Alternative Epinephrine Auto-Injector

Submitted to:

Dr. Michael Whitt, Professor

California Polytechnic State University, San Luis Obispo

1 Grand Avenue San Luis Obispo, CA 93405

Prepared by:

Tara Howard, Biomedical Engineering Undergraduate

Uriel Nieves-Cruz, Biomedical Engineering Undergraduate

Joshua Wong, Biomedical Engineering Undergraduate

California Polytechnic State University, San Luis Obipso

Date Submitted:

1 June 2020

Statement of Confidentiality

The complete senior project report was submitted to the project advisor and sponsor. The results of this project are of a confidential nature and will not be published at this time.

Statement of Disclosure

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

Table of Contents

Statement of Work

Executive Summary

Every three minutes, a person is committed to the emergency room as a result of a food allergy in the United States. Over the period of a year, roughly 200,000 people require medical attention for these severe allergic reactions as a result of anaphylaxis [1]. Anaphylaxis (also known as anaphylactic shock) causes your immune system to release a flood of chemical substances, including histamine from cells in the blood and tissues where they are stored. These released chemicals are caused by the interaction between an allergic antibody Immunoglobulin E (IgE) and the substance (allergen) causing anaphylactic shock [2]. Where even trace amounts of the allergen can cause a reaction of hives, swelling, and lowered blood pressure. The immediate treatment of anaphylactic shock consists of epinephrine typically delivered by an auto-injector. The most common adrenaline auto-injector is the EpiPen by Mylan which was prescribed to an estimated 3.6 million Americans in 2015 [7]. The price of an EpiPen is around $650 for a two-pack which has gone up from $93.88 from 2007 of an increase of 500%. Due to the dramatic price increase, many consumers are forced to hold onto their expired EpiPens at risk of anaphylactic shock as they can not afford a new prescription. As a result, the purpose of our senior design project is to create an affordable alternative to the EpiPen that will act as an acceptable generic in the current market.

Introduction

Project: Alternative Epinephrine Injector started as a solution for Bianca Aleman's little brother however the scope has evolved to include the many millions of individuals across the world who struggle with a life-threatening allergen. The stakeholders of this project are Cal Poly and Dr. Michael D. Whitt. Our goals are the following:

- Develop a foolproof method of injection that consistently delivers a dosage of epinephrine
- Be equal or less than the current size of an EpiPen (6 in)
- Be easy to transport or store when not-in-use
- Create an isolated environment where the epinephrine will not be denatured due to environmental changes (e.g. temperature, light sensitivity, etc.)
- Class II FDA Medical Device
- Deliver a fully functioning prototype of an alternative epinephrine auto-injector
- Stay within a budget of $200 - $700
- Do not infringe on Mylan or Kaleo's current patent

Background

Patients who suffer from severe allergic reactions causing anaphylaxis utilize the medication epinephrine, via a subcutaneous injection, to improve their symptoms and reverse swelling in

the throat to open up breathing. Currently, Mylan's EpiPen Auto-Injectors and EpiPen Jr. nearly corner the market for epinephrine injection products. These Mylan products, for non-insured individuals, can cost between $300 and $630, which is a 500 percent price increase since 2007 [6]. Other companies have released similar products, the Adrenaclick, Auvi-Q, and Symjepi, as well as some generic name products, but all of which are still highly expensive (the cheapest priced at $110, without insurance). From our research, we found a new product would impact a large market, with 32 million Americans suffering from food allergies, 200,00 of which requiring emergency medical care, and most of which being highly dissatisfied with the current options available for treatment [1].

Anaphylaxis is a life-threatening condition, brought on by serious allergic reactions. At-risk patients are typically prescribed epinephrine auto-injectors; however a large proportion of patients fail to fill their prescriptions due to high prices, which is due to the lack of regulations on price, given it is not classified as a preventative medicine [8]. Lack of patient adherence is a serious concern, as prompt facilitation of the medication is necessary for reducing hospitalizations and fatalities [3]. While the benefits of using epinephrine auto-injectors highly outweighs the risks, it is important to note them. When using auto-injectors, specifically when used by children, accidental injections of epinephrine to people not in anaphylactic shock have been known to occur, which requires medical attention due to the possibility of tissue death due to blood flow reduction. As well, many patients use expired devices due to their high cost. While some risks are associated with this practice, they are still effective and do not induce a higher risk [6].

A study performed on the importance of usability of auto-injectors as treatment for anaphylaxis showed that EpiPen Jr.'s were inferior to the design of the Auvi-Q [5]. The Auvi-Q, produced by Kaleo, is shaped more closely to a small box compared to the EpiPen Jr.'s near cylindrical, pen-shaped design. This study was evaluated by studying untrained adults' completion of injection tasks on child-sized mannequins, and showed a far higher rate of accidental injection (if needle had not been removed) when using the EpiPen Jr. and the when using the Auvi-Q, a much higher rate of injection into the desired region was found.

