Ergo Knife

The Ergo Knife Manufacturability Project

A Prosthetic Device

by

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Abstract

Millions of Americans' upper extremities have been rendered useless or amputated due to injury or illness. Without strength and dexterity in the hand or wrist, these people are in need of tools to help them in everyday activities. The Ergo Knife offers these individuals a way to cope with this way of life as a device that can assist them, primarily in food consumption and can also be expanded to many other applications. The purpose of this project is to further develop the Ergo Knife so that it can better assist these individuals and improve the necessary processes used to produce the knife.

The design of the handle will be improved upon to create a better mechanical advantage and manufacturability of the product. This will be accomplished by increasing the strength of the parts design and the processes that go into the production. The project will encompass an analysis of how the handle works, the construction and design of the mold, and a description of part production will be examined and improved upon so that the parts can be made as efficiently and easily as possible. The molds will be made with silicone and the plastic used for the handle is a thermoplastic two part mixture. A cost analysis of the product is also provided in order to see how to further the project into mass production. Ultimately, the parts will be produced and tested so that they can be given to those suffering from upper extremity amputations, injuries, or loss of dexterity.

Introduction

There are millions of people living with upper extremity defects due to injury or illness who require the use of a prosthesis or lack the hand and wrist strength to perform cutting operations. The Ergo Knife allows them to cut their food and give them assistance in their lives that have become more difficult. This paper will be discussing a way to create a manufacturable design of the Ergo Knife that is easy to produce and meets the requirements necessary to perform under the desired conditions.

The original idea of the Ergo Knife was created by Major Arthur Yeager and was inspired by his continual desire to help veterans who served in the United States Armed Forces. In 2005 He patented the technology that the design of the knife is based on; the use of a lever arm to maintain normal wrist position allowing the arm muscles to create the force necessary for cutting. However, the current prototype of the design has not been tested for strength or use by those who would use it in their everyday lives. Therefore, the current design must be created, tested, and improved upon.

Objectives

- Improve the Current Design for Strength
- Design for Manufacture
- Develop a Mold to create the Handle
- Produce a short run of Parts for testing

The design will require a mold so that the complicated form of the handle can be easily produced at a low cost of material and engineering work. The parts produced will be tested for performance as well as processing that will be necessary to create them. From these results, it

will be easier to detect and identify the improvements that will be necessary in the creation of a final design.

Background

The Ergo Knife is a tool that brings a sense of normalcy and an ease to a life that has been altered due to injury or illness that has severely limited the mobility and function of the arms and wrists. Those who have been effected by upper extremity amputation, arthritis, stroke, cerebral palsy, nerve damage, ALS, MS or broken wrists would be able to use the Ergo Knife for many purposes though this device is most appropriate in the function of eating. The knife will allow the user to exert force onto the blade using the arm muscles instead of using a compromised wrist or hand.

Millions of Americans have been and continue to be effected by injuries of their upper extremities every year; these individuals would benefit from a device such as the Ergo Knife. It is estimated that there are six to ten thousand upper extremity amputations performed every year in America; as of September, 2010, there have been 1,621 amputations performed on military personnel during Operation New Dawn, Operation Iraqi freedom, and Operation Enduring Freedom (Fischer 2010). According to the studies of the NHIS-D there are approximately 1.9 Million Americans living with limb loss (Winkler 2007). These individuals will require prosthesis to function, as they did prior to their loss, in their day to day activities. While a terminal device such as hooks or prehensors can function and

Figure 1.0 Military Amputee

move like hands, most amputees choose to have a more cosmetically pleasing, but much less functional artificial hand. Though there have been some innovative breakthroughs in the technology improving the capabilities of these "hands," the Ergo Knife allows those who choose a less functional device to have more independence and ease in their daily lives. Many already use prosthetic devices which are expensive and cost around $35,000 per year; therefore, a relatively cheap Ergo Knife would not only help them in their everyday functions but would cost significantly less and still provide advantages.

Aside from amputees, there are many individuals without amputations who have lost strength or function of their hands due to other injury or illness who would also benefit from the Ergo Knife. A major market for the Ergo Knife will be for those who have suffered wrist injuries and need a cast, for restriction of motion and support. Every year five hundred thousand individuals visit emergency rooms in the United States for wrist fractures. This field would greatly benefit from this low cost tool to help maintain daily functions while recovering. Furthermore, other degenerating diseases such as arthritis, which affects 49.9 million people, of which 21.1 million have Arthritis-Attributable Activity Limitation (AAAL), and have lost the ability to do simple activities; or ALS (Lou Gehrig's disease) which affects twenty to thirty thousand Americans,

Figure 1.1 Broken Wrist

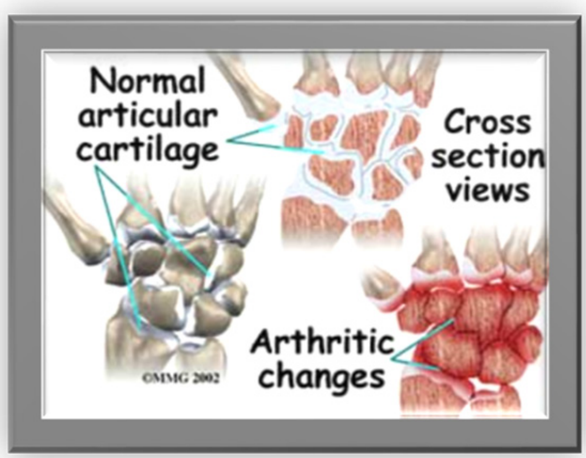

Figure 1.2 Effects of Arthritis

will also benefit from the Ergo Knife. All of these people have lost the strength to properly control their extremities as they once had and will need an assistive device such as the Ergo Knife.

Literature Review

In the creation of a product, it is necessary to understand all of the different processes used to produce a quality part. This project specifically deals with different types of ergonomics, mold fabrication, and part production. The first step is to develop a mold that work well for our Ergo Knife; in order to complete this, extensive research must be completed on rapid prototyping, silicone molds, injection molding, and inserts. Understanding these processes will also allow for part production that will satisfy and benefit the customer who needs such a tool as this one.

