DESTRUCTIVE AND NON – DESTRUCTIVE RING REMOVAL DEVICE

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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 prefer removal of the ring without damage. 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 there is a need 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 or physician's fingers. Traditional "tricks" exist to try to reduce edema 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 without destroying the ring.

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 snaps shut in the process of being pried apart. Therefore, there is a need to develop a new method that makes the process of removing a ring easier for medical professional from a swollen finger.

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.

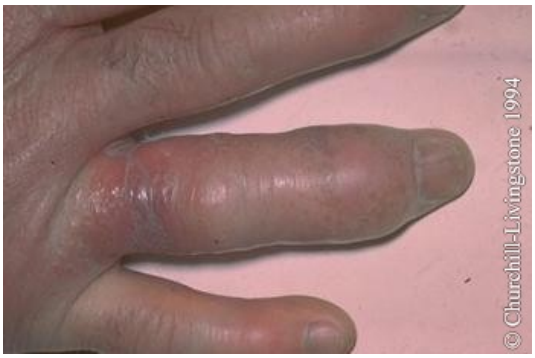

Figure 1 - Finger edema shown in a patient with a swollen finger
<http://www.worldortho.com/database/exam-orth/photos/eo0028.jpg>

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 necessary to use a destructive

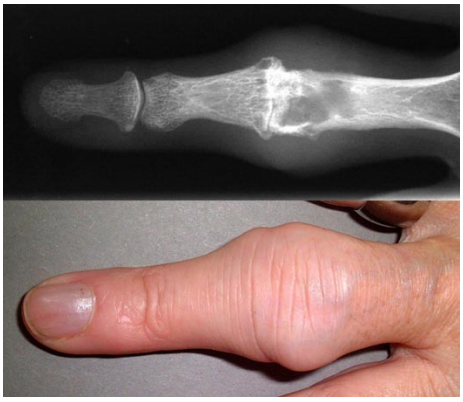

Figure 2 - Finger arthritis shown in a patient's x-ray (top) and gross anatomy (bottom)
<http://www.pncl.co.uk/~belcher/images/PIPJ%20arthropathy.jpg>

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 of pressure we can apply without cracking the bone in the axis perpendicular to the long axis. The bone will mostly break at the edge of the device were there is a boundary between compressed and uncompressed bone. The boundary will cause a sheer stress at that interface. The lower limit is based on instrumental compression for arm and leg edema, and the amount of force need to compress edema in the arm or leg was 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 non-permanent swelling, finger edema, the surgical glove or string method is considered, two methods that are used to aid in the removal of a ring without destroying the ring. These methods will be discussed later. These methods work 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**.**

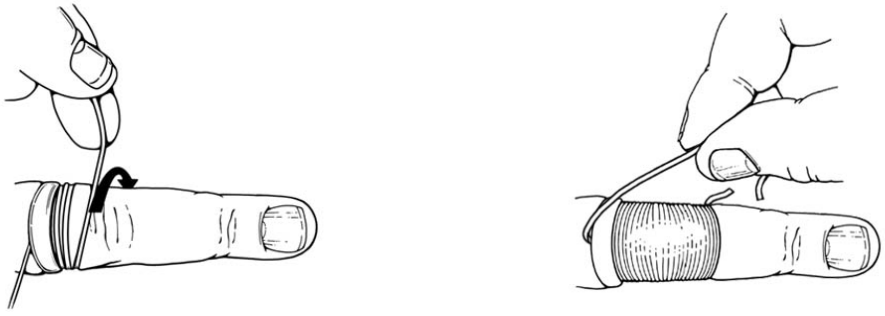

Figure 3 – Application of the string method. The string is wrapped around the finger (left) and then fed under the ring (right), allowing the ring to be slowly removed by unwrapping the string.

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.

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].

