Hand Exerciser

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BME 201
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Client: Dr. Alexander Yevzlin

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Abstract

Everyday, people all over go through a process called dialysis, or filtering of the blood. This involves attaching two blood vessels in the arm to form a fistula. After dialysis is performed, there are sometimes issues regarding the fistula. In order to help the fistula mature, an ordinary stress ball is used to exercise the hand and promote blood flow. Our client has presented us with the task of creating a device to record data regarding a person’s post surgery exercise regimen. He will then use that data to determine what the ideal plan is for a post dialysis patient.

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Problem Statement

Our client Dr. Alex Yevzlin has proposed to us the assignment of making a stress-ball-like device capable of recording and transmitting data. The device will record how hard a patient squeezes, how long they squeeze for, and how many times they squeeze per day. This will be used by Dr. Yevzlin to more accurately determine the ideal exercise regimen for post-surgery patients. The device will be contained in an ordinary stress ball capable of exercising the hand after surgery, or something similar to a stress ball. The device should be as low cost and user friendly as possible.

Background

Dr. Yevzlin works extensively in the field of dialysis. Dialysis is the process of filtering the blood, similar to what the kidneys do. When the kidneys no longer function properly, dialysis must be used to “clean” the blood of toxins. The process is accomplished by passing the blood across a semi-permeable membrane. In order for this to work the blood must be flowing at high enough rates to pass through the membrane.

Veins in the arm are incapable of supporting such high flow rates, so a surgeon must attach a vein to an artery in the arm to create an AV Fistula. This point of attachment ensures flow rates stay high enough for dialysis to work properly. Two needles are then inserted into the fistula, one to remove unfiltered blood and another to recycle filtered blood back into the body.

After dialysis, issues often arise with the fistula. Sometimes the fistula will not take and blood flow to the hand can be cut off. To combat this, patients are asked to squeeze a stress ball as much as possible post-surgery. This helps the fistula to mature and helps to promote blood flow to the rest of the hand. While many times, the squeezing alone is enough to mature the fistula, little is known about the ideal conditions for maturation. Our client would like to commission a study to determine just that by comparing his patients' progress with results from the device.

Current Devices

The only applicable device currently used is an ordinary stress ball. This is sufficient to exercise the hand but offers nothing to determine the ideal regimen for post surgery exercise. Our device will incorporate a stress ball with additional instrumentation. Other than that, current devices have little application to our device.

Other devices found that involved exercising the hand included a glove used for post stroke patients. While the range of motion of the hand is similar, a glove design would not allow us to gain the pressure readings we desire.

Design Constraints

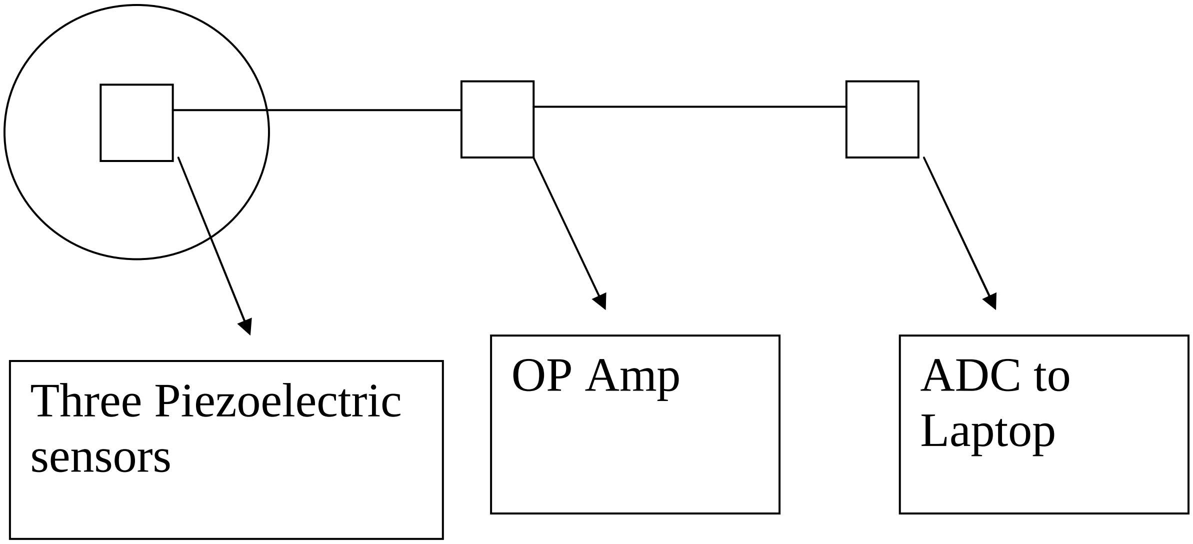
Our design must follow the constraints given by our client, who wants a device that is self-contained, portable and durable. He stated the device must be durable enough to allow it to withstand 30-60 minutes of squeezing from the user each day, but soft enough so that an elderly person is able to squeeze it comfortably. Ideally, the device would cost around $10 to manufacture, although a microcomputer kit necessary to make the unit self-contained costs $150 alone. Dr. Yevzlin also requires that the material the unit is composed of should be safe for human use and should feel smooth and comfortable in the user's hand. The current standard for the medical industry is a stress ball, so Dr. Yevzlin has expressed interest in using this in our design. He has also acknowledged that other materials would be satisfactory as well, as long as we clear them with him on a case by case basis.