Rapid Prototyping

It is necessary to acquire a better understanding of the part's design and function before going through the process and steps of creating a prototype of the part. The use of a prototype in the early steps of the manufacturing process helps to identify a difference in *theoretical concepts* and *actual* product performance. Rapid Prototyping is a process that creates an actual replica of a CAD part through four steps. The first step is to create a CAD mode of the design, the second step is to convert the CAD model to a to stereolithography (STL) file format, the third step is to slice the STL file into two-dimensional cross-sectional layers, and the final step is to grow the prototype (Noorani, 4). The way that the prototype is created is through the use of a physical layer model completed in two steps: first, a cross section is generated in the X-Y plane and joining this layer with the preceding one in the Z-direction (Gebhardt 2003). The X-Y plane is built using Vector, Raster, and Mask processes for the projection of the layer information. The types of Rapid Prototyping systems used in industry are Stereolithography, Selective Laser

Sintering, Fused Deposition Modeling, and PolyJet. When the prototype is complete, a physical part, including the dimensions and characteristics of the actual design has been been created.

At this point, the prototype is now a tool appropriate for use in creating another increment of the product, testing the product, and producing a mold design. By adding the prototyping step into creating a molded part, the lead time is greatly reduced in connection with mold design. This is because “the existence of a physical model of a geometrically complex part allows the mold designer to more quickly visualize and design the mold” (Ulrich 1995). The prototype can then be put into a silicone rubber piece which holds the shape of the materiel of the prototype which changes from a liquid to a rubber solid; the prototype can then be cut out which results in a solid mold of the prototype. This mold can be used to produce actual plastic parts that function as described in the design (Koch 2011). Prototyping is a great step in the mold making process that reduces the overall time of production.

Silicone Molds

The use of Silicone molds in casting resins in order to begin the stages of development for a short production run is a simple, rapid, and low cost method. The process of making silicone molds begins when a desired part of the feature is used as a negative and the silicone is poured around it and hardened. The resulting mold is used for producing parts that replicate the original. The tooling material and molding process for silicone molds is versatile, but has the required accuracy, detail, and durability to produce up to 200 molding cycles (Hickey 1973). Not only do these molds test the feasibility of the part, but also rapidly produce short run of production parts for low cost plastic parts due while keeping the tooling costs down. The things to be considered during the design of the silicone tools and molds are as follows; the number of parts to be manufactured, operating cycle of the tool in production, material to be cast in the

mold, type of silicone rubber material to be used, lead time available for producing the tool, tool cost per part, and the degree of automation of the process (Hickey 1973). This method will be used at the initial stages of the Ergo Knife production and design modifications.

<u>Silicone Mold Production and Use</u>

(Wheeler 2011)

Figure 2.0 ***Cut original prototype from Silicone***

Figure 2.1 Silicone Mold Cutout

Figure 2.3 Injection of Material

Figure 2.4 Breakout of Part

Figure 2.5 Finished Part with Mold

Injection Molding

Once the design has been finalized, the Ergo Knife handles will need to be made through an injection mold process. Injection molds are arrangements of hollow cavity spaces built to the shape of the desired product with the purpose of producing plastic parts or products (Rees 2002). The injection mold is necessary in the construction of any complex parts that require tight tolerances which cannot be formed by other methods (Wood 1963). The mold will have a cavity of the desired product shape, a partying line where the two mold haves connect, a "sprue" which leads the material from the nozzle to the mold and runners which lead from the sprue to the cavity and gates constrict the flow of plastic to the cavity. As the complexity of the mold increases, other parts such as an injection system and a cooling system will be added (Rees

2002). There are a few common defects of the part quality that come from injection molding such as short shots, flashing, sink marks and voids, and weld lines that cannot be removed from the processes only reduced. Also there is a shrinkage factor that comes into account during the cooling processes which can be accounted for before molding using the following formula for Cavity Size:

<u>Cavity Size</u>

$$DC = DP + DP*S + DP*(S^2)$$

DC = Dimension of Cavity   DP = Molded Part Dimension   S = Shrinkage Value

Taking all of this into account, a mold can be designed that will produce the correct part with the desired features in the mold. With the mold created it can be put on an Injection Molding Machine to produce the desired amount of parts. An injection molding machine takes a polymer and heats it up to a desired temperature then injects it into the mold cavity where it cools and solidifies to the cavity's design (Groover 2001).

Inserts

With the blade being made from steel it will not be made during the same injection molding process but will need to be permanently connected. The addition of external features to a mold is called an "insert"; in this case it will be the knife blade. Due to the similarity that the Ergo Knife has to normal utensil inserts, it would be wise to consider how the silverware industry assembles such products. During Muccio's discussion of how certain industries put inserts into plastic he discusses the way in which silverware is inserted into the plastic handles:

> **Silverware.** The cutlery industry has many requirements for assembling plastic handles onto steel flatware. Designs for pocket knives, dinner knives, forks, and spoons

> all use plastic handles. Induction heat is used to heat the tang of the flatware either before or after assembly to the plastic handle.
>
> In this application, a plastic handle is positioned on a pancake coil, and the flatware tang aligned at the end of the handle (opposite end of the coil). Power is applied to the coil, and the tang/handle is moved to the coil center position. The tang is pushed into the handle as the ABS melts, and the entire assembly is removed from the coil as the tang, fully seats. The time to complete the operation is 4 s. This application operates at 270 kHz and delivers 200 W of power raising the tang to approximately 177 C (350 F). This temperature allows the plastic to form correctly around the tang, but is not hot enough for the handle to lose its molded shape. The pancake coil is used so the staking process can be directly incorporated into the assembly line. (Muccio 1999)

There is a common practice used for inserts within ABS silverware handles. The other factors to account for when heating metal inserts are the Material resistivity, permeability, specific heat, and thermal conductivity (Muccio 1999)

Conclusion

Due to the nature of the Ergo Knife, there will not be a large demand for the product yet so there is no need for a large production processes. Instead of creating a large injection mold machine costing thousands of dollars in parts and engineering simple molds can be made from wax or silicone rubber that will produce the same quality with lower production volume. The simplicity and ease of creating these molds will cost less and produce parts sooner than a dedicated aluminum or tool steel injection mold. Also due to the complex shape that the part will require extensive machining it would most likely be less expensive to develop a CNC sequence to cut out the wax molds rather than cut out a tool steel or aluminum mold. There would be less cost of parts for the actual mold and the machining time would be less as well as the finish of the mold (Rees 2006).

