3-Point Bending Device to Measure Transmural Strains for Multilayer Soft Tissue Composite

Team 6
Jennifer Olson
Sarah Rivest
Brian Schmidtberg
Sponsor: Dr. Wei Sun

Client Contact:
Dr. Wei Sun
University of Connecticut Biomedical Engineering Department
Arthur B. Bronwell Building Rm. 207
(860) 486-0369
weisun@engr.uconn.edu
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>2</td>
</tr>
<tr>
<td>1.0 Introduction</td>
<td>3</td>
</tr>
<tr>
<td>1.1 Background</td>
<td>3</td>
</tr>
<tr>
<td>1.2 Purpose of the Project</td>
<td>3</td>
</tr>
<tr>
<td>1.3 Previous Work Done by Others</td>
<td>4</td>
</tr>
<tr>
<td>1.3.1 Products</td>
<td>5</td>
</tr>
<tr>
<td>1.3.2 Patent Search</td>
<td>5</td>
</tr>
<tr>
<td>1.4 Map for the Rest of the Project</td>
<td>6</td>
</tr>
<tr>
<td>2.0 Project Design</td>
<td>6</td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>6</td>
</tr>
<tr>
<td>2.2 Alternative Design</td>
<td>8</td>
</tr>
<tr>
<td>2.2.1 Alternative Design 1</td>
<td>8</td>
</tr>
<tr>
<td>2.2.2 Alternative Design 2</td>
<td>11</td>
</tr>
<tr>
<td>2.2.3 Alternative Design 3</td>
<td>12</td>
</tr>
<tr>
<td>2.3 Optimal Design</td>
<td>14</td>
</tr>
<tr>
<td>2.3.1 Objective</td>
<td>14</td>
</tr>
<tr>
<td>2.3.2 Subunits</td>
<td>16</td>
</tr>
<tr>
<td>2.3.2.1 Force System</td>
<td>16</td>
</tr>
<tr>
<td>2.3.2.2 Motor System</td>
<td>16</td>
</tr>
<tr>
<td>2.3.2.3 Sliding Mechanism</td>
<td>18</td>
</tr>
<tr>
<td>2.3.2.4 Programming</td>
<td>20</td>
</tr>
<tr>
<td>2.3.2.5 Image Acquisition</td>
<td>24</td>
</tr>
<tr>
<td>2.3.2.6 Mounting Baths</td>
<td>26</td>
</tr>
<tr>
<td>2.3.2.7 Temperature Regulation</td>
<td>29</td>
</tr>
<tr>
<td>2.4 Prototype</td>
<td>30</td>
</tr>
<tr>
<td>3.0 Realistic Constraints</td>
<td>35</td>
</tr>
<tr>
<td>4.0 Safety Issues</td>
<td>37</td>
</tr>
<tr>
<td>5.0 Impact of Engineering Solutions</td>
<td>38</td>
</tr>
<tr>
<td>6.0 Life Long Learning</td>
<td>39</td>
</tr>
<tr>
<td>7.0 Budget</td>
<td>40</td>
</tr>
<tr>
<td>8.0 Team Member’s Contributions</td>
<td>41</td>
</tr>
<tr>
<td>8.1 Jennifer’s Contributions</td>
<td>41</td>
</tr>
<tr>
<td>8.2 Sarah’s Contributions</td>
<td>41</td>
</tr>
<tr>
<td>8.3 Brian’s Contributions</td>
<td>41</td>
</tr>
<tr>
<td>9.0 Conclusion</td>
<td>42</td>
</tr>
<tr>
<td>10.0 References</td>
<td>43</td>
</tr>
<tr>
<td>11.0 Acknowledgements</td>
<td>43</td>
</tr>
<tr>
<td>12.0 Appendix</td>
<td>44</td>
</tr>
</tbody>
</table>
Abstract

The purpose of the proposed project is to design and construct a three-point bending device capable of performing flexure testing on soft tissues. The three-point bend test performed by the device will be able to monitor the behavior tissue composites undergo under deformation. There is currently no product in the market or patented devices that are similar to the proposed project. Custom-made three-point bending devices are in a few university laboratories for research purposes. A senior design group at the University of Connecticut also attempted the proposed project in 2009. This project did not meet all the needs of the client, so he has requested the project to be reattempted. The current project will utilize the positive aspects of the former project and contain some of the same components.

The device will be run and controlled by a LabVIEW program that will be written specifically for it. It will allow the user to apply a force to a tissue specimen submerged in saline solution at body temperature causing the specimen to bend. The deformation of the tissue will be tracked by a high resolution CCD camera. The data collected will be used by the LabVIEW program to calculate the flexure rigidity, bending stiffness, transmural strain, and transverse shear stiffness of the tissue. The completion of this project will result in a device that is able to assess the stress-strain relationship at low strains via an instantaneous effective modulus, identify the location of the neutral axis in multi-layered specimens; and provide a suitable environment for testing such that mimics the environment of the body and the data obtained are relevant and repeatable.

The maximum budget established for this project is $1,000 with a targeted cost of less than $800. The budget was allotted based on purchasing new products, however, the majority of the components needed were reused from the former senior design group including the CCD camera, computer, motion controller, stepper drive, stepper motor, linear actuator, and flow regulator. The only parts purchased were to construct the inner and outer baths and the force application system/camera mount. This resulted in a total cost of $115.64.

1.0 Introduction

1.1 Background

Our client Dr. Wei Sun and his research team deal heavily with the biomechanics of various soft tissues, especially heart valves. Biaxial testing is currently used in Dr. Sun’s lab to determine the stress and strain of responses of the soft tissues. This type of testing is very
limited and assumes the test specimen is a homogenous material. Most tissues are heterogeneous and consist of multiple different layers. In these types of tissues, bending is a significant form of deformation. At this time, Dr. Sun’s biomechanics lab has no effective method of evaluating this type of deformation.

An understanding of the mechanical properties of soft tissues can lead to better comprehension of tissue behavior. Experimental testing is necessary to provide data for the quantification and characterization of soft tissues. Current test methods are primarily accomplished through tensile mechanical testing, such as uniaxial or biaxial testing. Uniaxial testing involves loading of a tissue specimen in one direction, whereas biaxial testing is loading of the specimen in two axes. Tensile mechanical testing, however, is limited in that it cannot provide accurate quantification of the mechanical behavior of soft tissues in the low strain region and with different layers of fibers. Flexure testing is a more effective method of evaluating the force-deformation relationship of different layers of soft tissues. It is capable of measuring the mechanical behavior of soft tissues experiencing low ranges of stress and strain. Flexure testing is especially critical to Dr. Sun’s research of heart valves because it has been hypothesized that repetitive flexural stresses contribute to the fatigue-induced failure of bioprosthetic heart valves.

**1.2 Purpose of the project**

The purpose of this project is to design a device to aid the client and his research team in the University of Connecticut Biomechanics Lab with their current studies on the mechanical properties of various soft tissues, primarily heart valves. Their lab contains a biaxial testing machine, which is frequently used to determine the stress and strain response of tissues. Biaxial testing, however, is limited because it treats the test specimen as a homogeneous material. Soft tissues, such as blood vessels and heart valves, are heterogeneous and consist of multiple layers of fibers arranged in different networks. When biaxial testing is performed on the leaflet, the collected data is unable to indicate how the different layers of the leaflet response to the applied load because the leaflet is treated as homogeneous. The client desires a device that is capable of measuring transmural strains of native and engineered tissues.

