DO THIN ACETABULAR SHELLS INCREASE THE DISASSOCIATION RISK OF CERAMIC LINERS?

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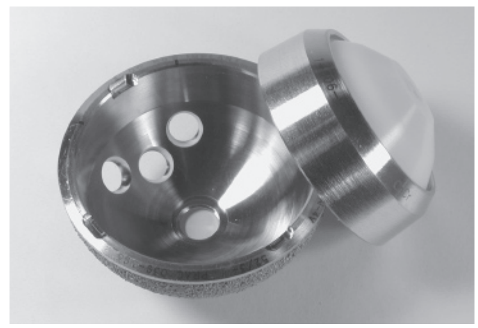
INTRODUCTION

The procedural standard for the fixation of metallic acetabular shells is under-reaming and impaction. Recently, concerns have arisen regarding achieving and maintaining secure ceramic liners when thin shells are deformed during normal insertion. Failure to achieve an adequate ceramic taper lock has been associated with clinical disassembly[1] and liner fracture.[4] Additionally, this phenomenon has been hypothesized as a possible cause of articular "squeaking", leading to revision in a small number of patients.[2]

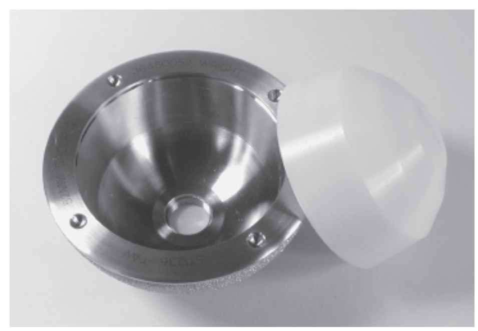
This study evaluates the influence of shell deformation on the locking mechanism integrity of contemporary modular acetabular designs employing ceramic liners.

THE DESIGNS

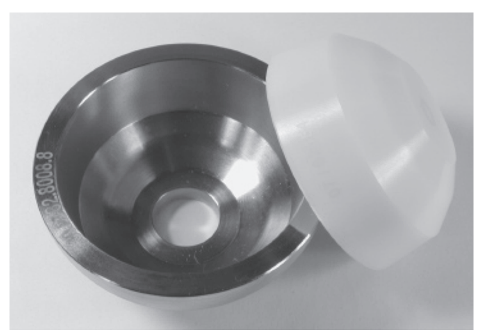
Testing was performed on two commercially available acetabular shell systems that typify contemporary design concepts and one laboratory control shell, all of which rely on a taper lock as the sole means of liner retention. One of the commercial designs, the Equator+ (Portland Orthopaedics Inc., St. Clair, MI, USA) uses a CoCrMo banded alumina oxide liner surrounded by a 4 mm thick Ti-6Al-4V shell with an apical and three fixation screw holes. The other commercial design, the Lineage® (Wright Medical Technologies, Inc., Arlington, TN, USA) employs an alumina oxide liner with a 6.5 mm thick Ti-6Al-4V shell and a single apical hole. The laboratory control uses an all alumina oxide liner with a 4.5 mm thick titanium shell and a single apical hole. (Figure 1)



Equator+



Lineage®



Control shell

Figure 1

THE METHODS

Analog Modeling

Squire, et al., reported in a clinical series that 19/21 under-reamed and impacted shells of a single design exhibited measurable diametric deformation, mean 0.16 ± 0.16 mm standard error.[3] They correlated this to between 0 and 1539 N of compression with the variance attributed to bone quality.

In order to reduce this variability in the current evaluation, a pilot study was devised to impact a shell into an under-reamed analog pelvis manufactured with a fiberglass cortex surrounding a rigid polyurethane foam cancellous core, (Pacific Research Laboratories, Inc., Vashon, WA, USA). This captured the general material properties of bone, as well as, the geometric structure of the pelvis. A non-holed 59 mm OD and 4.5 mm thick titanium spherical shell was impacted into the analog pelvis reamed to 58 mm and its deformation measured by laser profilometry (Hawk 3D laser scanner, model 5-4-4, NEXTEC Technologies 2001 Ltd., Tirat Hacarmel, Israel) and a dial bore gage (Mitutoyo Corporation, Kawasaki, Kanagawa, Japan). The maximum measured deformation in the analog pelvis was 0.12 mm. This data was a near perfect fit with that obtained from a dynamically loaded finite element (FE) model of the same shell under two-point compression. (Figure 2)