Part and Mold Design

Part Design

The current design of the Ergo Knife is that similar to the YeagerKnife that Major Arthur Yeager patented in 2005 as a utility knife that made use and handling easer by reducing strain from repetition. This current design is for a steak knife for handicapped individuals whose wrist movement has become restricted due to injury or illness. In designing a hand-tool for ergonomic purposes, it is important to take into account principles such as weight, grip sizes, shapes, twisting of the wrist, and in this case how people with disabilities can operate it efficiently (O'Shea 2003).

The original design of the YeagerKnife was for the purpose described in the abstract of the Patent as follows:

> The present invention is directed to an ergonomic handle for a tool such as a utility knife. The handle includes a body having a first end and a second end. The body includes a lever arm attached to the second end of the body and a grip connected and located perpendicular to the body. The lever arm rests against the back of a user's hand thereby stabilizing the handle during use. (Yeager 2005)

This first design for a utility knife instead of a steak knife was the basis for the current design of the Ergo Knife. The new design utilized the original idea of using the back of the hand to stabilize and the palm of the hand as a lever arm helping those who lack the ability to use their wrist. For those without handicaps such as amputations or arthritis, the position of the wrist affects the gripping capability of the fingers. It is recommended that hand tools be designed so that the user's forearm and hand's longitudinal axes are aligned. This alignment is even more important for those with wrists that have restricted movement (Greenberg 1977).

Handle Design

The handle acts as a tool that allows the user to utilize the larger muscles of the forearm which in turn allows the user to exert a larger amount of force into the knife blade for longer periods of time. These forces will need to be exerted downward from the knife blade without the use of the wrist and hand muscles. As the normal force of the cutting surface goes up against the knife blade another equal force will need to be exerted from the hand to stabilize the blade and handle, which will be discussed to greater extent in the Lever Arm section. For the forces or moments to be balanced, they must be balanced on some type of hinge. To balance the forces, the force being multiplied by the distance from the hinge will equal the opposing force multiplied by the distance from the same hinge. To create this hinge, a T-Grip was used so that the knife can rotate around the hand and allow the knife blade and lever arm's moments to balance out. The design properties of the T-Grip will be discussed in a later section.

To understand the way the different forces are being exerted on the knife and handle so that they will be static as they cut the surface, an analysis of the forces must be done. A free body diagram is given in Figure 3.0 showing how the forces(Fk) exerted on the blade(B) in the by the cutting surface and the force(Fl) exerted on the hand by the lever arm(L), as they are balanced about the T-Grip(T).

<u>Forces Acting on Ergo Knife</u>

Fk = (Fl * L) / X

- Fk = Cutting force exerted by the blade on the surface (Reaction force of Fb)
- Fl = Force exerted on the hand by the lever arm (Reaction force of Fh)
- L = Length from the center of the T-Grip to the point of contact between the lever arm and the hand (1.869 Inches)
- X = Length from the center of the T-Grip to the point of contact between the knife blade and the cutting surface (Length Unknown)

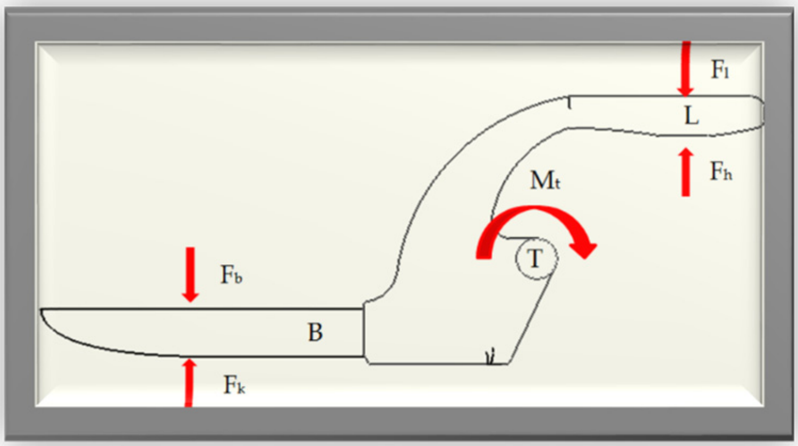

Figure 3.0 Ergo Knife Free Body Diagram

These forces balance out so that the knife blade cuts through the surface without using the wrist or hand muscles. As the knife is moved back and forth along the surface allowing the serrations of the blade to cut, there is a friction force. This force is exerted by the muscles in the arm as the knife is pushed and pulled through the surface but is not effected by the wrist or hand muscles. The downward force required for cutting is placed on the back of the hand instead of the wrist holding the knife down.

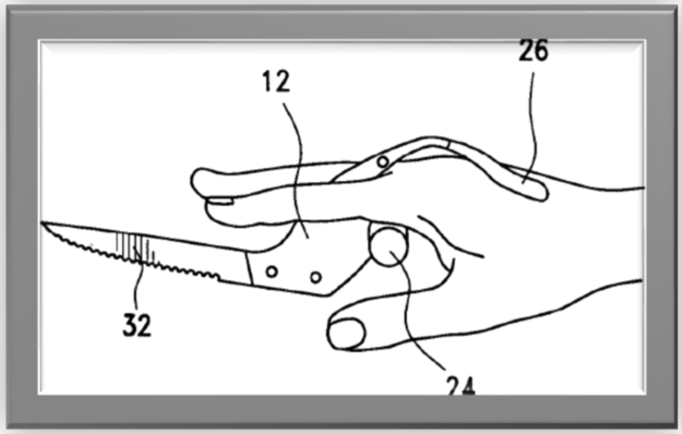

Figure 3.1 Ergo Knife Purpose

T-Grip

In order for the handle to be held by an individual who has suffered from an injury, there must be a way to eliminate the action of tightly gripping the handle which can cause strain and pain. The T-Grip design holds the force of the arm so instead of wrist or hand muscles the muscles of the forearm and upper arm are used to exert the force necessary to cut. These small muscles will be weak or nonexistent in prosthesis or injured arm, so being able to use the arm muscles will allow sufficient downward force to be applied to the cutting surface. If the user is lacking a thumb, the T-grip will allow for them to wield the knife without gripping it with an opposable thumb by locking the hand around the grip and spine and held in position with the lever arm.

