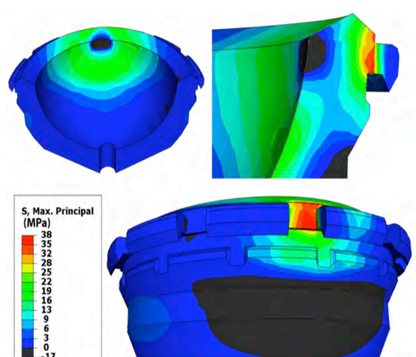
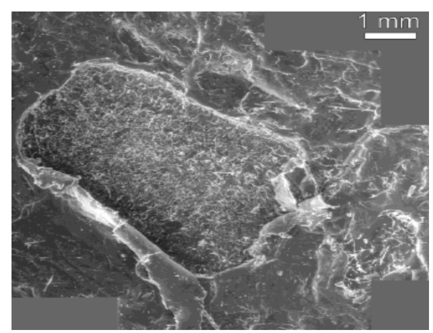
Tradeoffs in Crosslinked UHMWPE used in Total Joint Arthroplasty

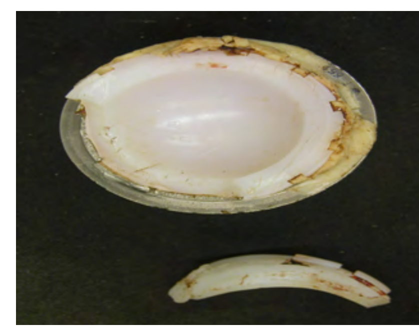
Lisa A. Pruitt, Ph.D.

Department of Mechanical Engineering and Bioengineering

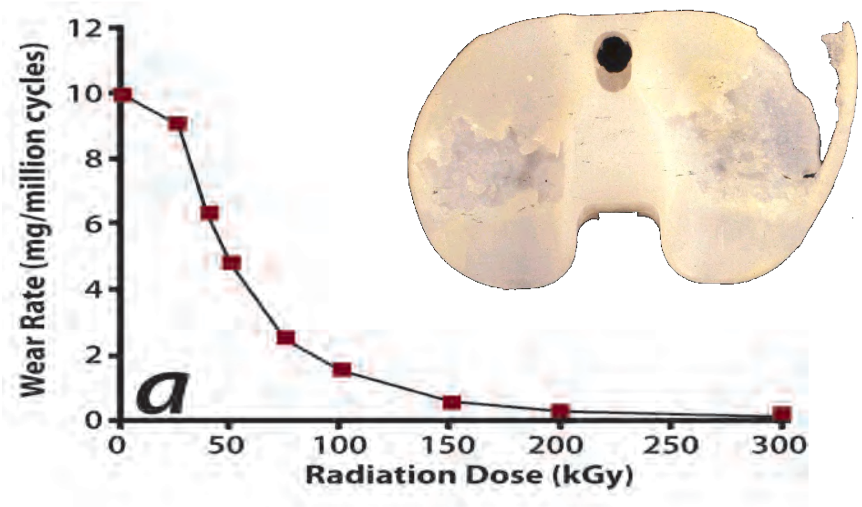
U.C. Berkeley



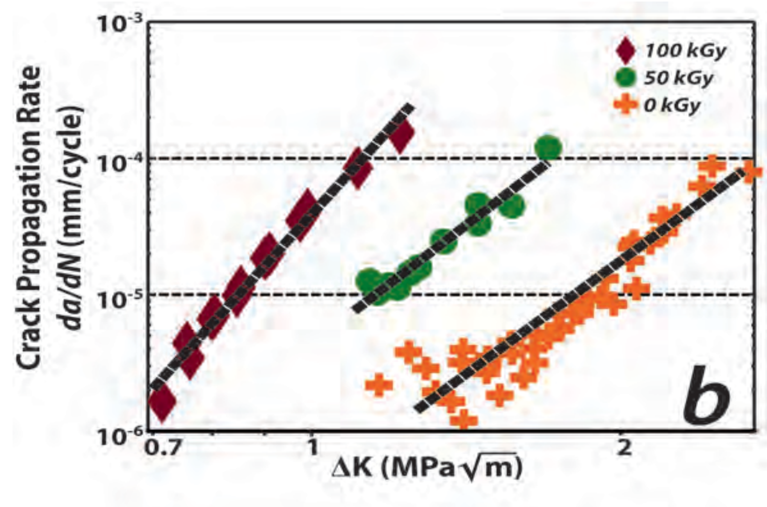




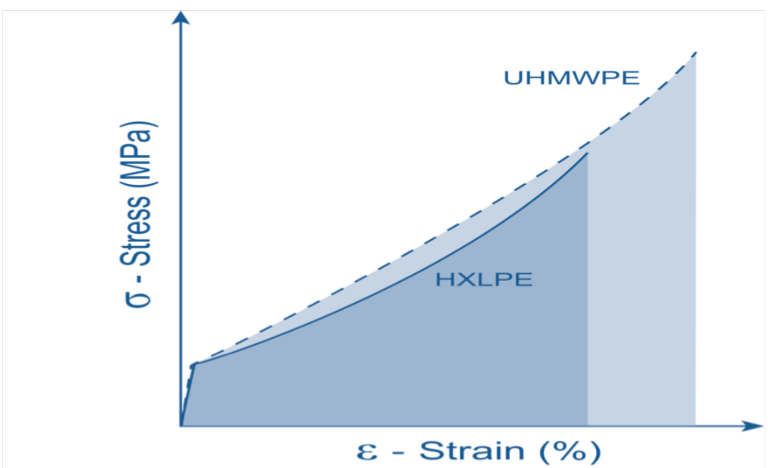
Crosslinking UHMWPE: Trade-offs

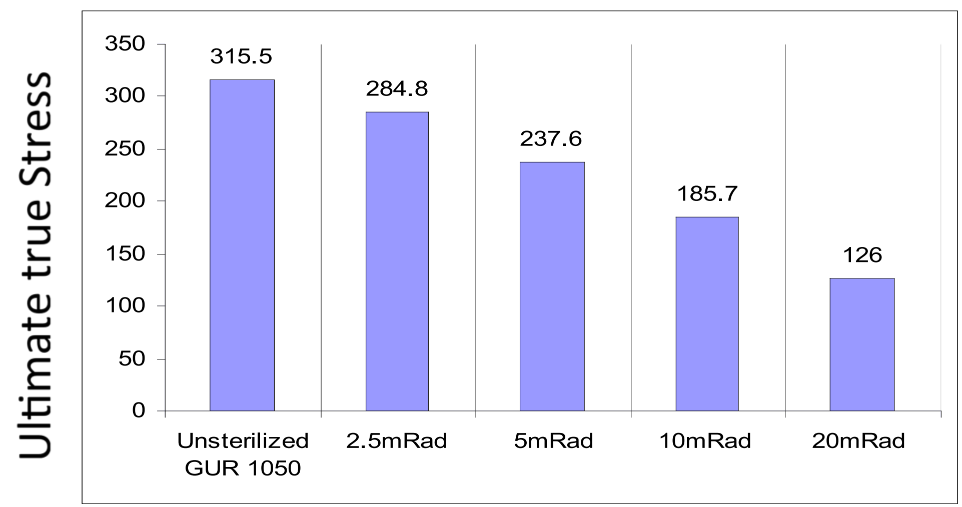


O'Connor et al., ORS, 1999.



