Syringe for Injectable Fillers

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3/3/06

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Abstract

Current plastic surgery procedures for lipoatrophy restoration, lip augmentations, and other cosmetic procedures are performed based on skills from past experiences of the physician and/or the general feel of the procedure. Our client has requested a device that would administer a known volume of injectable filler with each depression of the plunger. This would make the procedure more standardized and aid the physician in monitoring the progress of the procedure. The two fillers that are used the most with our client are autologous fat and Sculptra®. Our client uses syringes that range in size from 1cc to 5cc and would like an increment of 50-100μL administered with each depression. Three alternate designs have been created and are compared according to certain criterion. Whether the design can be assembled easily, handle back pressure, be adjusted for variable increments, and have minimal operation required by the physician. In choosing a final design we will have to determine which design will be most feasible to manufacture, considering that this was our primary difficulty last semester. The minimum force that is required to expel the filler from the syringe was measured last semester using the extreme viscous material collagen. This has a higher viscosity than fat or Sculptra® and will allow us to set a minimum force level. Construction and testing of the device will require the rest of the semester to complete.

Background Information

Project Motivation

The goal of this device is to make the process of using injectable fillers for plastic surgeons easier and more standardized. The current procedure requires the surgeon to constantly monitor the *amount* of filler being injected. A device dispensing a known

amount with each depression of the plunger would allow the surgeon to focus their attention on the *placement* of the filler under the patient's skin. The varying densities of the skin layers require an increase in force applied to the plunger and may result in an uneven application of filler if misjudged. In addition, one filler in particular – fat – has proven difficult at times due to the varied sizes of fat particles. If a fat particle is larger than the diameter of the needle, it may become lodged and require more force to be expelled. The result can be too much filler injected under the skin at one spot leading to a lumpy and uneven appearance.

Procedure

The current procedure for injectable fillers varies from one patient to another. Most of our client's patients use injectable fillers in the facial area. These fillers augment lips as well as remove wrinkle lines and fills hollowing of the cheeks. The procedure takes approximately 15 minutes on average and is relatively simple allowing the patient to be in and out in an hour. Depending on the area and depth of augmentation, different fillers are used. Fat is primarily used for large augmentations, such as filling nasolabial folds or sunken cheeks. Sculptra® is used for hollowing cheeks common to HIV patients. Sculptra® stimulates a natural increase in dermal thickness by promoting natural collagen growth [14]. Fillers containing varying levels of hyaluronic acid are the most versatile to fill fine lines, wrinkles and deep folds. Collagen is also used, but because a small percentage of patients have an allergic reaction to it, it is becoming less common. Injectable fillers are beneficial because the procedure is less invasive and the results are not permanent (lasting six to 48 months) [9].

One of the fillers primarily used by our client is autologous fat. A small amount of fat is harvested from the abdomen or thighs, or it is obtained from a concurrent liposuction procedure, as seen in Fig. I. The fat is then placed on gauze in a sterile environment and cleansed in a sterile saline solution. Once the fat has been rinsed, it is transferred to a 1cc, 3cc, or 5cc syringe.

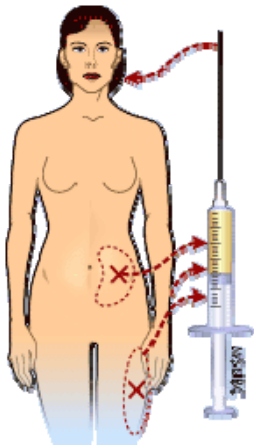

Fig. I: *Diagram of Sources of Autologous Fat.* Fat is harvested from the abdomen, buttock, and thigh.

Depending on the location of the injections, the procedure for fillers varies. The most common procedure is removing wrinkles from the outside of the eye and forehead as well as the nasolabial folds (Fig. II).