The client has requested for the construction of a three-point bending device capable of performing flexure testing on soft tissues. Flexure testing is capable of determining the amount of deformation of the different layers of soft tissues, which is crucial in analyzing the effect of applied loads on the different layers of the tissue. In addition, flexural deformation provides a more accurate method of evaluating the mechanical properties of the tissue, especially in the low strain range, since soft tissues have very low bending stiffness, which is often very difficult when using tensile mechanical testing.
Therefore, the goal of the project is to design and construct a three-point bending device capable of flexural testing of soft tissues. The device will allow for the flexural testing of tissue composites in phosphate-buffered saline solution at body temperature. The tissue will be sprayed with microdot markers. These markers will be followed by a high resolution CCD camera. The camera will follow the deformation of the tissue through the use of the markers. The data collected will be read into a computer program, specifically designed for this device, to calculate the flexure rigidity, bending stiffness, transmural strain, and transverse shear stiffness. The successful completion of this project will allow Dr. Sun to more accurately predict the mechanical properties of tissues where bending is a significant form of deformation.

1.3 Previous work done by others

Previous work has been performed that deals with the flexural testing of tissues. Dr. Fung, a founding figure in Biomedical Engineering, has done significant research in 3-point bend testing, including the location of the neutral axis in bending and Young’s modulus of different layers of the arterial wall. In Mark A. Nicosia’s article “A Theoretical Framework to Analyze Bend Testing of Soft Tissue” the author provides a theoretical basis of investigating the bending behavior of soft tissues. Both of these scientists’ research will aid in the design of this project, specifically in the calculations of the experimental results.

There are few three-point bending devices that are similar to the current project that were built previously by others. Like the current project, these devices are located in university laboratories and are primarily constructed by researchers of the labs for their research needs. In the Bioengineering Lab at the University of California in San Diego, there is a soft tissue-bending device consisting of a muscle bath, a system to apply and control force, a force-measuring system, a deformation-measuring system, and a photographic system. A force is applied on the tissue by a thin stainless steel wire. The wire is clamped at the top and free at the bottom, and it is deflected when a dead load is applied at the free end. The deflection of the wire is used to measure the force act at the tip on the tissue. At the Tissue Mechanics Lab at the University of Miami, there is also a three-point bending device that utilizes a thin bar of a known, homogenous material to apply force to a soft tissue in cantilever bending. A specimen is held in place between two stationary posts an adjustable distance apart, and the force is applied to the center of the specimen. All tests are recorded on a high-resolution CCD camera. These two devices are similar to the current project and many of their designs and constructions will be used towards the implementation of the project.

A senior design group at the University of Connecticut also previously designed this project in 2009. The device design consisted of a mounting bath system, force application system, temperature controller system, image acquisition system, calibration system, and program and interface system. The mounting bath system provided an area where flexure
testing of the tissue can occur. It is used to hold the solution, the tissue specimen, and the two posts. The force application system used a bending bar to apply a force to the tissue to make it bend. The system consisted of a bending bar, a reference bar, and a motor unit. The motor unit was attached to the bending bar, such that when the motor rotates, the bending bar moved linearly in one axis. The temperature controller unit is used to maintain the temperature of the solution. The image acquisition system was used to track markers on the tissue while flexure testing is performed. It is consisted of a CCD video camera and a camera mount. The CCD video camera captures images of the tissue while it is being tested and transmits the images to the computer. The calibration system was used to calibrate the bending bar. The calibration system consists of the CCD video camera, known weights, and the bending bar. The known weights are attached to the bending bar and the camera tracks the displacement of the bending bar for each known weight. The program interface system was used to connect all the previously mentioned systems together. The interface provided a display for the user to control the device. The program interface system also performed all the necessary calculations using the data obtained from all the systems. This device is currently not useable. This project also does not meet all of the project specifications because the CCD camera does not move with the movement of the tissue to accurately capture the behavior of the tissue composites. Aspects of the design of this project will be implemented into the new design and some of the components will be incorporated into the design as well, but significant improvements must be made.

1.3.1 Products

There are currently several three-point flexure test device products on the market, but they do not meet all the project specifications. ADMET Universal Testing Systems currently produces a universal testing machine that can be equipped with a 3-point bend fixture to determine the flexural modulus, flexural strength, and yield point. Instron® and Tinius Olsen also produce a 3-point bend fixture for their tensile testing devices. The products currently on the market are targeted more towards determining the flexural strength of plastics, metals, alloys, and ceramics. Although these devices are capable of performing flexure testing, there is no product on the market that uses a high resolution CCD camera and tissue markers to track the displacement of the tissues as the current project requires.

1.3.2 Patent search results

A patent search found numerous bending devices, but few patents found were testing devices. Patent number 7,283,891 invented by Werner Butscher, Friedrich Riemeier, Ru Rubbert, Thomas Weise, and Rohit Sachdeva involves a robotic bending apparatus for bending orthodontic archwires and other elongate, bendable medical devices. The device consists of a robot comprising of a six axis bending robot with gripping tools and a movable arm that can
move about three translational axes and three rotational axes. This device is suitable for use in a precision appliance-manufacturing center. Patent number 7,275,406 invented by Teruaki Yogo is a bending device, which includes a fixed mount having a chuck mechanism gripping workpiece and an articulated robot which moves a bending mechanism. The workpiece is clamped between a bending die and a clamping die. The bending and chuck mechanisms are moved by the articulated robot to bend the workpiece at a plurality of positions. Patent number US20050241405 invented by Sylvain Calloch, David Dureisseix, Gilles Arnold, and Inaki Zudaire Rovira provides a method, apparatus, and a machine for testing in pure bending. In the device, two mutually identical test pieces are subjected to optionally alternating opposing bending movements while conserving mutual symmetry about a point, under drive from two controlled motor assemblies that are free to move relative to each other. Although there are a variety of bending devices, none of the patented devices meet the specifications required by the client for the current project. There is currently no patented three-point bending device for flexure testing of soft-tissues.

1.4 Map for the rest of the report

The next part of the report will go through many aspects of the project design. A summarized outline of the client’s demands and specifications will be described followed by three alternative designs. The optimal design of the three alternatives will be described more in depth and reasons will be given for selection of the design. Subunits of the optimal design will be designated and described as well.

Because many factors are involved in the design of the project, the next few sections will talk about realistic constraints, safety issues, impact of engineering and life-long learning. Planning individual work and following budget are crucial parts of completing the project. A timeline with group and individual tasks is the next part of the report followed by an updated group budget as of the end of the semester.

Finally, individual team members contributions will be listed as well as acknowledgements and an appendix to put in any other relevant information that didn’t fit in the rest of the report.

2.0 Project Design

2.1 Introduction

The purpose of this project is to design and construct a three-point flexure testing device that meets the requirements of Dr. Wei Sun of the Biomedical Engineering and
Mechanical Engineering Departments at the University of Connecticut. The device should be able to perform flexure testing on a soft tissue specimen submerged in a phosphate-buffered saline solution at a temperature of 37°C. The data collected from the device should be able to calculate the flexure rigidity, bending stiffness, transmural strain, and transverse shear stiffness of the tissue specimen.

The device is divided into multiple subsystems that will work together to obtain the necessary data and calculate the desired results. The subsystems include the mounting bath system, temperature controller system, force system, image acquisition system, and program and interface system. The purpose of the mounting bath system is to provide an area where flexure testing of the tissue can occur. It is used to hold the solution, the tissue specimen, and the two posts. The purpose of the force system is to use a bending bar to apply a force to the tissue to cause deformation. The system consists of a bending bar, a reference bar, and a motor unit. The motor unit is attached to the bending bar and CCD camera, such that when the motor rotates, the bending bar and camera will move linearly in one axis. The temperature controller unit is used to maintain the 37° ± 1°C temperature of the solution. It is consisted of flow loops, a power unit, a centrifugal pump, a heater, contact plates, and a temperature recorder. The image acquisition system is used to track markers on the tissue while flexure testing is performed. It is comprised of a CCD video camera and the sliding mechanism it is placed on. The CCD video camera captures images of the tissue while it is being tested and transmits the images to the computer. Lastly, the program and interface system is used to connect all the subsystems together. The interface provides a display where the user can control and interact with the device. The program controls the function of all the subsystems and also performs all the necessary calculations using the data obtained from all the subsystems. A table of the subsystems can be seen below in Table 1.