Baker et al, JBMR, 2003.





Clinical retrievals exhibiting fatigue fractures

Greenwald, S. and Ries, M.D., New Polys for Old: Contribution or caveat. J Bone Joint Surg 2001: 83:S27-31.

Bradford L, Kurland R, Sankaran M, Kim H, Pruitt LA, Ries MD. Early failure due to osteolysis associated with contemporary highly cross-linked ultra-high molecular weight polyethylene. A case report. J Bone Joint Surg Am 2004; 5: 1051–6.

Halley D, Glassman A, Crowninshield RD. Recurrent dislocation after revision total hip replacement with a large prosthetic femoral head. A case report. J Bone Joint Surg Am 2004;4:827–30.

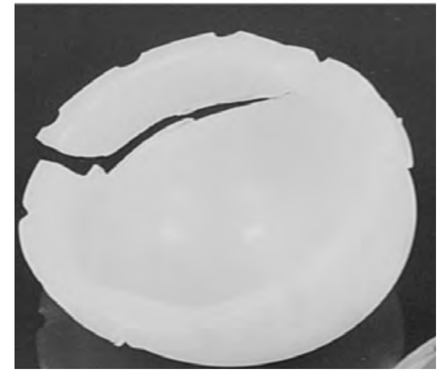
Tower, S.S., Currier, J.H., Currier, B.H., Lyford, K.A., Van Citters, D.W., Mayor, M.B., 2007. Rim cracking of the cross-linked longevity polyethylene acetabular liner after total hip arthroplasty. J. Bone Joint Surg. Am. 89 (10), 2212–2217.

Currier, B.H., Currier, J.H., Mayor, M.B., Lyford, K.A., Collier, J.P., Van Citters, D.W., 2007a. Evaluation of oxidation and fatigue damage of retrieved crossfire polyethylene acetabular cups. J. Bone Joint Surg. Am. 89 (9), 2023–2029.

Patten, E., S. Atwood, D.W Van Citters, B.A Jewett, L. Pruitt, and M.D. Ries, "Delamination of a Highly Crosslinked UHMWPE Acetabular Liner Associated with Titanium Deposits on the Co-Cr Head Following Dislocation: A Case Report," Journal of Bone and Joint Surgery (British) 92-B 1306-1311 (2010).

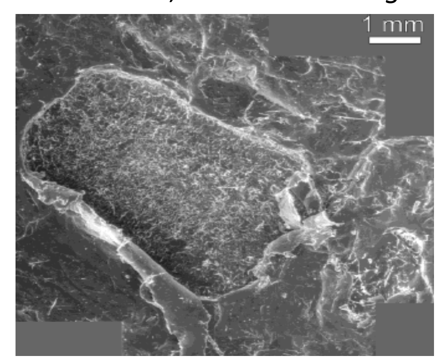
Furmanski, J., Anderson, M., Bal, S., Greenwald, A.S., Halley, D., Penenberg, B., Ries, M., Pruitt, L., 2009. Clinical fracture of cross-linked UHMWPE acetabular liners. Biomaterials 30 (29),5572–5582.

Furmanski, J., M.J. Kraay, and C.R. Rimnac. Crack initiation in retrieved highly cross-linked UHMWPE liners: an investigation of 9 cases, J Arthroplasty ,September 2010.



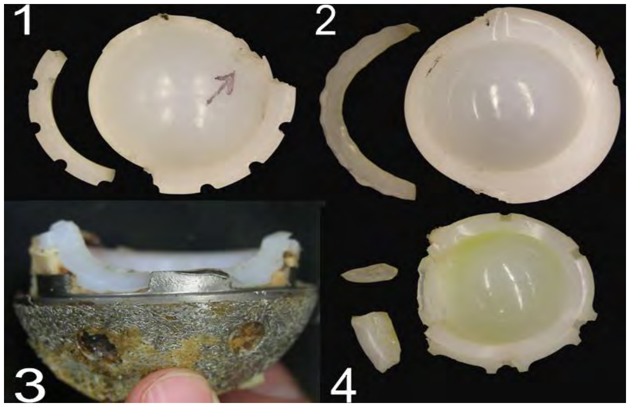
Halley , JBJS am ***86***, 2004

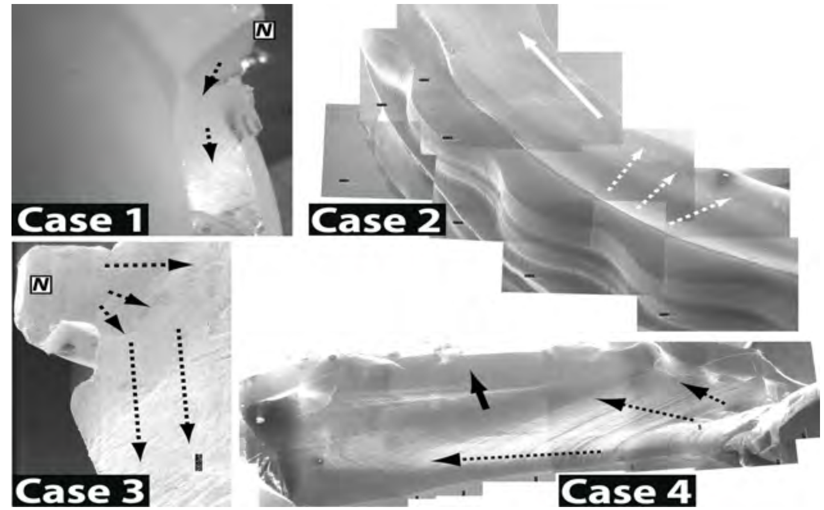
Greenwald, *J Bone Joint Surg* ***83***, 2001