Design 1: Piezoelectric

Overview:

The piezoelectric design is composed of placing three piezoelectric sensors in the center of the stress ball. The three sensors must be placed orthogonal to each other. The reason for doing this is so that the device is able to sense pressure from any direction. When experiencing external pressure, the piezoelectric sensor gives a voltage signal. This small voltage must be amplified by an Op Amp and processed by an analog to digital converter. This amplified digital signal could be transmitted to a computer, which is able to process the information and display it in graphical form. The program will operate by starting to record data after a set threshold is broken. After this threshold is broken, the program will record the number of peaks and height of the peaks of the graphs drawn by the program. By recording the height and number of the peaks the user would be able to see the record of many times they squeezed and how hard they squeezed.

Figure 1



Advantages:

The piezoelectric sensors are inexpensive, which is important for our client who wants manufacturing costs per unit to be less than $10. The sensor’s price can be as low as $1.85 if buying in bulk (Jameco.com). The piezoelectric sensors give a linear output and are accurate, which benefits our client. The sensors are very durable and are able to withstand strong loadings and are unaffected by electromagnetic fields which could be present in the environment. The linearity of the sensors allows accurate readings at varying pressures because the voltage output and the pressure have a linear relation to each other.

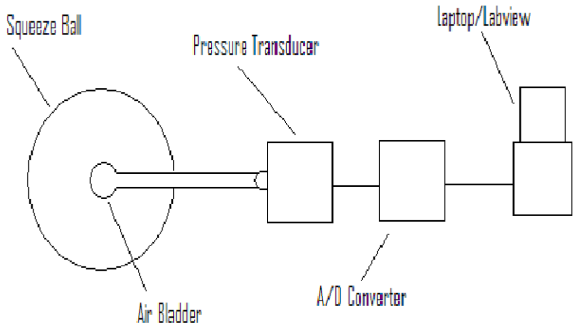
Cons:

Having three sensors, of dimensions 0.30 by 0.54 inches, inside the ball takes up a lot of room, which could pose a problem when trying to make the unit self-contained. (Jameco.com) Hand positioning from the user might also cause problems with directionality, which have not yet been tested by our team.

Design 2: Air Bladder

The second design that we considered involves the use of an air bladder. An air bladder is a thin, hollow piece of flexible plastic with a hollow marble-sized bulb on one end. The bulb end of the bladder would be inserted into the center of a squeeze ball with the tube end sticking

Figure 2



out. The tube would be attached to a pressure transducer whose output voltage is a function of measured pressure. After converting this analog voltage signal to a digital signal, we would compile and track the data with a laptop (and LabVIEW) as in Design 1. A sketch of this system is shown in Figure 2.

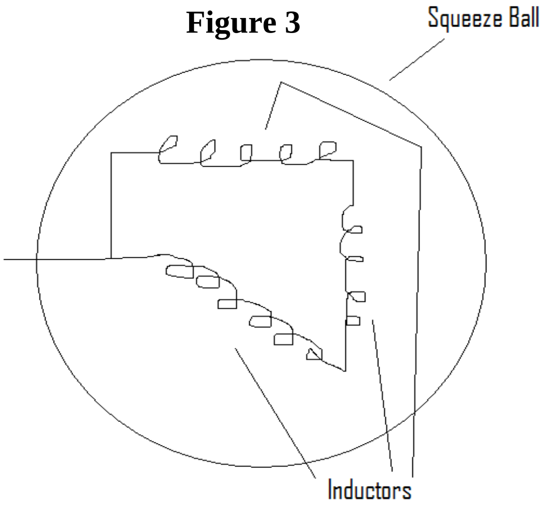
The pressure transducer we selected for this system is light (50 grams) and compact. While we are not attempting to build a self contained model this semester, this particular pressure transducer would likely be feasible if/when we try to take that step.

There are several positive aspects to this design. The first and foremost is that it would provide accurate and reliable results. Because it is the same shape as the squeeze ball, the bladder would experience a consistent pressure increase regardless of which direction the patient squeezed it from. The pressure transducer has a response time of less than 5 ms, so it would be able to detect the change in pressure over time of an individual squeeze. The circuitry involved in this design would be very simple, as it doesn't require any additional circuit elements or complicated wiring.

This design also has a few drawbacks related to the pressure transducer. Even our compact and lightweight transducer is too large to fit inside of a squeeze ball, so any eventual self contained device would need a different shape or design. The transducer costs $60 – far above the $10 "ideal" that Dr. Yevzlin proposed. Also, testing needs to be done on the air bladder to determine that it won't rupture from the pressure associated with a strong squeeze.

