SURFACE ASPIRATION SYSTEM: A NEW TESTING METHODOLOGY TO NONDESTRUCTIVELY ASSESS THE MECHANICAL BEHAVIOR OF ARTICULAR SURFACES

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INTRODUCTION

Articular cartilage is a resilient load-bearing material in diarthrodial joints that provides excellent friction and lubrication to allow continuous joint movement. To understand this tissue's ability to function, we examine its mechanical behavior. There have been many tests devised to show and explain the behavior of cartilage. Mechanical tests, such as confined compression, unconfined compression, tensile tests, and shear tests have yielded valuable information but are destructive in nature in that cartilage specimens must be removed from the articular surface [3,4,5]. The indentation test [1] nondestructively evaluates cartilage behavior in compression. In this new methodology, the concept of micropipette aspiration to measure membrane tensile characteristics of single cells [2] was adapted to the tissue level. The purpose of this study was to design a system to obtain tensile behavior of the cartilage nondestructively. Applications are foreseen for arthroscopic clinical use as well as laboratory studies.

MATERIALS AND METHODS

To apply an aspiration pressure and measure the tissue's response, two main issues in the system design were addressed: 1) selection of a device to provide the deflection of the cartilage surface under a negative pressure; and 2) design of a device to apply the pressure and support of the laser.

To measure deflection, it was incumbent to select a device that would provide continuous measurement of deflection (for theoretical treatment of the data) and be capable of doing so without requiring visual observation of the deflection (for use in arthroscopy where visual accessibility could be limited). Thus, the system could not adapt the measurement technique used in micropipette aspiration. Instead, laser measurement was investigated and a triangulation laser chosen with accuracy of up to 1 micron (LK-081, Keyence Inc., Woodcliff Lake, NJ). The laser measures absolute distances from the transmitter to the surface of interest. It has a workable range of 80 ± 15mm and includes a laser control (Figure 1). The light source is a red light semiconductor at a wavelength at 670nm.

To apply the aspiration pressure and support the laser, two requirements in the design were instituted. It must allow the laser to function in its workable range and the opening of the casing must be small enough to produce pure suction on the tissue surface without blocking the path of the laser. An opening too large would not produce pure suction because of joint surface curvature. An acrylic casing was designed to allow a vacuum pressure applied and be used with the laser to obtain cartilage surface deflections (Figure 2). It is called the Acrylic Laser Holster (ALH), made of Plexiglass, and allows the laser to be supported on top. The ALH was then fabricated for experimental testing

A vacuum pump was used to produce the negative pressure during testing. Any pump capable of creating and maintaining an aspiration pressure can be used. The aspirator was connected to the ALH by reinforced nylon tubing so as not to collapse under the pressure being applied. The tubing was attached to the acrylic aspirator nozzle, designed to fit common medical tubing (3/8").

To demonstrate the performance of this new methodology, the behavior of an excised porcine joint was studied. Aspiration pressure (~101kPa) was applied to three different cartilage surfaces while the laser measured deflection. The data was retrieved from the laser control through an A/D converter, connected to a computer and LabVIEW software (National Instruments, Austin TX). Testing ran for three thirty-second intervals. The first interval was the reference interval when no pressure was applied, and a reference distance was measured. During the second interval, the aspiration pressure was applied. For the third interval, the pressure was removed. Twelve trials were performed and the acquired data analyzed.

RESULTS

Trials were performed on the medial and lateral femoral condyles and medial tibial plateau (Figure 3). The first thirty-second interval "zeroed" the reading. Once the pressure was applied, a creep phenomenon of the surface deflection was observed for all cases. After the pressure was released, recovery of the deflection occurred although some residual deformation remained. Figures 3a and 3b show expected behavior of this tissue under a negative pressure. Figure 3c shows some irregularity in the second and third interval.

DISCUSSION

This new nondestructive testing methodology was devised, designed, and implemented to provide tensile characteristics of articular surfaces. It can also have application to other soft tissues for surface behavior. During experimental testing on cartilage surfaces, the hydration of the tissue was maintained with physiologic saline. However, during the pressure application phase, no fluid could be present in the ALH to avoid suction into the vacuum pump. Fluid aspiration from the tissue may be the reason recovery is incomplete in Figure 3a. Another possible error source is how the ALH is positioned relative to the tissue surface. To have complete suction, the opening of the ALH must be parallel to the articular surface and be in complete contact. If the ALH is not in complete contact with the tissue at the beginning of the test but is set slightly above the surface, a false reference distance would be measured and affect the calculation of surface deflection. This is believed to be the reason for irregularities in Figure 3c. Refinement of testing protocol will eliminate this problem. Due to physical impossibilities and physical specifications of the laser, it could not be designed as small as initially planned. Further work is warranted for refinement of the device, testing of articular surfaces, and in developing a theoretical model to aid in the assessment of the experimental data and provide material properties.

