed to investigate fracture risk and crack propagation for various implant designs, surgical orientations and patient factors.

METHODS:
A previously developed and physically validated [3] non-linear dynamic FE model of THA impingement was used to determine stresses developed during impingement scenarios for a two CoC implants (Fig. 1). For the 28mm implant (Fig. 1a), the effect of cup edge chamfer radius was investigated for four separate edge profile geometries (Fig. 2a). Four additional models were generated to investigate surgical cup orientation by varying the cup inclination between 30° and 60°, each with a constant 10° of acetabular anteversion. For these models, a lateral impingement challenge was modeled, using previously reported opto-electronic data [4].

RESULTS:
For the 28mm implant, fracture initiation was demonstrated to be sensitive to both cup orientation and cup edge radius, with fracture risk increased for sharper edges at higher values of cup inclination. Substantially higher occurrence of fracture was observed for the assumed flawed reduced fracture criteria analyses. Fractures occurred predominately at the cup egress region. For the 36mm implant, in the normal BMI simulations, 17 out of 50 fractures occurred in the alumina bearings with micro-impurities. Spatially, cracks occurred at an intermediate location between the liner edge (Fig. 3) and pole, at the inner edge, at the outer edge, and at the impingement site, in 41%, 41%, 18% and 6% of these fracture instances, respectively. No fractures occurred in the absence of alumina imperfections. In the high BMI group, fracture occurred in 39/50 simulations with micro-impurities, with fracture occurring in nearly 87% of these instances at the intermediate location, and only 13% at the cup edge. Fracture occurred in three simulations without imperfections, with cracks initiating at the cup edge in all three, which were for cups positioned in 0° of anteversion.

DISCUSSION:
Fracture of ceramic liners remains a serious concern. As opposed to fracture of the head, quantitative analyses for liner fracture risk are greatly lacking. At present, only a single computational study of ceramic liner fracture mechanics exists in the orthopaedic literature [5], although the methodology it used is not conducive to rapid parametric study of multiple patient-, surgical-, and implant-specific risk factors. The current XFEM methodology, by contrast, facilitates rapid systematic analysis of ceramic liner fracture.

SIGNIFICANCE:
Ceramic liner fracture risk was found to be higher for the 28mm implant versus the 36mm implant. Fracture risk was shown to increase at increased cup inclination and for sharp cup edge profiles.

REFERENCES:

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