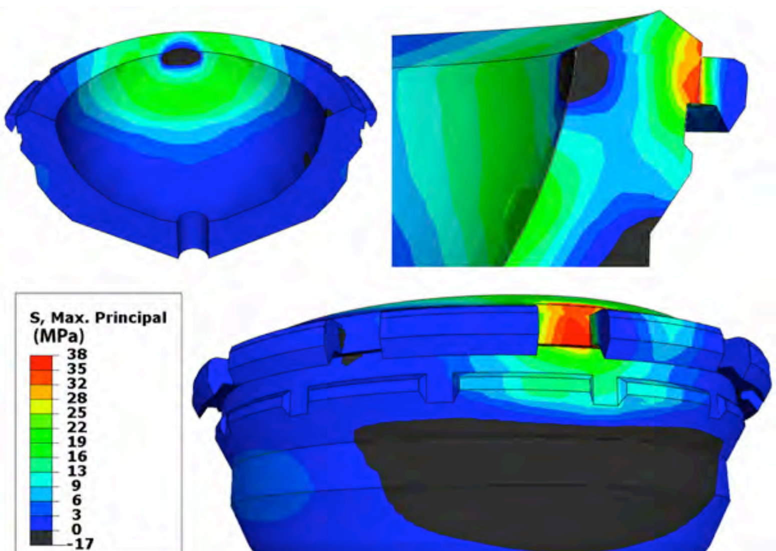


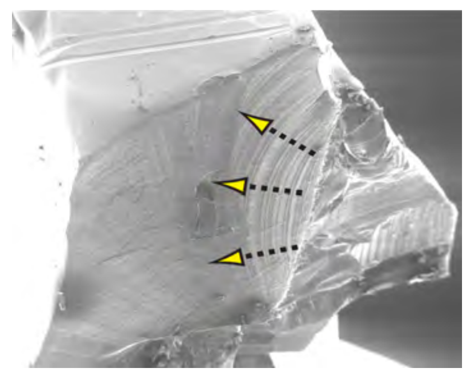
Patten, *J Bone Joint Surg* ***83***, 2010

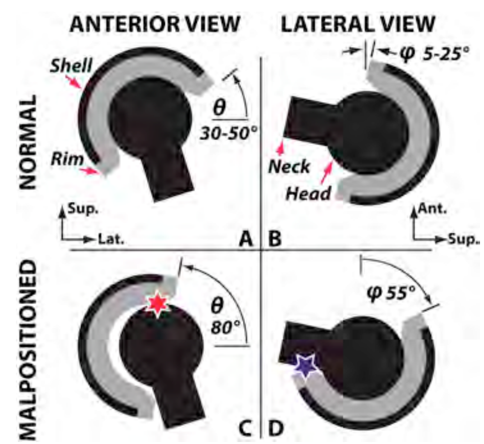
Clinical fractures: **initiated at sites of stress concentrations in crosslinked acetabular liners (4 manufacturers) ranging in crosslinking dose from 4-10 Mrad. No oxidation was detected (OI = 0.072 – 0.1). Time *in-vivo* : 3 mo - 5.5 yrs.**











Furmanski, J., Anderson, M., Bal, S., Greenwald, A.S., Halley, D., Penenberg, B., Ries, M., Pruitt, L., 2009. Clinical fracture of cross-linked UHMWPE acetabular liners. Biomaterials 30 (29),5572–5582.

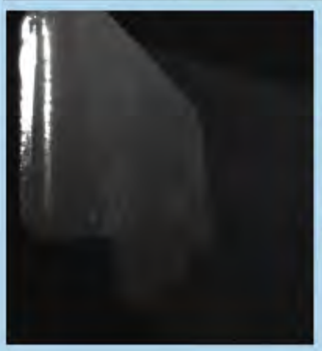


Figure 1.
Cracks initiate and propagate between machined vertical slots. Cracks join with circumferential locking slot. Many simultaneous initiation sites.

JEVAN FURMANSKI- MPBG/UCB 2007

Figure 2.
Top view of explanted liner and part of fractured rim.

ZIMMER TRILOGY/LONGEVITY

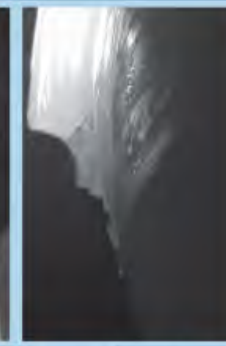
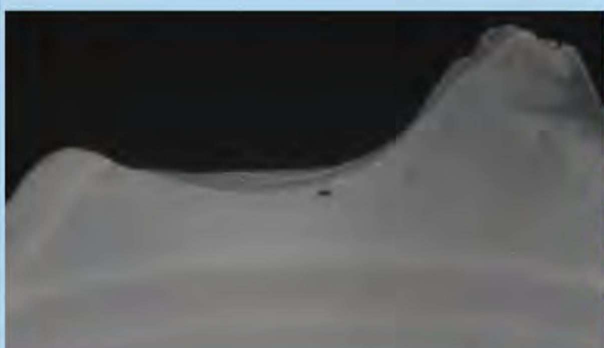
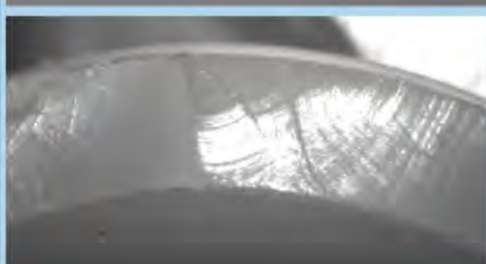


Figure 3.
Detail view of vertical slot crack initiation. Cracks curve down into the primary fracture plane





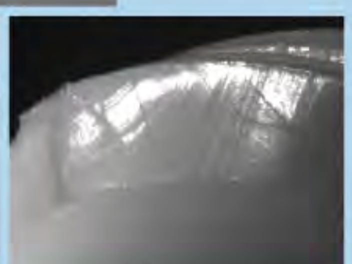
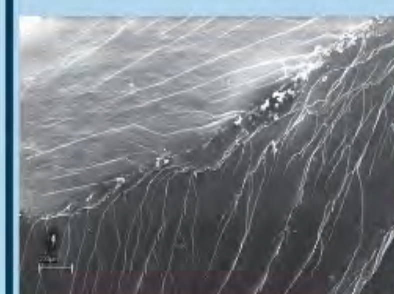
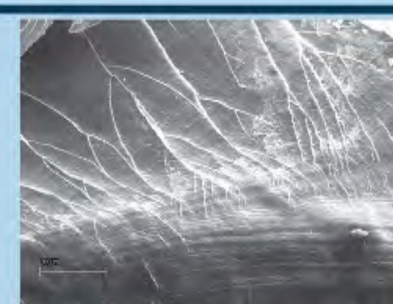


Figure 4.
Primary crack surface is non-planar and joins adjacent vertical slots. Striations spread from the peak, implying initiation at the now absent vertical slot.