With mobility and strength of the hand restricted due to injury or prosthesis, the T-Grip required a few specifics in the design. First, the product must be large enough in diameter for the hand to grab and have the necessary strength to take the forces being put on the handle from the arm. It also needed to be wide enough so that a finger can be supported on both sides of the grip. The spine of the handle must support the T-Grip and be thin enough to fit comfortably between

two fingers. The base of the T-Grip needed to be strong enough to take any torqueing forces that can be applied on both sides of grip. Fulfilling these requirements in the design improved the handle's ergonomics and ability to perform under the forces during cutting.

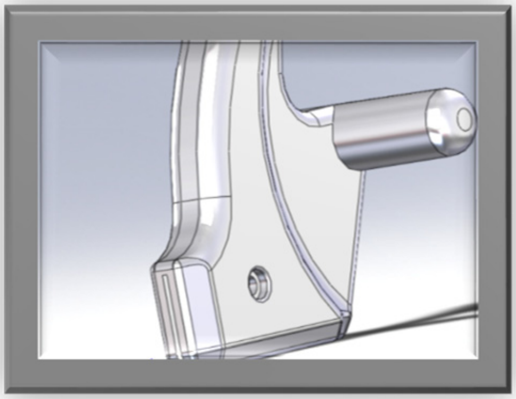

Figure 3.2 T-Grip Base

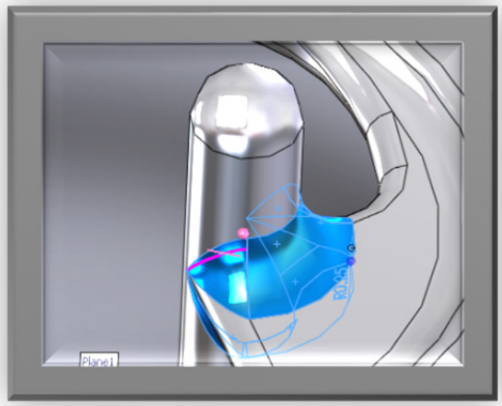

Figure 3.3 Addition of Fillet

Lever Arm

As the blade is placed on a cutting surface and forces are applied, the knife must be balanced while applying a sufficient reaction force to keep the blade static with the surface. This balance is provided by a lever arm on the back of the hand. The lever arm must be strong enough to take the forces without breaking and be large enough to disperse these forces to reduce pain and fatigue to the user's hand. The lever arm balances the forces being placed on the knife handle by using the back of the hand as a support so the knife can apply sufficient force on the blade to cut through a the required materials. The arm must be strong enough to take any amount of force that a hand can produce without breaking.

Material

The silicone molds work best through the use of a thermoplastic that is mixed together and forms inside of the mold. After discussing these materials with Smooth-On representative

Brook Wheeler, materials were chosen for testing and fabrication. A few different materials were tested: Smooth-Cast 300, Smooth-Cast 325, Smooth-Cast ONYX, Task 5, and Smooth-Cast 65D. Each material was poured into the mold and checked for strength and porosity. The materials all had certain benefits and drawbacks yet a decision was made to use the Smooth-Cast® ONYX®. The specifications for the ONYX®, that made it the best material for fabrication, are listed below.

ONYX

- No pigment necessary for black coloring
- Cal be polished and buffed to a high gloss shine
- Withstand up to 200 degrees Fahrenheit
- No mercury
- Easy and fast curing
  - 10-15 minute cure time
  - 100A:100B by volume mix ratio

Knife

In selection of the knife blade, it was key that the blade have serrations and an insert connection to the handle. The serrations allow the knife to cut food easier than a straight edged knife. Connecting the blade to the handle with an insert lets the two parts perform as one and reduce processes necessary to manufacture the Ergo Knife. With these ideas in mind a knife blade was selected based on function and cost.

The original design used a rivet to connect the knife blade and handle. This was changed to connect as an insert. The hole necessary to put the blade into to rivet the two pieces together would be very difficult to create inside of a mold. This would also be an additional step in the

manufacturing of the part and further prohibit practical manufacturing. The new design allows the plastic to form around the blade which forms a connection between the two parts.

A serrated knife blade was selected to perform a back and forth cutting movement that allows the handle to create the downward force as the knife's serrations do the actual slicing. Serrated blades have many points of contact, so there is less contact area on the knife blade making it easier to cut. The force applied from the handle becomes greater at each point of contact. With more points of contact at sharper angles the blade can cut through the material requiring less force. Serrated edge knives are best for food that has been cooked and does not need to perform a clean cutting action. The chosen knife's specifications are listed below.

Purchased Blade Specifications

- Width .0264
- Height .609
- Length 4.5
- .75 inside handle as insert

Using such an insert will keep the blade securely connected to the handle so that the handle and knife work together as one unit. It can be attached without a riveting or welding procedure being added to the manufacturing processes but be just as strong. This connection uses a shape that the plastic can form around and tightly secure the blade.

