Oxidation is Induced by Compressive Cyclic Loading in Conventional UHMWPE

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Statement of Purpose: Oxidation of ultrahigh molecular weight polyethylene (UHMWPE) can lead to failure of implants used in total joints. A previous study showed that UHMWPE oxidized more rapidly under cyclic load at an elevated temperature than at an elevated temperature alone [1]. However, that study used a sinusoidal reciprocating force; in vivo cyclic loading is predominantly compressive without an external restoring force. The objective of this study was to determine if a more clinically relevant accelerated aging test, which incorporated only compressive cyclic loading, affected the oxidation of UHMWPE.

Methods: All samples were machined from GUR1050 UHMWPE that was gamma sterilized in inert. Each test sample was secured against a platen inside an environmental chamber with circulating 80°C air. Compressive cyclic loading was administered by a 12.5 mm diameter load applicator affixed to a hydraulic testing system. In every trial, the test sample was exposed to load and heat with three heated controls that were not subjected to load.

Cyclic stress was applied between 0.4 MPa and a target maximum stress at a frequency of 5 Hz. To investigate the effect of increasing cycle count on oxidation, samples were cyclically loaded to a maximum stress of 10 MPa for 3×10^6 load cycles, 9×10^6 load cycles, and 15×10^6 load cycles. To investigate the effect of increasing stress levels on oxidation, samples were cyclically loaded for 15×10^6 load cycles to a maximum stress of 10 MPa, 20 MPa, and 30 MPa.

Microtomed thin films from all samples were analyzed via FTIR to quantify oxidation per ASTM F2102. Oxidation was measured through the depth of the test sample at targeted distances away from the applied load, ranging from directly underneath the center of the load applicator to 20 mm away. FTIR analysis was also performed on the heated controls.

Results: After 3×10^6 cycles of 10 MPa stress, there was no significant difference between the oxidation of the loaded test sample and the heated controls. There was significantly greater oxidation in the loaded test samples after 9×10^6 and 15×10^6 cycles of 10 MPa stress, indicating that more stress cycles can lead to more oxidation, as shown in Fig 1. Increasing the maximum stress level from 10 MPa to 20 MPa significantly increased the oxidation after 15×10^6 stress cycles across the entire test sample, from directly under the load applicator to 20 mm away (Fig 2). Samples tested under 30 MPa of cyclic stress oxidized so much that the material disintegrated during microtoming; therefore, the oxidation levels for this sample could not be measured directly under the load applicator.

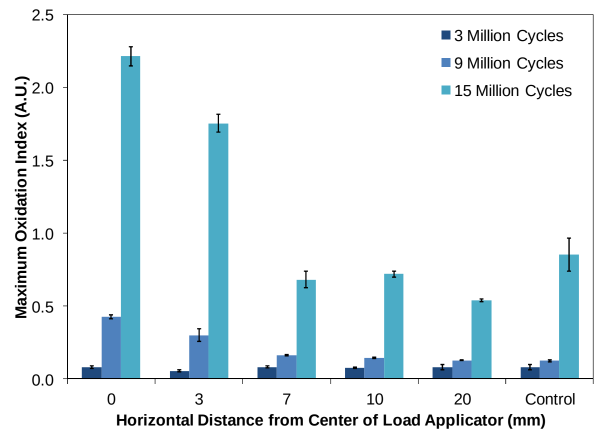

Fig 1: A bar graph summary of the maximum oxidation index measured in samples after 3, 9, and 15 million load cycles of 10 MPa stress.

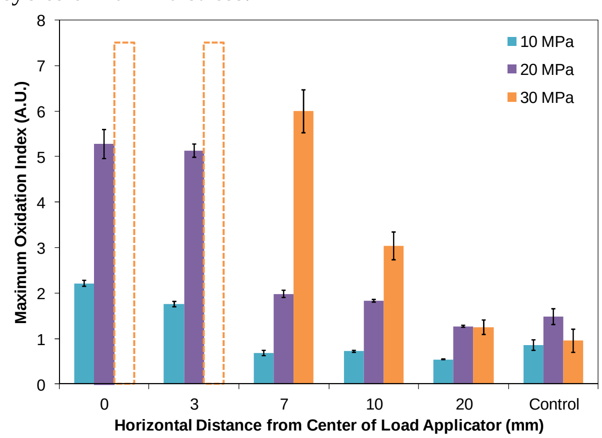

Fig 2: A bar graph summary of the maximum oxidation index measured in samples 15 million load cycles of 10 MPa, 20 MPa, and 30 MPa maximum stress. Samples under the load applicator could not be microtomed in the 30 MPa samples due to high oxidation levels.

Conclusions: In nearly all tests, areas under the load applicator showed significantly greater oxidation than non-loaded samples, likely indicating that compressive cyclic loading led to oxidation. The shortest test (3×10^6 cycles of 10 MPa stress) did not show this trend, indicating that the short duration of the test was not sufficient to produce detectable differences in oxidation between loaded and non-loaded samples. Increasing stress led to increased oxidation, and increasing number of stress cycles led to increased oxidation. Since in vivo components also experience compressive cyclic loading, their longevity may be affected.

Reference:

[1] Wannomae KK, et al. EFORT 2008: F265

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