Design 3: Inductors

Figure 3



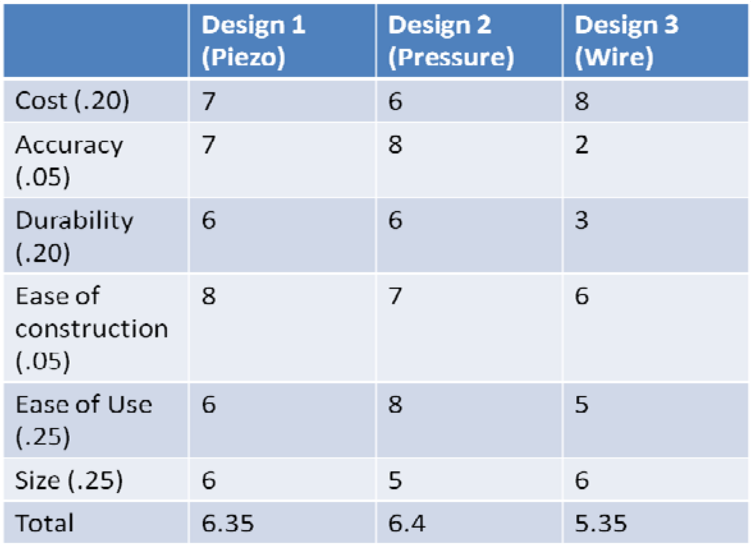
The third design considered involved the use of adjustable core inductors, and the fact that the inductance of an inductor is a function of its length (among many other factors). In theory, it would be possible to arrange a system of inductors within a squeeze ball such that the length of the inductors would change with each squeeze, therefore changing the inductance. Additional circuitry could be designed to detect this change in inductance, and ultimately convert to a change in pressure.

This design does have one very good feature: inductors are inexpensive, and the entire design has the potential to be very cheap. Other than that, this design isn't a feasible solution to our problem, as it requires much more knowledge of circuitry and design than we possess. Designing a way to orient the inductors so that the directionality of the squeeze doesn't matter would be extremely hard, and likely impossible in one semester's time. While inductors work well in theory, they are difficult to actually implement into a circuit – especially when considering the size constraint presented by the squeeze ball. Reliably calculating the pressure applied to the ball from a change in inductance would be very hard. Overall, this design is a much less realistic possibility than the previously mentioned designs.

Design Matrix

The three possible designs were rated in six different weighted categories: cost, accuracy, durability, ease of construction, ease of use, and size (below). These characteristics were weighted based on client demands. Dr. Alex Yevzlin requested that the device be self contained and cost under $10. While fulfilling both of these requirements seems impossible considering the cost of the parts needed, (microcomputers are over $100, according to Professor John Webster from UW-Madison) these properties are the most important to Dr. Yevzlin. This is why ease of use, size, and cost are all weighted heavily in the matrix. The reason that the device must be durable (.20) is that patients will be using a stress ball for long periods of time between hospital visits as their fistula matures. Ease of construction is not too important as long as something that works can be eventually built. The project will just have to be continued next semester if it ends up being too complex. Accuracy is also not of critical importance because all that is needed to be known about the patients' squeezes on the stress ball is the frequency and relative intensity. Because it is unlikely that the patient can consciously correct squeezes by fractions of a percent, the device will not have to have that level of precision.

Figure 4



	Design 1 (Piezo)	Design 2 (Pressure)	Design 3 (Wire)
Cost (.20)	7	6	8
Accuracy (.05)	7	8	2
Durability (.20)	6	6	3
Ease of construction (.05)	8	7	6
Ease of Use (.25)	6	8	5
Size (.25)	6	5	6
Total	6.35	6.4	5.35

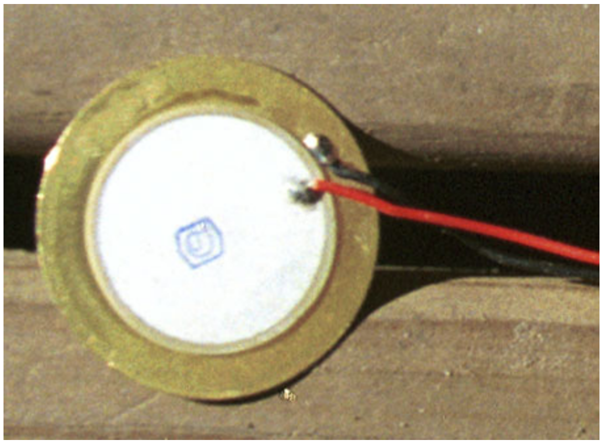
The main reason that the air bladder design had the highest total in the matrix (6.4) is that there is not a directionality problem with having a pressure bulb in the middle of the silicon ball. It is also the most user friendly design because the patient can hold the ball at any orientation while squeezing. The only worries with this design are whether the IOPI bulb can withstand pressures upwards of 50 PSI, and the cost of the pressure transducer. If three piezoelectric sensors were placed in the ball, the patient may have to orient the ball in a particular way while squeezing to ensure accurate readings. The inductive wire design posed a similar problem. It got the lowest score (5.35) because of worries regarding its durability. Inductors within the ball would have to remain at the same orientation and not deform in order to ensure accurate readings. In addition to this, the springs would have to be prevented from coming into contact with themselves or each other. All devices have a low score in the size category because, as of this semester, all designs require LabVIEW and a computer to run.