<table>
<thead>
<tr>
<th>Systems</th>
<th>Function</th>
<th>Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mounting Bath</strong></td>
<td>Provide consistent area for testing</td>
<td>Inner Bath</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Outer Bath</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tissue Fixation Posts</td>
</tr>
<tr>
<td><strong>Force</strong></td>
<td>Apply force to the tissue</td>
<td>Bending Bar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reference Bar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motor Unit</td>
</tr>
<tr>
<td><strong>Temperature Controller</strong></td>
<td>Maintain the 37°C ± 1°C temperature of the solution</td>
<td>Temperature Regulator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temperature Recorder</td>
</tr>
<tr>
<td><strong>Image Acquisition</strong></td>
<td>Track sprayed on microdots on the tissue specimen throughout testing</td>
<td>CCD Camera</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sliding Mechanism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Microdots</td>
</tr>
<tr>
<td><strong>Program and Interface</strong></td>
<td>Connect all subsystems Connect all necessary</td>
<td>Computer</td>
</tr>
<tr>
<td></td>
<td>Provide an interface for the user to control the device</td>
<td>LabVIEW program</td>
</tr>
</tbody>
</table>
Three designs were proposed and considered for the optimal design of this project. In the first design, acupuncture needles are used as the bending bar and reference bar for their sensitivity. The bending bar and reference bar will move simultaneously with the camera to accurately capture the deflection of the tissue specimen.

In the second design, metal bending bars are used with strain gauges attached. The strain gauges allow for the mechanical motion due to the deflection of the bending bar to be converted into a resistance value. This resistance value can then be equated to a strain value. The use of a strain gauge eliminates the use of a reference bar as well as significantly decreases the amount of calculation programming that needs to be done.

In the third design, four bending bars are used in combination with strain gauges to calculate the deflection as well as the force applied. In this design the camera is also kept immobile and the movement is confined to zoom only. Keeping the camera stationary will eliminate the programming of the linear actuator to move both the bending bars and camera simultaneously. It will also eliminate any focusing errors.

After careful consideration of the three designs, the first design was chosen as the optimal design because the metal bending bars used in the other designs would not be sensitive enough to capture the transmural strain values. Although, the second and third designs would be more simple to program, they would not provide the accuracy desired of this device. The successful completion of this project will allow Dr. Sun to more accurately predict the mechanical properties of tissues where bending is a significant form of deformation.

2.2 Alternative Designs

2.2.1 Alternative Design 1:

The objective of the project is to design and create a 3-point bending device to measure transmural strains for multilayer composite tissues. Design of this device requires a few major components: computer controlled stepper motors, a calibrated bending bar, a high resolution camera, a bodily temperature and pH environment and a PC equipped with LabVIEW.

Performing the 3-point bend test requires that a force provided by a bending bar be applied to a tissue situated on two stationary posts. Because this device will be testing tissues, the specimen must be kept in an environment similar to human in vivo conditions (37°C and pH 7.4). To satisfy these conditions, a bath within a bath setup will be used with the two stationary posts situated in the inner bath. Within the inner bath will be a phosphate buffered saline
solution to keep the tissue at a pH of 7.4. The outer bath will consist of constantly regulated water. The water will be pumped through a temperature regulator to keep it at 37°C. Heat exchange will occur from the outer bath to the inner bath to keep temperature consistent. The outer and inner bath design is shown in figure 1.

![Figure 1. Inner and Outer Bath](image)

A key part of the design is the sliding mechanism that will control the movement of the bending bar, reference bar, and CCD camera. The sliding mechanism will be placed on a track above the bath system. By using a rail system, a stepper motor and a linear actuator the mechanism will move along the track. By having the testing bars and CCD camera attached to the same sliding mechanism, only one motor and one linear actuator are used to systematically move the system. By placing the camera in between the two bars, the deflection of the bending bar during testing will be able to be captured. The CCD camera has a very high resolution so it will also be able to zoom in on the tissue to capture transmural strains. The top view of the sliding mechanism is shown in figure 2.
Before running any tests with the device it is extremely important to have the bending bar calibrated with the reference bar. Calibration will involve various weights and the CCD camera. Because a very thin acupuncture needle will be used as the bending bar the weights should not be overly heavy. The procedure will consist of adding a weight and determining the deflection of the bending bar from the reference bar by comparing images recorded from the camera. By performing this process with multiple weights, a linear graph can be created of deflection vs. load applied. The calibration of the bending bar will allow for the deflection of the bending bar from the reference bar during a flexure test to be compared with the standard curve to determine the load that is applied to the tissue at the specific time.

A PC equipped with LabVIEW will control all of the actions of the flexure test. A user will be able to control the movement of the sliding mechanism, which will allow control over the bend in the tissue. Temperature and pH readings will be sent to LabVIEW so that the user knows the environment is appropriate for testing. Flexure properties and transmural strains will also be determined using LabVIEW. Specifically, the instantaneous effective modulus and neutral axis determination will be calculated and outputted to the user.
2.2.2 Alternative Design 2:

The second alternative design will contain many of the same components as Alternative Design 1 such as computer controlled stepper motors, a calibrated bending bar, a high resolution camera, a bodily temperature and pH environment and a PC equipped with LabVIEW to fulfill the project specifications. The major alteration between Alternative Design 1 and Alternative Design 2 is the use of a strain gauge. The strain gauge will convert the mechanical motion due to the deflection of the bending bar into a resistance value. The change in resistance will be proportional to the strain experienced by the sensor. The strain gauge will be wired to a PC, where the data will be collected in LabVIEW. Calibration of the strain gauge through use of different weights will allow for the acquisition of a resistance vs. load relationship. These values will be used to create a standard curve, which will be programmed into LabVIEW so the results of the 3-point bend tests can be determined. The use of the strain gauge will eliminate the need for a reference bar, which will ultimately reduce the amount of LabVIEW programming necessary to obtain the results of the 3-point bend test.

In this design a different type of bending bar will be used to test the deflection of the tissue specimen. A metal bending bar will be used that will allow the attachment of a strain gauge to either side of bar. This design can be seen in Figure 4. The same sliding mechanism used in Alternative Design 1 will also be used to control the movement of the bending bar and CCD camera. The mechanism will slide across a rail system above the bath holding the tissue. Movement of the mechanism will be controlled by the stepper motor. By having the bending bar and CCD camera attached to the same sliding mechanism, only one stepper motor is used to systematically move the system. Also, the elimination of the reference bar will allow for the
CCD camera to have a closer view of the deflection of the tissue because it will not have to keep both the bending bar and reference bar in view.

The project specifications require that the tissue specimen must be in an environment equivalent to that of inside the human body. To satisfy these conditions the same bath within a bath setup as described in Alternative Design 1 will be used with the two stationary posts situated in the inner bath. Within the inner bath will be a phosphate buffered saline solution to keep the tissue at a pH of 7.4. The outer bath will consist of constantly regulated water. The water will be pumped through a temperature regulator to keep it at 37°C. The outer bath will keep the inner bath regulated at 37°C as well.

As in Alternative Design 1, a PC equipped with LabVIEW will control all of the actions of the flexure test. A user will be able to control the movement of the sliding mechanism, which will allow control over the bend in the tissue. Temperature and pH readings will be sent to LabVIEW so that the user knows the environment is appropriate for testing. Flexure properties and transmural strains will also be determined using LabVIEW. Specifically, the instantaneous effective modulus and neutral axis determination will be calculated and outputted to the user.

