DESTRUCTIVE AND NON – DESTRUCTIVE RING REMOVAL DEVICE

Mid-semester Report BME 301

Team Members
Tyler Allee – BWIG
Sujan Bhaheetharan – Communications
Steven Noel – BSAC Representative
Evan Rogers – Team Leader

CLIENT
SCOTT SPRINGMAN, MD
PROFESSOR OF ANESTHESIOGLY (CHS)
UNIVERSITY OF WISCONSIN MEDICAL SCHOOL
DEPT. OF ANESTHESIOLOGY

ADVISOR
PROF. WILLIAM MURPHY, PhD
DEPT. OF BIOMEDICAL ENGINEERING

Problem Statement

An improved method is needed to remove rings from a patient's swollen finger. Rings are valuable for emotional and monetary reasons to patients and they would ultimately like to have them back. Currently, it is necessary to push, prod, and hurt patients while trying to remove rings. Removal is necessary because some surgeries have a high risk of inducing generalized body edema, including fingers. If the finger swelling is too great, the blood supply to fingers may stop and potentially lead to gangrene. When is necessary to cut off the ring, an instrument that severs one part of the ring exists. We will create a mechanical device that will allow the ring to spread open easily without pinching the patient's fingers. Traditional "tricks" exist to try to reduce tissue water in the finger to help remove an un-cut ring. We will develop a process that may include these, while creating a new device to aid in ring removal.

Motivation

Our client expresses a concern with current methods used in the hospital to remove rings before surgeries or MRI examinations or in the event that the finger is injured causing finger edema. Current methods either don't have a high success rate or are cumbersome and time consuming. These methods likely end up destroying the ring and causing frustration for the nurse or doctor. Sometimes unnecessary pain is caused to the patient by the process and the person trying to remove the finger can be injured if the ring slips in the process of being pried apart. Therefore, the need to develop a need method that makes is easier for medical professional to remove ring is needed.

Background Information

Potential risks of circulation problems and gangrene infections exist if rings are not removed; it is necessary to remove all rings prior to surgeries. Difficulties with this procedure arise when the patient's finger is swollen. If pressure builds up behind the ring, blood will not flow to the distal end of the finger. Two main problems cause this inflammation: finger edema and arthritis. Finger edema (Figure 1) is the buildup of fluid in the intercellular spaces of body tissues [1]. Because the swelling in the finger is due to fluid, it can be compressed. This is the case where a non-destructive method would be utilized to remove the ring.

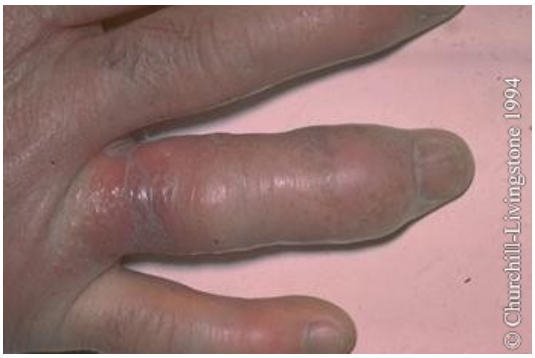

Figure 1 - Finger edema shown in a patient with a swollen finger
<http://www.worldortho.com/database/exam-orth/photos/eo0028.jpg>

The second disorder adding complexity to the ring removal procedure is arthritis. In its most basic form, arthritis is a disease that causes joint surfaces to wear away. In the fingers, specifically, arthritis leads to the development of nodules, shown in Figure 2, around the knuckles made up of bone spurs [2]. Because the enlargement of the finger is due to bone rather than fluid, it is not realistic to compress the finger down to a size where ring removal can be conducted. In situations such as these, it is