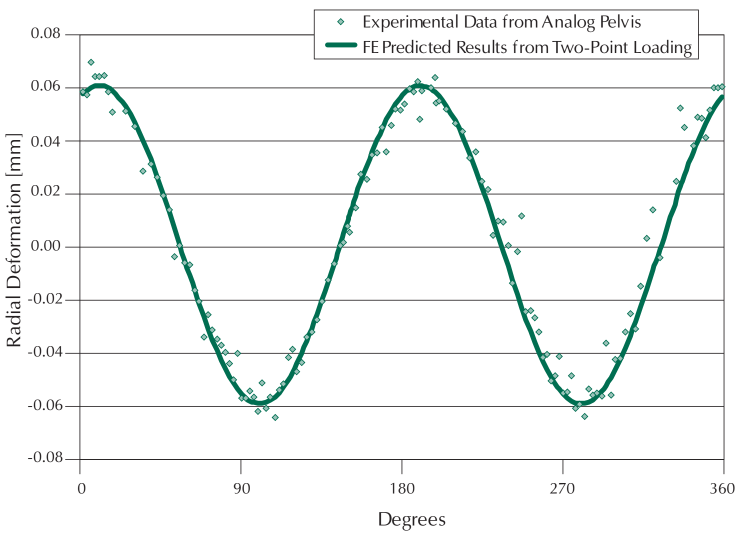


Figure 2: Comparison of circumferential experimental data measured by laser profilometry of the spherical shell impacted in the analog pelvis and the deformation predicted by finite element modeling under two-point loading. The match confirms that the shell deformation created by impaction into an under-reamed acetabulum can be modeled by a two-point loading configuration.

When the spherical control shells were placed under mechanical two-point loading, 725 N of compression produced 0.12 mm of deformation. System compliance was achieved with an in-line compression spring with a stiffness of 23.5 N/mm. (Figure 3) This compliance was necessary to permit the shell to expand when the liner is inserted. Although the exact compliance of the pelvis was not measured, it was noted that after impaction the analog pelvis bowed; implying that the strains associated with impaction were dispersed over the entire structure, mitigating the effect of viscoelastic strain relaxation.

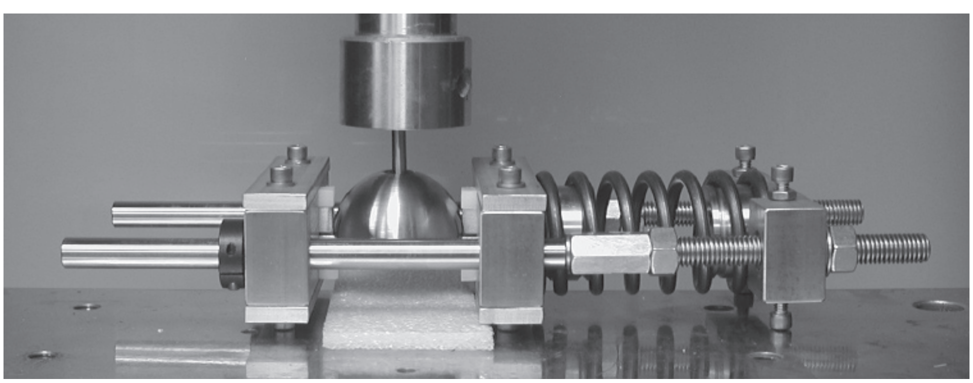


Figure 3: Two-point loading apparatus.

The Experiment

Deformation was induced in 52 mm OD shells of each design (n=3) under 725 N of two-point compression. (Figure 3) Deformation was measured by the difference along the load diameter before and after loading using the dial bore gage. Corresponding 32 mm ID alumina oxide liners were impacted into the shell by 3 dead drops of a 0.5 kg weight from 400 mm. The retention strength of the deformed and non-deformed shells was determined by the method of Tradonsky, et al.,[5] and ASTM F1820. The shells were rim supported and the liners pushed at 5.1 mm/min via a 6.4 mm pin in the apical hole until disassembly and the load recorded. The taper interface was examined via light microscopy for evidence of abrasion or damage.

RESULTS

The diametric deformation under 725 N and prior to liner impaction for the shell designs studied and the liner retention strength of the deformed and non-deformed shells are presented in Table 1. There was no statistical difference ($p>0.05$) in the push out strength between deformed and non-deformed shells using a homoscedastic, unpaired, two-tailed Student's t-test.

Table 1. Diametric deformation and push out strength for deformed and non-deformed shells.

(n=3)	Mean Shell Deformation [mm] ± SD	Mean Push Out (Deformed) [N] ± SD	Mean Push Out (Non-Deformed) [N] ± SD	
Lineage® Shell	0.086 ± 0.018	2485 ± 692	2175 ± 447	p=0.55
Equator+ Shell	0.245 ± 0.010	1121 ± 95	1076 ± 91	p=0.59
Control Shell	0.090 ± 0.010	869 ± 107	895 ± 91	p=0.53

