Mechanical Testing of Hydrogels with a Walking Gait Waveform

The Challenge:

Using a Customized Waveform to Mimic the Human Cartilage Mechanical Environment

Background

Approximately 40 million Americans suffer from localized damage to the cartilage and subchondral bone. This leads to pain, loss of joint function and osteoarthritis. There is a pervasive need for effective clinical treatments to repair cartilage injuries.

Regenerative medicine approaches are currently investigated through the replacement of the damaged cartilage with tissue-engineered cartilage constructs. Porous scaffolds not only provide a boundary for retention of cells, but also act as a substrate to which the anchorage-dependent chondrocytes can adhere.

Figure 1 - Bose® ElectroForce® 5500 Test Instrument

It is known that mechanical modulation has a significant impact on cell differentiation and proliferation. Thus, applying accurate and efficient mechanical stimuli is crucial in quality control of the tissue product. This may also in turn guide diagnosis and future therapy improvement. In this study, the Bose® ElectroForce® 5500 test instrument (Figure 1) was used to impose a customized waveform on a hydrogel, and the changes in sample properties were monitored over time.

Meeting the Challenge

Sinusoidal cyclic waveforms are typically used when studying relationships between cell growth and mechanical stimulation; however, there is limited information on using customized waveforms. It would be beneficial to use a waveform that mimics the mechanical environment of a human knee joint while walking during the in vitro tissue-engineered cartilage development.

The ElectroForce 5500 test instrument, in combination with WinTest® software, is ideal for mechanical studies in biomedical research. It provides precise force and displacement control throughout the experiment. Customized waveforms can be realized by externally importing them into the WinTest software at which point they can be reproduced by the patented Bose linear actuator that features a frictionless moving-magnet design.

Materials and Methods

Polyethylene glycol (PEG) hydrogel sheets (4" x 4") were purchased from Medline Industries. Hydrogel specimens, punched from the hydrogel sheet, were 12 mm in diameter and 6 mm in height (Figure 2).

Figure 2 - Hydrogel Specimen

The ElectroForce 5500 system has a maximum force capacity of 200 N and a maximum displacement of 13 mm. The system was equipped with a 200 N load cell and a pair of 25 mm diameter platens. A preloading force of 0.1 N was used to ensure that the entire scaffold surface was in contact with the compression platens prior to testing (Figure 3). External waveform is a feature of the WinTest software that offers users with the ability to run custom waveforms when more complex mechanical analysis is required. External waveform allows the importation of point by point files which define evenly spaced data points as a function of time.

Figure 3 - Specimen Loaded Between Compression Platens

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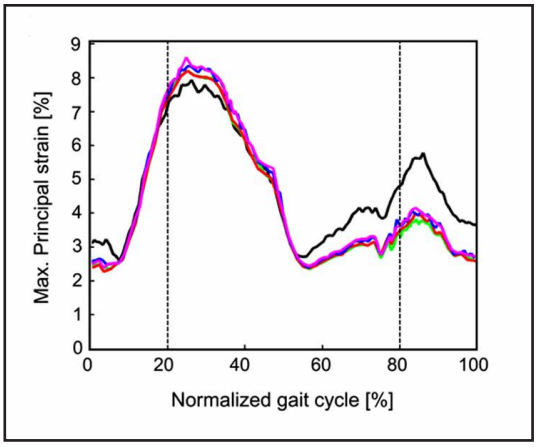

Figure 4 - Strain at the Contact of Joint Cartilage during the Gait Cycle (Halonen et al., 2013)

A waveform model (Figure 4, pink line) of strain vs. gait cycle based on simulation of human walking was used in this study (Halonen, et al., 2013).

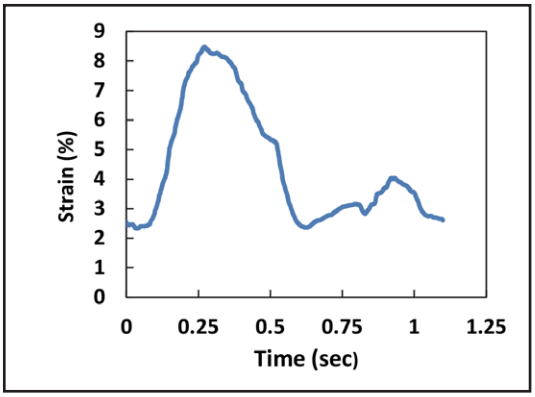

Figure 5 - Extracted Waveform

In order to create a WinTest® software readable point by point file, the following steps were used:

The waveform was extracted and replotted in Excel. According to normal human walking speed of 5 km/h, a one gait cycle time of 1.1 sec was obtained and used as a new X axis (Figure 5).

An ASCII file was constructed by the text editor. The Y axis strain points were scaled according to the specimen thickness and used for the ASCII file. The above waveform contained 1100 points, so the time interval between points was set to 0.001 sec to match with the gait cycle time.

Each pass through the waveform = 1100 x 0.001 = 1.1 sec.

The ASCII file was imported into WinTest software. A point by point file was exported and used for the test setup.

Results

Three specimens were tested with the external waveform, and displacement and load data were tracked during the test.

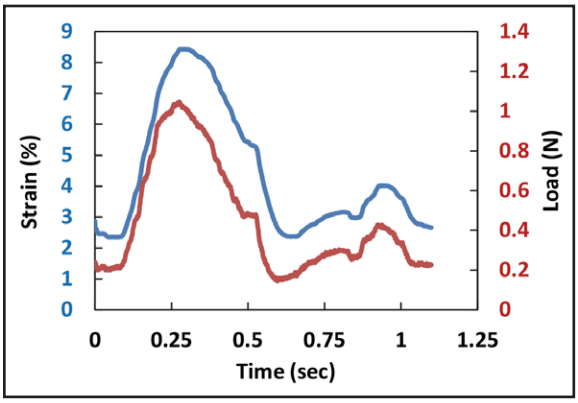

Figure 6 - Average Result of Three Specimens

The same external waveform was successfully applied to all the specimens (Figure 6). Similar testing results of three specimens were achieved and reliable repeatability of this testing method was demonstrated (Displacement difference between samples: <2.5%; Load difference between samples:<13.9%). Compared to the original extracted waveform in the ASCII file, the majority of the waveform details were retained accurately.

Summary

The Bose® ElectroForce® 5500 test instrument is a powerful tool, which is not only capable of generating sinusoidal, triangle, square, ramp and block waveforms, but also excels in precise waveform customization. Combined with easy to use WinTest software, the ElectroForce 5500 test instrument is able to deliver waveform profiles that fit the needs of a particular experiment and gives researchers the ability to implement their ideas.

Reference

(1) Halonen, K.S., M. E. Mononen, J. S. Jurvelin, J. Töyräs, and R.K. Korhonen. "Importance of depth-wise distibution of collagen and proteoglycans in articular cartilage - a 3D finite elment study of stresses and strains in the human knee joint." *Journal of Biomechanics (2013).*

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