![Side View of Alternative Design 2](image)

**Figure 4. Side View of Alternative Design 2**

### 2.2.3 Alternative Design 3

This alternative design is similar to the previously described designs because of the use of the computer controlled stepper motors, calibrated bending bars, a high resolution camera, using a water bath, LabVIEW as well as MATLAB calculations. Differences in this design vary
mostly in utilizing multiple bending bars as well as making the camera immobile and allowing the movement to be confined to zooming only.

This design will use four bending bars in combination with strain gauges to calculate the deflection as well as the force applied. One difficult aspect is attaching the strain gauges. The strain gauges available to use are too big to place on the thin acupuncture-like needles, however the force applied from these needles or bars are in question. Using these very thin, flexible needles will produce the smallest possible forces which will enable us to calculate the strains produced in the very small linear region in question. To incorporate strain gauges into this design, they would have to be fixed to something larger than the bending bar that will also come in contact with the bending bar. Using a sleeve to hold the tissue specimen in place will also enable the strain gauges to be held at a constant position. By incorporating the strain gauges into the sleeve, specifically at the posts holding the tissue, two of the bending bars can be positioned to press against the strain gauges as the linear actuator applies the bending bars at various forces. By having two bending bars and two strain gauges, this will give us more accurate results. It will enable the program to average the two found forces from the strain gauge to get accurate and reproducible results.

The third bending bar that is mobile will physically deform the tissue being tested. This third bar will move along with the linear actuator and deform the tissue while the other two mobile bars will be calculating the force applied. The amount of deformation of the tissue will be calculated visually in reference to the final bar being used as the reference bar. This fourth bar will not move at all but will be positioned at the beginning of the experiment in a horizontal line with the other three bars. The distance between the bar bending the tissue and the reference bar along with the force calculations from bars one and two be enough for all calculations.

Another main component of this design is to keep the camera at a constant position. Keeping the camera at a constant angle and position will eliminate the programming of the linear actuator to move both the bending bars and camera simultaneously. After determining the optimal angle of the camera to be able to capture the deformation of the extremely small markers, the camera will be placed as close to the tissue sample as possible allowing room for movement of the bars. The user will hopefully have the option of being able to zoom in and out of the reference frame from controls created through LabVIEW. By having the camera set to a specific frame, this will eliminate any focusing issues to create the clearest picture possible resulting in the most accurate results.

The bath will be similar to previous designs and circulate warm water around the inner bath. All LabVIEW and MATLAB programming will be used to program and calculate all components of this design. The figures shown below depict the various positions of this design.
2.3 Optimal Design

2.3.1. Objective
The client has requested the design of a 3-point bending device that will be able to provide accurate and repeatable results looking at a very small strain region. This design will take the ideas of a previous senior design group and advance the positive aspects of the design. While the previous group was able to achieve accurate and repeatable results, they were not able to meet all the client’s specifications and move the CCD camera simultaneously with the tissue deformation. There are many aspects that the client has asked for to improve his research testing abilities that have guided the design of this 3-point bending device.

**AIM I: Testing environment that mimics in vivo conditions**

To make the most precise and accurate test, the specimen being tested should be tested in an environment similar to *in vivo*. This will allow the specimen to sit in solution to maintain its natural properties while the tests are performed. This design will allow for the measurement of the specimen in a relatively short amount of time to limit the amount of tissue degradation.

**AIM II: Force application**

The device needs to be able to cause small tissue deformations that will come from small loading values. Because of the high cost of mechanical testing machines, the device needs to be able to produce results that are just as accurate as the expensive machines without costing the client the expensive price. A device will be machined and programmed to apply the desired force that will cause the tissue to deform.

**AIM III: Calibrate strain gauge and linear actuator**

In order to move the CCD camera as the tissue deforms, a strain gauge and linear actuator will be used. The strain gauge will take the value of the strain and then output it to the linear actuator to move the camera based on the strain value. This is crucial in receiving an accurate picture of the deformation of the tissue. Calibrating both of these to work as one will be essential for a smooth and accurate motion of the device.

**AIM IV: Neutral Axis Determination**

Determining the neutral axis is important in measuring the strain in terms of tissue thickness. This device needs to provide a structure that will enable the deformations to be viewed at such a resolution to pick up markers that are only a few microns in size.

**AIM V: Determination of flexural properties**

Flexural properties will be determined through LabVIEW as well as Matlab calculations. When characterizing the testing material, the client will need precise values from testing a
small region. Flexure rigidity, bending stiffness, transmural strain, and transverse shear stiffness of the tissue will be used to fully evaluate the material, as well as analyze the test results.

AIM VI: Measure transmural strains

To determine the tissue deformation and strain values, a CCD camera will trace markers placed onto the specimen. As the markers move, the camera will send the picture to LabVIEW which will then analyze the movement of the markers. Through various calculations, the transmural strain will be found through the stress-strain response and outputted to the user using LabVIEW as an interface.

2.3.2 Subunits

2.3.2.1 Force System

To apply the necessary force to the tissue specimen, a complex force system will be used. It has to be manually controlled by a user and must be designed such that a CCD camera can capture the entire deformation of the tissue during testing. To accomplish these tasks, the force system had to be broken down into two smaller subsystems. The two subsystems are the motor system and the sliding system.

2.3.2.2 Motor System

The motor system used to move the bending bar into the tissue specimen consists of a PC equipped with LabVIEW, a stepper drive, a stepper motor, a motion controller installed in the CPU of the PC, a linear actuator and a cable to connect the stepper drive to the motion PC. The process involves a user inputting the command to move the sliding mechanism (explained in the next section) by using LabVIEW. The motion controller receives commands and transmits them to the stepper drive through the appropriate cable. The stepper drive then converts the signal to current and sends the current into the stepper motor. Current is used by the stepper motor to create rotation. This rotational motion is then converted to linear motion by the linear actuator. The sliding mechanism can then slide linearly along a rail system and applies user-controlled force to the tissue specimen. A general schematic of the motion system is shown in figure 7.
Figure 7. Motion System

The exact makes and models of each device used in the motor system are displayed in Table 2 below.

<table>
<thead>
<tr>
<th>Device</th>
<th>Manufacturer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>Dell</td>
<td>User provides input through keyboard. Software loaded on PC for other parts of testing (Ex. LabVIEW, Vision Assistant, etc)</td>
</tr>
<tr>
<td>SH68-SH68 Cable</td>
<td>National Instruments</td>
<td>Connects the PC to the stepper drive</td>
</tr>
<tr>
<td>PCI-7332 Motion Controller</td>
<td>National Instruments</td>
<td>Receives the user commands from the user and sends commands to stepper drive</td>
</tr>
<tr>
<td>P70360 Stepper Drive</td>
<td>National Instruments</td>
<td>Takes signals from motion controller and converts them to current. Sends current to stepper motor.</td>
</tr>
<tr>
<td>NEMA 17 Stepper Motor</td>
<td>National Instruments</td>
<td>Rotational motion caused by current from stepper drive</td>
</tr>
<tr>
<td>WB Linear Drive</td>
<td>Danaher Motion</td>
<td>Uses the rotational motion from stepper motor and converts it to linear movement</td>
</tr>
</tbody>
</table>

* Table 2. Make and models of parts for force subsystem*
2.3.2.3 Sliding System

The sliding system consists of multiple parts. It has a frame equipped with sliding rails that surrounds the mounting baths. It has a cart that will slide along the rails of the frame depending on the input from the user and the motion of the linear actuator. It has a high resolution CCD camera to take images of the deforming tissue. Most importantly, it has a bending bar to apply force to the tissue and a reference bar to be used in determining the exact force applied to the tissue. A top view of the sliding mechanism is shown in figure 8.