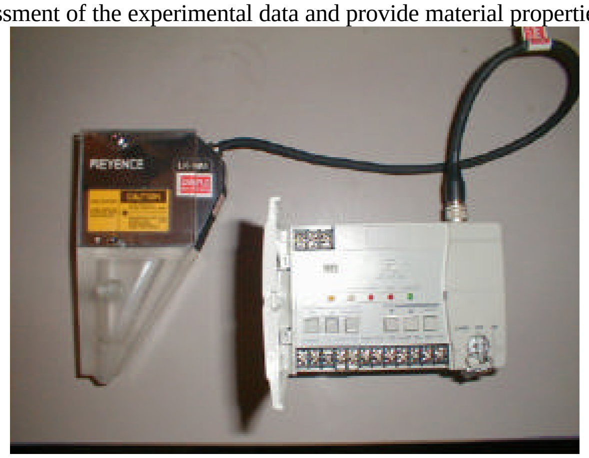

Figure 1: The LK-081 laser is held up by the acrylic casing on the left. The laser is also attached to the LK-2101 control on the right.

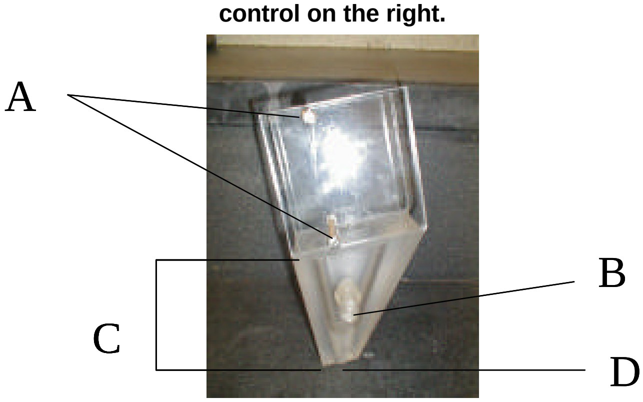

Figure 2: A) Screws that stabilize the laser to the acrylic casing. B) Nozzle where the aspirator tube is attached to produce a pressure. C) This internal area is hollow and sealed except for the narrow opening at D.

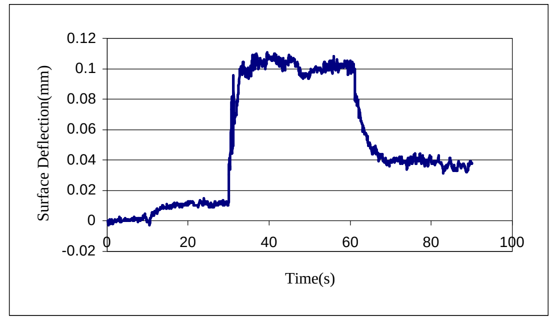

Figure 3a. Cartilage surface deflection of the porcine medial tibia.

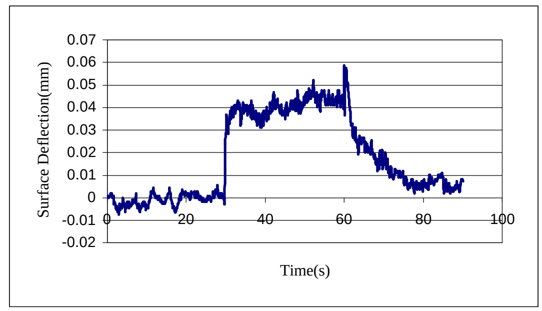

Figure 3b. Cartilage surface deflection of a porcine medial femur.

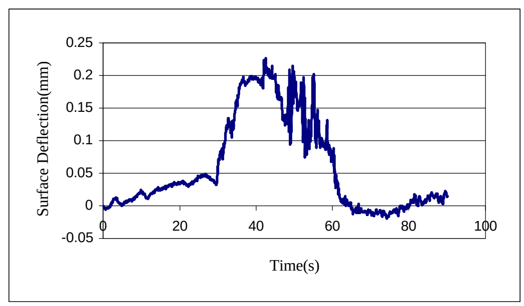

Figure 3c. Cartilage surface deflection of a porcine lateral femur.

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ACKNOWLEDGEMENTS

Jon Burgen from Keyence Inc.