Operator’s Manual

A Model to Demonstrate Compression Sleeve Technology on the Lymphatic System
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Important Safety Instructions

- Do not turn compressor on when solenoids system is unplugged
- Do not get any portion of the electrical items wet
- Do not run peristaltic pump more than five minutes with all packet outlets blocked off
- Do not pull on any electrical wires
- Do not pull on lymphatic tubing
- Do not touch electrical connections when turned on
- Be careful of any sharp metal items
- Make sure all hose clamps are secured before turning on compressor
Parts and Accessories

Bone

Stagnant Muscle

Air Muscles and Tubing

Lymphatic Packets

Lymphatic Output Tubes

Peristaltic Pump
Features

- Arm can be removed from stand
- Arm can be manually lifted to induce gravity effects
- The pump can work in a forward and reverse direction to input and take out fluid from the packets
- The varying voltages of the system are all controlled by a single adapter
- The skin is removable for viewing of lymphatic packets
- The lymphatic packets are removable for viewing of muscle design
- The solenoid system can be viewed in box
- Model is transportable
- Off switch activates solenoid to output air from compressor to atmosphere to protect against accidental backflow into compressor
- Different types of lymphedema can be demonstrated by closing and opening different packets using the blocks in the output tubes
- Different sleeves can be tested on the device because of its average dimensions and ability to change to different forms of lymphedema
- Different muscle states can be achieved
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1. Introduction

1.1 Overview

This arm model is used to demonstrate and replicate the flow of lymph through the lymphatic system of a person with lymphedema of the arm. This design demonstrates multiple systems on the arm and how they interact with the lymphatic system. The bones, muscles, skin and a compression sleeve all have an effect on the lymphatic system and the flow of lymph through the vessels. The bone system creates a structure for which other systems are able to interact. Additionally, it implements a hinge system giving the arm model the ability to manually move similar to a real arm. The muscle system allows a dynamic change within the arm model. It gives rise to changes in volume of the arm creating pressure forces from within. The skin layer provides an interaction between the lymphatic layer and the compression sleeve, similar to a real arm. The compression sleeve acts as the true parameter to be tested, as its effects are believed to be what reduces the symptoms that relate to lymphedema. The lymphatic system will uses a tubular network that will simulate major vessels of the lymphatic system.

The motion of the muscles and pressure due to the muscle, skin, and compression sleeve can be investigated by this project to let the bones, muscles, lymphatics, skin and compression sleeve all interact with each other. The lymphatic system incorporates different states using the interstitial fluid and lymph flow throughout the arm model to show fluid motion in a normal versus endemic arm. By using a microcontroller and switchbox, the arm is capable of being controlled by the person who is using the model. The switchbox allows the user to choose from multiple states for the arm in relation to muscle excitation and relaxation. The solenoids, in correlation with the microcontroller, allow the arm to change to specific states of excitation or relaxation. This ultimately allows the user to make choices of different states to see how the different states and movements may enhance or inhibit lymphatic flow.

The data and knowledge that is acquired from this model will be beneficial to clients, scientists, and engineers alike. It will display a primitive look at how lymphedema in contact with other physiological systems in the body, can be treated with compression sleeves. This knowledge can be passed on from doctors to patients, to further explain lymphedema, its causes, and effects on the lymphatic system. It will ultimately give a glimpse of how different pressurized compression sleeves will affect lymphedema and the types of treatment that are available to patients. Below, an image of the arm entirely assembled can be seen in Fig. 1.
Fig 1. Entire assembly of the arm.

Assembling Parts Together

1. Starting with bone stand, add muscled arm onto stand having the metal rod inserted into the shoulder side of the PVC pipe.
2. A pin is placed through the muscle and stand and the arm should look as seen here.

3. Begin to place the lymphatic system over the arm starting with the shoulder portion of the lymphatic design at the wrist of the arm.
4. Slowly bring the lymphatic system across the entire arm.