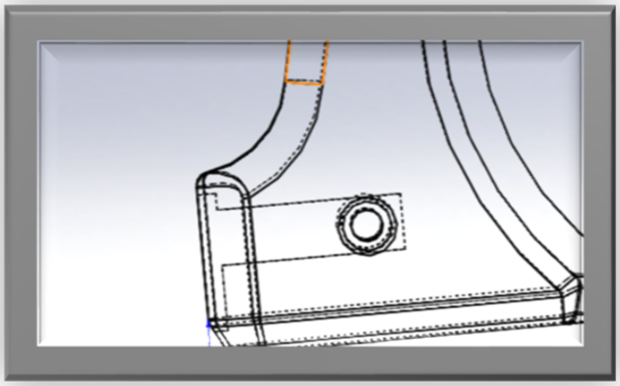

Figure 3.4 Original Rivet Design

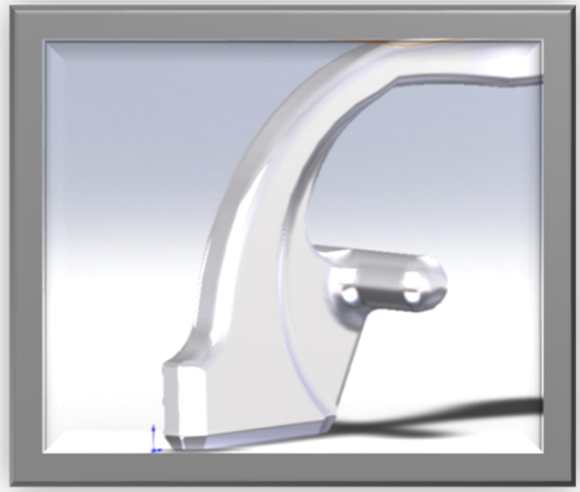

Figure 3.5 New Insert Design

Figure 3.6 Insert Shape

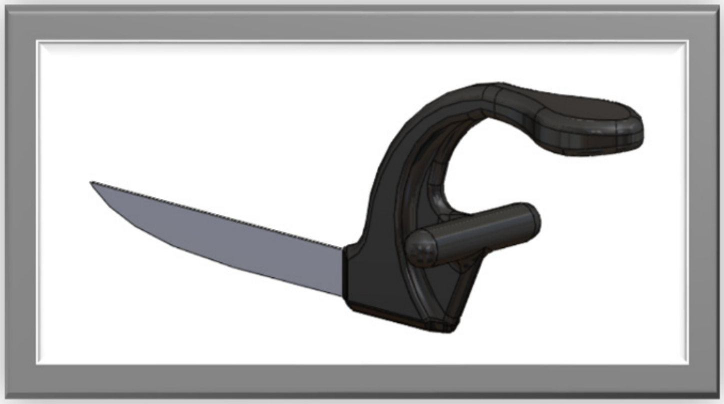

Figure 3.7 Finalized CAD Design

Mold Design

To manufacture the plastic handle, a silicone mold was used, allowing for easy use and a quick production time without the necessary large tooling and mold presses that would be implemented in mass production. The cavity needed to contain the desired shape of the handle so that the plastic can be poured or injected easily requiring little to no breaking off of the "spure" which the plastic came through. During this process, the knife blade insert must be connected to the handle, therefore, the blade must begin by being held securely by the mold so it is not lost or distorted during the molding process. The mold halves need to be easily joined together and stay tightly together so no flash is produced between the mold halves. As these requirements were met, a mold was created that can produce parts quickly and easily.

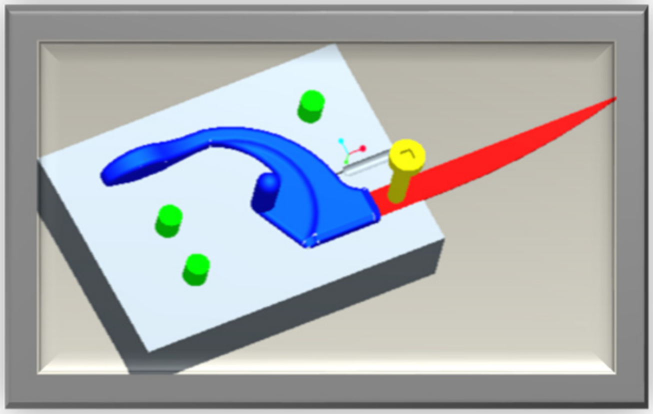

Figure 4.0 Mold design

To make a mold that could be produced quickly and require little machining or an injection press, a silicone mold was selected to be used. Silicone molds are easy to create and have a cavity that exactly represents the desired shape of the part that the silicone is poured around. These were made by rapid prototyping or machining out a cavity to pour the silicone into. The cavity has the features for the knife that represent alignment pins, a spure to pour the material through, and for the knife to be held in the mold.

Three alignment pins were needed to lock the molds together so that all of the features matchup between the mold halves. The pins also lock the halves in place so they do not move during the molding process. Based on the handle features there were three .5" diameter pins that are 1" in length. These are large enough to serve the desired purposes.

To pour or inject the material into the mold, a sprue must be made so that the material will fill up the mold without porosity or sticking in any of the features of the mold cavity. The size of the sprue will need to be large enough for the injection syringe to fit in and allow for the plastic to fill the cavity. The syringe tip length is 1 inch and the width tapers down from an outer

diameter of .25 to .125 inches. The gate would be .1 inch so that the material could be injected through and the excess could be easily removed by snapping it off.

The best place for this is down the middle of the two mold halves through the front of the knife handle cavity as it is held facing up. This allows the material to fill up from the bottom of the cavity, where the lever arm is located, to the top where the knife insert is located. As the cavity quickly fills with plastic, the smaller sections will harden and prevent the air from leaving through the sprue, causing porosity. Filling from the top allows all of the sections to fill from the bottom of the mold upward without letting the plastic harden unevenly. This will eliminate porosity and create a good fill of the handle with no sections lacking strength.

The part of the knife blade that is inside the mold acts as an insert, an external piece of material that will become connected to the plastic mold once it is poured. To create this connection, the blade must have a geometry that allows the plastic to form around it and hold it without slipping out; this geometry can be seen in Figure 4.2. The plastic will fill the hole in the insert and form around the odd geometry, permanently connecting the two parts together.