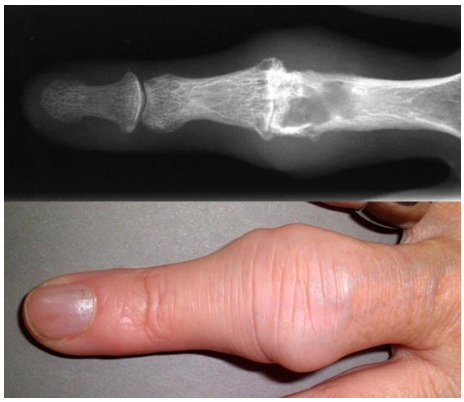

Figure 2 - Finger arthritis shown in a patient's x-ray (top) and gross anatomy (bottom)
<http://www.pncl.co.uk/~belcher/images/PIPJ%20arthropathy.jpg>

necessary to use a destructive method to remove the ring. Although it is mandatory to make a cut in the ring, damage to the ring is kept to a minimum. This allows the patient the option of soldering their ring together after it has been removed.

In order to create a prototype for the non-destructive methods, it is necessary to determine upper and lower limit physiological parameters for the region being studied. These limits form a window in which the force that is generated must fall. The upper limit is based on the sheer strength of bone, 68MPa [3]. Bone was selected as the upper limit because the pressure created must be smaller than the amount it takes to compress and crack bone. The lower limit is based on instrumental compression for arm and leg edema, and it is 6.67 kPa [4]. The contact surface areas of the arm and leg are much larger than the area of a finger. Using the relationship of pressure being equal to force divided by area, it is reasonable to assume this pressure should be more than enough to compress a finger.

Current Methods

Depending on the specific situation of each finger, three methods are currently used to remove rings. For fingers non-permanent swelling, finger edema, the surgical glove or string method is considered, because the finger is easily compressed to make it easier to remove the ring. Fingers enlarged due to arthritis require a destructive method since there is no way to reduce the size of the knuckle to remove the ring. This is done with a commercially available ring cutter. These methods can be assisted by common, “tried and

true” methods of lubrication, tissue temperature reduction, or elevation to help reduce the size of the tissue and muscle of the finger [5].

The string method consists of methodically wrapping a string from the distal end of the finger, towards the ring. The wrapping of the string causes a simultaneous force application to the finger, pushing excess fluid out of the finger and thus reducing the size of the finger [5]. The string is then fed under the ring and pulled toward the distal end of the finger. This causes the string to unwrap, forcing the ring to come off which can be seen in Figure 3**.**

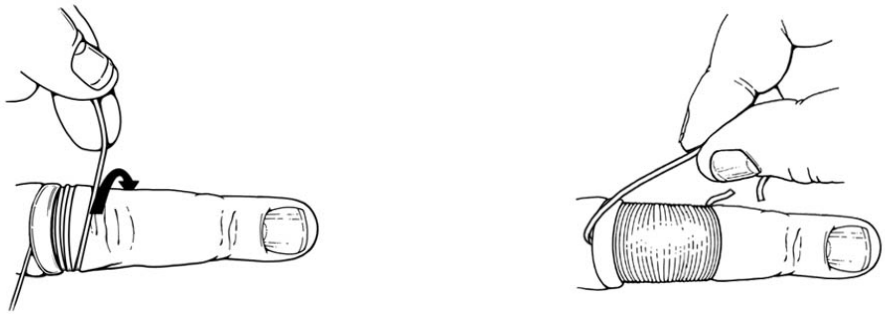

Figure 3 – Application of the string method. The string is wrapped around the finger (left) and then fed under the ring (right), allowing the ring to be slowly removed by unwrapping the string.

Although the string method may be effective, it is limited by numerous factors. The string method is limited by arthritis, and it can cause patient discomfort during its process. In addition it requires a high degree of patience and ability on behalf of the person executing the method.

