Biaxial Tensile Test System: Articular Cartilage Properties in Biaxial vs. Uniaxial Tension

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Abstract

Background. The articular cartilage of the femoral condyles is at the distal end of the femur and is a main load-bearing tissue of the knee. During skeletal growth, the condyles expand substantially, increasing in diameter in humans by ~54% from age 11 to skeletal maturity. During such growth, articular cartilage stretches biaxially, including in the anterior-posterior and medial-lateral directions. However, most previous studies of articular cartilage tensile properties have used a uniaxial configuration.
Hypothesis & Aims. We hypothesised that a biaxial stretch device would reveal that the tensile properties of articular cartilage are affected by stretch in both of the orthogonal axes. Thus, the aims of this study were (1) to develop a biaxial test system, and (2) to use the device to test if biaxial and uniaxial tensile properties of articular cartilage are different.
Methods. A biaxial test instrument was constructed to allow application of displacement and measurement of load along both vertical and horizontal axes. The system consisted of a scaffold system, pulleys, and two electronic scales. The scaffold provided a rigid vertical test frame with a horizontal cross-bar. Along the vertical axis, stretch was controlled by manual advancement of the cross bar along threaded rods, with load measurement via a scale underneath. Along the horizontal axis, stretch was controlled by manual movement of lines, redirected by pulleys, one of which pulled against a scale for load measurement. Cross-shaped samples were attached to the test instrument via four lines, two vertical and two horizontal, attached to clamps that secured the sample.

An articular cartilage sample was tested in uniaxial and biaxial tension. A porcine knee joint was obtained from a local butcher. An articular cartilage specimen, with the articular surface intact, was isolated by dissecting out a cruciform shape and undercutting the articular cartilage to release a sample with an $(8.1\text{mm})^2$ central region, four $(8.1\text{mm})^2$ arms with ~2mm for grasping, and a thickness of 1 mm. Samples were subjected to (1,2) uniaxial tests, in the (1) vertical and (2) horizontal directions, and (3) a biaxial test, with strains of 0% or 18%, 36%, or 54% in along one or both axes according to the test. Photographs and loads were recorded after each test increment.
Results. The desired strains (±1%) were achieved by adjusting the loading lines. The uniaxial loads (in Newtons) at 18, 36, and 54% extension were 7.74±1.24, 21.07±0.69, and 45.57±7.62 in the stretch direction and much lower 1.67±0.42 (-78%), 5.38±0.54 (-74%), and 10.07±2.46 (-78%) in the orthogonal direction (held at 0 extension). The biaxial loads in the stretch direction were substantially larger, 8.38±0.62 (+8%), 24.31±0.42 (+15%), and 61.25±6.24 (+34%) N, respectively.
Discussion. These results (1) establish a simple but functional biaxial tensile test system, and (2) confirm preliminarily that loads along the stretched axis are much greater with biaxial than uniaxial testing. Additional samples are currently being tested.

Keywords
Biomechanics, Cartilage, Biaxial, Uniaxial, Biomaterials

Biographies

Aadi Biswas is a 10th grader at the "Singapore American School". In June-December 2020, he completed courses in 'Biomechanics and Mechanobiology', 'Mammalian Cell and Tissue Culture', and 'Tissue Engineering and Regenerative Medicine' offered by Professor Robert Sah and the Department of Bioengineering of the University of California, San Diego. Through independent studies with Prof. Sah, Mr. Biswas learned about, and grew fascinated with, the world of biomedical technology, and how bioengineering, musculoskeletal medicine, and orthopaedic surgery can treat diseases such as Osteoarthritis and injuries. He became particularly interested in the biomechanics of tissue growth, and the tensile properties of both articular cartilage and bone. He is currently researching remotely with Prof. Sah on the tensile properties of articular cartilage of the femoral condyles, and their significance as related to medicine and biotechnology. His interests (professional and recreational) include Medicine, Biotechnology, Biomedical Engineering, Biomechanics, Computer Science, and Mechanical Engineering.

Van W. Wong, B.S., is a Development Engineer at Prof. Sah's Cartilage Tissue Engineering Laboratory in the Department of Bioengineering at the University of California, San Diego. He earned a B.S. in Bioengineering from the University of California, San Diego. He has published journal and conference papers. Mr. Wong has designed a variety of custom fixtures and equipment for tissue engineering, biomechanical testing, and imaging, as well as Bioengineering education. Mr. Wong also manages the Cartilage Tissue Engineering Laboratory.

Albert C. Chen, Ph.D., is a Project Scientist in Prof. Sah's Cartilage Tissue Engineering Laboratory in the Department of Bioengineering at the University of California, San Diego. He earned a B.S. in Bioengineering from the University of California, Berkeley, a M.S. in Engineering Science (Bioengineering) at Dartmouth College, and a Ph.D. in Bioengineering at the University of California, San Diego. He has published journal and conference papers. Dr. Chen has completed research projects on cartilage biomechanics, tissue engineering, and articular cartilage repair. Dr. Chen mentors students ranging from those in High School, to Undergraduate Students, Graduate Students, Post-PhD, and Post-MD researchers in Bioengineering. He has helped develop curricula for a variety of courses and also co-directs High School Outreach Programs.

Robert L. Sah, M.D., Sc.D., is Professor in the Department of Bioengineering and co-director of the Center for Musculoskeletal Research at the University of California, San Diego. He received a B.S. and M.S. in Electrical Engineering and an Sc.D. in Medical Engineering from M.I.T., and an M.D. from Harvard. His research interests are the biomechanics, mechanobiology, and tissue engineering of cartilage, synovial fluid, and synovial joints with the goal of improving the treatment, diagnosis, and prevention of diseases of skeletal growth and degeneration including osteoarthritis. He teaches courses including Introduction to Bioengineering, Cell and Tissue Engineering, and Musculoskeletal Bioengineering. He is a member of the Society of Professors of the Howard Hughes Medical Institute, a recipient of the Van C. Mow medal, a fellow of the American Institute for Medical and Biological Engineering, of the Biomedical Engineering Society, and of the Orthopaedic Research Society. He has served as a Board Member of the International Cartilage Repair Society, Orthopaedic Research Society, and Tissue Engineering and Regenerative Medicine International Society, and as well as an Advisor to Departments of Bio(Medical)Engineering including Georgia Institute of Technology and National University Singapore.