Early Work

Upon receiving the piezo buzzers and pressure transducer, we began to work with these parts to determine which design alternative we should pursue. We were pleased to note that both the buzzers and transducer were small enough to allow for an appropriately sized final design.

The piezo buzzers (Figure 5) would need to be taken apart in order to harvest the piezoelectric element we were interested in. Unfortunately, they were protected in a solid plastic casing without any cracks or joints to pry apart. To get them open, we cut carefully all the way around the top and separated the piezoelectric sensor from the rest of the buzzer.

Figure 5

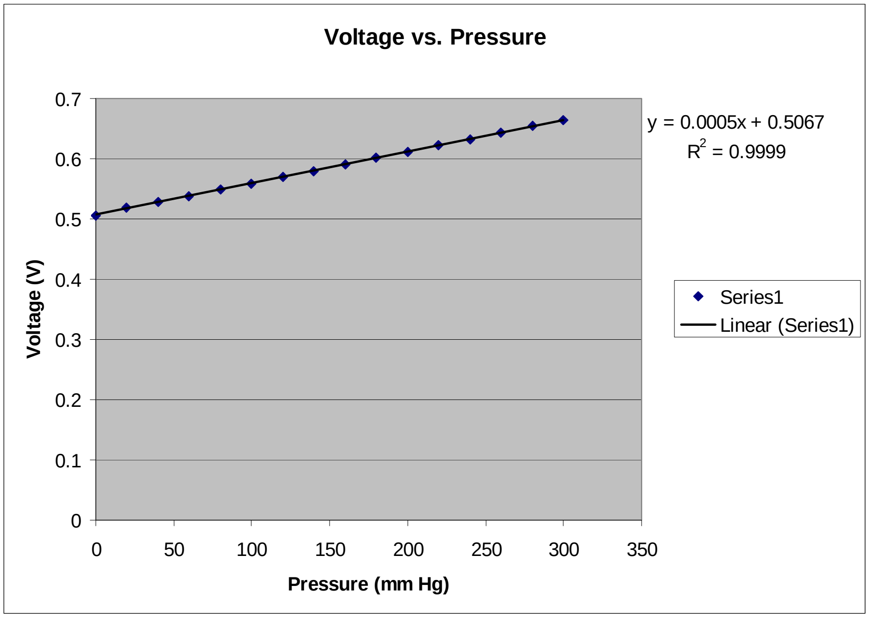


It was immediately apparent that the piezoelectric sensor was very fragile; even though we were as delicate as possible, the wires attached to the circuit board broke off during the above process, taking some fragments of the chip with them. We soldered the wires back on, but they broke again a short while later.

At that time we determined that the piezoelectric design wouldn't be feasible with the sensors from the buzzers. They were simply too fragile to be included in a device that would be subject to substantial external forces. There may be a piezoelectric sensor on the market that would be adequate for our purposes, but this one is certainly not it.

After coming to this conclusion, we turned our attention to the pressure transducer. To our delight the air bladder given to us by Professor Webster fit perfectly onto the transducer, giving a tight seal essential for accurate readings. We then hooked up our transducer to the required circuitry, and began testing by squeezing just the bulb. Using an oscilloscope in the lab we were able to generate the types of waveforms we had anticipated. Next it was essential to create a calibration curve which related applied pressure to voltage output. This was done by hooking up a blood pressure cuff (and the attached pressure gauge) to the transducer with the use of a T valve. By squeezing the blood pressure bulb we could apply a measurable amount of pressure to the transducer and read the voltage output from the multimeter. Performing this basic experiment produced a very nice calibration curve (Figure 6), which is shown on the previous page. It's important to note the .5 volt constant output with no applied pressure, as well as the tight linear fit of the data. This graph details the relationship between voltage and pressure for our device. The differences in voltage that are produced when squeezing the air bladder match up to the corresponding pressure on the calibration curve. Using this we can take out results in volts and accurately convert them to mm Hg (pressure).

Figure 6



Final Design

The final design (Figure 7) is based on the air bladder design mentioned above. It is made up of an IOPI bulb that is hooked up to a voltage pressure transducer and stuck inside a polyurethane, football shaped stress ball. The manufacturer (Omega) recommends that the pressure sensor be run on 5V. Currently, the pressure sensor is programmed with LabVIEW to take voltage and frequency readings ten seconds at a time. The voltage readings correlate to a pressure (Figure 6)**.** The air bladder design was chosen over the piezo electric and inductive wire design for a number of reasons (see design matrix).