![Top View of Sliding Mechanism](image)

*Figure 8. Top View of Sliding Mechanism*

The frame that surrounds the mounting bath and the rail system that lies on top of the frame are made from steel. The steel provides the necessary mechanical strength at a cost cheaper than most other metals. To keep precise dimensions, pieces of steel are bolted together instead of welded. The cart that slides along the rail system is made from steel as well. It is a custom made steel cart that has a hole cut such that the CCD camera fits on the cart with an open line of sight of the tissue specimen. Plastic wheels are attached to the steel cart. The wheels along with the linear actuator provide the necessary equipment for the cart to move along the rails.
On the bottom side of the cart, a bending bar and a reference bar are securely attached. The bars are made from surgical steel and are approximately 4” long and 0.5 mm in diameter. The distance between the two bars is 1.5”. The CCD is able to see the deflection in the bending bars by having them hit the tissue at a slight angle. Figure 9 demonstrates this concept. The angles at which the bars are placed are at the smallest angle possible such that the camera can distinctly recognize bar deflection.

![Figure 9. Bar/Camera Set-up](image)

Before running any tests with the device it is extremely important to have the bending bar calibrated with the reference bar. Calibration involves various weights and the CCD camera. Because a very thin acupuncture needle is used as the bending bar the weights used for calibration are extremely light (< 1 gram). The procedure consists of taking an image of the bending and reference bar at its original position (1.5” apart). By adding varying weights, the deflection of the bending bar from the reference bar is captured. Varying deflections at various loads are graphed to form a linear graph of deflection vs. load. Using this graph, the load applied to the tissue is determined by comparing the deflection between the two bars with the deflection vs. load graph created during calibration. Figure 10 shows the calibration process. Deflection determination is found by simply subtracting X1 from X2.
Figure 10. Bending Bar and Reference Bar with A) Original Position B) .5 g of load applied

2.3.2.4 Programming

A fully functioning, user controlled 3-point bending device requires extensive programming. Software such as LabVIEW 8.5, Vision Assistant 8.5, Motion Assistant and Measurement and Automation 4.3 are used in conjunction. The purpose of the software and the way it was used in the 3 point bending device are described below

**LabVIEW 8.5**

National Instrument’s LabVIEW is an example of a programming language that uses graphical user interface (GUI). It consists of a front panel, which is seen and manipulated by the user, and a block diagram, which consists of all the coding in a project. The coding is done through the use of virtual instruments (VI’s), subVIs, and wiring to connect everything together. A typical layout of a LabVIEW project is shown in figure 11. The left side of the window is the user controlled front panel. It allows the user to provide inputs and displays results when
applicable. All calculations necessary to determine an output are done in the block diagram, which is on the right side of figure 11.

![Block Diagram of LabVIEW Program](image)

**Figure 11. LabVIEW Program**

In our project, LabVIEW will be used so that the user can control all aspects of the testing, such as motion of the sliding mechanism and image acquisition using the CCD camera. The IMAQ USB palette was utilized in order to receive images from the CCD camera which connected to the computer via a USB cable. The user will also control when to calculate the results in LabVIEW. Calculations will be performed and graphs will be displayed by using LabVIEW through a MatLab script node, which holds specific equations to calculate flexural properties and transmural strains.

**Vision Assistant 8.5**

Vision Assistant 8.5 is another example of National Instruments software. It is image processing software that has various processing functions used to analyze images. Examples of
processing functions are Brightness, Threshold, Filter and Morphology. A vital characteristic of Vision Assistant is that the coding can be transferred to LabVIEW coding. Vision Assistant was used to simplify the coding process for analyzing images. Figure 12 displays the Vision Assistant interface.

![Vision Assistant Interface](image)

**Figure 12. Vision Assistant 8.5**

**Motion Assistant**

National Instruments Motion Assistant is software that can be used to develop different motion applications. It can be used in our project to configure movement of the linear actuator at user-determined speeds and distances. The code from Motion Assistant can also be transferred to LabVIEW coding. Figure 13 displays Motion Assistant's front panel.
Figure 13. Motion Assistant

Measurement & Automation 4.3

Measurement and Automation 4.3 is National Instruments software that is used to configure various pieces of hardware. It gives a unique identity to each piece of hardware connected to the PC. In our project, it will be used to recognize the motion controller. Figure 14 shows Measurement and Automation 4.3.
2.3.2.5 Image Acquisition System

The accuracy of the image acquisition system is crucial in the design of this device. This system is responsible for gathering location information for several key components: the bending bar, the reference bar, the two fixed posts, the inner and outer edges of the specimen, and the test specimen itself in many specific regions. The imaging system is also important for bending bar calibration, which is a crucial component in force determination and subsequent calculations.

A high resolution CCD camera will be used to track the positions of the desired components in real time. Positions on the tissue will be defined by sprayed on microdots as seen in Figure 15. The CCD camera must be capable of tracking the smallest of microdots, which are predicted to be 2 μm in diameter. The tracking of the microdots will enable data to be collected that will allow the determination of the stress-strain relationship of the test specimen. The imaging system will calculate strain by tracking displacement of the markers. Stress calculation will be derived from the imaging system through the bending bar displacement due to the tissue’s resistance and bending bar Young’s Modulus. The bending bar
displacement will be computed by tracking the positions of the tips of both the bending bar and the reference bar. Since their movements are coupled mechanically, any difference in their relative distance is due solely to reactionary force of the tissue against the bending bar. This displacement can be converted into force through the initial calibration of the system. The calibration procedure consists of observing the bending bar in a zero state condition and then applying a known load and observing bending bar displacement. By accounting for bending bar cross-sectional area, the stress-strain relationship for the bar can be calculated. As long as the known load caused elastic deformation, the slope of the line drawn between the stress-strain pairs is the Young’s Modulus for that specimen. When the bending bar is loaded by the test specimen, the displacement can be converted into strain and the strain can be cross-referenced to find the corresponding stress value. This stress value can be mathematically equated back to force as long as the cross-sectional area of the bending bar is known, which was previously determined during the calibration step.

Figure 15. Sprayed on Ink Microdots used for Image Acquisition

A key feature to the image acquisition system is the CCD camera will move as the tissue is deformed so the test subject will never be out of the view of the camera. The simultaneous
movement of the CCD camera with the tissue specimen will allow the CCD camera to be able to determine the extremely small transmural strain values that the client wishes to observe. This movement will be largely controlled by the motor and program subsystems, which is discussed in other sections.

### 2.3.2.6 Mounting Baths

#### Inner Bath

The inner bath will be part of the mounting bath subsystem created. This inner bath system is extremely important to house the tissue specimen in a testing environment that operates within the temperature of the physiological system which results in a temperature range of 37°C +/- 1°C. The solution within the inner bath will be phosphate buffered normal saline solution. This inner bath will have the smallest possible dimensions to limit the waste of testing solution as well as reduce the area that will need to be heated.

For testing purposes, a phosphate buffered normal saline solution will be provided with a pH of 7.4. This will mimic physiological conditions as closely as possible which provides the most accurate results. Only a small volume will be needed for testing since the tissues being tested should be relatively small samples. Creating a small volume within the inner bath also reduces the risk of many errors. By limiting the amount of solution interacting with the sample, this also reduces the risk of contamination within the solution which will help to maintain a homogenous solution. Also, by reducing the area of the inner bath also reduces the waste of PBS after being used for testing. Between separate tissue samples the PBS should be changed to provide the most accurate results. This ultimately reduces the overall cost of the testing process for this device.

