Quantification of Rim Notching from Micromotion in Retrieved Polyethylene Acetabular Liners

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Introduction
To answer whether unsupported crosslinked acetabular liner designs have increased susceptibility to crack initiation, we carried out a retrieval analysis of our crosslinked and non-crosslinked acetabular polyethylene liners of the same design, using micro-computed tomography (micro-CT). Micro-CT has been validated for assessing polyethylene damage in retrieval studies and can non-destructively examine the polyethylene surface and subsurface for cracks at high resolution [1]. Integrating this imaging technique, the purpose of this work was to determine whether (1) symmetrical notching patterns existed and demonstrated similar morphological properties in both crosslinked and non-crosslinked liners, (2) micro-CT was able to quantify the dimensions of these notches and examine underlying subsurface changes; and (3) whether the dimensions of these notches correlated with their duration of implantation.

Methods
Ten crosslinked liners (Longevity; Zimmer Inc, Warsaw, IN) and four conventional ultra-high molecular weight polyethylene (UHMWPE) liners (Trilogy; Zimmer Inc, Warsaw, IN) were collected post-operatively under an institutional review board approved protocol between 2003 and 2010 during revision surgery at our hospital. This represented all the crosslinked liners of this series in our retrieval library. The four conventional liners were matched to implant duration times of the shortest, mean and longest crosslinked liners, as well as the conventional liner with the longest time of implantation available. Patient information was systematically gathered through hospital charts to include: age at revision, BMI, implant details, time in vivo, revision history and reason for revision.

Visual examination of the liners was undertaken and followed previously established techniques. Crack inspection for the 14 liners took place under direct visual examination and light stereomicroscopy (to 10x) by one examiner. Liners were examined from all angles under various light conditions and magnification strengths with a binocular dissecting microscope (SZ-CTV, Olympus, Toyo, Japan) and any cracks were recorded at this time. Damage attributed to implant retrieval was omitted.

Each liner was subsequently scanned with micro-CT and analyzed using a previously described approach [1]. Liners were individually scanned and reconstructed using a laboratory micro-CT scanner (cExplore Vision 120, GE Healthcare, London, Ontario). Scans were completed using an isotropic resolution of 50µm over 1200 views, with 10 frames averaged per view at an exposure time of 16ms. The X-ray tube voltage was 90kV and used a current of 40mA. Three-dimensional micro-CT analysis software (MicroView v2.2, GE Healthcare, London, ON) was then used to analyze and quantify notches in the reconstructed scans. The presence of cracks in the rim and their location was noted. The digital line tool within the software was used to measure the crack dimensions including length, width and depth from the surface extending inwards.

Mean dimensional scores were calculated by averaging the four sets of dimensions (length, width and depth) of each indentation into a liner to create a single set of dimensions for each implant. To determine the relationship between mean dimensions and duration of implantation, a linear regression analysis was performed for both cohorts, which included determining whether the slopes of the regression were significantly different from zero. A p value < 0.05 was considered significant.

Results
All fourteen liners demonstrated identical notching indentations opposite each other in the anti-rotational scallops (Fig. 1A). Each notch was made up of two indentations into the polyethylene, producing a total of four areas of polyethylene deformation in each liner. These deformations in the liner were present in both the crosslinked and non-crosslinked cohorts. Additionally, a corresponding never-implanted crosslinked liner was obtained and demonstrated no instances of notching. Under the same lighting and magnification conditions, none of the liners examined demonstrated any signs of crack initiation or rim failure.

Micro-CT scans of the liners allowed for an in-depth assessment of notches extending into the liner. The line measurement tool allowed us to calculate three sets of dimensions (length, width and depth) for each of the four indentations in every liner (Fig. 1D-F). A diverse range of notches was seen, varying from no notching in a never implanted liner, true notching (Fig. 1B) and a "squaring-off" or gross indentation against the edges of the anti-rotational peg (Fig. 1C). In all cases, notches originated from the outside and propagated inwards in a radial direction. No subsurface changes were observed.

A weak positive correlation was found between the notch dimensions and the liners' respective duration of implantation. The greatest correlation was found for length in the non-crosslinked group (r² = 0.949, p = 0.026); none of the other regression line slopes were significantly different from zero. Notches appeared early (< 1 month) and remained relatively stable in size even at mid-term durations of implantation in both cohorts.

Discussion
Schroeder et al. [2] established that symmetrical notches existed within the anti-rotation scallops of the unsupported rim in their cohort of retrieved crosslinked and non-crosslinked liners, but their etiology was not confirmed. Using visual examination and micro-CT on never-implanted and retrieved liners, we support the theory that these notches are the result of liner micromotion at the cup-liner interface. The role of these notches as a point of origin for rim cracking and implant failure remains unknown. The protrusion of the rigid metal anti-rotational pegs into this susceptible area of the liner may contribute to the creation of an acutely hazardous environment for crack initiation. Other reports have demonstrated that liner thickness at the rim may affect the probability and severity of rim loading [3]. These conditions, coupled with notching in the root of the rim, may be a primary source of polyethylene stress fractures. However, the notches themselves are likely formed through plastic deformation, as they appeared early and remained stable in size.

Significance
Unsupported acetabular liner designs that use an external liner-locking mechanism may not be more susceptible to crack propagation and rim failure.

References

Figure 1. Photo of symmetrical notching in a retrieved liner (A). Micro-CT subsurface analysis demonstrating notching in a crosslinked (B) and non-crosslinked (C) liner. Micro-CT surface analysis of notching in retrieved crosslinked liners (D-F).