Figure 7

Two of the main problems that were experienced with the inductive wire and piezo designs are ease of production and ease of use. The air bladder design was easily constructed by drilling out a cylindrical shaped tunnel and sticking the IOPI bulb inside. The shape of the stress ball is a football so that the subject will naturally squeeze the ball in the right way without having to think about it (Figure 8). The IOPI bulb is then connected to the voltage pressure transducer, which is

Figure 8

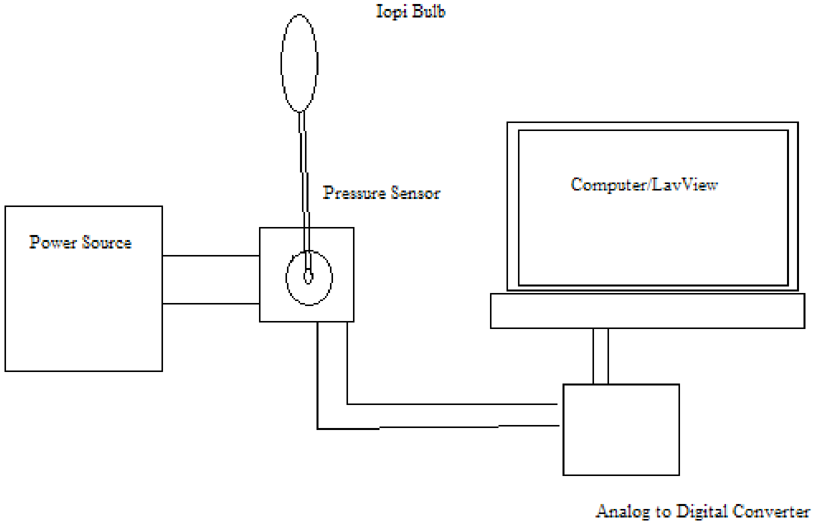
wired (Figure 9) into an analog to digital converter and easily programmed to work with LabVIEW.

The piezo design required the placement of three series of piezo electric plates within the ball so that forces from all directions could be sensed properly. If this were not done, the subject would have to squeeze the ball in a specific way so that accurate readings would be taken. Putting the sensors in a ball and orienting them correctly would be much more involved than with the air bladder design. The sensors that were ordered were much too fragile to be used for our intended purposes. Even if more durable sensors could be ordered, there is no easy way to replace one of them if it did break. A broken sensor would mean a useless ball. While the air bladder may prove to be just as fragile as the piezo electric plates, replacement of a broken bladder would be easy. People that are using the ball could be sent a few extra IOPI bulbs and a little instruction kit that takes them through replacing the bladder one step at a time. While the inductive wire design was never tested, it didn't have to be. It poses the same problems as the piezo design.

The final design is made out of polyurethane instead of silica gel. The material the stress ball that Dr. Yevzlin initially gave us is very problematic. Silicon is more expensive, heavier, and harder to work with than polyurethane foam.

The ball we used is made out of polyurethane foam which costs very little to make, and can be found for under a dollar retail (http://www.ebspromo.com/index.php?main_page=product_info&products_id=302). For mass production, all cavities necessary would have to be incorporated into the mold for the silica gel so that it solidifies into the desired shape, but there is still no guarantee that the ball would hold the shape too well.

Figure 9



The voltage pressure transducer is powered on 5V DC power. As the pressure from the IOPI bulb, which is inside the stress ball, is sensed by the voltage pressure transducer, a rise in voltage output occurs. This is caused by the linear decrease in resistance within the pressure sensor with respect to pressure. This voltage is then sent to the analog to digital converter to be converted to binary notation. The computer can now read the message and programs can organize the data. Figure 9 shows a general design for the circuit and if the object were to be self-contained, the computer and analog to digital converter would be replaced with a printed chip, a microcomputer, and a memory storage device. This memory storage device could then be hooked into a computer with a USB cord for the uploading of data.

Cost of Production

This aspect of our design made our work the hardest. Originally, Dr. Yevzlin asked us to make the ball completely self contained, meaning that a memory device, power source, and micro computer would have to be incorporated into the design. We also inferred that he would want the design to be relatively cheap so that it can be tested on a large number of patients. We later found out that microcomputers cost upwards of $175 and Dr. Yevzlin wasn't willing to help out at all with the cost of our prototype. Because of this, the design has not yet been made to be self contained, so the cost of the prototype is significantly less than a design ready for field testing would be.

Assuming that whoever uses our prototype has access to LabVIEW and a computer, the cost is $65.87. Once the air bladder design was decided upon, the search for the most affordable way to make the device work accurately began. For the reasons mentioned earlier, polyurethane foam, which costs $0.92 per ball, was used. The IOPI tongue bulb costs from $4-5 depending on quantity purchased (Blaise Medical, Inc.). A number of options are available for sensing pressure. The voltage pressure transducer was chosen because it was small, comparatively cheap ($60, Omega.com), durable, and accurate. The cost of individual parts would inevitably come down if the stress balls were to be mass produced.