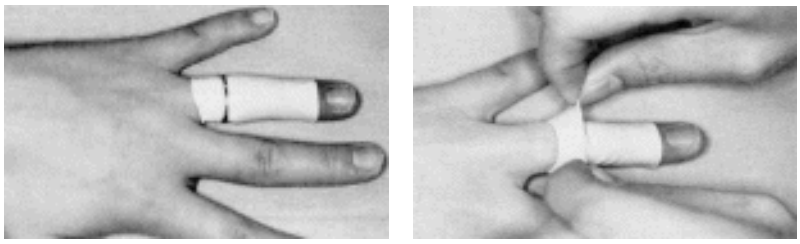

Figure 4 – Application of the surgical glove method. A finger is removed from a glove and thread underneath the patient's ring (left). The glove is then wrapped back over the ring to remove it (right).
<http://www.anesthesiology.org>

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 feed 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 since the enlarged knuckle can not be compressed.

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. The ring cutter works by sliding a protective metal guard on the ring to prevent cutting of the tissue. The guard and cutting wheel are squeezed together using the handle. Then the hand operated cutting wheel is turned and along with the clapping done motion the ring is cut. There is a motorized model of this device but it is not widely used. Opposing sides of the ring are not cut in order to avoid

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

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]. Although the procedure of cutting the ring is straightforward some rings are difficult to cut due to their material properties and the procedure may take several minutes. In additions prying the ring apart is difficult. The small space that cutting the ring provides makes prying the ring difficult. Also, will prying the ring apart there is possible that the ring may snap back during the process and injure the patient or the doctor.

Common methods, such as lubrication to help reduce the friction between the ring and finger, tissue temperature reduction to slow blood flow to the finger thus reducing the swelling, and elevation which gravity help to slow blood flow and drain excess fluid 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 designs will be used in a setting where quick responses are crucial. If a ring needs to come off of a patient's finger, there is not time to debate the removal. The designs need to be able to be used quickly and easily so as to not limit the nurses or doctors in anyway. 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 in expensive, because we don't want to design a high tech device that will cost much more than would be reasonable to fix this minor problem. We would like to keep our prototype under $100, so our production price would we lower than $100.

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. The temperature that separates the Austenitic and Martensitic phases is known as the Austenite Finish (A_f) temperature. A_f temperatures are around 15° C, depending on the amount of other materials added.

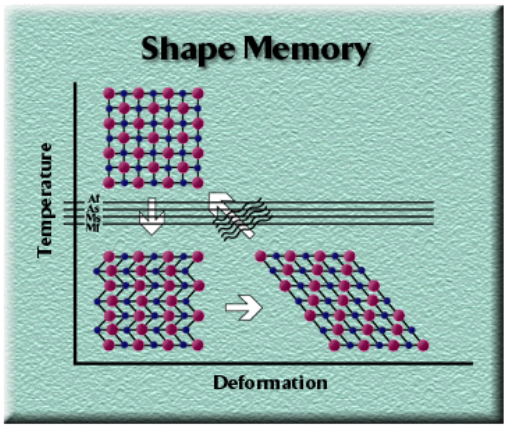

Figure 6- When the alloy is below the Austenite Finish temperature, it is in the Martensitic phase and the bonds are easily deformed (two bottom pictures). When the material is heated up, it returns to its original form. The cubic structure of the Austenitic phase is shown top left.
<http://www.nitinol.com/3tech.htm>

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.

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 tube made of Nitinol that can fit over the finger. Nitinol is the trade name for a shape memory alloy 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 using the force produced by the Nitinol tube. 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 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.

If the force that the Nitnol produces is small than or upper limit, bone shear strength, a tube with radius smaller than the finger will be used. The tube will be used to compress the finger so the ring can be removed. 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 – Latex Balloon

For the non-destructive method we chose to adapt the surgical glove method to become more efficient and effective. We used a latex water balloon to replace the glove because the properties of the balloon better suited the ring removal process. The pressure is focused at the neck of the balloon, which is where the maximal swelling exists, immediately distal to the ring. Latex water balloons would cause greater constriction of the finger tissue and fluid in comparison to the glove currently used in the non-destructive method. The pressure in the finger of a regular latex surgical glove is evenly distributed throughout the material. The material structure of latex water balloons is inhomogeneous. It has a greater thickness at its head (opposite end of open end) then its neck (area between head and open end). This being the point of contact with the finger tip allows the balloon to undergo immense elastic forces and not rip easily.