The sides of this inner bath will be created from Lexan. Lexan has been found to be a clear polycarbonate resin thermoplastic which has excellent corrosion resistance. This material was chosen because it is clear, enabling the user to see the tissue strain from all angles without the camera. It is lightweight, inexpensive and easily machined to the shapes needed. There will be no input or output of solution while the test is being performed. Because of the static nature of the PBS, it will need to be thoroughly cleaned each time. This inner bath will be fixed on four posts as described later in this section. Testing for the inner bath will come from filling the inner bath and making sure the sides are sealed and fixed so that leaks cannot occur.

#### Outer Bath
The outer bath is integral in maintaining an accurate testing environment. The other bath will provide the necessary area to maintain the necessary temperature. This outer bath will be larger than the inner bath and will circulate the water around the inner bath. By circulating the water around the inner bath, this reduces the error that might occur during testing. The only force acting upon the material should be the bending bar, not any forces created from the flow into or out of the inner bath.

The outer bath will have four fixation posts that will hold the inner bath. It will hold it approximately 10 mm above the floor of the outer bath. This will allow the water to better circulate throughout the outer bath and allow the inner bath’s sides to be completely surrounded by heated water. The amount of heat transferred from the water of the outer bath through the wall of the inner bath to the PBS will be determined through different properties of heat transfer.

To maximize the budget, the outer bath should be the smallest possible dimensions to reduce the amount of water needed to be heated as well as lower the material cost. The walls of this outer bath also need to be small enough not to interfere with any of the linear actuator motion. There will be an inlet and outlet nozzle as seen below in Figure 16. Testing for the outer bath will need to be done around the input and output nozzles.
**Tissue Fixation**

To ensure accurate results, the tissue needs to be stationary throughout the entire testing procedure. To accomplish this, removable posts will be used in the inner bath. These removable posts are small plastic, non-degradable pegs that will allow the user to choose between a few options based on the type of tissue being tested.

Removable posts will allow the user to determine the optimal spacing for each tissue. For samples that are larger, the posts should be spread out slightly farther to have the bending bars applied with the tissue being stationary at the posts. The pegs will have pre-drilled holes that will be the same diameter that will simply allow the user to pull out the post and place it in whichever position gives the desired distance.

Another option that the user will be given is to use a removable sleeve that will hold the tissue in place. This sleeve will be removable on the posts and the tissue will be placed inside this. The user’s discretion will be necessary to determine if the positives outweigh the negatives for the specific sample and size of the tissue. This sleeve will enable the tissue to remain stationary but at the expensive of having the camera see the markers through not only the PBS but as well as the sleeve’s wall. While this will be clear, there is still another added component for the camera to see through. Using the sleeve should not change any calculations for the transmural strains.
2.3.2.7 Temperature Regulation

The temperature of the water in the outer bath will be controlled using a Fisher-Scientific Temperature Regulator. This machine is currently in use in the client’s laboratory with other devices. This machine regulates a constant, programmable flow that is necessary for testing. Figure 18 shows the device that will be used. Nylon tubing will be used to connect the outer bath to the device via small barbs. While the outer bath and tubing should not come in contact with any testing materials, in case there is contamination within the tubing, nylon can easily be autoclaved and sterilized.
The temperature control subsystem for this device is used to create and maintain a temperature of 37°C +/- 1°C. This temperature has been known to be the normal physiological temperature and to create the most accurate results the in vitro testing of tissue should be performed as close to this temperature as well. To accomplish this, the design of this subunit will primarily use the previously designed system for temperature control. Our team was asked to build upon a previous group’s work to achieve the client’s need for testing. Many components of the previous group’s design are maintained in this current design to reduce the cost by reusing parts as well as allocating the group’s time to more efficient tasks.

2.4 Prototype

The prototype was designed using the specifications of the optimal design and the client’s additional input. The prototype consists of the fabricated portion of the device, stepper motor and linear actuator, stepper drive, motion controller, and PC with a LabVIEW program, which controls the motion of the device, image acquisition, and calculates the results through MatLab.

2.4.1 Subunits

As described previously, the project design consists of subunits, which are all integrated into the complete device.

Mounting Baths
The mounting baths were designed and fabricated to maintain and control a proper testing environment for accurate and repeatable testing. The test specimen provides an area to place the test specimen and the outer bath controls the testing environment. The outer bath is connected to the Fisher-Scientific Temperature Regulator via hose barbs and nylon tubing. The finished product can be seen in figure 19.

![Figure 19: Mounting Baths](image1)

**Sliding Mechanism**

The sliding mechanism is the key component to the force application system and also mounts the camera. The device holds a removable bending bar piece, where the bending bars are placed. The bending bars apply force to the test sample so deformation can be observed. The piece is removable for easy calibration and storage. The camera is mounted on the device to ensure the camera captures the deformation of the test sample.

![Figure 20: Temperature Regulator](image2)
Motor System

The motor system provides motion needed to push the sliding mechanism and apply the force to the sliding mechanism. The motor system consists of a linear actuator connected to a stepper motor. The stepper motor is connected to a stepper drive, which connects to an NI motion controller in the computer, so the motion can be controlled via a program developed in LabVIEW.
Image Acquisition

The CCD camera is mounted on the sliding mechanism to enable it to move as the test specimen deforms. The piece it is mounted in is adjustable to allow for an easy adjustment of the frame of view. The camera is connected to the computer via a USB cable. The images are acquired into a LabVIEW program designed specifically for this device.
The integrating aspect of this project is through a LabVIEW program designed specifically for this device. The program was originally developed by the 2009 Senior Design team that attempted this project. The program integrates all the hardware, controls the motion of device, acquires images, tracks markers on the images, and calculates results through a MatLab script node. The LabVIEW program was edited to acquire clearer images and more accurately track markers on the images. Additionally, the MatLab calculations were reworked to account for the differences in test method between the newly fabricated three-point bending device and the original device.

The first user-controlled module of the program is the motion control of the device. Here the user can start and stop the motion as well as change the speed of the motor. The next module is the image acquisition. In this module the user can see the image coming in from the camera and adjust the settings to acquire an optimal image for testing. The user also can define the area of interest of the test sample and size of the markers the user wishes to track. Lastly is the testing module. This part of the program allows the user to input in all the necessary information prior to actual testing. Once the start button is pressed the testing will be performed automatically through the program. The testing module controls the movement of the motor, while simultaneously acquiring images through the camera and tracks markers on the images. In addition, while the motor and camera are performing their functions, the testing module also output all the critical information, such as the positions of the markers and the time. After the testing is completed, the output data will be written into a text file. This data is used to calculate all the necessary results in MatLab, which are then outputted so the user can view them.
3.0 Realistic Constraints

When designing and building the 3-point bending device, there are many constraints and potentials for error that may affect the project. These constraints must be considered throughout the construction of the device.

*Engineering Standards*

It is important for this device to be held to strict engineering standards because of the extremely small values the device must calculate. The margin for error must be kept appropriately small to ensure the accuracy and validity of the data. It is important for the device to be properly calibrated, as previously discussed, as well as to be kept on a calibration schedule to maintain the integrity of the data.

Environmental changes must also be carefully monitored. If testing is performed on the same tissue at two different environmental conditions there will be two different responses. Therefore it is necessary to make sure the water bath is closely monitored as well as the testing environment the device is kept in.

The possibility of imaging error is another important factor. The device must track the change of position of the test specimen over time. If this data is altered due to errors from imaging, all the results acquired will be inaccurate.
Error may also occur during force recording. The device must record the change in force applied to the tissue over time. The tissue stress calculations will be based on this force measurement. If the force read by the device differs from the actual force applied, the data will be compromised. A possible cause of this error could be an unaccounted-for loss of force such as friction.

