Thin-Walled Cross-Linked Acetabular Liners Need Not Exhibit Reduced Locking Strength

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Use of larger diameter femoral heads has emerged as a promising strategy to reduce the risk of dislocation after total hip arthroplasty, but thinning the walls of cross-linked ultra-high-molecular-weight polyethylene (UHMWPE) acetabular liners to accommodate these larger heads may compromise the locking mechanism of the liner. The purpose of this study was to test the mechanical integrity of the locking mechanism in cross-linked and re-melted UHMWPE acetabular components with reduced wall thickness. The locking mechanism of cross-linked (100 kGy/re-melted) acetabular liners in sizes 50/28, 50/36, and 52/36 mm of 1 design was evaluated by lever-out tests and torsion tests. Torsion tests were performed at 2 angles to isolate the liner’s locking tabs independent of the contribution of its central post. Lever-out testing demonstrated nominally reduced failure strength in 50/36-mm liners (13.3 N·m) compared with 50/28-mm liners (12.3 N·m; P=.0502), whereas the lever-out strength of 52/36-mm liners was 12.2±0.94 N·m. Failure torques were similar between 50/28- and 50/36-mm liners at 45° and 90°, but the failure torque of size 52/36-mm liners was significantly higher at each angle. The use of larger diameter femoral heads does not compromise the locking mechanism of thinned MicroSeal (Signal Medical Corp, Marysville, Michigan) acetabular liners. Use of a cross-linked UHMWPE acetabular liner, with a locking mechanism that is not compromised when the liner is thinned to a thickness of at least 2.86 mm, appears to be a biomechanically sound construct when articulated with large diameter femoral heads. [Orthopedics. 2015; 38(8):e727-e732.]

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In the past decade, the use of larger-diameter femoral heads (≥32 mm) has been shown to reduce the incidence of dislocation following total hip arthroplasty (THA). Initially, concerns were voiced about the increased volumetric wear of these larger components; however, the introduction of highly cross-linked and re-melted ultra-high-molecular-weight polyethylene (UHMWPE) as a bearing surface in THA has markedly improved the wear resistance of acetabular liners, with excellent reported results when used in conjunction with larger femoral heads.

Although cross-linking improves the wear resistance of UHMWPE, it has been shown to reduce its tensile strength and resistance to fatigue crack propagation, and studies have indicated that subsequent thermal processing such as re-melting further compromises these properties. As a liner is thinned to accommodate the increased diameter of the larger femoral head, one of the elements most prone to failure is its locking mechanism, where stresses are concentrated.

Rim fracture and subsequent failure at the locking mechanism, resulting in liner dissociation, have been documented in a variety of modular hip systems. Recent case reports of rim fractures in cross-linked UHMWPE liners suggest that this is also a potential problem with current designs that use thin polyethylene liners or designs where the locking mechanism is insufficiently supported. Evaluation of the fracture surface with scanning electron microscopy in these case reports revealed damage consistent with fatigue cracking. Given these concerns, it is reasonable to presume that thinning the polyethylene through the rim could increase the risk of failure through the peripheral locking mechanism.

The purpose of this study was to test the mechanical integrity of the locking mechanism in cross-linked and re-melted UHMWPE acetabular components of one THA design wherein the liner’s wall thickness was reduced to increase its inner diameter and accommodate large-diameter femoral heads. The locking mechanism of the system tested comprises a plurality of pegs and ridges that protrude from the polyethylene surface to engage slots in the metal shell. It does not have grooves or recesses that penetrate the polyethylene around the peripheral rim. Therefore, the authors hypothesized that the locking mechanism would not be affected by increasing the inner diameter of the liner and that the liner would maintain its lever-out strength and torsional load to failure.

**MATERIALS AND METHODS**

Stock 50/28-mm acetabular liners and custom 50/36- and 52/36-mm liners of the same design (MicroSeal; Signal Medical Corp, Marysville, Michigan) were machined from GUR 1050 medical-grade UHMWPE that was cross-linked to 100 kGy, re-melted, and then donated for testing in this study. The minimum nominal rim thickness varied from 2.86 mm (size 50/36 mm) to 7.04 mm (size 50/28 mm) (Table 1). All liners had stock backside surfaces and locking mechanisms, which consisted of 12 locking tabs around the rim and a central post at the dome (Figure 1A). Eight liners of each size designated for lever-out testing had an additional hole drilled in the inside surface, allowing a bar to serve as a lever to lift it out of the shell (Figure 1B). Six to 9 liners of each size used for torsion tests had radial and concentric grooves created on the interior surface (Figure 1C) to facilitate a mechanical bond with the acrylic cement used to affix femoral head fixtures within the liner.