5. Put on the lower arm skin using the Velcro.
6. Put on upper arm skin using the Velcro.

7. Put on sleeve.
8. Insert tubing into pump.

9. Make sure pump is plugged into wall.

1.2 Step-by-Step Instruction On Using Device
1. Begin with the muscle attached to the arm stand.

2. Attach lymphatic system onto the arm by sliding the lymphatic sleeve for the shoulder on starting at the wrist.
3. Continue to slide the lymphatic sleeve on until the lymphatic sleeve for the forearm is on the forearm of the arm.

4. Continue to slide the lymphatic sleeve on until the lymphatic sleeve for the upper arm is on the upper arm.

5. The skin layer is represented by two foam pieces labeled “4” and “5”. This skin is for the forearm.
6. Wrap the foam around the forearm so the Velcro edge matches up with the area that does not have IV bags laying on it. Apply the Velcro.

7. The skin layer is represented by three foam pieces labeled “1”, “2”, and “3”. This skin is for the upper arm.
8. Wrap the foam around the upper arm so that the edge where the velcro ends lays where no IV bags are located. Attach velcro to this edge.

9. The finished result should look like that above.

10. Attach tubing to input and output of the pump.

11. Make sure that the pump’s electrical system is connected to the wall.
12. Have all outlet tubes from the arm blocked or closed.

13. Make sure input of the pump is attached to the input volume container and make sure the output of the pump is attached to the input of the arm.

14. With the pump put to the settings seen above(The switch on the right set to “PRIME”, the knob set to “5”), turn the switch on the left to “FORWARD”. Set timer for 2 minutes at
this moment. At this point, the arm is being set to a “lymphedema state” where the arm is getting filled to a volume of about 180 mLs.

15. When the two minutes is over, turn the pump off.

16. With no fluid outlets open and the pump still off, begin to put the compression sleeve on.
17. At the elbow, run the outlet tube (still blocked) labeled “1 + 4” through the hole in the sleeve and place it back into the “1 + 4” cup.

18. Finish sliding the rest of the sleeve onto the arm.

19. Plug in the voltage supply for the muscle components. Turn the switchbox “ON” and set the switchbox to the desired position of “1”, “2”, or “3” using the knob. Note that Position “1” leaves the arm in a relaxed state where no air is administered to the arm muscles, Position “2” puts the arm in a state in which the arm continually extending and relaxing itself by activating and deactivating the triceps and the extensor located on the lower portion of the arm, and Position “3” puts the arm in a state in which the arm is continually flexing and relaxing by activating and deactivating the flexors, brachioradialis, and biceps.
20. The Arduino should be seen to be on if the green light is activated on the Arduino board.

21. Additionally, depending on state chosen, the two smaller solenoids should be either lighting up alternatively or just singly and constantly. If they are alternating lighting up, one of the larger solenoids should be clicking as well indicating that the valve is opening and closing correctly.

22. Make sure the compressor’s pressure is set to approximately 40 psi (1.9 kPa).
23. At this point, the compressor switch should be off.

24. Turn the compressor on using the switch.

25. Set the peristaltic pump so that the switch on the right is “FAST” and the knob is set to “5”.
26. Set the peristaltic pump’s switch on the left to “FORWARD” and set timer for 2 minutes.

27. Immediately unblock all outlets into their corresponding cups except for outlet 8, which represents the damaged axillary node.
28. After two minutes have passed, turn pump off by setting the switch on the right to the middle.

29. Also immediately close all fluid outlets.
30. Turn the compressor off and unplug the muscle voltage supply.

31. Once the outlets are blocked, set the switch on the right on the peristaltic pump to “PRIME” and set the switch on the left to “REVERSE.”
32. Measure the volume output of the fluid from the various cups and compare to other states.