SEM micrograph of primary initiation site.



Border of tearing and faceting propagation on extreme surface.



Detail showing transitions from initiation striations to include a tearing mode. Upper portion does not show as much tearing.

Liner Locking Mechanism Failure of a Crosslinked Acetabular Liner Caused by Impingement

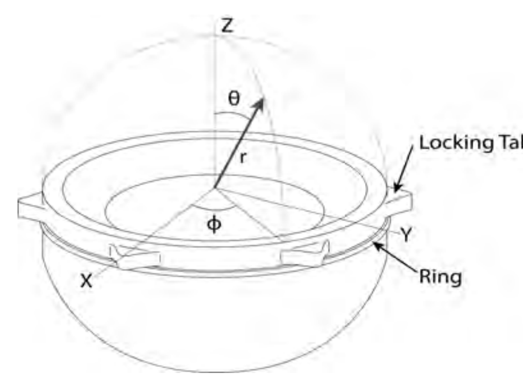
A 65 year-old male (240 lbs., BMI = 30) underwent right total hip arthroplasty in 2002 for osteoarthritis.

Implants were an S-ROM femoral stem, 28mm+3 CoCr femoral head, 58mm Pinnacle shell, and 5 Mrad Marathon XLPE liner (Depuy, Warsw, IN).

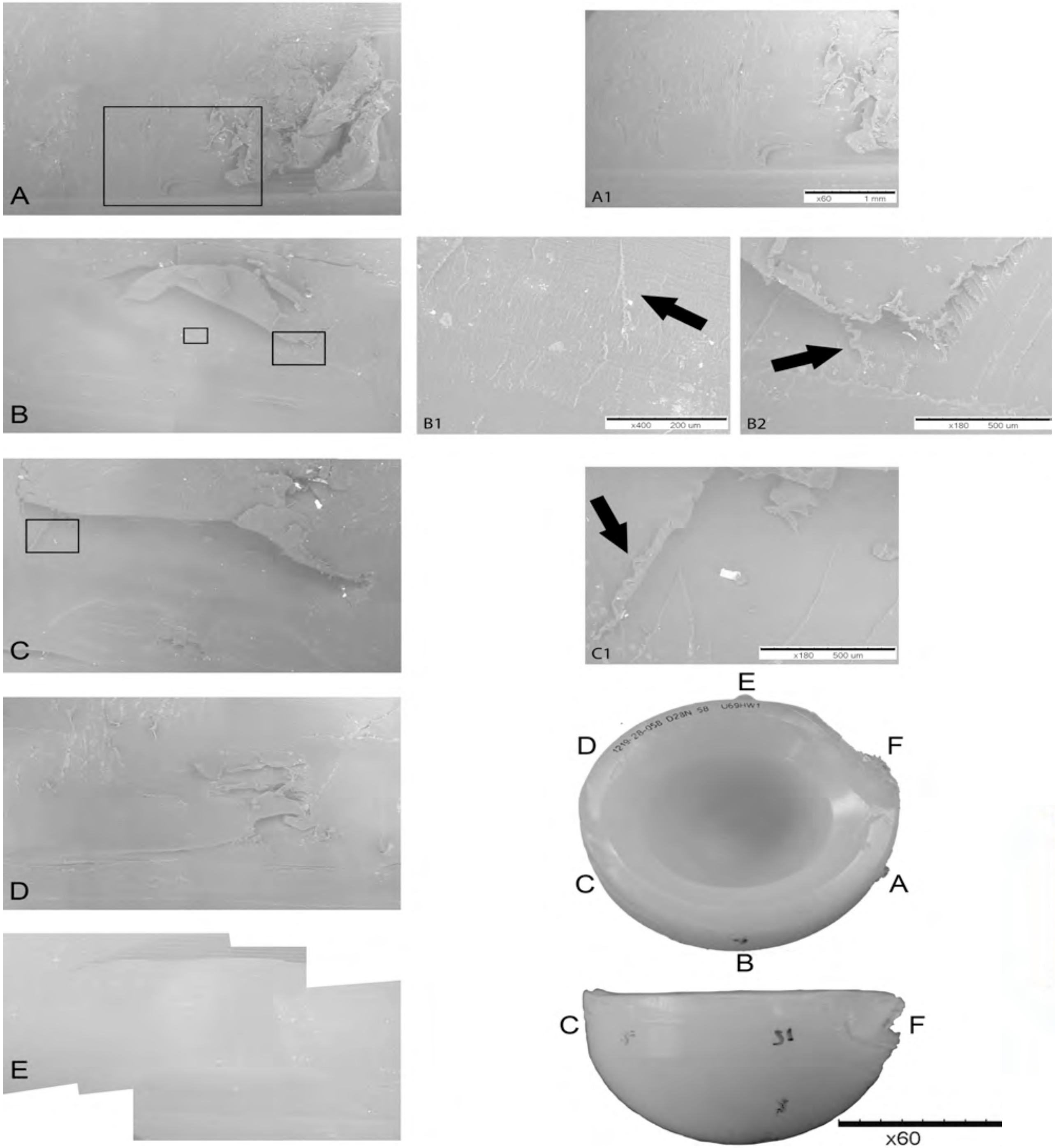
In September 2010, the patient presented after rising from a chair and feeling a sharp pain in his right hip and groin accompanied by a popping and grinding noise.