**Economic**

Economic constraints are an important consideration in the development of this project. A limited budget is available for this project, which makes it necessary for the team to use parts that are readily available in the Biomechanics lab at the University of Connecticut. During the purchase of additional materials, it is important for the team to find the most cost-effective materials.

**Environmental**

For proper tissue mechanical response, the tissue must be maintained in conditions that simulate the in vivo environment. By creating specific bounds for the environmental conditions the device is more likely to provide reproducible data. This will inevitably make the device more attractive to researchers and industrial scientists.

The environment of the 3-point bending device is extremely important. By having a phosphate-buffered saline solution at normal body temperature the tissues are tested under similar temperature and pH conditions as the human body. If the temperature and pH falls out of the acceptable bodily ranges then 3-point bending tests will create impractical data.

**Manufacturability**

Whenever possible, parts will be manufactured in-house at the University of Connecticut machine shop. In the acquisition of additional parts, parts will be purchased that are not going obsolete.

**Sustainability**

Non-corrosive parts have been chosen whenever possible to create a more sustainable device. All potentially corrosive parts will be periodically replaced. Any components subject to friction will be lubricated periodically to prevent wear and unnecessary error. The system will be monitored closely during prototype development to identify any aspects of the device that may deteriorate over time. These measures will increase the reproducibility of the data obtained using this device.

**Ethics**
A limited budget was allotted for this project. Therefore it is important that all purchased parts will be thoroughly researched so that the most reliable and cost-effective component is chosen in each case. All the vendors used will be ethically chosen based on credibility and the best prices. All funds spent will be used solely for the purchase of parts and services. The client will be kept informed of the initial budget along with periodic updates on all purchases made and consulted prior to any necessary deviations from the budget.

**Health and Safety**

The device will be routinely cleaned because the tissues used may expose the device to harmful bacteria. Surface materials should be chosen such that they are smooth and capable of being sterilized after each use.

**4.0 Safety Issues**

The completed three point bending device will consist of many parts that pose safety concerns. There will be parts of the device with the potential of chemical, mechanical or electrical safety issues. A list of parts and possible safety concerns are displayed below.

- Stepper motor – possible electrical and fire hazard
- Temperature Regulator – electrical and fire hazard
- Chemical Medium (Phosphate Buffered Saline solution) – chemical risk
- Bending Bar/Inner bath – Chemical risk because of constant contact with tissue specimens

Many preventative measures will be put in place to minimize dangerous components of the device. The stepper motor will be enclosed such that electrical and fire hazards will be minimized. The wires coming from the stepper motor will be thoroughly insulated so that the user cannot accidentally touch it and get electrocuted. Insulation will also help prevent electrical fires from occurring.

The temperature regulator has all components enclosed. Tubing will be thoroughly attached to the regulator so that fluid cannot leak out. The design of the regulator will also prevent fluid from coming in contact with any of the electrical components. The chemical medium was chosen to resemble human bodily conditions. Coming in contact with PBS is minimally harmful. The only negative of PBS is that it may catalyze corrosion in other materials of the device. It is extremely important to clean materials in contact with the PBS thoroughly after each trial and to have spare components if economically permitting.

The testing area on the surface of the inner bath provides another health concern. Through the design of the bath within a bath, many of these concerns are negated. Live tissues
will be used on the surface of the inner bath which may lead to bacterial growth. By having the inner bath separate from the constantly regulated outer bath, the bacteria cannot spread throughout the entire system. It is also important that the inner and outer bath system be made from Lexan. Lexan is nonporous and can readily be sterilized. Frequent sterilization of the Lexan surface will prevent bacteria from reaching a harmful level.

The bending bar also has the potential of bacterial growth. By using a surgical steel needle, the bending bar is easily sterilized. Because surgical steel needles are inexpensive, it will also be possible to replace needles after multiple tests. Instructions for needle sterilization, as well as inner and outer bath sterilization will be provided as a reference for the user.

5.0 Impact of Engineering Solutions

Global Impact

While there are three-point bending devices available on the market, they test mainly for metals, composites and ceramics. There are small three-point bending devices for soft tissue that can be found in a few small labs throughout the nation, our client, Dr. Sun, does not have his own device to test on. This is detrimental to his research which is published internationally.

This device will specifically enable the most accurate testing of cardiac tissue with a heart valve implant. Many of the current valve designs fail prematurely due to the interface between the natural soft tissue and the implant. This area needs to be tested more thoroughly to determine the properties of cardiac and soft tissue through many layers. If this can be determined, this will lead to improvements in heart valve designs which can potentially save millions of lives in the near future.

Economic Impact

Current three-point bending devices on the market cost thousands of dollars and are not able to test all materials. This device will only test soft tissues, which drastically reduces the overall practicality, but will test exactly what the client is looking for making this the most practical testing device available. This device will only cost a fraction of the industry produced machines and could possibly be patented once the device is fully developed.

This device could possibly affect the budget of a professor in biomechanics or testing of soft tissue. By creating a device that would be drastically less than any other three-point bending device and will be able to calculate values quickly and easily, allows researchers to apply their budgets to other more expensive machines. This would further their own research and make it possible to fund more thorough experiments.
Industry can also gain an economic advantage from this three-point bending device. With a better understanding of soft tissues, this will result in better designed implants. Better designed implants will reduce the cost of trial and error experiments as well as reduce the cost of the engineer’s time being spent searching for these specific properties.

**Environmental Impact**

This device will not impact the environment in either a positive or negative manner.

**Societal Context**

With a better understanding of soft tissue properties, this will lead to better designed implants. With better implants this will decrease the amount of replacement surgeries as well as the cost of implants. This benefits society since it will be more feasible for a person to get the necessary implants and surgeries needed at a lower risk and cost. Decreasing the amount of surgeries would improve a person’s health. By understanding these properties, it can also lead to longer lifespans of the patient as well as the designed implant.

**6.0 Life-long Learning**

The techniques acquired and new material learned in the design of this project will be valuable tools for the team members in life after college. First, the team had to learn the background of Dr. Wei Sun’s research on the biomechanics of soft tissues. Learning the goals of Dr. Sun’s research was helpful in determining what components needed to be implemented in the device design. The process of communicating with a client to produce a project will be a consistent aspect of a career in Biomedical Engineering.

Project planning is another integral aspect of this project. Making deadlines and meeting those goals is crucial in the completion of the project. Microsoft Project will be used to keep tasks and deadlines in order. Experience with Microsoft Project may be useful at the future workplaces of the team members. Learning to set achievable goals in a timely manner will be a helpful experience in any future workplace settings. Proper project planning and management is key in any successful career.

Teamwork is an important part of this project. Learning to operate as a team was essential in the successful design of this project. Teamwork involves constant communication and working together to achieve the same goals. Tasks were be divided and delegated to ensure the efficiency of the team yet the team worked together to ensure the integration of the different aspects of the project.

This project also required the use of a CAD program. Knowledge of Solid Works will be a necessary aspect of the planning process. Building and adjusting a CAD model will aid the final
design of the project, by allowing the team to visualize the device before it is built. The CAD model will help reduce errors and therefore increase the productivity of the team. The skills acquired from using Solid Works will be valuable in future research and development projects.

In addition, many other skills valuable to a career in Biomedical Engineering were dramatically enhanced through the completion of this project. Extensive LabVIEW programming was needed, thus improving the team’s LabVIEW programming skills. Mechanical skills were also improved during the construction of the bath and sliding mechanism. The team also worked with a stepper motor, linear actuator, as well as a CCD camera. All of these skills could potentially be used in the team member’s future careers.

Lastly, throughout the construction of this project the team was faced with many setbacks and challenges. The team learned from these experiences without being discouraged. Over the course of this design project, the team learned valuable designing principles and various engineering skills, which will be utilized throughout the engineering careers of the team members.