2. Maintenance

*Electrical Maintenance*

**Compressor**
- Make sure the compressor is turned on when performing tests involving muscle activity
- Make sure no water ever touches electrical components of compressor

**Solenoids** (Never perform maintenance on solenoids while they are plugged in)
- Make sure solenoids are always mounted onto the box and are not loosely moving within box. If not, may require the remounting of solenoids to inside of box
- Make sure solenoids electrical areas are never touching. If they are, secure and remount solenoids so they are no longer touching
- Make sure no wire connections on solenoids are loose. If they are, may require resoldering of wire connections
- Make sure the wire connections to the solenoids never interact with water

Arduino Uno (Never perform major maintenance on Arduino while the voltage supply is plugged in)
- Make sure that the Arduino has all the correct connections on it
- Make sure Arduino light is turning on when voltage supply is plugged in
- Make sure connections are not too loose on the Arduino’s pins
- Make sure the Arduino never comes in direct contact with water

**Mechanical Maintenance**

**Compressor**
- Make sure compressor is connected to the air muscle tubing
- Make sure the knob valve on the compressor is open
- Make sure to never run the compressor while the solenoid system is shut off
- Make sure that the pressure gage on the compressor does not exceed 50 PSI
Lymphatic Design
- Make sure fluid is running into and out of the peristaltic pump.
- Make sure the peristaltic pump maintains the correct speeds on the knob and switches during procedures.

Air Muscle Design
- Make sure that the hose clamp connections on the tubing up to the air muscles are all tightened to ensure that when the compressor turns on, the tubing does not fly off.
- Make sure all air muscles are connected to the air muscle tubing or the air muscles will not fill up.
Micellaneous
-Make sure a timer is available to run the protocol

Environmental Maintenance
Compressor
-Make sure that the pressure gage on the compressor does not exceed 50 PSI

Lymphatic Design
-Make sure that the bags are drained after each use using the peristaltic pump
-Make sure that the input volume container is full to establish a constant pressure at the input
-Make sure output tubes are always exiting to an output cup
-Make sure IV bags are never leaking
-Make sure all surfaces, especially the arm stand are wiped off from any excess fluid to ensure the wood of the arm stand is not warped.
-Make sure that outlet tubes are blocked off so that when fluid is taken out of the arm using the peristaltic pump, it is not taken out of the output cups and excess fluid does not need to be retained

Switchbox
- Make sure that the switchbox is on when running a test
- Make sure that the knob is set to the correct position for muscle activity

Skin Design
- Make sure that the skin layer is fully secured
- Make sure that the foam is never exposed to extremely frigid temperatures—it may freeze

3 Technical Description

Solenoids
The solenoids, seen in Fig. 2 as diagram representations of flow are used as valves to open and close air to the system. For these solenoids, when the solenoid is turned on, the valve is opened to allow air into the system. The two solenoids being used are called a 3/2 solenoid and a 2/2 solenoid. The 3/2 solenoid means that the solenoid has three ports through which air can flow through, and 2 ways in which the air can flow. The 2/2 solenoid means that the solenoid has two ports through which air can flow through but only two ways which air flow occurs.
Figure 2. (A) A 3/2 solenoid, or the larger solenoids in this project. Displaying two states of airflow in the diagram and (B) A 2/2 solenoid, or the smaller solenoids in this project. Displaying two states of airflow in the diagram.