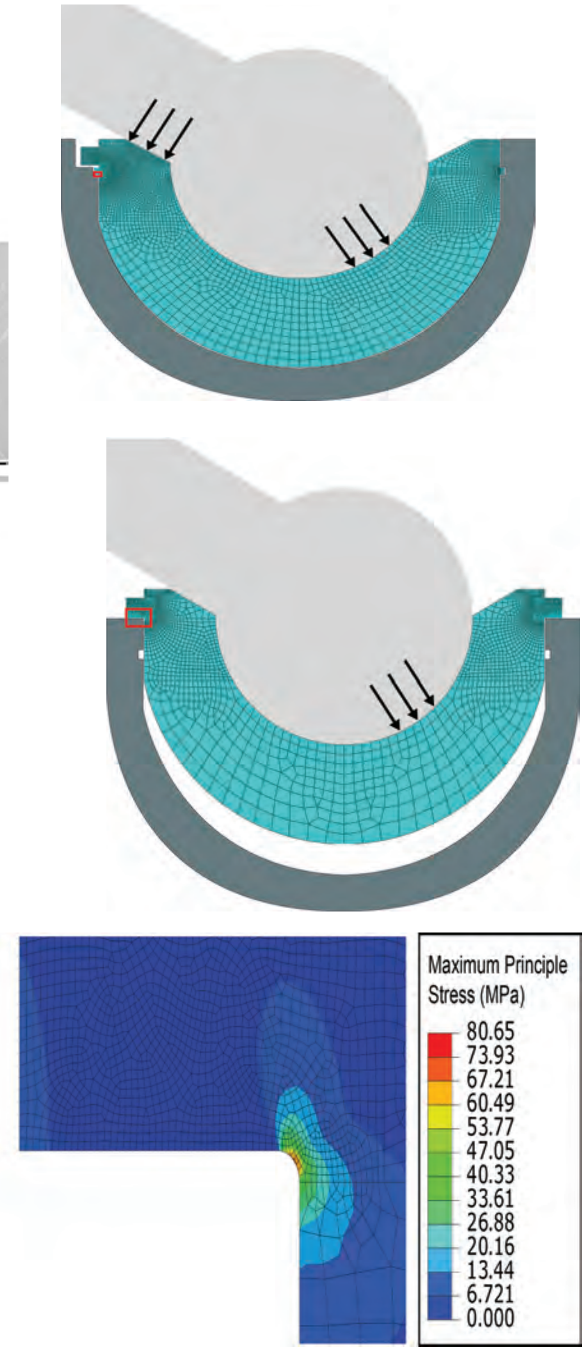
Radiographs demonstrated eccentric position of the femoral head within the acetabular shell consistent with dissociation of the liner.

Revision total hip arthroplasty was performed during which displacement of the liner from the acetabular shell was confirmed



5 of the 6 liner locking tabs fractured.


A
A1
x60 1 mm
B
B1
x400 200 um
B2
x180 500 um
C
C1
x180 500 um
D
E
E
D
F
C
A
B
C
F
x60


Maximum Principle Stress (MPa)
80.65
73.93
67.21
60.49
53.77
47.05
40.33
33.61
26.88
20.16
13.44
6.721
0.000

Tradeoff in Fatigue Crack Propagation and Fracture Behavior in Crosslinked UHMWPE

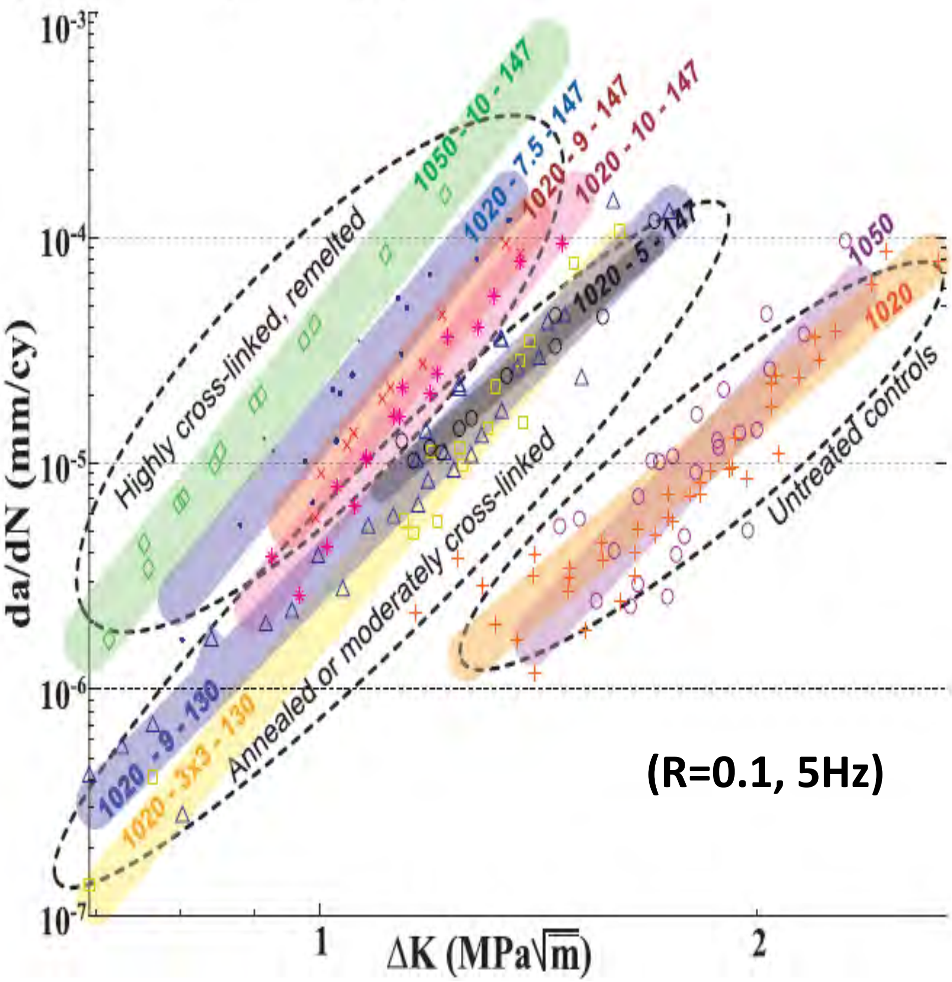
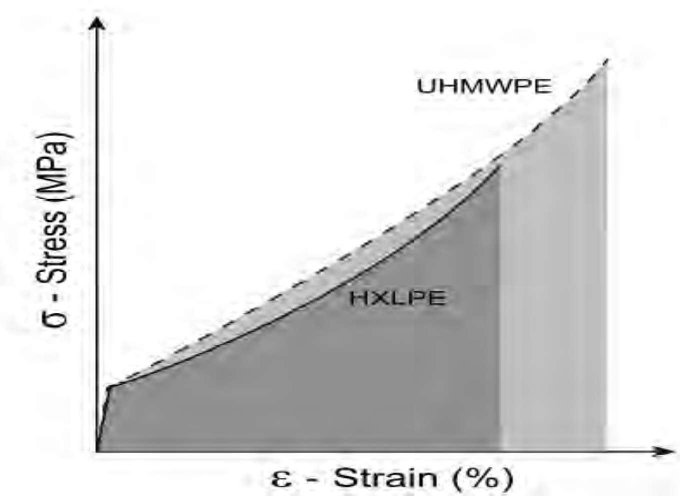