Figure 10

Material	Cost
Voltage Pressure Transducer	$60
IOPI Bulb	$4.95
Polyurethane Stress Ball	$0.92
TOTAL	$65.87

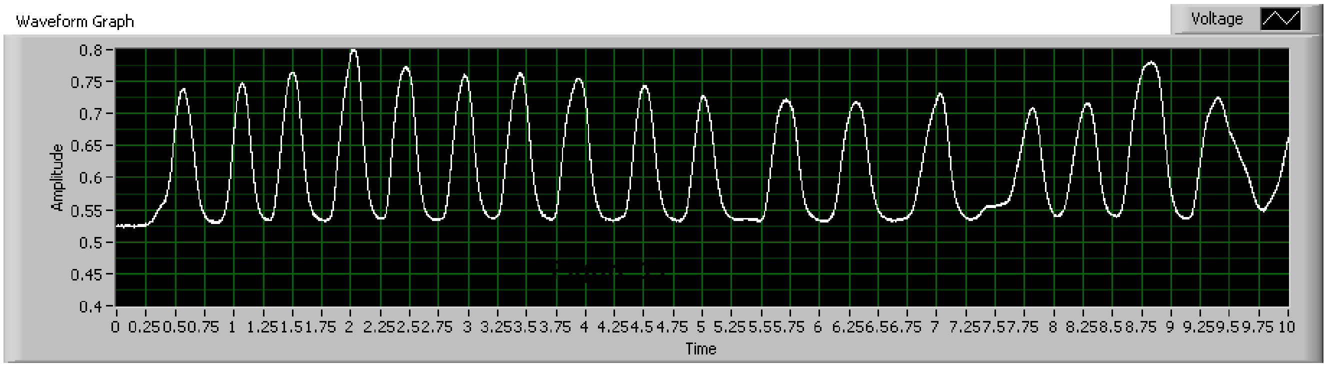
Final Design: Testing and Validation

After selecting a casing for our device, our next goal was to hook our device up to a computer to be able to graphically record and store data. By recommendation from

Professor Webster, we decided to use LabVIEW to present our data. This was extremely difficult for us as none of the members in our group had ever used LabVIEW. To make up for our lack of experience, we decided to work through some of the labs required for BME 310 to help us be more comfortable with the program. We also attended a workshop for beginners using LabVIEW. We then obtained the help of one of the TAs in the BME department, Amit Nimunkar, to help with our LabVIEW problems. Amit helped us greatly and showed us step by step how to write a LabVIEW program to fit our device.

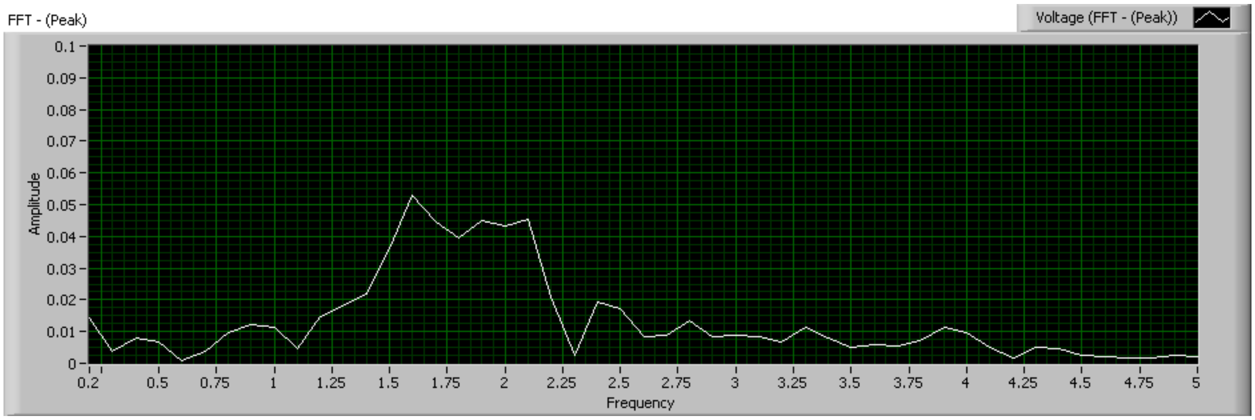
Our first tests consisted of us simply using the ELVIS program to display our data on the computer. We hooked up our pressure transducer according to the circuitry diagram shown earlier. We then ran 5 V through our circuit and repeatedly squeezed our device. We were able to use the program to view voltage differences as our device was squeezed. The ELVIS program was able to show voltage changes but only numerically and not graphically. We did, however, use an oscilloscope to display a graph of our data. The issue with an oscilloscope is that the graph it displayed was a continuous graph showing only the last few seconds of data. The oscilloscope fails to record the amount of data that we need for our device.