When Arduino supplies a small voltage to the transistor, the transistor jumps to a state in which the solenoids can also be activated. As previously written, both solenoids are capable of taking on two ways in which airflow can occur. For the 3/2 solenoids, when 24 volts are supplied to the system, the solenoids turn on and the solenoids are capable of taking air in from the 2/2 solenoids and passing it on to the air muscles. The port labeled “E”, is exhaust, which is used to empty out air into the atmosphere when deflating. This port is closed. Therefore, no air can escape when the port from the 2/2 solenoid is open. This is seen in the box on the left of Fig. 2, part A. When the Arduino does not supply a voltage, the transistor switches to a ground state and the solenoid is not supplied 24 volts. When this occurs, the box on the right of part A of Fig. 2 occurs. Air can freely flow from the air muscle to the exhaust and out to atmosphere. A similar occurrence happens for the 2/2 solenoids, which are supplied 12 volts. When the Arduino sends out a voltage to the 2/2 solenoid, the transistor activates allowing 12 volts to power through the 2/2 solenoids. This cause the two ports on the 2/2 solenoid to open and for air to freely flow from the compressor to the other port of the solenoid. This is seen in Fig. 2’s Part B on the left-hand side. Alternatively, when the Arduino applies no voltage, the transistor remains in a ground state causing the solenoid to remain without voltage. This causes the two ports of the 2/2 solenoid to close allowing no movement of air through the solenoid. The two 2/2 solenoids are used together where one is used to open and close to the 3/2 solenoids and the other is used to open and close to the atmosphere. This is done so no backflow will ever occur while the solenoid system and compressor are both on.

A total composite of the flow of air through the solenoids can be seen below in Fig. 3.
Figure 3. A diagram of airflow through the solenoids.

The solenoids have three connections on them. Two connections are in parallel with a diode, which prevent current from going back into the transistor and breaking the transistor. One of the connections is directly supplied to the voltage source (either 12 volt or 24 volt) while the second connection is connected to the collector pin of the transistor with the other pin of the diode. The third connection, typically found lower than the other two connections on the solenoid, is the ground, or common. This is used to prevent electrocution. However, it is heavily advised that the solenoid not be touched when powered in case these preventative measures fail. It is especially important not to touch these metal connections on the solenoid when the power is on as they carry a high voltage and current that can be a major risk to one’s life.

Compressor
The compressor is used to take low-pressure air and turn it into high pressure air. This is typically done by supplying a certain amount of work to the system in the form of a fan. The compressor is connected to a power supply that plugs into the wall. This power gives the fan the ability to move, which in turn, supplies the proper amount of work to the system to create a high-pressure air output. The compressor being used is capable of converting air at atmospheric pressure to as high as 125 psi (6 kPa).

Peristaltic Pump
A pump is used to take a low pressure liquid, such as the water, and convert it to a high-pressure liquid. In the case of the peristaltic pump, the pump interacts externally to the tubing pushing rather than pulling the fluid via pulsations of the tubing causing pulsatile flow within the tubing. This causes a heartbeat-like movement within the lymphatic system.

Diodes
A diode is a two-terminal electronic component. In one direction there is a zero/very low resistance to a current flow. In the other direction there is a high/infinite resistance to current flow. The function of a diode is to allow an electric current to pass in one direction (forward direction) while blocking current in the opposite direction. This behavior is called rectification and it can be used to convert alternating current to direct current. 1N4004 diodes are used in the circuit of the arm model to prevent current kickback from the solenoids to the transistor, which is connected the Arduino microcontroller. The diode essentially acts as a safety mechanism for the important electrical components of the system.

![Figure 4. An example of a diode used in the circuit.](image)

**Transistors**

A transistor is one of the electrical components used in the circuit diagram for the electrical portion of this design. The function of a transistor is to act as an amplifier by increasing an electrical signal. In addition it can serve as a switching device within the circuit for processing and storage of information switch. This is accomplished by using a small amount of electricity to control a gate on a much larger supply of electricity.

Transistors are composed of three parts: a base (B), a collector (C) and a emitter (E). The base is the gate controller device for the larger electrical supply. The collector portion collects the large electrical supply, and the emitter is the outlet for the supply.

![Figure 5. An example of a Darlington Transistor.](image)

In the electrical design of the arm model, Darlington TIP102 transistors were used as a switching device between the Arduino board and the solenoids.
Switches
The switches on the switchbox were implemented to allow the user to interface with the design in an easier fashion than manually opening and closing valves to the air muscles. The switchbox contains three separate switches.