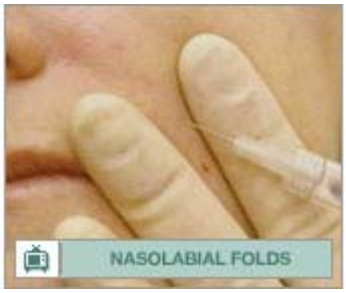

Fig. II: *Nasolabial Fold Augmentation.* Physician injects filler into the fold to diminish its appearance.

For example, in a procedure using fat as the filler, the doctor will use an 18 gauge needle and make as few insertions as possible. The needle is inserted into the subcutaneous fat layer, which is below the dermis and epidermis. Slowly the doctor starts to apply pressure to the syringe while pulling slowly out of the subcutaneous fat layer [8]. The doctor will reinsert the syringe many times back into the subcutaneous fat layer to make a fan-like pattern (Fig. III). Once the fan pattern is established, the doctor removes the needle completely from the skin and reinserts it at a location near the first injection site. This creates another fan pattern that is applied on top of the previous layer to make a cross-hatch fan pattern [9].

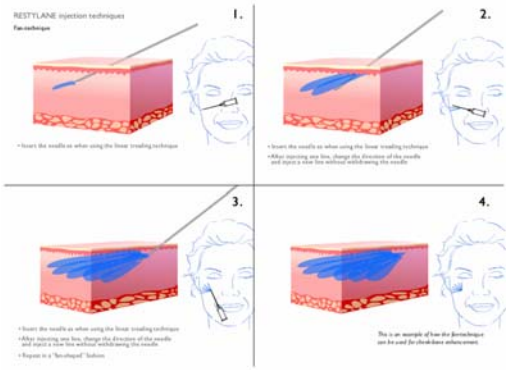

Fig. III: *Diagram of Fan Pattern.* The surgeon inserts needle into the dermis and rotates side to side to create fan pattern.

There are very few risks associated with this procedure, especially when used with fat filler. There is no risk of rejection or allergic reaction in the patient because the fat is harvested from their own body [8]. With the other products that are used there is a low risk of a reaction. There may be some puffiness around the injection area that will disappear within a couple days. As with all surgical procedures, there is a risk of infection near the injected areas, but this is also rare because the injection wound is smaller than an incision in the skin [8].

Injectable Fillers

A common injectable filler is adipose or fatty tissue. This is the main storage site for fat. The fat cells in adipose tissue can be unilocular or multilocular. Unilocular cells contain a single lipid droplet and can range in size from 25 to 200 microns. Multilocular cells contain many small lipid droplets and can reach a diameter of 60 microns [13]. Typically twice the volume of adipose tissue is removed than required because only a 40-50% rate of fat cell survival is expected [10]. Fat tissue has a wide range of properties. Tissue mass is a function of cell number and size [13]. The typical dynamic viscosity of subcutaneous visceral (abdomen) fat is about 3 Pascal seconds. This viscosity is less than that of collagen most likely because the extra cellular matrix surrounds the cells in the adipose tissue [5].

Sculptra® is a synthetic sculpting agent composed poly-L-lactic acid. It is used to treat lipoatrophy, which is the hollowing of the face commonly found in HIV patients. Lipoatrophy causes symptoms such as fat loss behind the skin, sunken cheeks (Fig IV), indentations and hollow eyes.

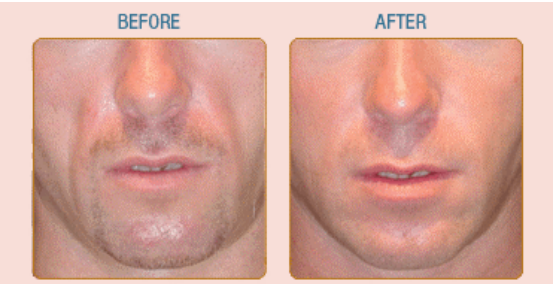

Fig. IV: *Lipoatrophy before and after.* The injection of Sculptra results in restored dermal thickness.