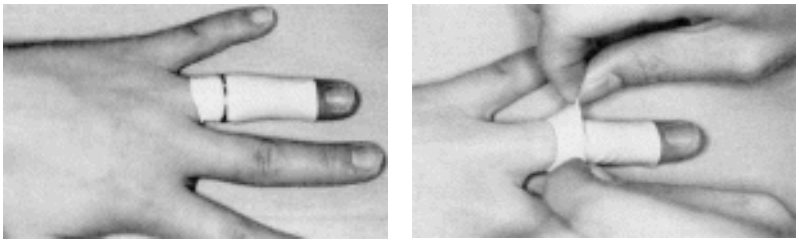

Figure 4 – Application of the surgical glove method. A finger is removed from a glove and thread underneath the patient's ring (left). The glove is then wrapped back over the ring to remove it (right).
<http://www.anesthesiology.org>

The surgical glove method consists of feeding a single finger of the glove under the ring on the patient's swollen finger. The glove, after it has been fed under the ring, is then pulled back over the top of ring, and is pulled towards the distal end of the finger. Similar to the string method, pressure is applied simultaneously to cause the finger edema to reduce in size [6]. This procedure forces the ring off the subject's finger as shown in Figure 4. Nevertheless, it is very difficult to feed the glove under the ring because the space between the ring and the finger is tight and requires compression of the tissues to fed the glove underneath. Due to the elastic properties of surgical gloves, there is a high probability for the glove to fail when undergoing immense tensile and compression forces. This technique is also limited by arthritis.

When the ring must be destroyed, a ring cutter is used. The device used to cut the rings (Figure 5) is only used to cut the ring at one end. Opposing sides of the ring are not cut in order to avoid possible permanent destruction to the ring. Once cut, the ring is then pried open, and carefully removed. The ring can then later be soldered back to together [7].

Figure 5 –Shown above is the device used to cut one side of the ring.
<Courtesy of Dr. Scott Springman>

Although the procedure of cutting the ring is straightforward, prying the ring apart is difficult. It is possible that the ring may snap back during the process and injure the patient or the doctor.

Common methods, such as lubrication, tissue temperature reduction, and elevation are occasionally used alone to attempt to remove the ring. These unaccompanied methods provide a low rate of success when serve edema occurs and are as well limited by arthritis.

Product Specifications

The constraints for our design were developed around the physiology of a human finger, the patient, and features that the client would like to see in the final device. The first and most vital of these parameters is patient safety and comfort. Developing a device that may potentially cause harm is not an option, as there are current methods that are successful without harming the patient. However, our device will be applying substantial pressure to the finger to reduce swelling, and may cause slight distress. Our device must use the minimum amount of force needed to properly compress the finger so the ring can be removed, while minimizing patient discomfort.

The ring removal device must not take a high degree of difficulty to use for proper operation. The design must incorporate ergonomic factors in the final prototype. The string method is relatively successful at removing rings, but it is not widely used and is unpopular with doctors and nurses because of the high degree of skill required. The

device must also expedite the current removal process. Ring removal is performed in emergency rooms, so time can become a key factor. For example, we want to improve upon the string method, which takes a long time for wrap the entire finger. We would like our device to take less than a minute. The device must also be cost-effective.

Taking into account for permanent swelling and client suggestions, two devices will be designed, created, and tested. One device will be utilized along with the ring cutting device and will accommodate for permanent enlargement of the knuckles due to arthritis. A non-destructive method will be designed for the case in which the swelling of the finger can be reduced in size.

Design Solutions

Design 1 – Nitinol Sheath

The first design is for the non-destructive method. This design employs the use of a shape memory alloy. Shape memory alloys have two characteristic phases, an Austenitic and a Martensitic phase. The difference between these two phases is the structure of the molecules. In the Austenitic phase the molecules are arranged in a hard cubic structure. In the Martensitic phase there is a change in structure that allows the bonds between molecules to be deformed.

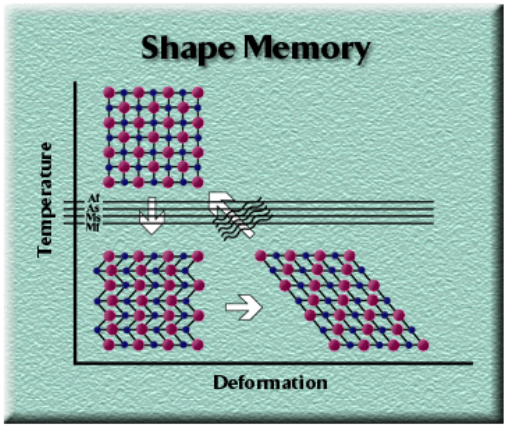

Figure 6- When the alloy is below the Austenite Finish temperature, it is in the Matensitic phase and the bonds are easily deformed (two bottom pictures). When the material is heated up, it returns to its original form. The cubic structure of the Austenitic phase is shown top left.
<http://www.nitinol.com/3tech.htm>

The phase between the Austenitic and Martensitic phases happens at a temperature known as Austenite Finish (A_f) temperature. A_f temperatures are around 15° C, depending on the amount of other materials added.