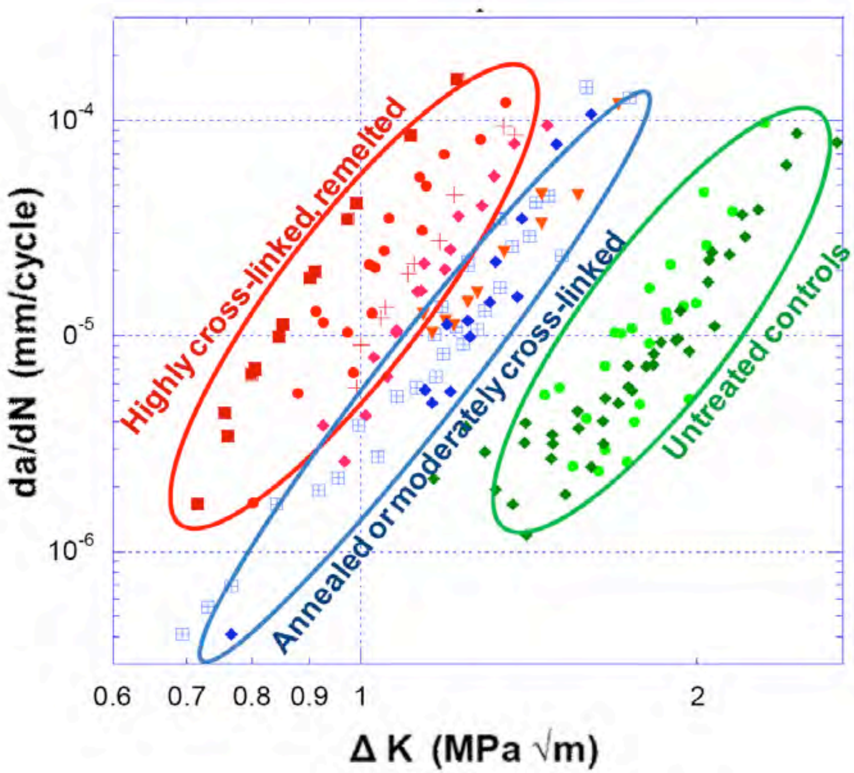
Table 1. Comparison of mechanical properties for conventional UHMWPE and XLPE.

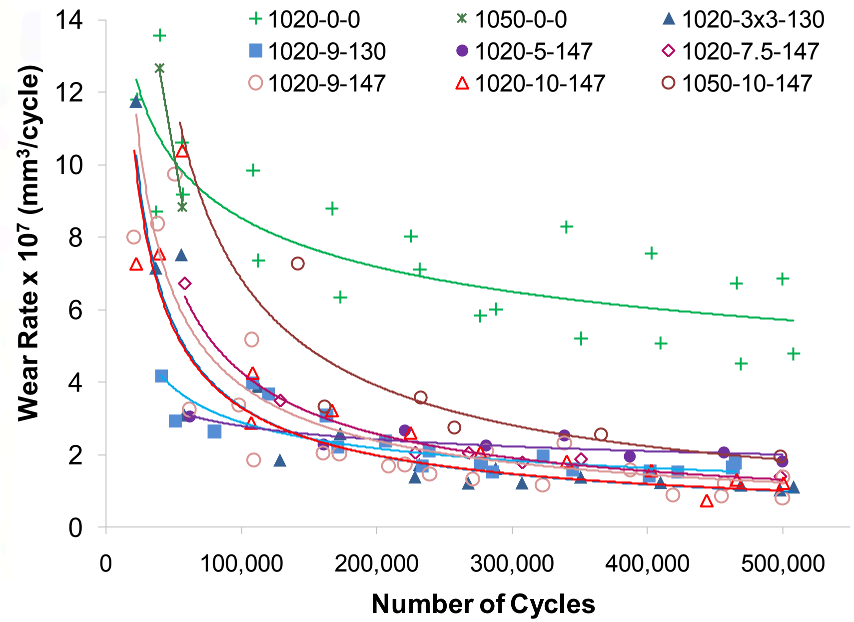
Property	UHMWPE (0 kGy)	XLPE (100 kGy)
Ultimate true strain (%)	1.82	1.5
Ultimate true stress (MPa)	315	185
Yield stress (MPa)	20	20
Fatigue threshold (MPa√m)	1.4	0.7
Fracture toughness (MPa√m)	2.5	1.0

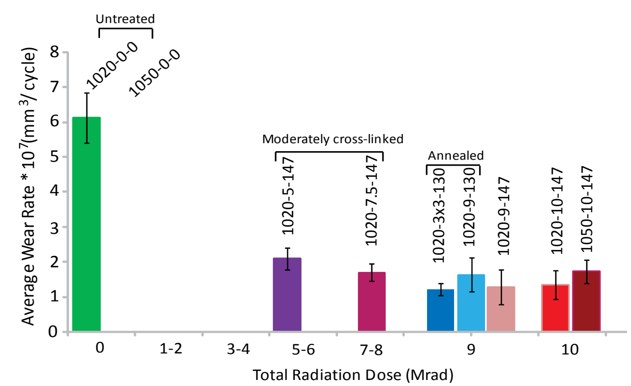


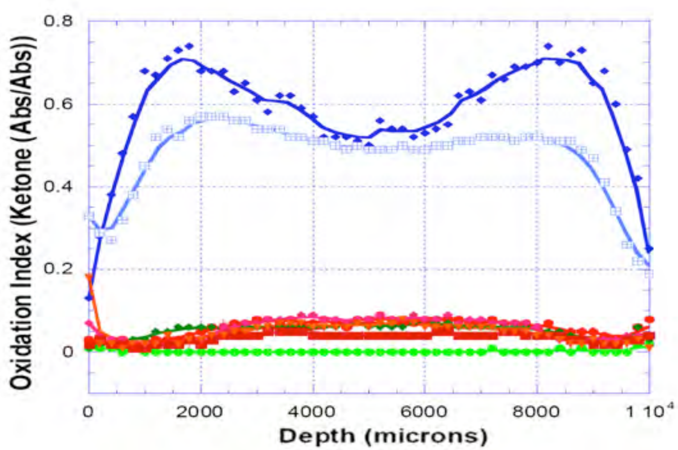
S. Atwood et al, Journal of Mechanical Behavior of Biomaterials and Tissues, 2011.