Sculptra® is the first product to be FDA approved for lipoatrophy. Injection of Sculptra® is a very quick procedure with minimal side effects which are limited to injection related symptoms such as bleeding, inflammation and discomfort. Sculptra® works by first filling the depressed area with the injected volume, which is followed by water absorption, causing the reappearance of the depression several days after the

procedure. Within several weeks, Sculptra® is able to stimulate a natural increase in dermal thickness. Poly-L-lactic acid is a biocompatible material, meaning it will not cause any adverse effects in the body; it is also biodegradable, so it will be naturally broken down by the body. The results typically last about 2 years, compared to other products which usually last 6 to 9 months [14].

Force

The force that is required to expel the injectable filler from the syringe is an important parameter that must be considered in the device to ensure it is strong enough to expel the filler. To determine the force we used a simple gravity test in which varying weights were placed on a syringe filled with expired collagen from INAMED. We determined the minimum weight to expel the collagen was 427.034 grams giving a force of 4.1892N. After extensive research, there were few explicit viscosities to be found. The viscosity of human fat was found to be 3 Pa_s [5], but the variability in the diameter of the fat particles may still cause the force required to be increased. Because collagen is more viscous than fat [5] and Sculptra®, this can be used to determine the minimum force required to expel a viscous material through the syringe.

Current Device

Byron Medical manufactures the Dispos-a-Ject™ System (Fig. V), a current device on the market that is very similar to what the client has requested. This device is expensive at $375 for the system and fits both a 1cc syringe and 10cc syringe. The syringes used for this device are BD Luer Lock syringes. The material used is surgical grade stainless steel and weighing 2-3oz. The device expels about 0.9cc's with a full pull on the 10cc syringe, requiring 11 full pulls to empty the syringe. This is similar for the

1cc syringe, expelling about 0.1cc per full pull. The company sold 59 systems during the year of 2004 and has sold 42 this year up until September 16, 2005. The device is not limited to only fat injections, but is also used for the application of hair glue [3]. The client has requested a device that is both inexpensive and more compact.

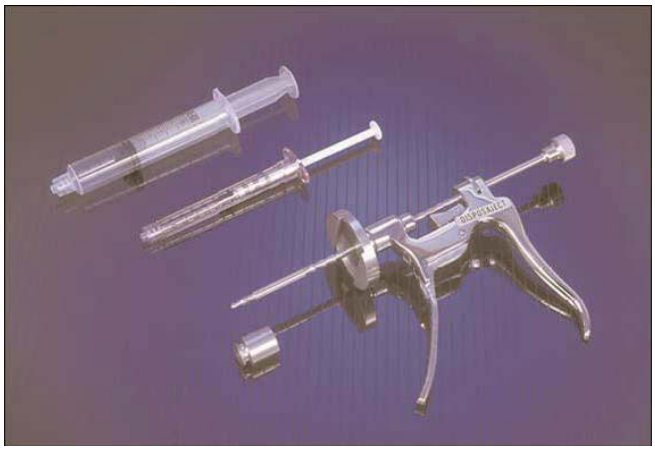

Fig. V: *Dispos-A-Ject*™. This is the current device is on the market. Our client would like us to design a more compact design with movements similar to common syringe movements.

Previous Design: Step-Meister 1.0

Our design from last semester is a device that expels an increment size of 100μL with each depression of the plunger. It incorporates a tube that locks into the existing finger grips of the syringe (a friction fit groove). The inside of the tube contains diagonal grooves connected by horizontal grooves. When the physician pushes the device's plunger, it rotates down the diagonal grooves and pushes on the syringe's plunger, which expels the filler. The plunger will rotate down until it hits the horizontal section where the physician will manually rotate the plunger back the other way. The physician will then be able to expel more filler in increments with the same repeating motion.

Fig. VI: *The Step-Meister 1.0* Our design from last semester incorporated an increment size that was controlled by a diagonal groove.