After our testing of our device using ELVIS, we decided it was necessary to write our LabVIEW program. As stated above, Amit Nimunkar was tremendous help in writing this program. LabVIEW allows us to record longer periods of time as well as store old data. As of right now, we are less concerned with the data storage which will be a larger issue when we make the device self contained and has a computer chip. LabVIEW allows us to produce graphs of voltage versus time as shown below (Figure 11). Each peak represents a different squeeze, which helps us to accomplish one of our goals of determining the number of squeezes a user accomplishes. We can also measure the voltage difference and correlate it with our calibration curve (Figure 6) to determine the amount of pressure per squeeze, another project goal. The x axis of the graph displays the time which helps us to determine the amount of time spent squeezing per day. The second graph displays the frequency of squeezing (Figure 12).



As of now, we can use our LabVIEW program to meet the goals we set out to accomplish. Our current setup shows the proof of concept we set out to achieve at the start of the semester. Our next step in our work with LabVIEW will be to create a method of long term data storage required by our client. Our device should ultimately be capable of consistently recording data like that in Figure 11 and storing it as well.

Figure 12



Future Work and Conclusions

The next step in our design process is to try to make a self-contained device. During our last meeting with our client we showed him the progress we have made, and he informed us that sufficient funds would be given to us to continue the project – enabling us to purchase a microcomputer and other parts needed to make the device self-contained. The microcomputer kit we will purchase is the BASIC stamp kit for $159.95 (Parallax.com). Our client also informed us that the device no longer had to be shaped like a ball but instead could be shaped like a cylinder. A cylindrical shape will allow the circuitry, microcomputer, memory, power source, and pressure transducer to be stored away from the area where the user would be squeezing the device.

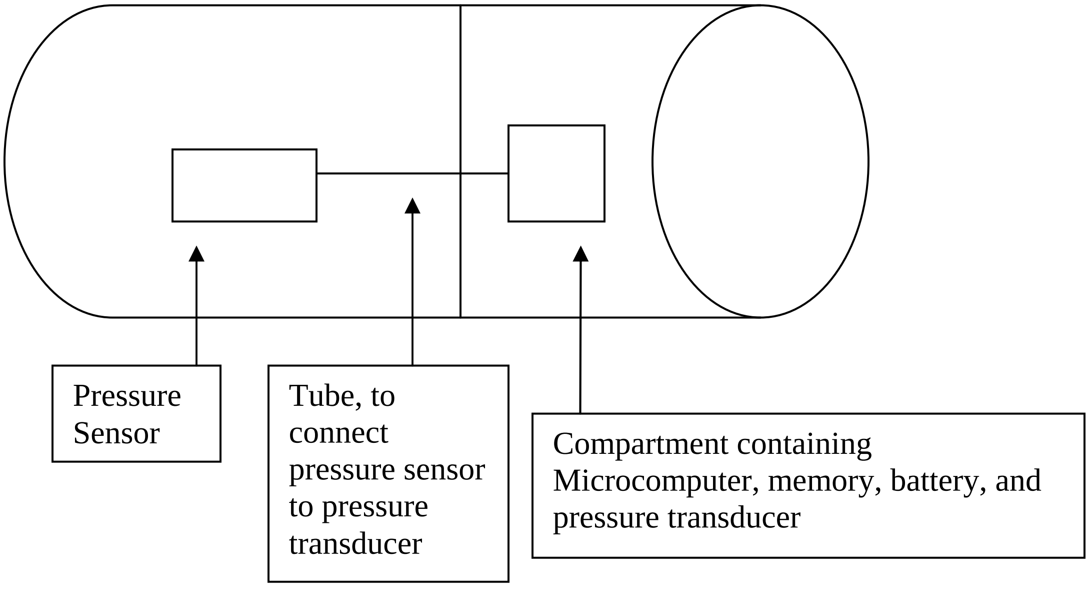
We are using LabVIEW to test our device. In the future, our group will need to balance the space needed for internal software with the space needed for data storage. Our device will need to record and store a week's worth of data from a patient. LabVIEW has worked in our testing of the device, but we are unsure if it's the most effective way to record the data and be able to output the data in the graphical form our client wanted. Our client wants to be able to plug his device into his computer and be able to view the total number of squeezes and the pressure of each squeeze both in graphical and tabular form. We will need to focus on how to sync the device to a computer through the use of a USB cable. More research will need to be done to determine how this can be done.

The material used to fabricate the device has migrated from silicon to a foam material. The team changed the fabricating material because it is easier to work with and we believe is much more cost-effective. In the future, we must determine whether this is the best material to use with special consideration of its durability for everyday use.