The process will consist of four major steps. The balloon will be fashioned in a way that allows for it to be rolled onto the finger, similar to a condom. The progressive application of the balloon will force the fluid towards the proximal end of the finger, pushing the swelling behind the ring. Once the base of the balloon reaches the ring, a surgical clamp can be used to both push and pull the balloon underneath the ring. The balloon offers an advantage in this area when

compared to the glove method. The lip of latex around the base of the balloon is flexible, yet durable. Because of this fact, it will not tear when pulled through by the clamp. Following this step, the finger will be placed in ice water for two minutes. The cold temperature of the water will cause a decrease in the swelling of the finger. The finger will then be dried off, and a lubricant will be applied to the exterior of the balloon. The balloon is added before the water entry, so that the balloon can shrink along with the finger. This application will reduce the friction between the latex and the ring. The lubrication must be water-based because oil-based lubricants can damage the latex. KY Jelly is a potential substance that could be used. The ring will be rotated, while being pulled towards the tip of the finger to remove it. Similar to the lubrication, the rotation minimizes friction between tissue edema from the patient's finger and the ring. Due to the combination of the compression from the balloon, the reduction in swelling from the water, and decrease in friction from the lubrication and rotation, removal will be easily facilitated.

When initially designing the non-destructive prototype, a new elastic material was thought to be needed. Therefore, due to latex's elastic properties and the fact it is readily available, three forms were analyzed: small latex water balloon, regular size latex water balloon, and general purpose latex finger cots. To understand these materials properties better, the Young's modulus (25.1) of 3% agarose gel solid was used to represent the finger properties [11]. The materials were then tested upon a non-swollen finger. Compression forces and elastic properties of the materials were measured at increments of 5% the initial length on the finger. Multiple trials were conducted. None of the materials caused the subject pain, irritation or marks. Using Young's modulus equation and data gathered through experiments, the force of application can be seen in Figure 9.

	Small Latex Water Balloon	Regular Latex Water Balloon	General Purpose Latex Finger Cot	Latex Finger Glove
Compression Forces upon Finger (Newtons)	0.006	0.0039	0.0022	0.002

