MECHANICAL PERFORMANCE OF CERAMIC ACETABULAR LINERS UNDER CONDITIONS OF IMPINGEMENT

+++Maher SA; *Lipman JD; **Gilchrist MD, **Curley LJ, *Wright TM

+Laboratory for Biomedical Mechanics and Materials, Hospital for Special Surgery, 535 East 70th Street, NY 10021

Introduction
Evidence of femoral neck-acetabular rim contact (or ‘impingement’) has recently been observed in up to 56% of retrieved polyethylene acetabular liners1. Impingement of polyethylene liners typically leads to localized pitting and delamination, whereas impingement of ceramic liners has led to fractures, with a reported incidence as high as 1% in the 1970s2. Ceramic manufacturing techniques have improved since then, but the effect on reducing the likelihood of impingement related fracture remains unknown.

The objective of this study was twofold: to develop a test capable of simulating impact-impingement of a ceramic liner and to use the test to explore if fracture of a new generation of modular ceramic liner was likely to occur in vivo.

Materials & Methods
The experimental approach was to establish a threshold force below which the ceramic liner did not fracture under multiple impacts and to compare this threshold force to forces likely to occur physiologically, thus establishing whether or not fracture would likely occur in vivo.

The acetabular component tested was a modular design, consisting of a titanium alloy shell into which an alumina ceramic liner is to be press-fit at the time of surgery. Each ceramic liner (n=12) was inserted into its metallic shell using a CeraLock Insertion Instrument (CeramTec, Plochingen, Germany). The assembled acetabular component was seated into a hemi-spherical cavity in a custom designed aluminum holder, and a locking rim was placed over the face of the shell to fix it securely to the holder. A replica of the femoral neck (hereafter referred to as the indenter) was machined from precipitate-hardened stainless steel. The acetabular holder was attached to the base of the drop weight impact machine (Rosand, Gloucestershire, UK); the indenter was attached to the upper platen. The fixation points for the holder and the indenter were designed so impact occurred at the corner of the ceramic rim.

Four loading conditions were simulated with average maximum impact forces of 23, 21, 15, and 12 kN (n=3 at each force). After each impact, the liner was macroscopically and microscopically examined for evidence of fracture. If no damage was evident, the ceramic liner was re-used, however, in drawing too strong a conclusion; if we had increased the number of impacts beyond 20, we may have created fractures below the threshold is illustrated by a dashed line.

Discussion
No published data exist to establish the impact resistance of ceramic acetabular liners. Despite the lack of reliable data, features have been designed into ceramic liners on the presumption that protection against impingement fracture is needed. Some examples include a recessed ceramic liner, a polyethylene layer over the face of the ceramic liner, and a cushion of polyethylene between the ceramic liner and metallic shell3. These design features may be unnecessary and, more importantly, they may adversely affect implant longevity, for example, by introducing the potential for wear debris and osteolysis in an otherwise polyethylene free joint.

In this research, the liners fractured at an impact force of 23 kN, but below a threshold force of 12 kN fracture did not occur even after repeated impact cycles. The impact forces on the acetabular component of a total hip replacement have never been directly measured. Hip joint forces of up to 8 times body weight (4.4 kN to 4.8 kN) occurred when two patients, who had received telemeterized hip replacements, stumbled while data were being recorded from their implants4. Even in the unlikely event that a patient was to stumble and the neck was to impinge the acetabular liner with this amount of force, a factor of safety of 2.5 would exist (12kN/4.8kN = 2.5). In a biomechanical analysis, the peak impact forces on the greater trochanter in a sideways fall ranged from 2.9 kN to 9.9 kN5. Even if a total hip patient was to fall and the neck impacted the liner with this total force, the safety factor remains above one (12kN/9.9kN = 1.21).

In a study of 190 elderly residents in geriatric centers, the rate of falls was 0.66 per person per year6. Even if each fall resulted in hip impact, it would take at least 30 years before the hip was exposed to the 20 impacts simulated in our study. The authors believe that 20 impacts is a reasonable cut-off point for the tests herein described. Caution should be used, however, in drawing too strong a conclusion; if we had increased the number of impacts beyond 20, we may have created fractures below our stated threshold. Nonetheless, the well delineated threshold force of 12 kN below which no ceramic liner fractured is large in comparison with most estimated physiological forces to which the hip is subjected during falls or stumbling, suggesting that ceramic liner fracture caused by impingement is unlikely to occur in vivo.


List for additional author affiliation: **Department of Mechanical Engineering, National University of Ireland - Dublin, Belfield, Dublin 4, Ireland.

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