After seeing and testing our device, the client had a few suggestions. He liked knowing the increment size was precise and accurate, and he also liked the size and weight of the device. However, because the procedure is requires precision the manual rotation introduced some movement which could affect the visual results or the comfort of the patient. He also commented on the ergonomics, especially that the plunger's thumb holder should be larger.

Design Constraints

The primary design constraints as defined by our client include: delivering a known volume with each increment (50-100μL), withstanding the high temperatures of an autoclave (121°C) or being disposable, accommodating syringes of 1cc or 5cc, and minimizing the amount of moving parts to facilitate easier sterilization and cleanup. Each increment should expel the same amount of filler within an error margin of 5-10% and precision is preferred over accuracy. The device should be made of a non-porous sterile metal and last up to 2500 uses. Alternatively, the device could be made of disposable plastic for one time use. The total weight of the device and syringe should not exceed 500g. There should be no obstructions at least 5cm from the distal end of the syringe and if necessary a window should be included in the design to allow the surgeon to monitor the amount of material remaining in the syringe. Only one prototype is

requested at this time. The client has also requested that there finger rings be added for stability.

Materials

Two materials we are considering for construction of our prototype are stainless steel and plastic, specifically flouropolymers. Our client has no preference between these two options. If the device is made of steel or another metal it would be autoclaved and allowing for multiple uses. On the other hand, a plastic device would be of one time use and disposable. Important properties of these materials are their density, temperature constrains, elastic modulus, and cost.

The main type of stainless steel used in medical applications is stainless steel grade 420. One of the distinguishing characteristics of this material is that it must contain between 12% and 14% chromium content as it helps fight against corrosion of the metal. The typical tempering temperatures for grade 420 range from 204ºC to 650ºC. The different tempering ranges give the metal different inherent properties related to tensile strength (between 655-1600MPa). When autoclaved the characteristics of the metal will be unchanged. The density is approximately 7.750g/cm^3 - an important property that will determine the weight of our final product. The elastic modulus, a measure of the force required to elongate the material, is 200GPa and is sufficient for the requirements of the device [2].

Fluoropolymers are a group of plastics that are easy to machine. This plastic would be ideal for the construction of our device because it is inexpensive and strong. The elastic modulus is 0.393 GPa which is significantly lower than steel. However, with a one-time use, deformations would not be problematic. Fluoropolymers can operate in a

maximum temperature of 327ºC allowing them to be autoclaved if necessary[15]. The density of this material 1.5 g/cm^3 and its cost is \$2.41 cost/in^3 [16]. Because of its cost and density fluoropolymers would create a lighter and less expensive device than steel.

Alternative Designs

Step-Meister 2.0

Our first design is a modified step-meister. It utilizes the same ideas behind the original step-meister, however incorporates a few improvements. The groove increment size would become smaller, moving from 100 to 70µL with each depression. The manual rotation would also be eliminated by the use of a torsion spring. A straight, vertical groove would be added and would run the length of the diagonal groove. One end of a torsion spring would lock in to this groove while the other end would be placed on the plunger rod. As the plunger rotates down the diagonal, it will also be rotating away from the vertical groove. The tension will build in the spring until the plunger hits the horizontal groove. To release the tension, the spring will automatically rotate back into the top of the next diagonal groove and is ready for the next depression.

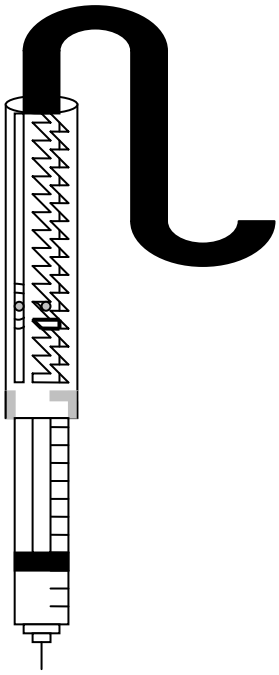

Fig. VII: *The Step-Meister 2.0* A torsion spring minimizes manual rotation while using the same mechanism as the Step-Meister 1.0