7.0 Budget

Budget

Maximum Budget: $1000

Saved: $884.36

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>$47</td>
</tr>
<tr>
<td>Accupuncture Needles</td>
<td>$23.89</td>
</tr>
<tr>
<td>Lexan</td>
<td>$13.07</td>
</tr>
<tr>
<td>Hose Barbs</td>
<td>$5.48</td>
</tr>
<tr>
<td>Shoulder Screws</td>
<td>$3.96</td>
</tr>
<tr>
<td>Ball Bearings</td>
<td>$22.24</td>
</tr>
</tbody>
</table>
8.0 Team Members Contribution to the Project

- **Jennifer Olson**
  Jennifer has been focusing on the image acquisition system of the three-point bending device. Initially, this has consisted of downloading the correct drivers to install the CCD camera to the assigned computer. After the camera was confirmed to be working, the ranges and focus of the camera had to be tested and optimal height had to be determined for mounting the camera onto the sliding mechanism. Jennifer also worked on integrating the image acquisition of the camera into LabVIEW through the use of the IMAQ USB functions. Working off the LabVIEW VI developed by the 2009 Senior Design team, she edited the program to capture clearer images so markers could be tracked more effectively.

- **Sarah Rivest**
  Sarah has been primarily responsible for the programming for transmural strains and flexural properties. She has been programming MatLab calculations for transmural strains and flexural properties that integrate into LabVIEW. Additionally, she has wired the stepper motor to the stepper drive ensuring the controlled motion of the sliding mechanism.

- **Brian Schmidtberg**
  Brian concentrated his efforts on the overall design of the sliding mechanism, motor system and mounting baths. He completed SolidWorks designs for each aspect and fabricated each part based off of the SolidWorks. He also worked on the programming necessary for motor control of the entire mechanism through Motion Assistant and LabVIEW. Weekly reports, papers and presentations were all uploaded to the team’s website by Brian.
9.0 Conclusion

Successful completion of this device provides Dr. Sun with a three-point flexure testing device that calculates the flexure rigidity, bending stiffness, transmural strain, and transverse shear stiffness of soft, multi-layered tissues. The device originates from ideas worked on previously and improves the functionality to fit the client’s specifications.

The device is easy for the user to operate and produces results that are accurate and reproducible. The main components of this device include the mounting bath, force-application system, image acquisition system, and the user interface. The sample specimen is submerged in saline solution that will be kept at a constant 37°C to mimic the environment inside the human body. Testing the sample in an aqueous environment produces results most similar to *in vivo* results. The force-application system provides enough force to cause the minimum amount of tissue deformation. The LabVIEW program takes the markers found on the specimen and performs many calculations to determine the various flexure properties in question. The data is outputted and displayed through the LabVIEW interface and MatLab graphs for easy to read results for the client.

Meeting the client’s wants has been the main focus while designing our device. A previous group has attempted this same project and did not fulfill the client’s expectations. Being able to use many of the parts already purchased by the previous group greatly reduced the costs of this device. This device fulfills the requirements for the client’s testing needs as well as comes under the budget assigned for this project. As with all technology however the device can continue to be improved through continued programming, which would make the device more user friendly and may increase the accuracy of the results.
10.0 References

5. *Danaher Motion*. [www.danahermotion.com]

11.0 Acknowledgements

Team 6 would like to thank Dr. Wei Sun for sponsoring this project as well as providing direction in the design of this device. Eric Sirois was also helpful in acquainting Team 6 with the components and design of the 2009 project. Kewei Li and Thuy Pham provided additional help and guidance in the Biomechanics Lab. Pete and Serge were very helpful in the fabrication of our device. A special thanks also goes to Dave Kaputa for his guidance with LabVIEW programming. We would also like to thank Dr. John Enderle who oversaw our project progress as well as our TA Emily Jacobs.
## PURCHASE ORDER REQUISITION - UCONN BME SENIOR DESIGN LAB

Instructions: Students are to fill out boxed areas with white background. Each Vendor will require a different purchase requisition.

<table>
<thead>
<tr>
<th>Date</th>
<th>Team #</th>
<th>Total Expenses</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 28, 2011</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

**Student Name:** Sarah Rhode

**Ship to:** University of Connecticut
Biomedical Engineering
U-2247, 260 Glenbrook Road
Storrs, CT 06269-2247

**Attn:**

**Project Name:**

---

### ONLY ONE COMPANY PER REQUISITION

<table>
<thead>
<tr>
<th>Catalog #</th>
<th>Description</th>
<th>Unit</th>
<th>QTY</th>
<th>Unit Price</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accupuncture Needles</td>
<td>1</td>
<td>$23.89</td>
<td>$23.89</td>
<td>$23.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Price Quote:**

**File Name:**

**Yes or No ** Vendor Accepts Purchase Orders?

**Vendor:**

**Address:**

**Phone:**

**Contact Name:**

**Shipping:** $0.00

**Total:** $23.89
PURCHASE ORDER REQUISITION - UCONN BME SENIOR DESIGN LAB

Instructions: Students are to fill out boxed areas with white background
Each Vendor will require a different purchase requisition

Date: February 15, 2011
Team # 6

Student Name: Brian Schmidtberg
Total Expenses

Ship to: University of Connecticut
Biomedical Engineering
U-2247, 260 Glenbrook Road
Storrs, CT 06269-2247

Attn:

Lab Admin only:

<table>
<thead>
<tr>
<th>FRS #</th>
<th>Student Initial Budget</th>
<th>Student Current Budget</th>
<th>Project Sponsor</th>
</tr>
</thead>
</table>

Project Name:

ONLY ONE COMPANY PER REQUISITION

<table>
<thead>
<tr>
<th>Catalog #</th>
<th>Description</th>
<th>Unit</th>
<th>QTY</th>
<th>Unit Price</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hose Barbs</td>
<td>1</td>
<td>$5.48</td>
<td>$5.48</td>
<td>$0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments

Price Quote

File Name:

Vendor Accepts Purchase Orders? Yes or No

Vendor: McMaster-Carr

Address:

Phone:

Contact Name:

Authorization:

Shipping $0.00
Total: $5.48
# PURCHASE ORDER REQUISITION - UCONN BME SENIOR DESIGN LAB

**Instructions:** Students are to fill out boxed areas with white background. Each Vendor will require a different purchase requisition.

<table>
<thead>
<tr>
<th>Date:</th>
<th>February 28, 2011</th>
<th>Team #: 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Name:</td>
<td>Brian Schmidtberg</td>
<td></td>
</tr>
<tr>
<td>Ship to:</td>
<td>University of Connecticut</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biomedical Engineering</td>
<td></td>
</tr>
<tr>
<td></td>
<td>U-2247, 260 Glenbrook Road</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Storrs, CT 06269-2247</td>
<td></td>
</tr>
<tr>
<td>Attn:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Name:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## ONLY ONE COMPANY PER REQUISITION

<table>
<thead>
<tr>
<th>Catalog #</th>
<th>Description</th>
<th>Unit</th>
<th>QTY</th>
<th>Unit Price</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shoulder Screws</td>
<td>1</td>
<td>1</td>
<td>$2.08</td>
<td>$2.08</td>
</tr>
<tr>
<td></td>
<td>Ball Bearings</td>
<td>1</td>
<td>1</td>
<td>$22.04</td>
<td>$22.04</td>
</tr>
</tbody>
</table>

**Comments**

- Price Quote:
- File Name:
- Vendor Accepts Purchase Orders? Yes or No
- Vendor: McMaster-Carr
- Address:
- Phone:
- Contact Name:

**Total Expenses:**

- Shipping: $0.00  
- Total: $24.12

**Authorization:**

---

46