Fig 6. The switchbox.
The on/off switch contains three connections. The pin of the on/off switch that is golden is the ground. The other two switches are used to power and connect to the Arduino to turn the system on and off. One switch is directly connected to a 5-volt source. The other is connected to an input into the Arduino. If the switch is powered “on”, then this 5-volt source travels through one pin, into the other pin, which is connected to the input of the Arduino. This activates the Arduino to put it into a state where different muscles states can be chosen. Alternatively, if the switch is powered “off”, the input pin is connected to the ground, where ground is defined as a zero-voltage source. This inputs zero volts into the Arduino telling the Arduino that it should not be activated, and therefore not allow various muscles states to be chosen. Instead, the Arduino will activate so that the 2/2 solenoid will turn on to open to atmosphere in case the compressor is accidentally switched on. A picture of the underside of the switchbox with the on/off switch boxed out can be seen below in Fig. 7.
The reset button contains two connections. One connection is set to ground while the other is connected to the “Reset” pin on the Arduino. If the button is pressed, the Arduino program resets. This essentially means that the program will start again at the very beginning and assess the state of where all the knobs are set on the switchbox. It is a safety precaution in case any connections go awry and the system needs to change to a different muscle state immediately. However, the only way it will truly change is if other knobs or switches are chosen as well. The underside of the switchbox can be seen below with the reset button boxed out.
The position knob on the switch contains thirteen pins. Maximally, the knob could have allowed six different states for the system to choose from. However, because the design only required three states, pins were connected together so that they would represent the same position. For this reason, each muscle position clicks twice before it is set into a different muscle position. A pin in the center of the underside of the knob is called the pole. The pole is supplied five volts of power at all times. The three positions are hooked up to the ground, or are in other words, set to zero. However, they are also hooked up to three separate inputs into the Arduino. As the knob turns to each position, the five volts from the pole will power through the selected position. While the other two positions still have zero volts being sent through them, and therefore have zero volts going into the Arduino, the one position selected will have five volts that run through to one of the three input pins on the Arduino. Because the Arduino is able to read this voltage input and is programmed to react to it, this will cause the Arduino to output five volts to whichever transistors will activate the desired solenoids. The underside of the switchbox can be seen below with the position knob boxed out.

![Figure 9. The underside of the switchbox. Focusing on the reset button.](image)

**Arduino**

The Arduino is used as the brain for the dynamic muscle system of this project. The Arduino has a program that has been inscribed onto it so that when the Arduino is powered into an “on” state with five volts of power, it is capable of running this program. The Arduino is powered on when the component referred to as the “On Light” seen in Fig. 10 is turned green. The Arduino had a program that was written for it and input into it using a basic USB to printer cable that also works on the Arduino. This cable is plugged into the “USB to Arduino Connection” seen below. Once the program is run once on the Arduino, as long as the Arduino has a five-volt power supply, it will remember the program until it is overwritten with a new program. The Arduino must be hooked up to a five-volt power supply as well as ground in order for the Arduino to be properly controlled and run. They are plugged into the pins called “Voltage Input” seen below.
Also noted from below, is a manual reset button. This can be used alternatively to the reset button on the switchbox. However, it will contain the same effects as the switchbox. Also shown is the reset button input that is used for the switchbox. Though the Arduino inputs five volts, it is also capable of outputting those five volts to other components within the circuit. This is achieved by using the pins called “Voltage Output.” Initially, when running the design to test the switchbox, this was used to power the “on/off” switch and position knob. The section labeled “Input/Output Pins” is used to by the Arduino to interact with other components on the board. The restriction in these pins is that they do not output to the Arduino any more than five volts. If they were to, the Arduino may become damaged. However, if the component were to be acting as an input into the Arduino, it would be supplying input voltage into the Arduino to communicate with the Arduino’s program (not to supply a voltage but to tell the Arduino that it is activated). Alternatively, the Arduino may use the pins as outputs. In this case, the Arduino outputs five volts to the component connected to this output pin. Any of the pins may be used as inputs or outputs once the program identifies them this way. If the program is not written to identify them this way, the pins will not act as an input or an output as desired.