The advantages to this design are that the manual rotation and the increment size have both been improved from our previous design. It is also an advantage that our team is familiar with the manufacturing of this design. Knowing how to make part of our prototype will also help to make visual and mechanical improvements. However, with the reduced increment size, it will be more difficult for us to manufacture. Making a groove that is smaller than 100 μL could be out of the capabilities of our team which would require us to hire a professional to help make this groove which will increase the cost of the prototype. The other disadvantage of this design is that the use of the torsion spring may cause unwanted movement during the procedure. When the spring pulls the plunger back into place, even a small jerk could be risky to the procedure.

Design II

Our second design is similar to a mechanical eraser. Teeth are cut running down the length of the tube where a complimentary bar can lock into place. The device uses a button to advance the plunger. A bar that locks into each increment and is pushed down

while the user slides the button forward to the next increment, then the button is let up and the bar locks into the next increment. This device uses a spring for the locking bar and a pliable material for the button. The increment size would depend on the amount of teeth cut; this amount could be easily changed to fit our client's specifications on increment size.

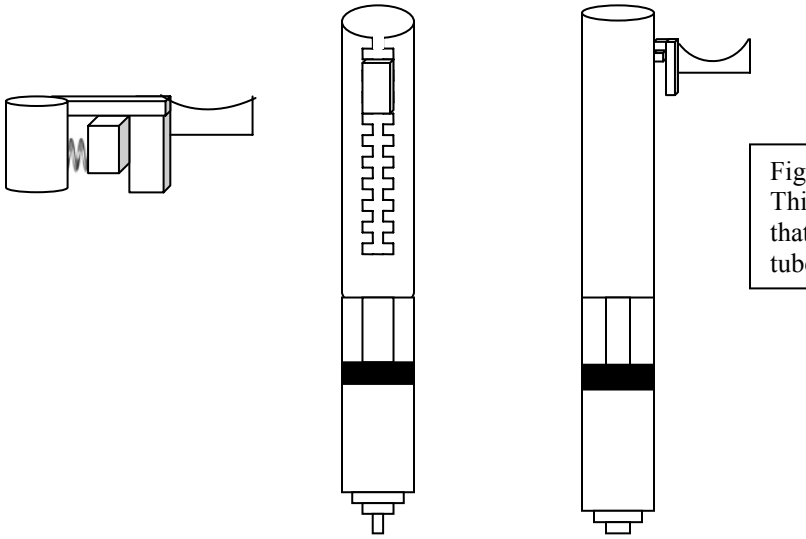

Fig. VIII: *Design II*
This design incorporates a button that locks into teeth cut along the tube

One advantage of this device is that it can offer varied increments. If the physician wants multiple increments they can simply keep the button depressed as they slide it down until the appropriate amount has been expelled. This could, however, be problematic if the physician unintentionally keeps the button depressed and too much filler is expelled. The way the physician manipulates this design is similar to pushing a normal syringe and would therefore be an easy transition. This device would take some practice to accurately push down and let up on the button to give the desired amount of filler. Another advantage of this device is that there are relatively few small parts making construction less difficult.

Design III

Our third design uses a tube that fits over the back of the syringe. Tabs would be set into the tube where the physician would put their fingers to hold onto the device. As they apply pressure to these tabs, connecting rods pull down an L-shaped wing near the top of the tube. These wings lock in place to prevent the doctor from expelling filler. Once they are pulled down, the physician would then be free to push down the device plunger to inject filler. Once they release pressure on the tabs, springs in compression push the L-wings back into place. The wings would then catch on notches cut into the device's plunger, which would prevent the doctor from advancing the plunger.