Lever-out tests followed a previous protocol and used a hydraulic testing platform (Instron 8501; Instron, Norwood, Massachusetts) to displace the free end of a steel bar that rested on a hard fulcrum with the other end mounted inside a hole in the test liner. The actuator was lowered at a speed of 2.9 mm/s, and a pair of pillow bearings allowed the free end of the lever to trace an arc at approximately 1.3 rad/min. Failure was defined as dissociation of the liner from its shell.

Torsion tests were performed in rotation control (1°/s ramp, up to 20°) on the same hydraulic testing platform. Liners were driven into an acetabular shell fix.
ture, and then femoral head fixtures were cemented into the liners at 90° (perpendicular) using Fastray acrylic dental cement (Harry J. Bosworth Co, Skokie, Illinois). Although this setup does not represent physiological loading conditions, it measures the relative strength of the 12 locking tabs independent of the liner’s central post. After the acrylic cement was dry, femoral head fixtures were connected to the actuator of the hydraulic testing platform using a steel, 2-piece, clamp-on coupling and the complete specimen was lowered into a “yoke” mounted into combined load/torsion cell, which mated with a fin on the backside of the acetabular shell fixture and thus resisted torque when the actuator was rotated (Figure 2). These specimens were tested with a compressive load of 334 N to prevent dissociation, with failure defined as yielding or complete avulsion of the locking tabs.

A second round of torsion tests had a similar setup, except that the yoke was fixed to a sine plate at 45° and the femoral head was likewise cemented at 45° to simulate a more physiological neck-shaft angle of 135°, which is within the range of reported anatomical findings.30-32 In these tests, the acetabular shell fixture was lowered to within 0.5 mm of the yoke, with no compressive load applied, which allowed the more clinically relevant failure mode of dissociation of the liner from the acetabular shell fixture (Figure 3).

For each test, data from the 50/28- and 52/36-mm groups were compared with data from the 50/36-mm group using a heteroscedastic 2-tailed t test (Excel; Microsoft, Redmond, Washington) with P<.05 for significance. Post hoc statistical power was evaluated by Power on X (MMISoftware, Newcastle upon Tyne, United Kingdom), with power greater than 0.8 deemed sufficient to avoid making type II errors.

**RESULTS**

The lever-out data revealed similar dissociation torques among acetabular liner sizes, although the failure strength of the 50/28-mm liners (13.3±1.2 N · m) was slightly, but not statistically, greater than that of the 50/36-mm liners (12.3±0.34 N · m; P=.0502). The lever-out strength of 52/36-mm liners (12.2±0.94 N m) was not different from that of 50/36-mm liners (Table 2). Damage to the acetabular liners following lever-out tests was observed mainly at the liner’s central post (Figure 4).

All acetabular liners mounted at 90° exhibited severe damage to their locking tabs when loaded by torsion with yielding

**Table 2**

<table>
<thead>
<tr>
<th>Liner Size, OD/ID, mm</th>
<th>Failure Torque, Average±SD, N · m</th>
<th>Different From 50/36 mm?</th>
</tr>
</thead>
<tbody>
<tr>
<td>50/28</td>
<td>13.3±1.2</td>
<td>No; P=.0502, power=.56</td>
</tr>
<tr>
<td>50/36</td>
<td>12.3±0.34</td>
<td>N/A</td>
</tr>
<tr>
<td>52/36</td>
<td>12.2±0.94</td>
<td>No; P=.73, power=.05</td>
</tr>
</tbody>
</table>

Abbreviations: N/A, not applicable; OD/ID, outer diameter/inner diameter.

*For each size, n=8.

**Figure 2**: Photograph showing torsion setup at 90°. The femoral head fixture was clamped to the actuator of the hydraulic testing platform and fixed in the acetabular liner using acrylic cement. The shell fixture was lowered into a “yoke” mounted on the load/torsion cell.

**Figure 3**: Photograph showing torsion setup at 45°. The femoral head was fixed in the acetabular liner at a 45° angle. The “yoke” was also mounted at 45° to a sine plate producing a neck-shaft angle of 135°.

**Figure 4**: Photograph showing acetabular liner with minor damage to the central post (highlighted) following lever-out testing.
or complete avulsion of the tabs (Figure 5A). All liners tested at 45° exhibited moderate damage to their tabs and to the central post before they dissociated from the acetabular shell (Figure 5B). The torsion data (Figure 6, Table 3) revealed that load to failure decreased by about one third when the liners were angled at 45° and allowed to dissociate from their acetabular shell. Size 50/28- and 50/36-mm liners exhibited similar failure torques at each mounting angle, whereas 52/36-mm liners exhibited significantly higher failure torques at each angle tested.