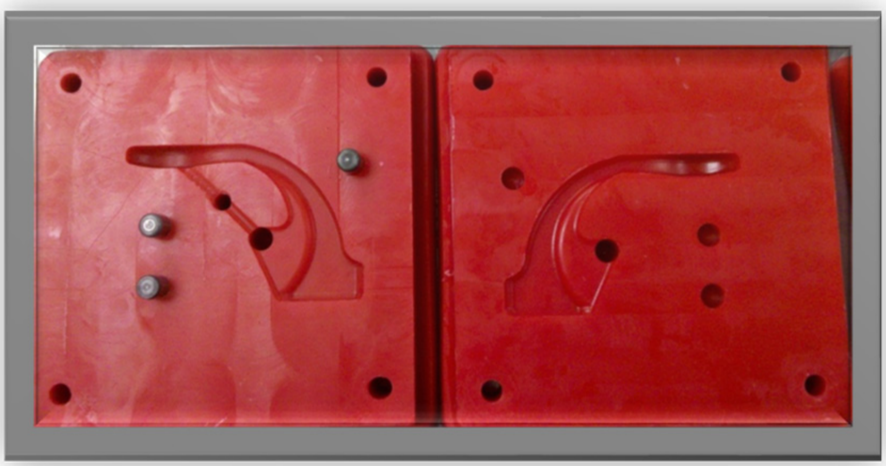

Figure 4.1 Mold Design and Dimension

Figure 4.2 Knife Blade Insert

Methods

Manufacturing Molds and Producing Parts

To successfully begin producing the Ergo Knife, there were a few processes that were tested. These different methods were used in order to create the best mold for the Ergo Knife. First a Rapid Prototyped Knife was made and the silicone was poured around it and removed using mold maker cuts (Figure 7.1). This did not work due to the intricacy of the design. Mold halves were then created using Rapid Prototyping to pour the silicone into, forming two mold halves. This mold lacked surface finish and correct gating to fill the mold completely. Finally, a machinable wax was cut to form two mold halves in. This was the chosen process, being that it gave a desirable surface finish and was easy to create. The order of operations, taken through each step in the production of the Ergo Knife, is listed below.

Rapid Prototyping

To begin testing the parts and procedures there needs to be physical objects to interact with instead of CAD drawings on a computer screen. It is necessary to create a handle using a rapid prototyping machine in order to understand the ergonomics and dimensions. In making the molds it will be much easier to create a mold cavity to pour into rather than machine it out. These real parts will come out with the dimensions of the CAD drawing without the use of tooling or machining.

The original part was created using Solid Works until it was given the desired shape and dimensions that would be best. The part was then converted into an STL file where the CatalystEX software can create the layout that the rapid prototyping machine will use. The build-up of material and support material can be seen in Figure 5.0 below. This was then sent to print

on the Dimension uPrint 3D Printer, a rapid prototyping machine which uses ABS*plus*™ Thermoplastic and Soluble Support Technology (SST) as the support material. The layers of the thermoplastic and support material were built up at .010 inches. This layering became an issue when dealing with the surface finish of the mold and handle. Due to the material's strength and the cavity's tough features, the surface finish produced by the Rapid Prototyped cavity could not be fixed by sanding. These two parts are built up and the support material was dissolved in a parts washer. The Dimension uPrint uses an 8 X 8 X 6 build area, allowing the Ergo Knife and mold cavities to be built with no restrictions. The Ergo Knife (Figure 5.1) took three and a half hours to build while the mold cavities took 12 hours each.

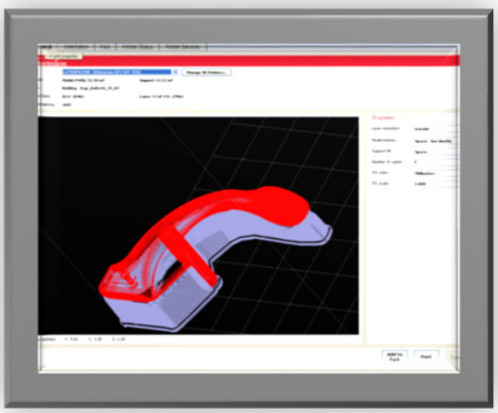

Figure 5.0 Rapid Prototype Software

Figure 5.1 Rapid Prototyped Handle

Figure 5.2 Rapid Prototyped Mold Half

Wax Machining

To create the mold cavities to pour the silicone into, the rapid prototyping is insufficient due to lack of surface finish and cost. A machinable wax is an extremely hard and durable wax made for machining properties, meaning that, it can be machined, cut, or shaped using standard metal working equipment. It results in a high quality part with surface detail and accuracy, for this prototyping phase it meets all the requirements without the difficulty and cost of cutting metal. Using a machinable wax allows for the desired surface finish at a very low cost that can be produced quickly and eventually be recycled. The wax is machined on a HAAS OM-2A office mill to the desired shape so that the silicone mold could be created from it.

Once the wax had been cleaned and recycled from its last use, it can be melted and poured into an aluminum baking pan. When it cools into a block it was faced into an 8 X 8 X 1.5 block with holes drilled .5 inches from all four corners to lock it into place for future milling operations. The desired part features were created using Solid Works or Pro/Engineer, then

Pro/Manufacture to create the tools and machining sequences used to machine the wax. The following tools were used to remove the material from the block quickly and get the best surface finish possible.

Tools and Running Parameters

- ¾ Flat End Mill
    - Roughing Cut
    - Spindle Speed: 20000 RPM
    - Feed Speed: 200 FPS
    - Tool Length: 1.5"
- ¼ Ball End Mill
    - Finishing Pass
    - Spindle Speed: 20000 RPM
    - Feed Speed: 100 FPS
    - Tool Length: 1.5"
    - Passes at 45 % and 315% with .005 step overs
- 1/16 ball end mill
    - Finishing Edges
    - 20000 SS
    - Feed Speed: 20 FPS
    - Tool Length: 1"

Figure 6.0 Wax Machined Cavity

Figure 6.1 Wax Machined Cavity

Silicone Mold

The silicone mold chosen is Mold-Star 15 from Smooth-On. This mold is an extremely accurate and detailed mold that forms a negative mold of the exact features and surface finish of what it forms around. This method was chosen because it requires low costing materials and promotes a significant savings in tool making labor. This process can be repeated with the machined wax an unlimited amount of times due to the wax's strength as long as the cavity and pattern are not deformed from heat or breaking. The material will transmit and dissipate the heat created in the injection process of thermoplastics and acts as a good insulator while the thermoplastic sets. The normal expected life of a silicone mold is one to two hundred parts depending on tolerances and the temperature of the materials. The mold will last a long time in storage and exhibits very low long-term shrinkage.