Below the A_f temperature the alloy is in the Martensitic phase. When the alloy is in the Martensitic phase it is easily deformed and the deformation is kept until the alloy is heated above A_f. During heating, the bonds in the alloy reform to make a more cubic structure and the alloy returns to its original shape. The change between phases generates a useable force and strains up to 8% can be recovered, hence the name shape memory alloys. They can be elastically deformed and they always return back to their original memory shape [8].

Our design consists of a deformable made of Nitinol that can fit over the finger. Nitinol is the trade name for a shape memory that is comprised of equal weights of Nickel and Titanium. Since the force that can be produced by the deformation is unknown, we have two possible ways to use the force produced by the Nitinol cylinder. If the force generated is high enough to expand an uncut ring or severed ring, a cylindrical tube that has a radius greater than the finger will be used. The tube will be deformed in its Martensite phase to fit underneath the ring. One of the constraints of this

Figure 7- Cylinders of Nitinol are shown above. The proposed design would have the cylinders deformed to fit underneath the patient's ring and expanded to allow the ring to be removed.

design is the thickness of alloy we can make. If the alloy is too thick it will not fit under the ring, so this idea would not work. Once the alloy is threaded under the ring, the patient's hand will be placed in warm water, returning the Nitinol cylinder to its Austenitic phase. Since the Austenitic phase has a diameter larger than its deformed state, an outward force will be produced to expand either an uncut or a cut ring. This design is highly dependent on the thickness of material able to create sufficient force to deform the ring.

A tube with a radius smaller then the finger will be used, if we can control the amount of force and get a value close to our lower limit of 6.67 kPa we will use the Nitinol to compress the finger. The shape memory alloy will be stretched to fit over the finger and placed either right up next to the ring or underneath it. The alloy will then be heated and returned to its memory state. The radius of the cylinder will be smaller then the current finger radius, thus compressing the finger. If the material is thin enough to fit under the ring, the ring could slide off over the top of the alloy when the cylinder shrunk. If the material is too thick and cannot fit under the ring a tourniquet must be used on the forearm. The tourniquet will be used to stop the flow of blood back into the finger once the alloy is removed from the finger. After the alloy is removed and while the tourniquet is still in place, the ring can be removed from the finger due to its reduced size from the Nitinol sheath.

Design 2 - Polyurethane Compression Sheath

The second design is a polyurethane compression sheath, and is very similar to the surgical glove method. However, the polyurethane sheath is fed under the ring using plastic hooks. The plastic hooks are not sharp enough to injure the subject and assist in threading the finger sheath under the ring (Figure 8).

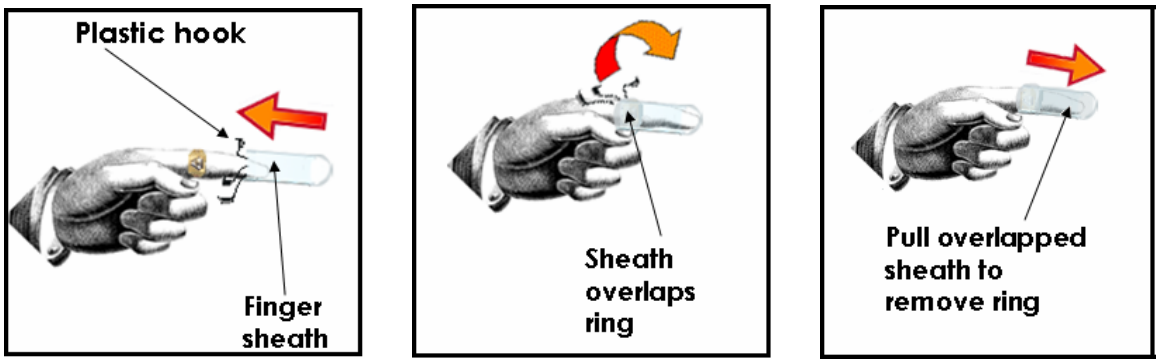

Figure 8- A series of three images displays the polyurethane method of ring removal