Figure 9- Applied compressive force on subject's finger by three materials

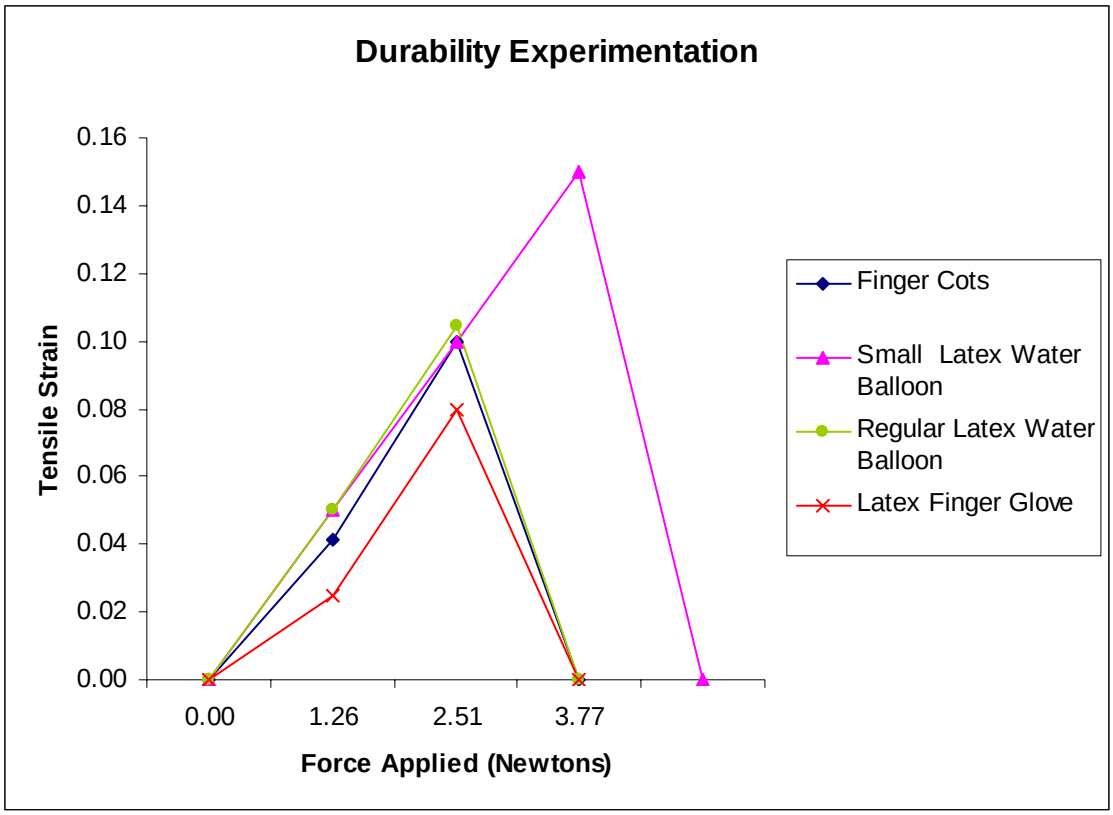

Figure 10- Tensile forces vs. Applied Forces to three materials

In measuring the material's tensile strain, it was concluded the small latex water balloons could undergo a significant amount elastic strain, which can be seen in Figure 10. In comparison to the other materials, the small latex water balloon provided the greatest amount of compression forces to the finger. With such great elastic and compressive force strengths, the small latex balloon was chosen as the best option for removing the ring as a nondestructive method.

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 in order to be removed. The proposed device will use a hand crank design to allow hospital personnel to remove the ring.

The design was created to give the user maximal mechanical advantage of approximately 10 times the input force due to the dimensions of the device. The device will also spread the ring 0.130 inches for every tooth on the gear, which is 14.5 degrees of rotation of the handle. A computer rendering of the design is shown in Figure 11. 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. These plates will slip between the parts of ring that have just been cut. The design consists of a fixed handle, connecting piece and gear shaft. The gear inside the box is fixed to the shaft by a set screw inserted to keep the gear fixed. The gear shaft is inserted inside a large cylinder that is fixed to the faceplate of the gearbox. The large cylinder will be the place where the user holds the device and keeps it steady. The user will rotate the handle in a clockwise direction, thus causing the gear to move the gear racks in opposite directions. This

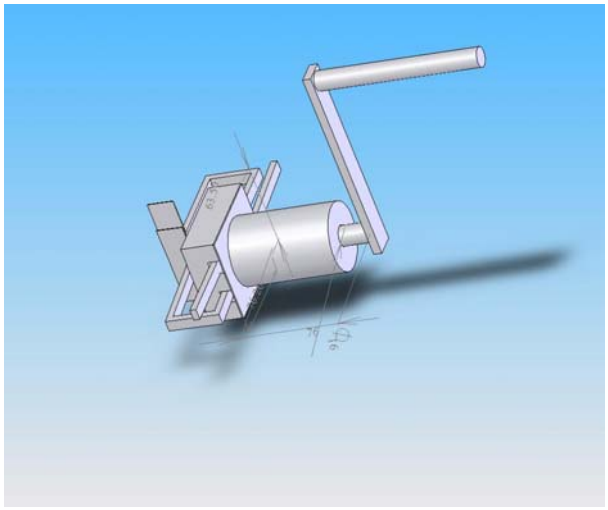

Figure 11 – SolidWorks rendering of destructive device prototype.

movement will cause the spreaders welded to the end of the racks to open the ring. A ratchet mechanism will be included in the gearbox so that the spreaders cannot slip, thus eliminating potential harm to the patient still needs to be designed an implemented.

The device was fabricated of steel of varying carbon contents. We used steel because of relatively inexpensive price, machinability, and weldability. If we had more money we would probably use aluminum for all parts that do not have high stress applied to them to cut down on the overall weight of the device. The parts where extra stress is applied would use stainless steel for its strength and anti-corrosive properties. All the parts for the prototype were purchased from McMaster-Carr and a list of the parts are in Figure 12.