Smooth-On Mold-Star 15® Directions

- Mix part A and B, 1 to 1 ratio and stir
- Pour around pattern.
- 4 hour cure time

Figure 7.0 Silicone Mold Pouring

Figure 7.1 Mold Cut Out

After the silicone is poured around rapid prototype of original design and has set the part will be cut out of mold after it sets with “mold maker cuts” around the part leaving two mold halves. The Ergo Knife could not use the mold due to intricate features and small surfaces to create the parting line, so it was necessary to create two halves of the part inside a box using the RP machine to pour the silicone into.

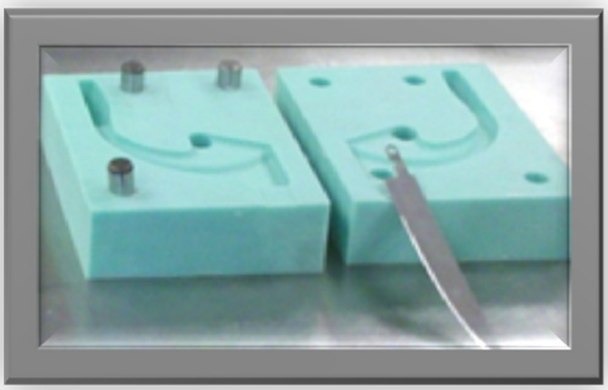

Figure 7.2 Final Mold Halves

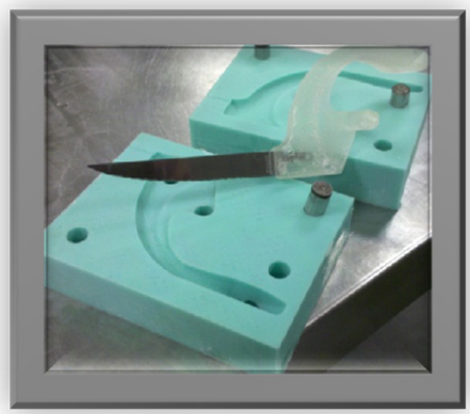

Figure 7.3 RP Mold Halves and Part

Unfortunately the surface finish lacked cleanliness due to the way in which the printer built up the rapid prototyped parts. Therefore, a machinable wax was used which gave a good surface finish with previously listed feeds, speeds, step overs, and angles.

Plastic Injection

Once the molds were made, they were able to be injected using a thermoplastic. The chosen material, Smooth-Cast® ONYX®, produces a casting that “reflects perfect detail and is a deep, rich black color,” has a Shore D hardness of 80, and its lack of mercury and that it can take temperatures up to 200 degrees Fahrenheit, which will be necessary if the Ergo Knife is to be put

in a dishwasher (Wheeler 2011). Initially the plastic was poured into the sprue of the mold but this was both sloppy and unsuccessful due to the quick set time of the plastic. To improve this process a syringe was added to put all of the material into the mold cavity quickly and cleanly. Once the plastic had set for 15 minutes the mold halves were spit and the part was taken out. The sprue was sawed off and sanded to match up with the rest of the knife pattern. This process allowed for quick, quality production part of the Ergo Knife.

Figure 8.0 Mixing ONYX® (1A to 1B)

Figure 8.1 Plastic Injection

Figure 8.3 De-mold and Sprue Removal

Figure 8.4 Finished Parts

Testing

Once the parts had been produced, they needed to be tested so that they could be distributed to those who need them. The three parts of the knife that had to be tested for strength were the lever arm, T-Grip, and connection between the knife and handle. To test the lever arm, the knife was placed on a surface and the grip was pressed down so a large force would be placed on the arm. To test the T-Grip, the whole handle was held and the T-Grip was twisted. The connection was tested by securing the knife in a vice and pulling the handle. The knives passed the lever arm and connection test but failed the T-Grip test.

Figure 8.5 Testing

Results

The parts produced achieved all of the initial requirements that were necessary for its basic purpose. The surface finish was great with the wax pattern being cut using 45 and 315 degree cuts with .005" step over. The material performance of the ONYX® was impressive as a finished product that was both strong and lightweight. The other materials failed due to the following reasons.

Material and Failure

- Smooth-Cast 300
  - Too brittle allowing lever arm to break.
- Smooth-Cast 325
  - Poor surface finish and brittle lever arm.
- Smooth-Cast 65D
  - Final Product was too soft and lever arm bent.
- Task 5
  - Could not take high heating temperature, resulted in bending.
- ONYX® (Chosen)
  - Strong, can take high temperature, and smooth surface finish.

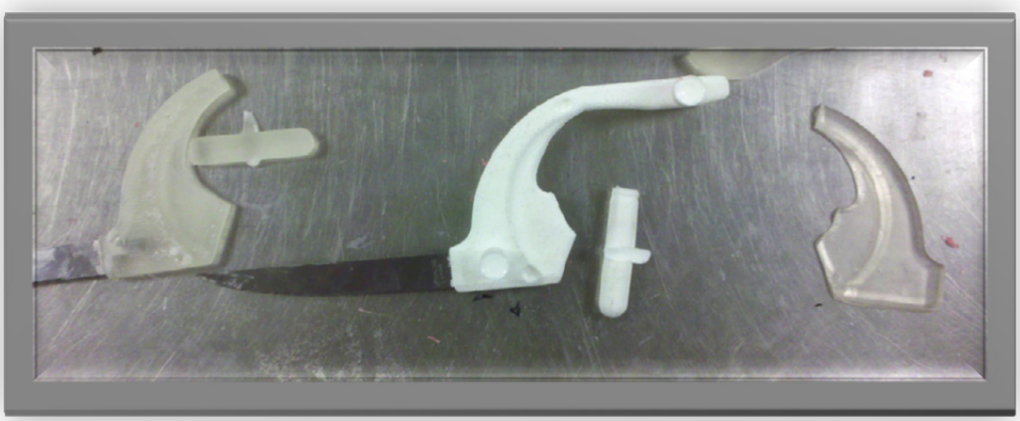

Figure 9.0 Material Failures

A small run of parts were sent to Major Yeager for testing and the results were mixed. The insert connectivity was found to be very strong as if the knife blade and handle are one piece of material. The main force will be exerted on the lever arm by the hand during cutting. This was tested by locking the blade down and pressing down on the T-Grip by an abled body arm. With extreme this downward force there was no show of fracture in the connection, between the knife and blade, or the lever arm. There are some parts of the knife that will need to be improved as the project goes forward to more testing and eventually mass production. The T-Grip base will break from excessive torqueing forces along the Y-axis due to lack of strength and material thickness at base. This has been fixed by the addition of a filet to increase the strength of the T-Grip's base and its connection to the rest of the handle.