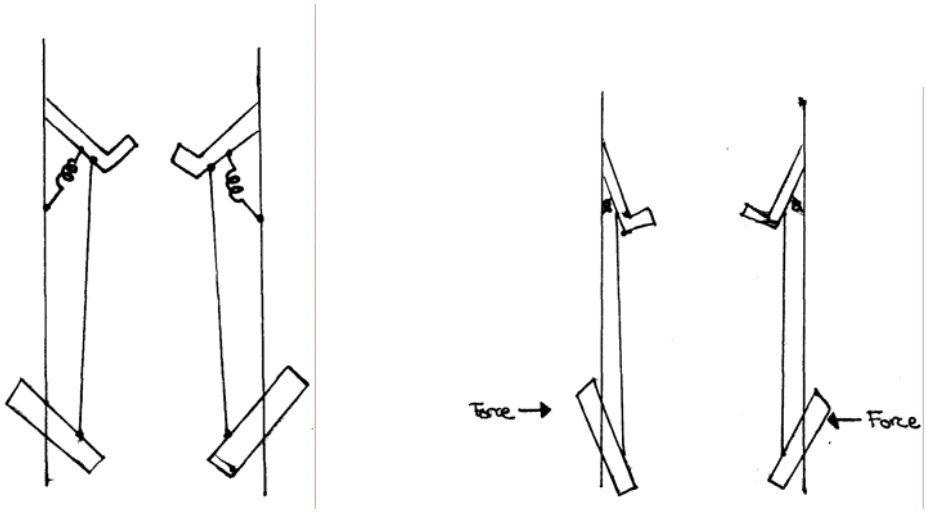

Fig IX: *Design III* This design uses L-shaped wings to lock the plunger into each increment

One advantage of this device is that it allows the doctor to use his discretion in expelling more than one increment at a time. The mechanism employed in operating the device is also fairly simple, and thus reliable. Unfortunately, the parts required to make this device are quite small. While they may not be difficult to manufacture individually, assembling them into a working prototype would be a challenge. The device retains the

normal movement of using a syringe for the doctor, but complicates the procedure by adding an additional motion to make the device work.

Design Matrix

Our design matrix for this project is slightly different than a standard matrix created in a design project. Our primary design constraints of delivering a known amount of filler each time, withstanding the high temperatures of an autoclave (121°C), accommodating 1cc or 5cc syringes, and be made of a metal or plastic were all accounted for in every design. We also considered the size and ease of use. The current device by Bryon Medical and our previous design, Step-Meister 1.0, introduced unwanted and unfamiliar movement which we will try to minimize with our design. The categories that were included were done so because of the variability in each of the designs with respect to these factors. There is a weighted maximum point value assigned to each parameter to distinguish the constraints that are more important to our client. A low value signifies that the design does not address the parameter well, while a high value indicates that the design excels in the particular category. The device that receives the highest score will heavily influence our choice in a final design.

	Step-Meister 2.0	Design II	Design III
Many, small parts (10)	8	6	3
Back Pressure (5)	5	4	4
Varied Increments (5)	2	4	5
Manipulation (10)	5	7	5
Total (30)	20	21	17

Future Work

The future work we have ahead of us for the rest of the semester begins with finalizing our design. Currently, our primary choice is Design II. Our decision was based upon the design matrix and our client's input after evaluating the alternate designs. We will need to research manufacturing possibilities to build this device. Some skills required to achieve small increments may be beyond our capabilities, and we will be looking into manufacturing companies to provide assistance. We will work to improve our metal working skills in order to fashion an aesthetically pleasing device for the client. The remainder of the semester will consist of construction and the testing of our device.

Ethical and Intellectual Property Considerations

Although our device does not actually enter the human patient, it is possible that the injectable fillers that would be entering the patient would be in contact with our device. For this reason, it is important that we autoclave the device after each surgery and design it to make this possible. We would also need to make sure that it would not be abused for applications other than the original intention. There is a current device on the market made by Byron Medical. Our device should not infringe on any patents and our design should be unique and distinct from the Dispos-a-Ject™ product sold by Byron Medical.

