Raman Microspectroscopy of Polyethylene Structure, Strain & Oxidation Using New Glenoid Prostheses to Demonstrate Effects of Design and Manufacture

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Statement of Purpose: Polyethylene deformation and wear are major causes of glenoid prosthesis loosening and failure.(1) To date, the majority of studies have focused on elements of design and fixation. However, studies have not focused on the microscopic structure, level of oxidation or internal strain of the polyethylene prostheses and their influence on long-term clinical performance.

Polyethylene has a lucency that makes it particularly open to non-destructive testing by raman microspectroscopy.(2) The application of this type of spectroscopy with a confocal technique allows a layer-by-layer, three-dimensional mapping of the polyethylene to a depth of 3 mm, as opposed to 5 microns in ceramics. The aim of this study was to explore the application of raman spectroscopy to unused polyethylene glenoid prostheses, to look for variations in the structure of the polyethylene, internal strain and level of oxidation. Our hypotheses were: 1) that exposure to air would increase the oxidation index of the polyethylene similar to hip components, and 2) that variations in design might cause variations in microstructure, strain or oxidation.

Methods: 1) To study the effect of exposure to air, two identical glenoids were compared: one was fresh from the manufacturers package, the other had been open to the air for an extended period (18 months); 2) to compare the effect of design elements, two prostheses from the same manufacturer that differed only in the thickness (7 mm vs. 4 mm) of their articular portion were studied. Studies were carried out on a raman spectrum microscope (T-64000, ISA Jovi-Ivon/Horiba Group, Tokyo, Japan) with a high-resolution (CD camera). These specimens were studied to determine: the crystallinity volume fraction, the amorphous volume fraction, the orthorhombic volume fraction which is used to calculate the degree of oxidation and the previously applied strain within the material.

Results: 1) Compared to a unexposed prosthesis, a prosthesis with a longer exposure demonstrated a decrease in the amorphous fraction and an increase in the oxidation index (figure 1), but no change in the internal strain of the material; 2) in comparison with a thick glenoid prosthesis, a thin prosthesis showed an increase in the oxidation index but no change in the internal strain or amorphous and crystallinity fractions (figure 2). This is the first study to use this non-destructive technique to study effects on internal structure of the polyethylene glenoid. Long-term exposure to air showed increased oxidation in a manner similar to that reported by Kurtz in polyethylene acetabular cups. A difference in oxidation level in glenoids differs only in thickness as an unexpected finding, as oxidation occurs across the surface boundary and no difference in ambient oxygen had been anticipated. The changes in internal strain were felt to perhaps be more likely.

Discussion and Conclusions: In this initial study, we have used a non-destructive technique to study effects on the internal structure of a polyethylene glenoid. Exposure to air has led to increased oxidation as shown previously. A difference in oxidation level in glenoids that differ only in thickness is an unexpected, and as yet unexplained, finding. As oxidation is a surface exchange no difference had been anticipated. Changes in internal strain had been felt to be more likely. The importance of small variations in structure, oxidation and strain can only be established in the long-term study of retrieval specimens. The technique of non-destructive testing, however, should be of importance in the short-term for manufacturers and designers wishing to look at the immediate effects of variations in design upon the microscopic structure, oxidation and internal strains of polyethylene.

References:

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2. H. McKellop, F.-W. Shen, B. Lu, P. Campbell, and R. Salovey, J. Orthop. Res. 17:157-67, 1999.

Figure 1: Oxidation index. Wrapped Glenoid on left, exposed on the right.

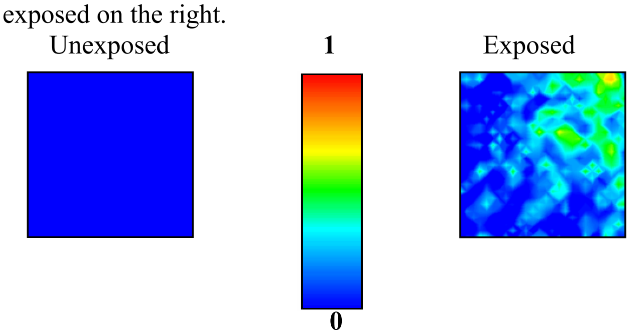

Figure 2: Oxidation index. Thin Glenoid on the left, thick on the right.