Part #	Part	Material	McMaster-Carr Order #	Price
1	Gear	Plain Steel	6325K81	$7.81
2	Racks	Steel	6295K13	$23.96
3	Gear Shaft/ Handle	W1 Tool Steel	8890k91	$10.12
4	Gear Box/Face Plate/Spreaders	Low Carbon Steel	9517K1	$5.86
5	Grip	12L14 Carbon Steel	90075K311	$17.68
6	Cross Member	Low-Carbon Steel	8910k847	$28.15
7	Spreader Plates	Steel	9516K122	$11.55
8	Flat Point Standard Socket Set Screw	Steel	COE Machine Shop	FREE
			Total	$105.03

Figure 12- A detailed parts list of materials used to build the prototype purchased from www.McMasterCarr.com.

The gear box was fabricated on a mill machine to cut the excess material away for the starting material from Part # 4 with dimensions 3.0 inches X 2.495 inches X 1.0 inch. The dimensions of the material removed are shown in Figure13.

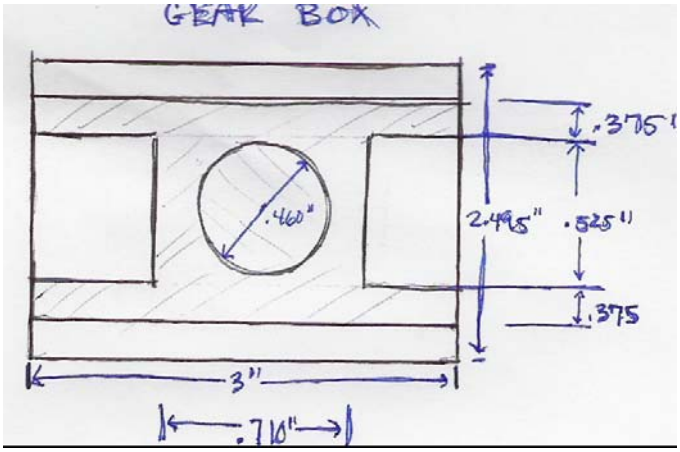

Figure 13- Drawing and dimensions of gear box.

The depth of all the pockets are 0.375 inches except for the center hole which is 0.75 inches deep to accommodate for the part of the gear without teeth to fix the gear in two directions in the same plane. The face plate was cut from the same material as Part #4 with the same dimensions but with a thickness of 0.250 inches. In addition a circular hole was cut out of the middle to allow the gear shaft with a radius of 0.3 inches to be placed through it. The gear shaft and handle were cut from Part #3 with lengths of 4.0 inches and 5.0 inches, respectively. The gear shaft was lathed down at one end to fit inside the gear and the gear was secured to the shaft with a set screw. The grip was cut from Part #5 with a length of 4.0 inches. A hole was lathed out in the center with a radius of 0.6 inches so the gear shaft could run through it. The two gear racks were cut down to a length of 4.0 inches. The spreaders were cut from Part #4 with the dimensions seen in Figure 14. Everything was welded together to get our final prototype which can be seen in Figure 15.

