ALTERNATIVE DESIGNS REPORT

THREE-POINT BENDING DEVICE FOR FLEXURE TESTING OF SOFT TISSUES

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INTRODUCTION

The objective of this project is to construct a three-point bending device capable of performing flexure testing on soft tissues. The device will consist of a mounting-bath system, a force-application system, an image acquisition system, a temperature controller system, and an interface. In order to prevent redundancy, the purpose and implementation of the systems that are common to all three alternative designs are described as follows.

Interface System

The interface will consist of a computer monitor, a central processing unit (CPU), and keyboard and mouse. The CPU will contain a PCI card and USB readers to provide connection and control to the motor(s) and camera and temperature controller, respectively. The monitor will provide an interface for the user to control the device. It will display a customized LabVIEW program written specifically for the device, which gives the user complete control over the functioning of the device.

Image Acquisition System

The image acquisition system will consist of a high resolution CCD camera and a camera mount. The camera mount will be used to mount and stabilize the camera directly over the mounting bath and the tissue when it is experiencing flexure. The CCD camera will be used to track the markers on the tissue during flexure. The displacement of the markers will be used to calculate the strain.

Temperature Controller System

The temperature controller system will consist of a temperature recorder, a centrifugal pump, contact plates, power supply, heater, and pipes. The temperature recorder will be used to record the temperature of the solution in the mounting bath. Data from the temperature recorder will be monitored by the LabVIEW program. If the temperature of the solution deviated from the default value of 37 ± 1°C, then the program will activate the contact plates connected to the heater. The contact plates will be powered by a power supply. When the contact plates are activated, the heater will either stop running or continue to run to decrease or increase the temperature of the solution, respectively, to the default value. The centrifugal pump and pipes will be used to pump the solution from the mounting bath to the heater and then back to the mounting bath.

Force-Application System

The force-application system will consist of a bending bar, a reference bar, and two posts. One of the posts will have a sleeve to which the tissue is attached to; the other post will be used to
stabilize the tissue. The bending bar will be used to apply a load to the tissue. The displacement of the bending bar when it is applying a load to the tissue, in reference to the reference bar, will be used to calculate the amount of load that is applied to the tissue.

**Mounting Bath System**

The mounting bath will be used to hold the solution, the tissue, the posts, and the reference bar. The purpose of the mounting bath is to provide an area where flexure testing on the tissue occurs. Figure 1 below shows a diagram of the top view of the whole device.

![Fig. 1 – Top View of Device]
ALTERNATIVE DESIGN 1

The first alternative design will consist of a movable mounting platform. The movable mounting platform will be surrounded by an outer bath to prevent the solution inside the mounting platform from leaking and to provide a track for the platform to move. Figure 2 shows a cross-sectional side view of the mounting bath system. The platform will be attached to two wheels, which will run on tracks located inside the outer bath. The purpose of the tracks is to keep the platform moving linearly in only one direction and to prevent the wheels from deviating from their course while running.

![Diagram showing cross-sectional side view of mounting bath system with a movable mounting platform surrounded by an outer bath, attached to two wheels running on tracks inside the outer bath.](image)

**Fig. 2 – Cross-sectional Side View of Mounting Bath**

For this system, the platform will be connected to a motor. The motion of the motor, including the speed and the direction, will be controlled by the computer program. When the motor moves, the platform will move. Figure 3 shows a top view of the mounting system which consists of the platform being connected to the motor. As can be seen, the posts will be attached to the platform and used to hold the tissue. The bending bar, on the other hand, will be attached to a bending bar fixture located outside of the mounting bath system. Hence, when flexure testing is to be performed, the platform with the tissue will move towards and come in contact with the bending bar, causing the bending bar to apply a load to bend the tissue.
The solution from the mounting platform has to flow out of the bath to the heater and then back in to the bath in order to achieve temperature control of the solution. Figure 4 shows a side view of the mounting system. From Figure 4, it can be seen that the outer bath will consist of two opening, one on each side of the bath. These openings will provide direct connections of the pipes and the inner mounting platform. These connections will allow the water to move in a loop out of the platform on one side, and then back into the system on the other side. In addition, these openings will allow the pipes to move with the platform as the platform moves back and forth.
ALTERNATIVE DESIGN 2

The basic theory behind the three point bending device requires three posts to apply a central load to the tissue wherein the stress, strain and neutral axis can be measured. Each design must contain these essential components in order to accomplish the necessary function of the device; however, exactly how the tissue is fixated and the load is applied can be altered. In this design the central bending bar is moved while the two secondary fixation posts remain stationary.

