CINEMATIC MEASUREMENT OF CARTILAGE PLUGS IN UNCONFINED COMPRESSION

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INTRODUCTION

Modeling natural diarthrodial contact requires material constitutive properties that accurately describe the dynamic deformation patterns of articular cartilage. To fill the knowledge gap between whole joint loading experiments and measurements of chondrocyte and cell substructure material properties, we adapted a SMITH+NEPHEW Dyonics arthroscopy system 4-mm 0° arthroscope (Figure 1A) to record real-time streaming video of cyclic cartilage loading in a purpose-designed triaxial compression vessel [1].

METHODS

Endoscope optics produce a 'fisheye' view (Figure 1B), which is deconvoluted by a transform that was generated by placing the arthroscope tip 4 mm from a geometrically homogenous pattern and unwarping the digital image to known fiducia [2].

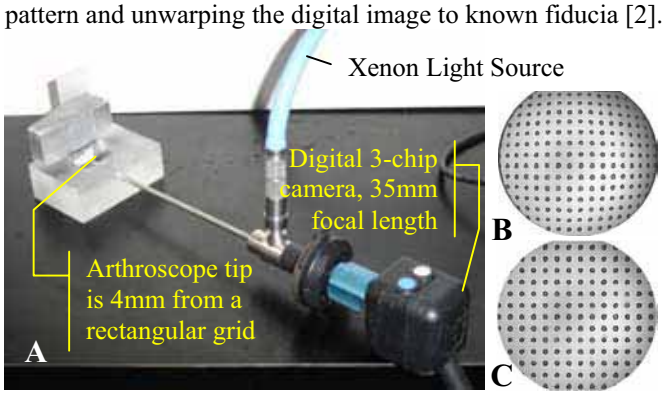

Figure 1 (A) Arthroscope configured for image calibration. The 'fisheye' view of an arthroscopic image (B) is deconvoluted (C) to the known grid geometry.

A 4-mm right-circular cylinder (plug) of human tibial plateau articular cartilage, 1.9 mm thick, was cyclically compressed with 0.1–2.0 MPa between porous platens in the nutrient-filled triaxial chamber (Figure 2). The 4 mm-wide platen (400 pixels, 10µm resolution) provided an in-image scale. Vertical movement of the upper platen was measured directly within each cine-frame (30/second) via pixel separation of fiducial grooves on the upper and lower platens. Motion of the upper platen was also recorded by a DVRT monitoring movement of the driving axial piston.

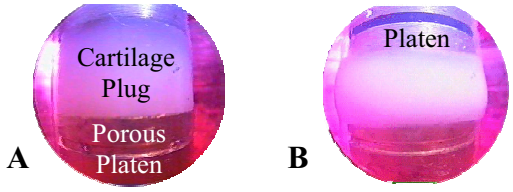

Figure 2 (A) The cartilage plug as seen before loading and (B) after 0.6 mm of axial compression.

Cartilage was stained with calcein-AM to fluorescently label live chondrocytes. An excitation filter (488 nm) was inserted between the xenon light source and the arthroscope and a yellow dichroic barrier (≥515 nm transmission) was inserted at the eyepiece to allow visualization of live cell distribution in the matrix (Figure 3A). Optical resolution is sufficient to distinguish local chondrocyte columns in the deep zone (Figure 3B).

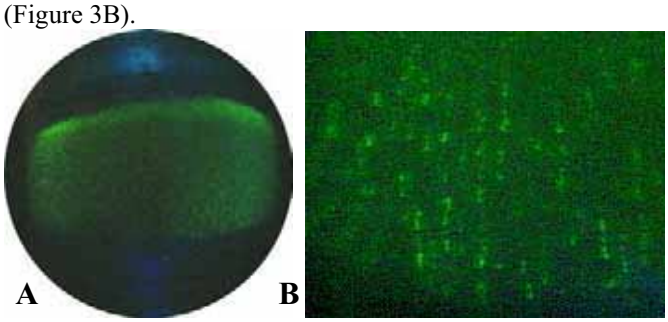

Figure 3 Chondrocyte morphometry in arthroscopic images; (A) Whole plug with highly fluoresced superficial zone. (B) Chondrocyte columns fluoresce in the deep zone.

RESULTS AND DISCUSSION

During unconfined axial compression between porous platens, an articular cartilage plug will bulge radially (Figure 2). The tissue will gradually lose height as water is forced from matrix voids under 1 Hz cyclic compression (Figure 4).

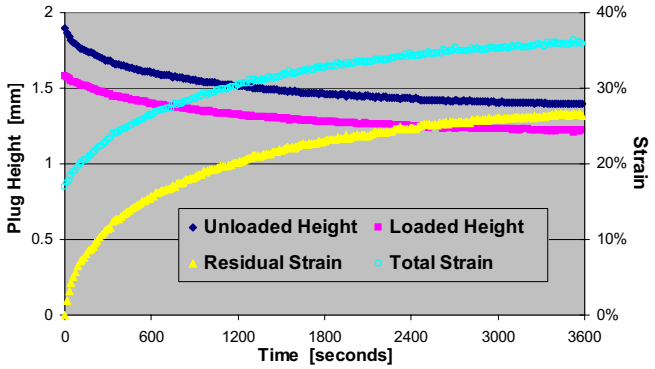

Figure 4 Plug heights and axial strains over 1 hour of loading

Articular cartilage consists of fluid and solid components. The changing shape of the cartilage plug's silhouette is indicative of the underlying biphasic material behavior. Finite element poroelastic model values of void ratio-dependent hydraulic permeability and depth-dependent modulus can be varied to match dynamic deformation patterns [3].

We present a method of real-time visualization and measurement of tissue deformation in living cartilage. Fluorescence labeling of chondrocytes provides internal fiducial markers that can be used to analyze intra-tissue strains and cell viability during dynamic loading.

REFERENCES

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