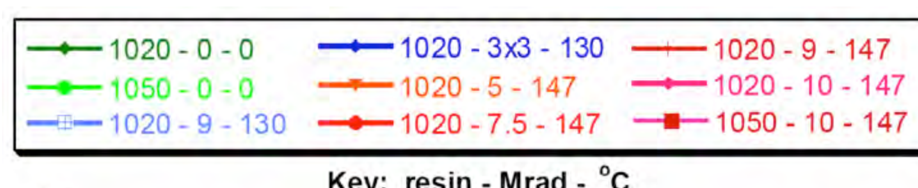
Fatigue Crack Propagation Resistance, Wear and Oxidation Behavior





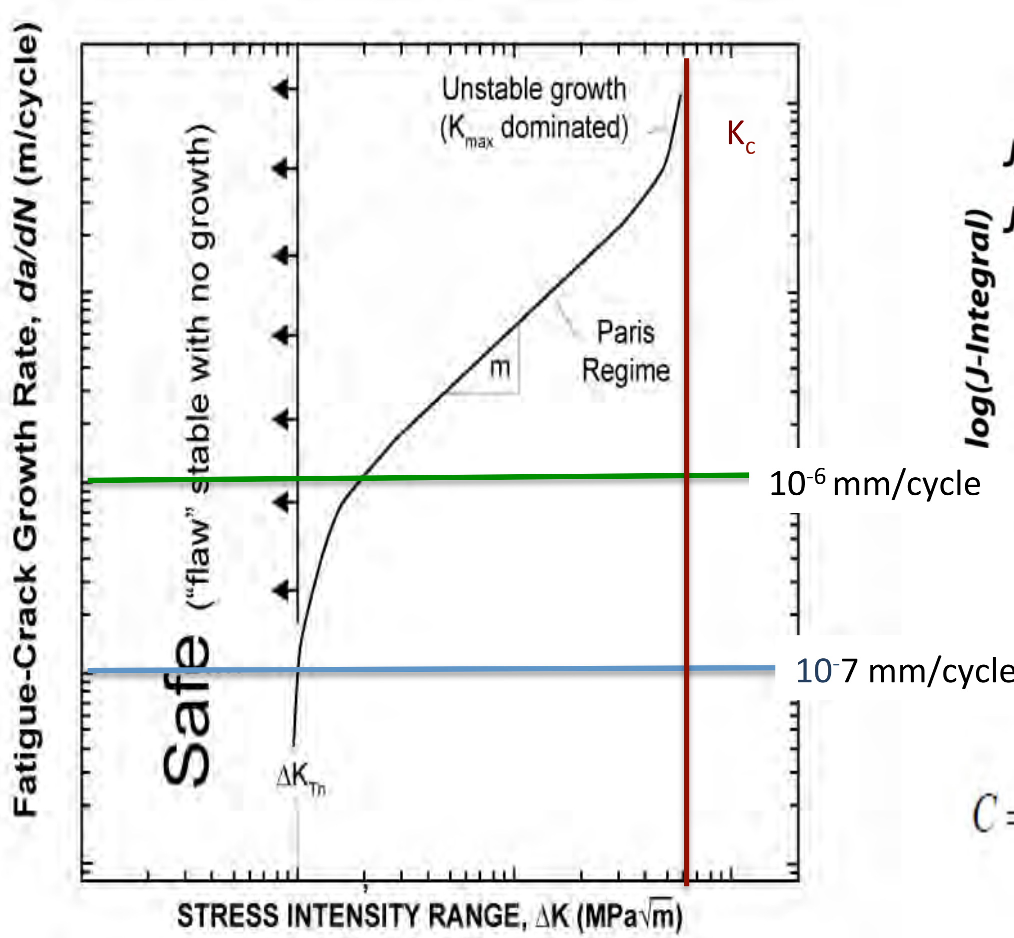


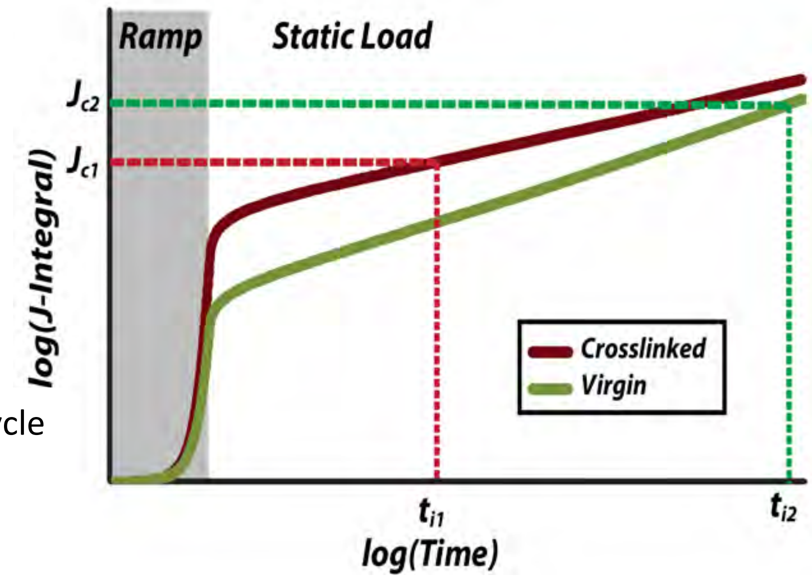




S. Atwood et al, JMBBT, 2011.

Fatigue Fracture Design





$$C=\frac{1}{E_0}\left(\frac{t}{\tau_0}\right)^d \Rightarrow J=J_0\left(\frac{t}{\tau_0}\right)^d \Rightarrow \frac{t_i}{\tau_0}=\left(\frac{J_c}{J_0}\right)^{1/d}$$

Pruitt and Furmanski, JOM, 2009;
Furmanski, Rimnac and Pruitt, DYF, 2009.