Figure 10. Arduino schematic.

A full-scale description of the connections made to the Arduino are shown below (but is given again in the Troubleshooting Section for reference) in Fig. 11. In the figure below, “Position 1 Input”, “Position 2 Input”, and “Position 3 Input” all are inputs from the switchbox that are
received by the Arduino. If the input passes five volts into the Arduino, this puts the input pin into a state of known as “HIGH”. If this is done, often the Arduino reacts by outputting to other output pins. For example, if the switchbox is changed to “Position 2” using the knob, it is used as an input pin on the Arduino and five volts are passed into that input pin of the Arduino. The Arduino’s program reacts to this by running a part of the program that is used to activate the extensor and triceps muscles on the arm. This program knows to turn solenoids 1, 2, and 3 on and off for varying amounts of time. The Arduino does this by outputting five volts to the specified output pins that are denoted as the specific solenoid output pins (in this case, “Solenoid 1 Output”, “Solenoid 2 Output”, and “Solenoid 3 Output”). This, in turn, activates the transistors, which activates the solenoid to turn on for however long the output pin is activated. However, when the position knob changes to a different position, “Position 2”’s input pin would no longer be supplied five volts by the pole on the position knob. Because zero volts are now flowing through “Position 2’s” input pin, it is denoted as “LOW”. This causes the Arduino program to stop output to solenoids 1, 2, and 3 and change to a different part of the program that is now being activated, such as the first or third position knobs.

![Arduino schematic](image)

**Figure 11. Arduino schematic.**

The “On/off Input” is an input pin on the Arduino that reads from the “on/off” switch. If five volts from the “on/off” switch is activated to connect to the “On/off Input”, the Arduino will activate the program that can be used to changes the muscles into varying states.
Unlike the input and output pins in the upper section of the picture, the “5 Volt Input” and “Ground Input” are not necessarily treated to interact with the program. Rather they are a voltage supply to the Arduino, keeping it on as already denoted. As stated before, the “Reset Input” is used so that the Arduino program will go back to the beginning of its run-state using the button on the switchbox.

Printed Circuit Board
The printed circuit board, or PCB for short, interacts with the program used on the Arduino. The PCB contains all the components that will act to turn the solenoids on and off, the components that convert the voltage supplied from the wall’s voltage to different voltage values (the Arduino’s five volt input as well as the solenoid’s 12 volt input), and contains the connections to the switchbox before they output to the Arduino.

The PCB is valued as an ideal component when finalizing the design because of the wire connections, known as traces, are imprinted onto the board. For this reason, they are immobilized and the connection is never lost as a result of movement of the PCB. This is more ideal than the testing board previously used because when moving the boards, wires are easily disconnected. Additionally, the board allows items to be soldered permanently onto the board ensuring a good connection. However, resoldering may need to occur over time due to the solder wearing down over time.

In Fig. 12, the finalized PCB can be seen where the red denotes the traces that are found on the bottom of the board and the green denotes the traces found on the top of the board. The traces on the bottom of the board are the initial voltage inputs from the voltage supply. These two voltages are the ground (a common, zero voltage input into the board) and the 24 volts. The 24 volts are supplied to the board, passing directly to the two 24-volt solenoids and diode in series with these 24-volt solenoids but then also sent to two separate regulators on the board. The two regulators are used to change the value of the voltage that may be supplied to certain components on the PCB or Arduino. The “5 Volt Regulator”, seen below is supplied the 24 volts and then passes its supply of five volts to what can be seen below as the “Position and on/off connections”. Additionally, it passes onto a pin in the bottom left of the PCB that connects to the Arduino—this is the Arduino’s power supply. Alternatively, the 24 volts pass to the “12 Volt Regulator”, which changes the voltage that is output through the trace to 12 volts. These 12 volts are seen to be supplied to the 12-volt diodes but the 12-volt solenoids as well. The ground supply connects to many different components on the board. The trace of the ground can be followed in the red and can be seen to attach to components including, the resistors used in the “Position and on/off connections”, “5 Volt Regulator”, “Transistors for 24 Volts”, “Transistors for 12 Volts”, and “12 Volt Regulator”.