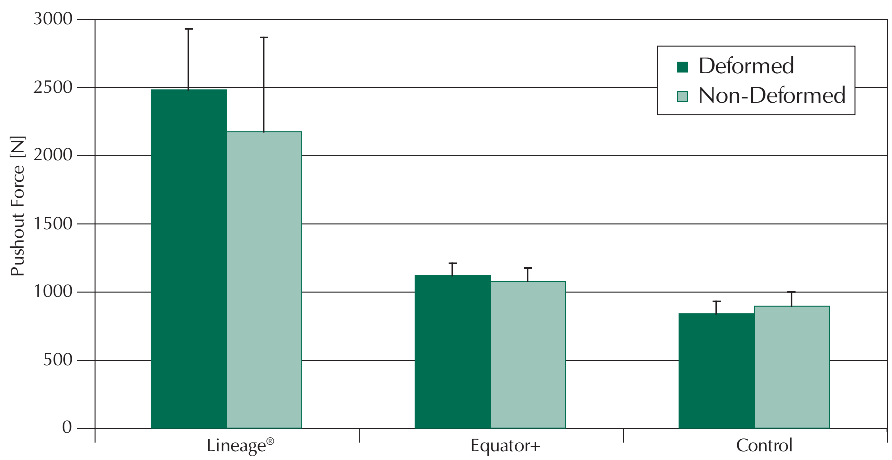
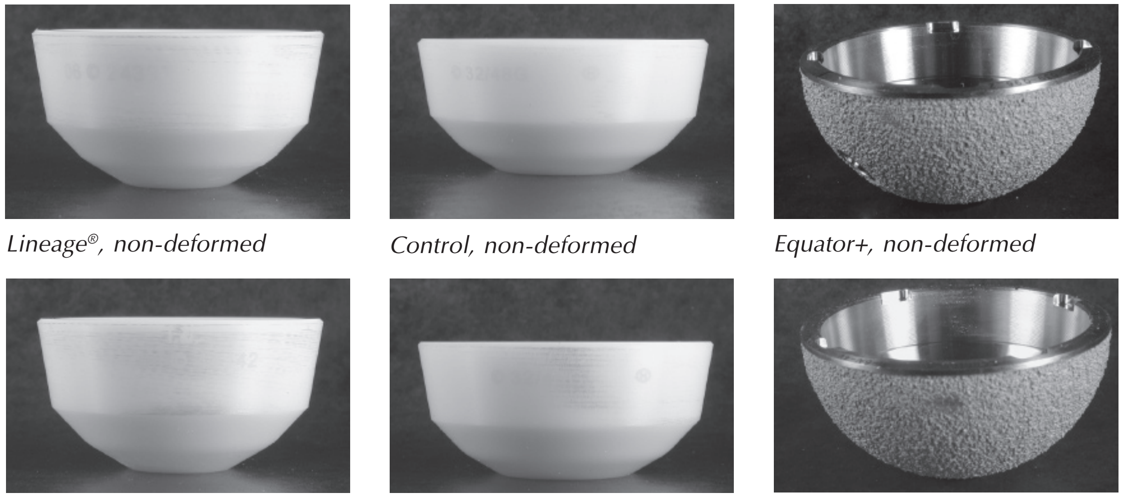


Figure 4: Comparative push out strength for deformed and non-deformed acetabular shells.

Optical analysis of the taper surfaces revealed significant differences in taper damage. (Figure 5) In the two solid alumina oxide liners, metal striping was symmetric and circumferential in the non-deformed shell. This was not true in the deformed shells, where metal striping was asymmetric and predominately on the line of loading. In the banded liners, damage to the shell was evident on the line of loading and at the lip in the deformed shells, but no damage was found in the non-deformed shells.



Lineage®, non-deformed — *Control, non-deformed* — *Equator+, non-deformed*

Lineage®, deformed — *Control, deformed* — *Equator+, deformed*

Figure 5: Optical analysis of the deformed and non-deformed acetabular tapers.

DISCUSSION

This study suggests that contemporary modular acetabular shell designs employing ceramic liners deform during implantation where acetabular bed under-reaming is employed. The liner retention strength did not degrade by comparison to non-deformed shells using ASTM static push-out methods. A larger question, however, is the influence of this deformation on liner retention strength over time when both bone remodeling and cyclic activity occur.

The idealization of component seating in the laboratory where surface contaminants, component position, and loading are controlled does not typify the operating room environment where liner seating is often an issue. Nevertheless, in this optimal situation, shell deformation was consistently observed as was striping on outer ceramic liner surfaces. Factors influencing the failure to seat components, as has been reported, need to be further documented.

This study evaluates both metal banded and non-banded ceramic liners of like ceramic composition where a taper lock is utilized to achieve fixation. A further consideration, in this regard, may be the mismatch of shell-band stiffness where both CoCrMo and Ti-6Al-4V are employed. It is more likely that a CoCrMo band will diminish the possibility of any ceramic liner deformation because of its increased stiffness.

Any amount of ceramic liner deformation can impact ceramic couple function particular to clearance and sphericity, which in turn may adversely affect fluid-film lubrication and wear. Elimination of a regional clearance around the joint space opening could account for observed ceramic surface alterations and suggests a potential causality of striping and the squeaking phenomenon. The shell deformation measured in this study could be an initiating factor of these processes. If this is a manifest cause, a logical operative alternative would be the advocation of stiffer shells or line-to-line reaming and augmentation with fixation screws.

These ongoing studies are an attempt to identify factors which influence ceramic couple performance, a topic of contemporary clinical interest.

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