Linear beam theory is used is this method to compare the relative bending stiffness of the tissue samples. The specimen is held in place between two stationary posts an adjustable distance apart. One post has a removable tube (sleeve) that is attached at one end of the specimen and the other end rests freely against the opposite stationary post. The tube allows for frictionless rotation of the specimen about the fixation as the central load is applied. The bending bar is a thin rod of known, homogeneous material that is used to apply force to the sample in cantilever bending. A fourth reference bar is included a known distance from the bending bar and is used to measure the displacement at the location of force application. Stepper motors are attached to the bending and reference bars moving them a known distance. The difference between the tip of each bar is determined as the displacement of the tissue. A series of separate bending bars are used to apply a distinct force for tissues of varying stiffness and rigidity. These bending bars are calibrated by displacing the tip of the bending bar a known distance and measuring the load. The resulting data points are fit to a linear regression and the slope is used as a scale factor during analysis of the tests. This device design was previously utilized by a group at the University of Miami and this is where much of the device parameters and specifications came from {Sacks}. This technique is readily reproducible and offers a valid method of determining the stress strain relationship in the material, but it is based on linear theory and proves to have limitations in its final application.

Tissues tested are often comprised of many separate layers displaying distinct mechanical behavior and these are overlooked when assuming that the specimen is a homogeneous uniform beam. The client requests that the transmural strain, as well as, the neutral axis of the specimen in bending also can be calculated. In turn this means that the image capturing high resolution camera must be capable of tracking the area of displacement with absolute accuracy. With the bending bar moving the region of flexion will also be moving and it may be difficult for the camera to follow the specimen. This adds to the complexity of the design because the camera must also be capable of displacing a distance equal to that of the bending and reference bar. For these reasons this design is optimal for finding the flexural stress and strain of the tissue, but lacks in determining the transmural strain.
ALTERNATIVE DESIGN 3

The three point bending device, no matter how it is configured, will require 3 posts to carry out the principle function of bending the tissue. What we must choose then is which components should be mobile and which stationary. For each alternative approach we should also identify the advantages and disadvantages of each choice. This alternative method calls for the two outer bars to be moved in against the tissue and for the inner bar to remain stationary.

Transmural strain measurement, and thus the ability to identify the location of the neutral axis, requires extremely high resolution imaging to track marker movement. For this device, markers will be as small as 20 µm. In order to track markers across the thickness of the tissue, which can be up to 400 µm wide, very little allowance is left for the tissue itself to move radially. Thus, measurement of transmural strain can only be accomplished by either focusing on a region with little or no radial movement, or by making the imaging device move along with the tissue. For this design alternative, we chose the former. This approach was previously employed by a group at UCSD (Fung). The UCSD group produced the only reported three point bending device capable of measuring transmural strain. Since measurement of transmural strain and identification of the location of the neutral axis are two of our client’s requests, it is natural that we should attempt to reproduce a version of the UCSD device. The reason that this device was successful at measuring transmural strain was that it bended the tissue around the central post. Since the central post was stationary, a high resolution camera (actually in this case it was a microscope) could be used to focus on the stationary area. This device not only provides the advantage of a proven track record of strain measurement, but also will allow us to measure transmural strain without designing complex automation controls and image-control feedback to move the camera. Such an additional movement system would be very costly, and may make production of the device not feasible.

A notable downside of this alternative design is that the stationary region near the central post appears to be a stress concentration point when a mock-up of the system is analyzed using finite element software (Fig. 1). Such stress concentrations are known to mask the true tissue stress-strain response. It is thus normally desirable to measure strain in a region not affected by peak stresses. One other disadvantage is that this method provides either a less accurate or more expensive method of measuring force applied to the tissue. The originally intended method for force measurement (force applied to the tissue) was to monitor the displacement of the central post as compared to the position of a reference post. With the material properties known, this displacement could be equated to strain on the metal. The corresponding stress could then be calculated and the force easily determined. Using a stationary central post may require that the central post either not move at all during loading or be stiff enough that it moves very little during the application of force. In the case where the
post is so stiff that it doesn’t move at all, a separate method for determining force will be required. This separate method would be a force transducer, which could be costly for an application such as this where a high degree of accuracy at very low loading would be required. The other case, where the post only moves a short distance, would require a stiffer metal than originally planned for. Lower bar displacement would allow for bar location measurement error to play a more significant role in the data obtained.

Since two of our overall goals for this project are to provide accurate data to the user and to maintain the cost as low as possible, the drawbacks of this alternative design pose (at best) a tradeoff of accomplishing one objective at the cost of another. This is, however, the only known method of calculating transmural strain and must therefore remain a viable design option.

![Finite Element analysis of the 3-point bending system.](image)

**Fig. 5** – Finite Element analysis of the 3-point bending system. Highlights the region of peak stresses, which is unfortunately also the region of least tissue radial movement in this alternative design and thus the region used for transmural strain measurement.