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For the image of the real PCB seen in Fig. 13, without any components soldered in, the Arduino’s connections can be seen in the lower left hand portion of the PCB. Additionally, the three solenoid inputs for the four solenoids can be seen. On the PCB, there is a label to denote the ground pin for the solenoid connection and the other two solenoid inputs.
**Voltage Supply**
The muscle system and Arduino system requires a 24 volt supply that is used as 24 volts but is also converted to supply 5 volts and 12 volts. The power supply can be seen below in Fig. 14.
Air Muscles

The dynamic muscles of the arm model are represented pneumatic air muscles for the biceps brachii and triceps, brachioradialis, flexors and extensors. The pneumatic air muscles are made up of an inner rubber tube of 3/8” in (9.52 mm) inner diameter and 1/2 in (12.7 mm) outer diameter cut to length of the specific muscle. Over the rubber tubing is Techflex® 1/2 in clean cut nylon mesh sleeving. This outer mesh can stretch width wide to a certain point, allowing the air muscle to inflate to that certain amount and hold a fully inflated shape. The rubber tubing and mesh are placed on a 3/8 in x 3/8 in (9.52 mm x 9.52 mm) hose barb on one end to allow air in, and a 3/8” bolt on the other end to keep the air inside. The rubber and mesh are held onto the bolts and barbs by small metal hose clamps. An image of what a typical air muscle looks like that was created for this design is shown in Fig 15.

![Image of the air muscle.](image)

Figure 15. Image of the air muscle.

To operate the air muscles, a 3/8 in (9.52 mm) diameter tube must be connected to the hose barb that attaches to an air supply. When the air supply offers enough air pressure 30-40 psi (207-276 kPa) the rubber tubing of the air muscle inflates to the size allowed by the mesh sleeve (contraction). When air supply is shut off or removed from the muscle, the muscle deflates and moves back to a relaxed state.

Lymphatic System

The lymphatic system was created off of the following schematic:
In the above image the blue boxes represent the lymphatic packets. The lymphatic packets model groups of lymph nodes in different areas of the arm. There are four packets for the upper arm and four packets for the lower arm, where four of these are oriented along the top portion while four are spread across the bottom portion to represent lymph nodes in those areas. Each lymphatic packet is connected by two tubes, representative of the input and output vessels. These tubes are made out of C-FLEX® tubing (Model Number 190-026-001, IL, USA), with a 3/32 in. (2.38 mm) inner diameter. There is one initial input tube that starts at the wrist of the shoulder and through a series of branching reaches each of the lymphatic packets. The input tube is connected to a peristaltic pump, which by input of the user, can send fluid into the arm variable speed and flow to cause different states of edema.

Each packet also has its own output tube with the exception of packets 1 and 4, which have outputs connected together by a y-connector that drains at the elbow. The rest of the packets have their own tubes that come out of the shoulder. All output tubes have a valve on the end, allowing fluid output to be either turned on or turned off. When the valve is shut off, fluid drainage is blocked from the packet, and fluid must either drain to other packets via the input tubes or stay in the packet causing a swelling in the area or in essence “lymphedema”.

Skin
The skin layer is manufactured out of polyeurathane foam (Quick-Recovery Super-Resilient Foam, Very Soft, Plain Back, ¼” Thick: McMaster Product # 86375K212). The use of the very
soft 1/4 in (0.635 cm) thick skin was based off the data for arm thicknesses displayed in Table 1 below.