Figure 9.1 T-Grip Break at base

Cost Analysis showed below determined that for a run of 100 parts the cost per part would be approximately $8.26. The analysis shows an inexpensive part even for a prototyping stage of the product development, which can be reduced as mass production is examined.

Cost Analysis

Current State

- Silicone Mold
  - $170.94 per Gallon (Mold Start® 15)
  - 30 Ounces = 0.234 Gallon
  - $40 per 2 part mold half
- Plastic
  - $94.08 per Gallon (Smooth-Cast® ONYX®)
  - 4 Ounces = .0234 Gallon
  - $2.94 per knife handle
- Knife Blade
  - $0.25 per blade
- Labor
  - Setup Time = 30 Minutes
  - Machine Time = 2 Hours
  - $17 Per Hour
  - $42.5 Per Mold
  - Operator Time = 15 Minutes
  - $4.25 Per Part
- Total $8.26 Per Part
  - $84.84 For First Part

Small Scale (100 Parts)				
	Stock	Used	Baseline	100 Parts
Silicone Mold	$170.94	0.234	$40.00	$0.40
Plastic	$94.08	0.03125	$2.94	$2.94
Knife Blade	$0.25	1	$0.25	$0.25
Initial Labor	$17.00	2.45	$41.65	$0.42
Operator	$17.00	0.25	$4.25	$4.25
Total				$8.26

Large Scale Production

- Aluminum Mold
  - Material $55.58 Per Half (McMastercar)
  - Setup Time = 1 Hours
  - Machine Time = 2 Hours
  - Morgan Press Setup = 1 Hour
- Knife Blade
  - $0.25 Per Part
- Overhead
  - Electricity = $6.70 Per Hour
  - Operator = $20 Per Hour
  - Machine Cost = $13 Per Hour
- Plastic
  - $2.00 Per Pound
  - 3 Ounces Used
- Total $4.11 Per Part
  - $183.09 For First Part
  - Breakeven at 28 Parts

Large Scale Production (1000 Parts)				
	Stock	Used	Baseline	1000 Parts
Aluminum Mold	$55.58	2	$111.16	$0.11
Plastic	$2.00	0.1875	$0.38	$0.38
Knife Blade	$0.25	1	$0.25	$0.25
Initial Labor	$17.00	4	$68.00	$0.07
Overhead	$39.70	0.0833	$3.31	$3.31
Total				$4.11

Conclusion

The Ergo Knife is still in testing stages but it is expected that the device will be able to assist many people who will need such a tool to make their lives easier. A short run of parts has been given to Major Yeager for testing with his patients; the product will be further developed but currently it has proven to be a quality product. With a total production cost of around ten dollars, device construction would be a cheap and product purchase would be accessible for the Quality of Life Plus Organization which gives such products away to those who have lost a limb during service to the United States. The manufacturability has been proven for a small amount of parts for the design, which can be altered to help benefit the customer as the project continues. The processes currently used to manufacture the part can now easily be repeated to improve the Ergo Knife during further prototyping stages.

The main objectives have been completed but there is still much work to be done as the part evolves and is improved upon. Alterations to the knife's T-Grip and use of an insert have made the handle easier to produce, but there is still room for improvement. A finalized mold design has been created with a short run of parts have been produced for testing. The design can still be altered and will need to be created so it can be easily manufactured.

More improvements can be added to the current design as the purpose for the product becomes more targeted. Sizing down the handle but building up certain support sections will be necessary in improving the strength and aesthetic appeal. There will also be an adaptation of the knife into a Multi-Tool; this will require the insert will need to sufficiently lock the tool in place unless released.

Appendix

Tables and Figures

Table 3. Count of Individuals with Amputations by Service for OIF, OEF, and Unaffiliated Conflicts, 2001 to September 1, 2010

Theater	Type of Amputation	Army	Marine	Navy	Air Force	Foreign	Other	Total
OIF	Major Limb	620	158	18	8	4	8	816
	Partial (Hand/Foot, Toes/Fingers)	272	49	7	11	0	3	342
OEF	Major Limb	145	53	5	6	4	4	217
	Partial (Hand/Foot, Toes/Fingers)	24	6	0	2	0	0	32
Unaffiliated Conflicts	Major Limb	94	12	25	31	1	26	189
	Partial (Hand/Foot, Toes/Fingers)	20	1	2	1	0	1	25
Total								**1,621**

Table 10.0 Military Amputations

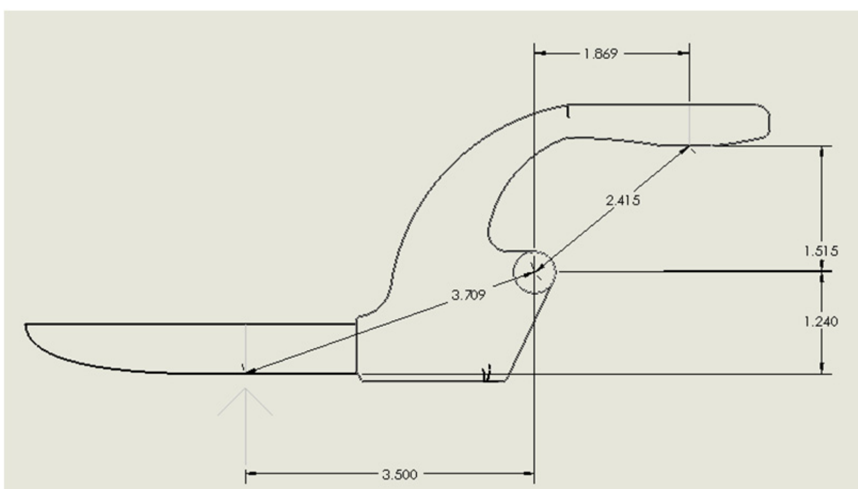

Figure 10.1 Ergo Knife Dimensions

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