In the future the team will have to use a printed circuit in order to eliminate the breadboard we have been using. The printed circuit will then need to be encased in a plastic housing to protect the circuitry. By having a cylindrical shape, the storage can be placed away from where the user is squeezing the device and further protect the circuitry (Figure 13). The cost of a printed circuit board from Parallax is relatively cheap and costs around $5 (Parallax.com). Our team has not yet determined how much power would be needed in order to run all the components of the device. We also need to determine how to incorporate an internal power supply (most likely some type of battery) so the device will no longer have to be powered by an external power source. The device will also need an on/off switch in order to maximize the battery life.

The design has also been based around the IOPI bulb. The IOPI bulb has worked well during our testing; but due to the time constraints we have not been able to test how the bulb's durability. If a leak were to occur in the bulb, the device would not work

Figure 13



properly. Therefore, more testing and research must be done to see if there are other bulbs made of different material that would be more durable.

Our client also informed us that after his research is completed, and he has found the optimal pressure a patient should squeeze at, he would like to have a light on the ball to indicate when the patient is squeezing at that pressure. The research would be done using a working model of the stress ball and recording the data of a patient.

Acknowledgements

We would like to thank a few people who shared their knowledge and/or experience to help us with various elements of our project. We would like to thank:

- Professor Webster, for his help in determining initial design options and general guidance throughout the design process.
- Amit Nimunkar for his help in the BME 310 labs – setting up the circuit to calibrate our transducer, and help with LabVIEW.
- Professor L. Burke O’Neal for his help in selecting an appropriate pressure transducer to order and helping with budget issues.
- Dr. Alex Yevzlin for bringing this idea to us and giving us background information on the topic of dialysis.

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Appendix A: PDS

Product Design Specifications
Hand Exerciser
5/3/08

Team

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Matt Hoffman (BSAC)

Function

Develop a stress ball type hand exerciser capable of recording and transmitting data to be used in medical studies. The stress ball should be low cost and capable of exercising a hand post surgery.

Client Requirements

The device must be able to measure:

- Pressure (PSI) per squeeze
- Repetition of squeezes per time period
- Duration of time spent squeezing

The device should also be:

- Low cost
- Self Contained
- Able to run off internal power source
- Extremely user friendly
- Able to be used by elderly/disabled patient

Physical and Operational Characteristics

a. *Performance requirements*: The device will need to withstand 30 minutes to 60 minutes of squeezing every day. The device also needs to also be able to record pressure, number of, and duration of the squeezes, and be able to output the information.

b. *Safety:* The device should not be used in excess and the patient should follow their doctor's guidelines. The device should not have any external wires and should not present any safety issues.

c. *Accuracy and Reliability*: The device should be within + or – 5% in order to give accurate enough readings for a doctor to see if the patient is showing improvement and completing exercises.

d. Life in Service: The device needs to be able to withstand 30-60 minutes of squeezing a day. The device should be durable enough to be reused, for cost's sake.

e. *Shelf Life*: This device should not have any shelf life requirements that are applicable.

f: *Operating Environment:* Needs to be able to withstand repeated loads and be able to withstand idle times of up to 24 hours.

g. *Ergonomics*: The device should feel comfortable in a person's hand while he or she is squeezing the device.

h. *Size:* The device should be portable and be able to fit in the average person's hand.

i: *Weight:* Device should be of reasonable weight so that a person in questionable health would be able to lift and squeeze it.

j. *Materials:* All materials must be safe and non hazardous, and be able to exercise the patient's hand

k. *Aesthetics, Appearance, and Finish:* The device will have to have a smooth surface that is comfortable to grip. The inner workings of the device should not be exposed.

Production Characteristics

a. Ideally Dr. Yevzlin would like to make a ball that can be given to all fistula patients to monitor their usage. The initial study would require less devices but eventually the production should increase.
b. The target product cost including the cost of the ball and sensors is $100. While the ball does not need to be particularly affordable, the cost must be kept under control so that insurance companies agree to cover it. There aren't any products created specifically for this purpose, but there are contraptions that monitor and record pressure priced as low as $50 and as high as $1000.

Miscellaneous

a. *Standards and Specifications:* The FDA requires that all medical devices that fall under "electronic devices which emit radiation" be regulated. Electromedical devices and ranging/detection equipment fall under these requirements, and therefore our product may require FDA approval.
b. *Customer:* Our customer has indicated a preference for a self-contained device similar in appearance to the current stress ball.
c. *Patient-related concerns*: We want patients to be able to use our device without focusing all of their attention on it. (i.e. a patient should be able to use our product while watching TV). It is unlikely that a patient would stick to a hand exerciser regimen that required them to set aside substantial time for its use.

d. *Competition*: A Google search for “instrumented hand exerciser” yielded a few interesting items. There are currently a few glove-shaped systems, used for physical therapy by post-stroke patients. No handheld products were found, and none for speeding the maturation of a fistula.

Appendix B

Table from calibration curve

Pressure (mm Hg)	Voltage (V)
0	0.506
20	0.518
40	0.528
60	0.538
80	0.549
100	0.559
120	0.57
140	0.58
160	0.591
180	0.601
200	0.612
220	0.622
240	0.633
260	0.643
280	0.654
300	0.665