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<th>Lower Arm</th>
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</table>

Table 1. Data discussing thickness of lower arm and upper arm.

The final firmness of the polyurethane foam was estimated to fall into the “Very Soft” category listed on the McMaster-Carr website given the firmness or deflection was 1-5 psi (6.89 kPa - 34.47 kPa) which was in the range of soft tissue firmnesses documented based off of two researched articles discussed in the final report.

The skin layer is broken up into lower arm skin and upper arm skin. The lower arm was divided into two skin strip sections, where the upper arm was divided into three strip sections. These strips were then cut to conform around the designated area. The strips of the lower arm and strips of the upper arm are sewn together stay in place and to keep correct order. The strips are secured around the arm using Velcro strips attached to each end. This allows the skin to be removable if need be.

4 Troubleshooting
It is advised that if the arm model is not working that the maintenance section be looked over and considered before troubleshooting process begins.

Circuit Testing
Arduino and Circuit Connections
One thing to check is to make sure that the solenoids, switchbox, and voltage supplies are set to the correct pins on the Arduino seen in Fig. 17. They should be set as below. To make sure that these connections are correct, reference the PCB to see if the traces labeled on Fig. 18 and Fig. 19 are going to the correct output.

Figure 17. Arduino Schematic.

Figure 18. PCB Schematic
Checking Voltage
To check the voltage on the PCB, use a multimeter and change it to a voltage reading. Place the black lead on the white circle as seen on each of the pictures below. Given the system is turned on, set the red lead to various locations on the PCB. Given the position that the knob is set to, the following values should read off the multimeter given the various position it is set to seen below in Figs. 20-22.
Figure 20. Voltage schematic of PCB when position knob is set to position 1.
Figure 21. Voltage schematic of PCB when position knob is set to position 2.
Figure 21. Voltage schematic of PCB when position knob is set to position 3.

Checking Soldering Connections
If any connections seem to be loose, the connections can be resoldered with either new braided wire or the original piece.

Peristaltic Pump Testing
If the peristaltic pump is not working properly, first check all electrical connections to make sure it is properly connected to a voltage supply, this includes the plug to a wall socket and the entrance to where the power supply enters the pump shown below in Fig. 22.
Input and output tubes must be manually connected to the pump. Therefore if fluid is not flowing correctly through the system a couple items must be checked. First, make sure all the tubing openings are securely attached to the peristaltic pump barb, if there is leakage at the connections of the tubes, they are not fit tightly enough.

If fluid seems to stop flowing through the pump while the pump is still on, make sure the input bucket is not empty and no air is getting into the tubes. If the fluid seems stuck in the tube, the pump can momentarily be turned to reverse, and then turned back to the forward position to try to get the flow to continue.

**Skin Adjustment Testing**
The skin must be properly secured onto the arm to apply the correct pressure to the model. The skin foam has been cut to appropriate size to offer this pressure to the arm. To make sure the skin layer is attached properly, the edges of each foam strip must touch and align properly. The Velcro strips attached to the end of the foam must be completely covered by the top Velcro piece provided. Extra caution must be taken when applying the skin layer, as it is prone to tearing if one is to pull at it too hard. Make sure to use only the ends covered in electrical tape when pulling the foam into place. If Velcro strips become loose, some type of adhesive, such as super glue can be applied to the backing to reseal the strips.

**Air Muscle Leakage Testing**
Sometimes when pressure buildup occurs, the air muscle’s connections will begin to lose strength and detach from the air muscle. For this reason, the air muscle may require reassembly. To reassemble, undo the hose clamp on the air muscle and replace the bolt or hose barb that has fallen out by using needle nose pliers to attach the silicone tubing to the bolt or hose barb. Use an adhesive such as gorilla glue to reapply the bolt or hose barb to the tubing. Gorilla glue the mesh to the tubing and then attach the hose clamp to the design. Let dry for approximately 24 hours before testing air muscle unit again.