**Table 3**

<table>
<thead>
<tr>
<th>Liner Size, OD/ID, mm</th>
<th>Liners Mounted at 90°</th>
<th>Liners Mounted at 45°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failure Torque, Average ±SD, N · m</td>
<td>No.</td>
</tr>
<tr>
<td>50/28</td>
<td>68.6±4.1</td>
<td>9</td>
</tr>
<tr>
<td>50/36</td>
<td>65.4±4.0</td>
<td>9</td>
</tr>
<tr>
<td>52/36</td>
<td>80.4±7.4</td>
<td>6</td>
</tr>
</tbody>
</table>

Different From 50/36 mm?

|                       | No; P= .11, power= .35 | No; P= .76, power= .05 |
|                       | No/A                   | 64.3±2.2               | N/A                  |
|                       | Yes, P= .0027          | 52.0±4.3               | Yes, P= .0053        |

** Abbreviations: N/A, not applicable; OD/ID, outer diameter/inner diameter.**

**DISCUSSION**

This study found that the overall strength of this type of acetabular liner locking mechanism did not significantly change when the inner diameter was increased from 28 to 36 mm. This 59% reduction in liner thickness from 50/28 to 50/36 mm corresponded with an 8% reduction in lever-out strength. This reduction is not likely to be significant in a clinical context given its small magnitude. Increasing the outer diameter to 52 mm did not increase lever-out torque. Torsion tests likewise revealed no reduction in locking mechanism failure strength when comparing the 50/28- and 50/36-mm liners, regardless of the angle of the test. The significant increase in failure torque observed from 52/28-mm liners is as expected due to the larger moment arm provided by the increased outer diameter of the liner.

The current study has several limitations. First, as a biomechanical study, several aspects of the physiological environment were not considered to avoid introducing confounding variables; liners were tested in air (instead of inside a bovine serum bath) and at room temperature. However, given the consideration for fluid uptake in load-soak control specimens in hip simulator studies, it could be reasonable to presume that such conditions may in fact ensure a tighter fit between the liner and shell, thus enhancing the performance of the liner’s locking mechanism. In addition, this study only...
considered one design of acetabular liner (MicroSeal), whereas other liners and locking mechanisms may behave differently as their walls are thinned. Finally, it should be noted that the etiology of liner dissociation is a multifactorial issue including causes such as poor intraoperative component positioning and oxidative degeneration, which were beyond the scope of this study.\textsuperscript{24,34}

The lever-out data in the current study were within the range of previously reported values for 52/32-mm conventional, non-cross-linked, UHMWPE modular systems.\textsuperscript{29} Among the acetabular liners examined by Tradonsky et al,\textsuperscript{29} the lever-out strength of MicroSeal’s locking mechanism was most comparable to that of the HGP II (Zimmer, Inc, Warsaw, Indiana). Using a similar but not identical protocol, Hoffmann et al\textsuperscript{35} used 49.2/32-mm Durasul liners (Zimmer, Inc) as a control in a study investigating the cementation of the UHMWPE liners into acetabular shells. However, it is difficult to compare our data as theirs expressed in N, rather than in N · m without providing a lever arm length for conversion.

The data from the current custom torque fixtures clearly illustrated that the overall strength of the acetabular liner’s locking mechanism was not significantly reduced when the inner diameter was expanded to accept 36-mm heads. When mounted at 90°, each of the locking tabs resisted approximately the same amount of torque and were viscoelastically deformed until failure. When mounted at 45°, the central post could also resist torque, but the tabs were not loaded equally and the liner could not resist as much torque before dissociation of the liner from its shell. In the current study, the 90° torsion findings for the 50/28- and 50/36-mm liners were comparable with previously reported results from the 49.2/32-mm Durasul inserts,\textsuperscript{35} and the 52/36-mm liners performed considerably better still. The torsion data support previously reported finite element studies, which suggest that increased contact stresses should not limit the use of large-diameter femoral heads with thinner liners.\textsuperscript{15,36} Finally, early results from 2 studies using a different design and thin acetabular liners made of sequentially cross-linked/annealed UHMWPE have been promising. Sayeed et al\textsuperscript{27} reported no clinical failures of 3.8-mm thick liners after a minimum 2-year follow-up, and Johnson et al\textsuperscript{38} found no evidence of liner failure due to fracture and cracking after 2.4 million cycles in a hip wear simulator, even in liners that were just 1.9-mm thick. Because the current study used liners with a minimum thickness of 2.86 mm (for size 50/36 mm), the relative durability of 1.9-mm thick liners is encouraging.

**CONCLUSION**

Use of a cross-linked UHMWPE acetabular liner, with a locking mechanism that is not compromised when the liner is thinned to a thickness of at least 2.86 mm, appears to be a biomechanically sound construct when articulated with large diameter femoral heads.

**REFERENCES**