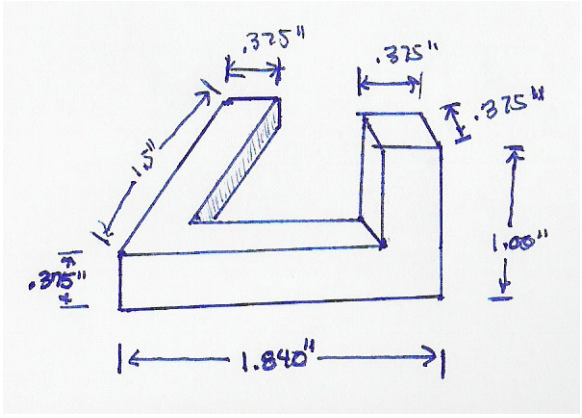

Figure 14- Spreaders

Figure 15a- Gearbox

Figure 15b- Gear shaft and gear

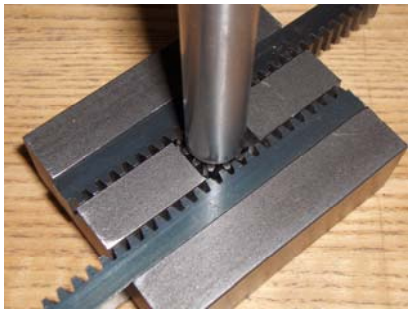

Figure 15c- Gearbox with track and gear shaft inserted into box

Figure 15d- Gearbox covered my face plate and grip around gear shaft

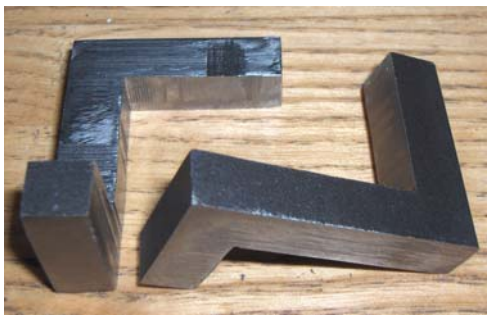

Figure 15e- Spreaders

Figure 15f- Spreaders connected to spreader tracks

Figure 15g- Full assembly without spreaders.

Evaluation of Alternatives

Both destructive and non-destructive devices were 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 16. The device worked as a hand clamp with the user providing the force to clamp down the grip, forcing the ring open. This is a much easier design than the spreader device, but a more incremental approach was requested by the client. 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.

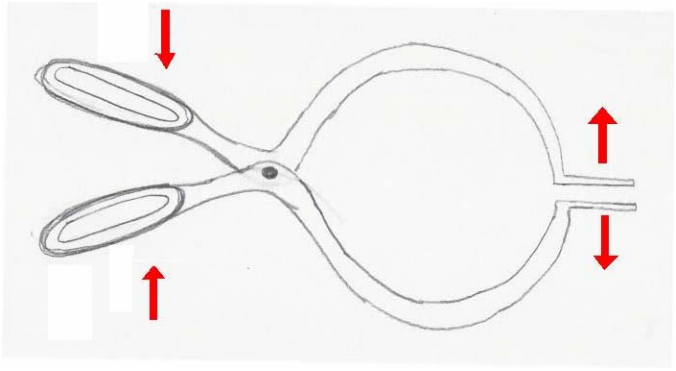

Figure 16- Alternative ring spreader design

The non-destructive device analysis was more difficult to discern between. The Nitinol design offers an innovative and fresh outlook to solving the problem. If the cylinder was coupled with common methods, the chances of success are higher. The latex balloon design expands upon the current surgical glove method. Intuitively, a material is stronger than the current surgical gloves will give an advantage to creating sufficient force to compress the finger inflammation. The latex balloon design was pursued as the top choice for the non-destructive method. The Nitinol device was not feasible for the amount of time and money available. The latex balloon was a simple alternative to the problem, but a custom made balloon specifically designed for the purpose of removing rings provides a better solution.

Future Work

A different material could be applied to the balloon concept developed. A more durable material, such as polyurethane, could be a future route for this project. Similarly, an adjustment could be made to the base of the balloon. A small wire inserted into the lip at the base would allow hooks to be inserted. These hooks would make it easier for the latex to be pulled under the ring. Due to the wire, significant force could be applied to the pull without tearing the lip.

Testing the non-destructive prototype on swollen fingers that do not require the destructive method will allow us to see if the device is accurate and efficient. Increasing the material's tensile forces by reconstruction of the material properties would allow even further constriction of the fluid and muscle in the finger, allowing greater ease to removing the ring. Nevertheless, subject injury must be avoided when adjusting material property.

The destructive prototype must be tested with a platinum ring, as this will be the most difficult material to spread. After the prototype has demonstrated the ability to separate platinum, the device will be able to used on human subjects in a hospital setting. If the prototype were to be rebuilt, weldable aluminum offers advantages over the steel that was used. While it is more expensive, the device will be much lighter and therefore easier to use. The aluminum will also be more corrosion-resistant than the steel used to create the initial prototype. Another feature to be incorporated into the destructive prototype would be a ratchet mechanism that would keep the gear fixed at its current position. This would allow the ring to be spread and the user could let go of the handle and grip and manually remove the ring from the patient's finger.

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