Once the finger sheath is threaded underneath the ring, the polyurethane is pulled back over the top of the ring towards the distal end of the finger. The tensile force created when the sheath is pulled distally creates compression forces circumferentially inward along the long axis of the finger. This phenomenon is due to the material acting with respect to its Poisson ratio, which states a material shrinks in one direction when it is elongated in an orthogonal direction (Figure 9). The compression forces will allow contraction of the edematous tissue from the patient's finger. The finger sheath will undergo various stress concentrations, and therefore will be designed with varying

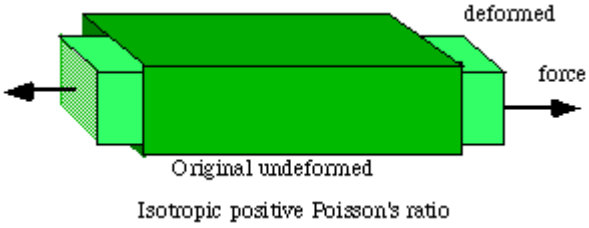

Figure 9- Depicted above is the property of the Poisson's ratio when a material is deformed. As the material is stretched on the long axis, the material shrinks on the short axis.

thicknesses to accommodate for differing stress concentrations. Polyurethane has a high elasticity value of 11.7 [9]. In addition, it has a high shear and stress value and has been shown to be able to possess a Poisson's ratio greater than 1 [10]. These properties allow the material to respond in a flexible manner, as well as providing a stronger material than the surgical glove.

Design 3 – Ring Spreader

When a patient with arthritis needs a ring removed, there is no option but to cut the ring. The ring cutter, as mentioned before, only cuts the ring on one side. This cut then requires the ring to be pried open. The proposed device will use a hand crank design (Figure 10) to allow hospital personnel to remove the ring.

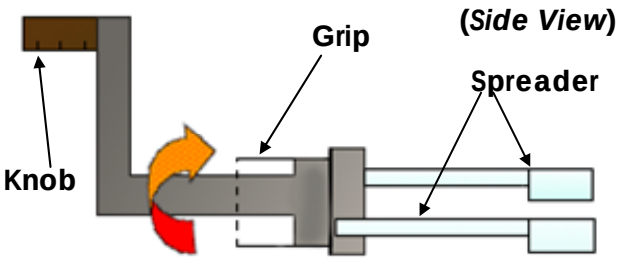

Figure 10- Side view of ring spreader. The patient will hold the spreader at the location of the knob and the arrow on the grip.

The main component of the design is a gearbox that will contain a gear that will separate the ring using the thin plates on tracks inside the box (Figure 11). These plates will slip underneath the ring on either side of the patient's finger. A ratchet mechanism will be included in the gearbox so that the spreaders cannot slip, thus eliminating potential harm to the patient.

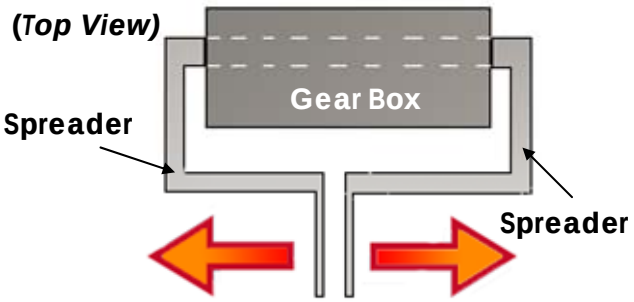

Figure 11- Frontal view of ring spreader showing the motion of the spreaders when cranked relative to the gear box spreading them.