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Appendix A

Syringe for Injectable Fillers
(2/3/06)

Team Members: Therese Rollmann, Jennifer Wager, Joseph Cabelka, and Mark Yarmarkovich
Advisor: Professor Thompson
Client: Justin Piasecki, M.D.

Function: The goal of this project is to develop a syringe that is used in plastic surgery and delivers a known increment of injectable filler, such as autonomous fat or Sculptra®, without regard to the pressure applied to the plunger of the syringe. These fillers are injected into various tissues of varying densities and as the needle moves from a more dense tissue (dermis) to a less dense tissue (subcutaneous fat), the pressure required on the plunger is significantly decreased. One filler in particular, human fat, can clump requiring a large force to dispel it. Due to this increased force or decreased density of the tissue, excess can be injected into the patient and lead to an uneven look under the skin. In addition to the aesthetics of this procedure, a more standard method of injecting fillers is preferred for plastic surgeons. If a consistent amount is delivered each time without regarding various human errors and ranges, the procedure is easier to perform and oversee. The incremental mechanism of this device will also allow the physician to focus on the location of the needle under the skin instead of the amount left in the syringe. There is a current device on the market similar to what we have been asked to develop. The device should be disposable or made of an autoclavable material such as metal.

Client Requirements:
- Delivers known amount of filler with one depression of plunger
- Compact design
- Syringe volume of 1cc and 5cc
- Made of metal or disposable

Design Requirements:

1. Physical and Operational Characteristics

A. *Performance Requirements* – The volume of each increment should be from 50 to 100 μL, preferably closer to 50 μL. If the product is made of plastic, it will only be a one-time use. If metal is used, it should withstand use and abuse for at least 10 years.

B. *Safety* – A standard needle will be attached so appropriate caution should be used when handling the device. There should be no sharp edges on the device. If the device is disposable; no safety legislations apply since only the needle is invasive. If the device is for continued use, sterilization measures would apply.

C. *Accuracy and Reliability* – The range of error must lie within 5-10%, and a consistent error is preferred over imprecise values.

D. *Life in Service* - If the device is made of plastic, it will be disposable. The same device may be used multiple times for one patient during one operation. If it is made of metal, it should last up to 2500 uses.

E. *Shelf Life* – The shelf life of the device should be 5-10 years.

F. *Operating Environment* – The device will be stored and operated in room temp (~20°C). While in operation the environment will be sterile, also requiring syringe and/or device to be sterile. Syringe/device must withstand an autoclave temperature of 121°C or be disposable.

G. *Ergonomics* – Strain on the fine hand and forearm muscles should be reduced as much as possible. Rotation of the thumb in operation should be minimal.

H. *Size* – A handheld device with no obstructions at least 5 cm from the distal end of the syringe. The device should be fit either a 1cc or 5cc syringe.

I. *Weight* – The total weight of the syringe and device should be less than 500g.

J. *Materials* – The syringe should be made of a non-porous material. Medical grade plastic, titanium, and stainless steel are possibilities.

K. *Aesthetics, Appearance, and Finish* – A window is necessary on the device in order to see the volume of filler left in the syringe. The finish should be matte to reduce glare. There should be some attempt to make it attractive to patients.

2. Production Characteristics:

A. *Quantity* – Only one prototype is requested at this time.

B. *Target Product Cost* – The cost should be kept to a minimum, but a budget of $500 is provided by the client

3. Miscellaneous:

A. *Standards and Specifications* – There are no known standards for a syringe of this type at this moment.

B. *Customer* – The client would prefer that finger rings are attached to the end of the syringe where it is held. This increases the stability of the syringe. Metal is preferred over plastic for durability. Rotation of the thumb should be minimal.

C. *Patient-related Concerns* – The syringe will need to be autoclaved between

uses in patients.

D. *Competition* – Byron Medical is a company that makes the device, the Disposa-Ject™, which is very similar to what our client is requesting.