Troubleshooting a Bending Device with Tissue and Non-Tissue Verification

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Introduction

Flexure testing is needed in order to properly determine the mechanical properties of various tissues in the body which deform by bending *in vivo*. Such a device works by tracking changes in curvature resulting from applied loads as described by the Euler-Bernoulli equation. However, before any reliable measurements for tissue can be ascertained using such a device, the exact methodology for its use must be determined. The validation of the accuracy of the results was done by testing a variety of reference and tissue samples. The effective modulus of elasticity (E) for each sample aligned with published data, indicating a reliable device.

The Bending Device

The Bending Device (BD) [Fig.1] is comprised of three main parts, aside from the computer program. The program is a custom program in LabView that tracks fiducial markers on the sample to compute moment and curvature. The other parts are:

1. **Bending Beam**-A beam of known stiffness is used to determine the force being placed on the sample.

2. **Transverse Bar**-This connects the sample to the Bending Beam

3. **Tank**-holds the sample in place while still allowing it to move. Also holds PBS or other fluid used to keep sample pliable and to mimic *in vivo* conditions.

4. **Track**-Allows the tank to actuate up and down to perform tests, as well as left and right to adjust the camera view.

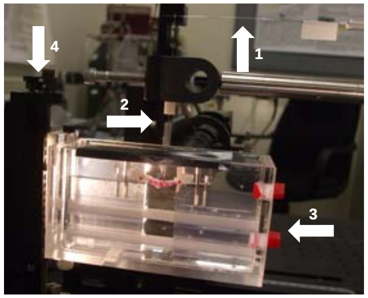

Figure 1: The Bending Device

Methods

Resolution: The resolution for the camera was determined by measuring the number of pixels/mm in triplicate and averaging them.

Calibration: Bending Beams with varying stiffnesses are calibrated by adding known weights to the Transverse Bar and measuring the displacement in triplicate. The average of the slopes of best fit lines is taken as the calibration constant.

Loading Curves: The BD allows the user to test both with and against the natural curvature of the sample. LabView measures the curvature and moment by tracking markers on the sample. Excel was used to analyze the moment vs. curvature graphs to find E for each marker. Equations used included the second moment of area ($I=t^3*w/12$) and the Bernoulli-Euler equation ($M=\kappa EI$).

Unloading/Hysteresis Curve: The goal of this portion of the test is to test the hysteresis E of the samples in the same manner as above.

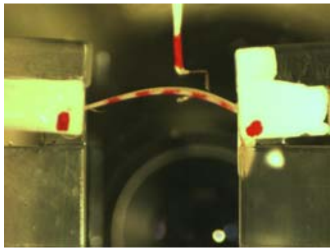

Figure 2: A Bend Down test using rubber

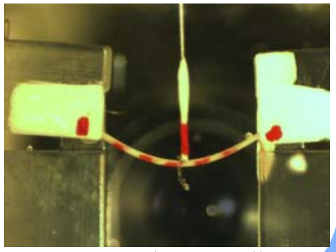

Figure 3: A Bend Up test using rubber

Results

Resolutions

Sample in PBS	.033708 mm/pixel
Sample Alone	.034091 mm/pixel
Sample nearer Camera	0.03333 mm/pixel

Figure 4: Resolution values

Calibrations

4.0 Beam	0.037 ± 0.003 g/mm
8.0 Beam	0.067 ± 0.002 g/mm
10.0 Beam	0.076 ± 0.005 g/mm
Stiff Beam	0.804 ± 0.017 g/mm

Figure 5: Calibration constants for beams used

Loading Curves

-Tests gives more accurate results if the samples have initial curvature

-The more intensely red the tissue markers, the more accurate the test

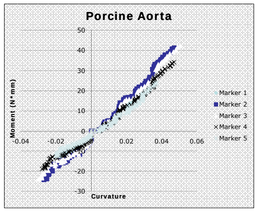

Figure 6: Typical combined Bend Up and Bend Down graph for porcine aorta

Sample	Accepted E	Experimental E
Porcine Aorta	357 kPa ±118 kPa	280 kPa ±97kPa
Tissue Scaffold	206 kPa ± 16 kPa	218 kPa ± 18 kPa
Rubber Sample	2300 kPa ± 100 kPa	2220 kPa ± 160 kPa

Figure 7: Accepted and Experimental values of E for tested samples

Unloading/Hysteresis Curves

-Attempted to gather information with Bend Up tests, but the weight of the Bending Bar prevents the sample from returning to its original shape.

-Bending Down tests allow the sample to regain original shape

-The average value of E for loading was 2219kPa; for unloading, it was 2051kPa

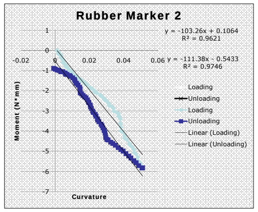

Figure 8: Example of loading and unloading curves for rubber

Future Implications

This device will be used in future studies in the lab to test micromechanical properties of both natural human tissue as well as tissue engineered specimens. The tests will further the pursuit of a perfectly engineered replacement for various tissues, specifically heart valve leaflets. One of the more valuable facets of this device is its ability to track the hysteresis of a tissue, something that has been done only rarely before but will help establish elasticity of various tissues. Some of the first samples that will be tested on this BD will be tissue engineered heart valve leaflets that were implanted into and then explanted from sheep at different time stamps.

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