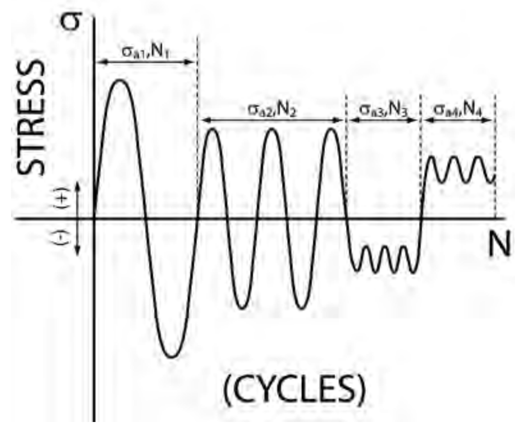
Factors affecting Fatigue Crack Propagation Resistance

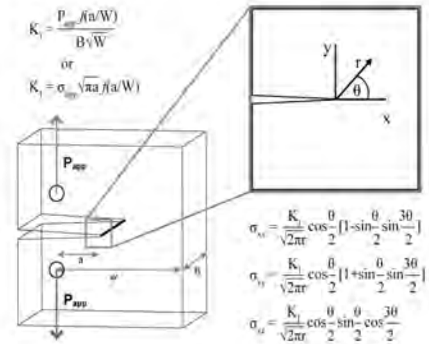
Testing
- Stress ratio (R ratio)
- Frequency or strain rate
- Waveform
- Temperature

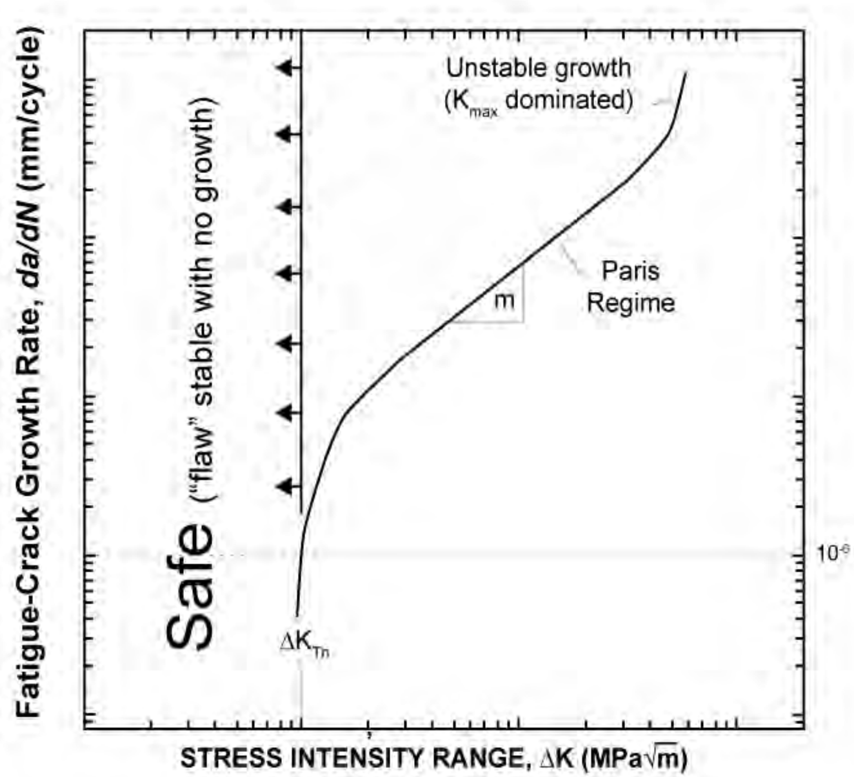
Molecular Structure
- Crystallinity
- Morphology
- Crosslinking
- Entanglement density
- Molecular weight

Environmental
- Aging
- Serum, Saline, or Air
- Oxidation

Mechanical
- Notches
- Peak Stresses and overloads
- Multiaxial or variable amplitude





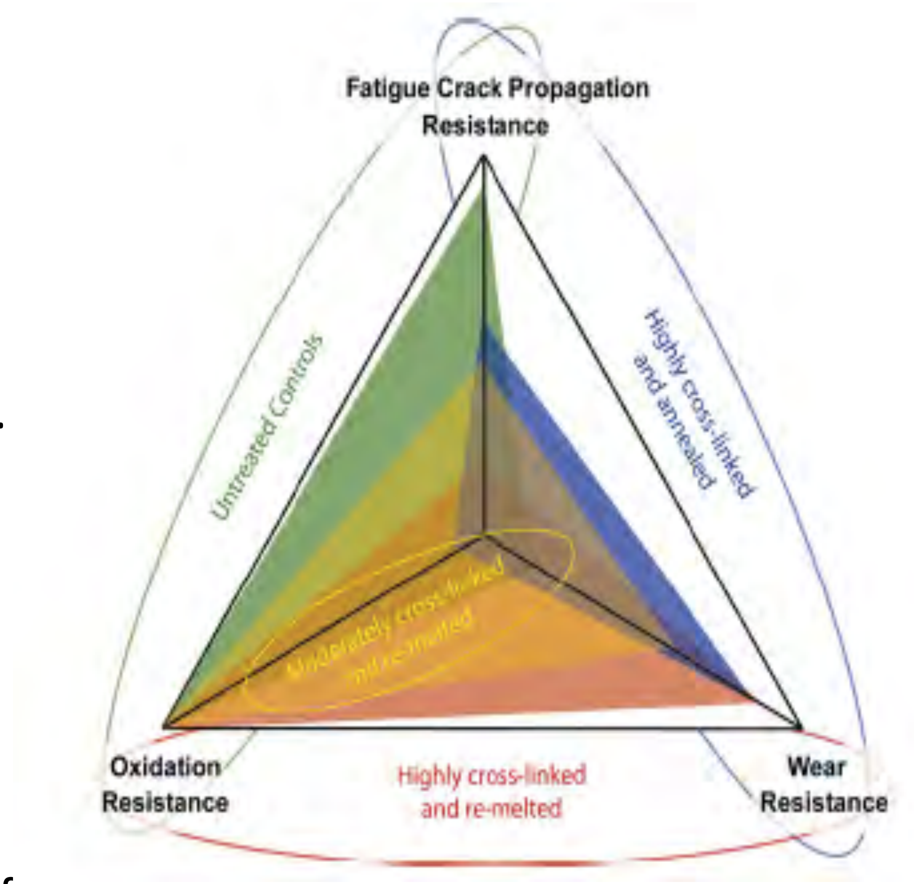


Recommendations

-Crosslinked UHMWPE are susceptible to fatigue and fracture in vivo. A better understanding of fracture mechanisms is needed.

-Special considerations for creep effects and viscoelastic crack growth is warranted. Static stresses in implants cannot be discounted in implant design.

-There is a need for the development of standard test(s) that can be used for the characterization of fatigue - fracture resistance and coupled design parameters associated with crosslinked formulations of UHMWPE used in TJA.



S. Atwood et al, Journal of Mechanical Behavior of Biomaterials and Tissues, 2011.