The location and design of the spreaders must be so as to be long enough to reach underneath the patient's fingers and keeping the box far enough away from the finger to avoid any possible injury.

The proposed spreader will consist of:

- Knob – Designed ergonomically to fit the hand
- L – Shaped piece – Attaches to knob as well as has male end of rotating gear box
- Grip – Fixed, female piece that allows the user will hold while rotating the knob
- Gear Box and Gear – Contains a gear that will rotate at an incremental pace and allow it to slowly slide the spreaders along the tracks opening the ring
- Track -- Contains the attachment points for the actual spreader plates
- Spreader plates – Made of a material that will allow them to be very thin while still being able to withstand the large amount of force required to separate the ring.

Alternative Evaluation

Both destructive and non-destructive devices are required for the project. The ring spreader has been selected as the destructive device. An alternative design for the destructive device is shown in Figure 12. The device worked as a hand clamp with the user providing the force to clamp down the

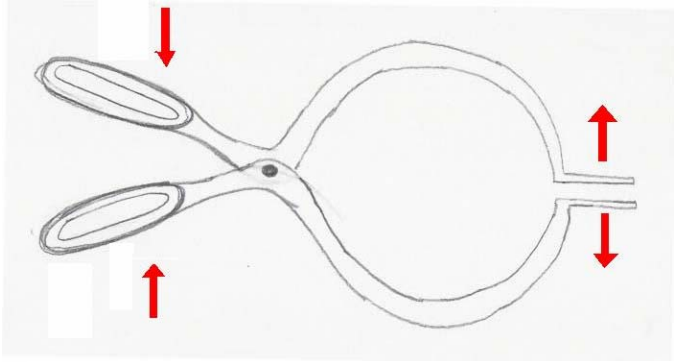

Figure 12- Alternative ring spreader design

grip, forcing the ring open. This design was modified because a more incremental approach was requested. The strength needed to operate the incremental device will be much smaller than the hand clamp model. The initial design of the ring spreader did not include a mechanism to prevent slippage. The gear box design was modified to include a notch lever to catch the gears if they were to buckle.

The non-destructive device analysis was more difficult to discern between. The Nitinol design offers us an innovative and fresh outlook to solving the problem. If the cylinder was coupled with common methods, the chances of success are higher. The polyurethane design expands upon the current surgical glove method. Intuitively, a material stronger than the current surgical gloves will give an advantage to creating sufficient force to compress the finger inflammation. Both ideas are still currently being pursued until the feasibility of one is dismissed. The polyurethane method will be pursued as the top choice for the non-destructive method. If the Nitinol presents itself as a viable alternative, the design focus will shift back to it.

Future Work

The designs for the destructive device need to be finalized with dimensions and material to be used to construct the devices. Construction of an early prototype will allow for easier communication when discussing the device. This will allow for an enhanced material property selection process with information gained from material experts. After

proper materials are selected and acquired, a final prototype will be created for testing. Our client will supply rings obtained from his colleagues for testing the rings.

The non-destructive method for the future will hinge largely on the force produced with each device. In the case of the polyurethane the amount of force we can produce will depend upon the maximum tension we can apply without material failure. The tensile force we need to apply might be too high to get a proper circumferential force and the polyurethane will fail. If this is the case we will have to rethink our idea or find a stronger material. The problems with the Nitinol design are relatively the same. We are unsure the circumferential compression force that can be produced because the actual thickness of material has yet to be determined. There is also work to be done on the process by which each of the devices can be made. We have not looked into forming methods of polyurethane. As for Nitinol we might just be able to use an already made tube with a constant radius, but this is unlikely the case since the finger size varies along its long axis. Therefore, a tube with a greater diameter towards the distal end will need to be produced, which could turn out to be costly. Where as most polymers like polyurethane are easy to work with and can be formed into many shapes easily.

Along with the devices we produce we want to develop a method of using our device to increase the probability of removing the ring. This includes icing the finger, lubrication, or elevating the hand in order to reduce the swelling as much as possible before our device will be used. We must also test all of our design to ensure success in removal of rings. Changes will be made to our design to fix any problems that may be encountered.

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