BIOTRIBOLOGY: THE WEAR RESISTANCE OF REPAIRED HUMAN ARTICULAR CARTILAGE

Nils A. Steika1, Michael J. Furey1
Hugo P. Veit2 and Mats Brittberg3

1School for Biomedical Engineering and Sciences, Virginia Tech, Blacksburg, VA 24061-0238, U.S.A.
2Biomedical Sciences and Pathology
VA-MD College of Veterinary Medicine
Blacksburg, VA 24061-0442
3Cartilage Research Unit, University of Goteborg
Goteborg, Sweden

ABSTRACT

Normal, mature articular cartilage does not spontaneously repair itself back to hyaline cartilage after an injury or degenerative disease (e.g., osteoarthritis)—problems of increasing importance in an aging population. A promising new approach is to repair damaged cartilage by a method known as Autologous Chondrocyte Implantation (ACI)—a technique pioneered and further developed by the Cartilage Research Unit at Goteborg University in Sweden. However, the tribological properties of the repaired cartilage, including the important property wear-resistance, are unknown. How durable is the repaired cartilage? How long will it last?

One of the co-authors, Dr. Mats Brittberg, has provided 16 samples of 2mm diameter human biopsies from the knees of eight Swedish patients for testing in our biotribology device. This paper presents results of wear experiments on cartilage repaired by Brittberg’s ACI technique and, for comparison, two other methods. Four of these samples (2 pairs) were from patients who had undergone the ACI procedure while another four were from those who had other methods of repair. A pair consists of a biopsy from the repaired area of the joint along with a sample from nearby "healthy" cartilage from the same joint. Thus, each pair allowed for a direct comparison of the tribological properties of the repaired cartilage to those of "normal" cartilage from the same joint.

The results of this study show that the ACI method of cartilage repair gave substantially less wear than that of normal cartilage while spontaneous repair and abrasion arthroplasty produced higher wear. Friction levels were in the boundary lubrication regime and, in line with our previous experience, had no correlation with wear. Results obtained with cartilage from the remaining patients will be discussed in future papers.

KEYWORDS: biotribology, cartilage wear, repaired human articular cartilage, autologous chondrocyte implantation

INTRODUCTION

Autologous Chondrocyte Implantation

The capacity of hyaline cartilage to heal following injury is poor. The Gothenburg (Goteborg) group has developed and used Autologous Chondrocyte Implantation (ACI) and Transplantation (ACT) since 1987. The basic approach is to introduce healthy cartilage cells into the injury. Autologous chondrocytes from arthroscopy are cultured in a Petri dish. The cells in high numbers (6 - 8 million) are implanted into the defect. The defect is then covered with a perioseal patch which serves as a cover and stimulus for hyaline cartilage synthesis. Details of the technique may be found in references [1, 2].

Biotribology Research

Research on biological lubrication or "Biotribology" at Virginia Tech began over 20 years ago. The studies were aimed at exploring possible connections between tribology and mechanisms of joint lubrication and degeneration (e.g., osteoarthritis) [3-5]. The research involved bovine cartilage, using a device and techniques designed for "in vitro" measurements of cartilage wear and friction under controlled conditions. In recent years, this research on biotribology has been enhanced by collaboration with Dr. Hugo Veit of the Virginia-Maryland College of Veterinary Medicine and Dr. Mats Brittberg of Goteborg University.

EXPERIMENTAL

For the present study, the cartilage wear experiments were carried out using our biotribology device and techniques previously described [4]. Since the cartilage specimens provided by Brittberg were smaller (2 mm diam.) than our usual specimens (6 mm diam.), a special holder was designed and made to accommodate them in the device. The mounted cartilage specimens were loaded against polished (0.023 µm CLA roughness) stainless steel disks having a diameter of 25.4 mm. The normal load applied was 6.08 N, producing an average pressure of 1.94 MPa for comparison with earlier results. Reciprocal sliding motion at a frequency of 30 cycles/minute and amplitude of 1.6 cm was used in this study. Test temperature was controlled to 22°C while the test duration was three hours. Buffered saline solution was used as the lubricant. Cartilage wear debris was collected from washings at the end of a test plus any transferred material to the disk.

Cartilage wear is determined from analysis for hydroxyproline—a characteristic amino acid of collagen. Hydroxyproline analysis was carried out on all cartilage specimens, wear debris collected from washings, and material transferred to the stainless steel disks. The method is extremely sensitive; analyses were carried out in triplicate to ensure accuracy. Details of the test procedure may be found in references [6, 7].

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RESULTS
The results of the eight experiments on four pairs of cartilage specimens are discussed separately.

ACI Repair
Table 1 summarizes the cartilage wear obtained on specimens from patients 2 and 5, each having received the ACI method of cartilage repair. Patient 2 is a female born in 1965 while patient 5 is a male born in 1968.

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The total wear for the normal control for patient 2 was 3624 µg; for ACI repair on the same joint, the total wear was 450 µg—remarkably lower. However, the normal control value is suspiciously high. We believe that a large fragment of cartilage was detached from the plug by the wear process (e.g., by delamination) and ended up in the washings.

Looking at the data for patient 5, it is seen that the normal control produced a total wear of 1380 µg while the ACI specimen gave a total wear of 1059 µg or lower by 23%.

Other Repair Techniques
Table 2 is a summary of cartilage wear data obtained from biopsies taken from patients who had undergone other methods of cartilage repair (see [6]). Patient 1, a male born in 1938, showed an example of spontaneous repair. Patient 7, a female born in 1950, had received abrasion arthroplasty repair.

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It can be seen that spontaneous repair produced almost twice as much cartilage wear as the normal control specimen while abrasion arthroplasty gave over three times the wear of the normal control cartilage.

CONCLUSIONS
In a collaborative study of the wear-resistance of repaired articular cartilage, 16 specimens of human cartilage from the knee joints of eight Swedish patients were examined in a biotribology device to measure cartilage wear and friction. It was found that the Autologous Chondrocyte Implantation (ACI) method of cartilage repair developed by the Gothenburg group gave less wear than that of "normal" cartilage from the same joint while two other methods—spontaneous repair and abrasion arthroplasty—produced higher wear. The significant transfer of cartilage to the highly polished stainless steel suggests that adhesion plays a role in the wear mechanism. Friction levels in all cases were in the boundary lubrication regime (0.13-0.20 avg. coefficients) and, in line with our previous experience with bovine cartilage, showed no correlation with wear.

To our knowledge, this research represents the first controlled "in vitro" study of an important unknown in cartilage repair, i.e., the wear-resistance of the repaired cartilage. It shows that the ACI technique developed at Goteborg produces a cartilage with very good wear-resistance. These collaborative studies of the wear-resistance of "normal" and repaired human articular cartilage are continuing.

The authors are fully aware that these conclusions are based on a limited number of experiments and caution against making sweeping generalizations. From a statistical point, more cartilage specimens from a given joint would be desirable; however, from the point of view of the patient, this is not possible. Future studies will tell us if the trends observed here will continue.

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REFERENCES