Table 1. Current products on the market

Patent #	Potential Infringements
10,406,288	The specific parts in which comprises the delivery mechanism for an auto-injector. The delivery mechanism's drive members.
10,320,439	Utilizing a smartphone case as a housing for an epinephrine auto-injector
10,369,292	The plunger assembly for a fluid dispensing syringe, such as the one in an auto-injector
10,525,206	The creation of an auto-injector that is not sufficiently unique from this definition.

10,500,337	The creation of an auto-injector utilizing a piston that is not sufficiently different from this definition.

This device would most likely be classified as a class II device, per the FDA regulations for medical devices. With this classification, to move to the market, the most critical regulation would be the 21 CFR, most specifically the 21 CFR part 807 - the Pre-Market Notification 510(k). Once a prototype is developed, it may go into clinical trials in laboratory environments. Next, it must be submitted for a pre-market notification to get FDA clearance. Once approval is received, the device must stay in compliance for its lifetime.

Objectives

Problem Statement

- Develop and deliver an alternative epinephrine injector suitable as a replacement for the market's leading medical device.

Boundary Definition

- Explicitly includes:
    - Alternative epinephrine injector
    - Auto-injection mechanism
    - Safety mechanism
    - Isolated environmental chamber
        - Resists temperature fluctuations
        - Reduces exposure to light
- Explicitly does not include:
    - Infringement on current Mylan EpiPen patent or Kaleo Auvi-Q
        - Mylan: US Patent No. 7,794,432
        - Kaleo: US Patent No. 8,920,377

Summary of Customer Needs/Wants

- From information received in needs assessments with actual consumers, we found the customers need a highly reliable and safe epinephrine auto-injector for use during life-threatening anaphylactic shock.
- As well, we found customers wanted an alternative to the current market leaders (EpiPen and Auvi-Q), in that they want a device that is smaller, more user-friendly, and cheaper.

Product Specifications Matrix

- *See 'House of Quality' document for in-depth analysis.*

Specification Measurement

- *See 'Specification Development' on page 13.*

High-Risk Specifications

- The high-risk specification we face is the injection mechanism as a drug auto-injector is considered a class II medical device.

Project Management

The first stage of the design process is to create and identify how the auto-injector will deliver the epinephrine into the subject. After the mechanism is designed, the environmental isolation chamber which houses the epinephrine will need to be created as it will house and protect the drug from potential environmental factors. Then, we can create a housing for both subunits which covers the delivery mechanism and environmental chamber.

The project timeline and critical path will be delivered at a later date after the second revision of our network diagram has been completed.

Special analysis techniques will be reviewed later as we approach a prototype.

Conclusion

The purpose of this statement of work is to finalize and confirm our project's scope, explain the background and market need for a new product, and detail our design process. In the coming weeks, a shortlist of potential final design concepts can be expected. We ultimately plan to have completed our research and design specifications by 2/18 and our final prototype design by 3/9. Our written documentation of our product will be finalized by 3/15 so we can present our critical design report on 3/16. We plan on using the rest of our time to manufacture, test, and finalize our product as to have a design review poster presentation during the senior project exposition by 6/6. Throughout the process we will strive to reach all of our deliverables on time while maintaining a high-quality of work.

Network Diagram

	Task Mode	Task Name	Duration	Start	Finish	Prec
1		Reseach Current EpiPen Designs	2 days	1/23/2020	1/24	
2		Formulate Design Ideas	7 days	1/25	2/3	
3		Indication of Use Statement	1 day	1/25	1/25	
4		Statement of Work	1 day	1/29	1/29	
5		Pros/Cons Statement	1 day	1/25	1/25	
6		Budget Analysis	3 days	1/27	1/29	
7		Evaluate and Chose Idea to move forward with	1 day	2/4	2/4	2
8		Drug Delivery System	3 days	2/5	2/7	7
9		Concept Sketches	10 days	2/14	2/27	
10		Pros/Cons Statment	1 day	2/7	2/7	
11		PUG Chart	2 days	2/10	2/11	
12		Conceptual Model/FEA	4 days	2/22	2/26	
13		Intermediate Design Report	3 days	2/21	2/25	
14		Begin Materials selection process	21 days	2/26	3/25	7
15		Purchasing Immediate Materials	1 day	3/4	3/4	
16		Refine Design Idea	3 days	3/5	3/9	14
17		Critical Design Report	34 days	1/21	3/6	
18		Purchase Intermidiate Materials	1 day	4/1	4/1	
19		Status Update Memo	1 day	4/12	4/12	
20		Build Prototype	31 days	3/16	4/27	
21		Test Plan Report	4 days	4/15	4/20	
22		Functional Prototype Video	26 days	3/16	4/20	
23		Testing Phase	14 days	4/28	5/15	20
24		Update Prototype	14 days	5/18	6/4	23

Figure 1a. Network Diagram including Critical and Non-Critical Tasks

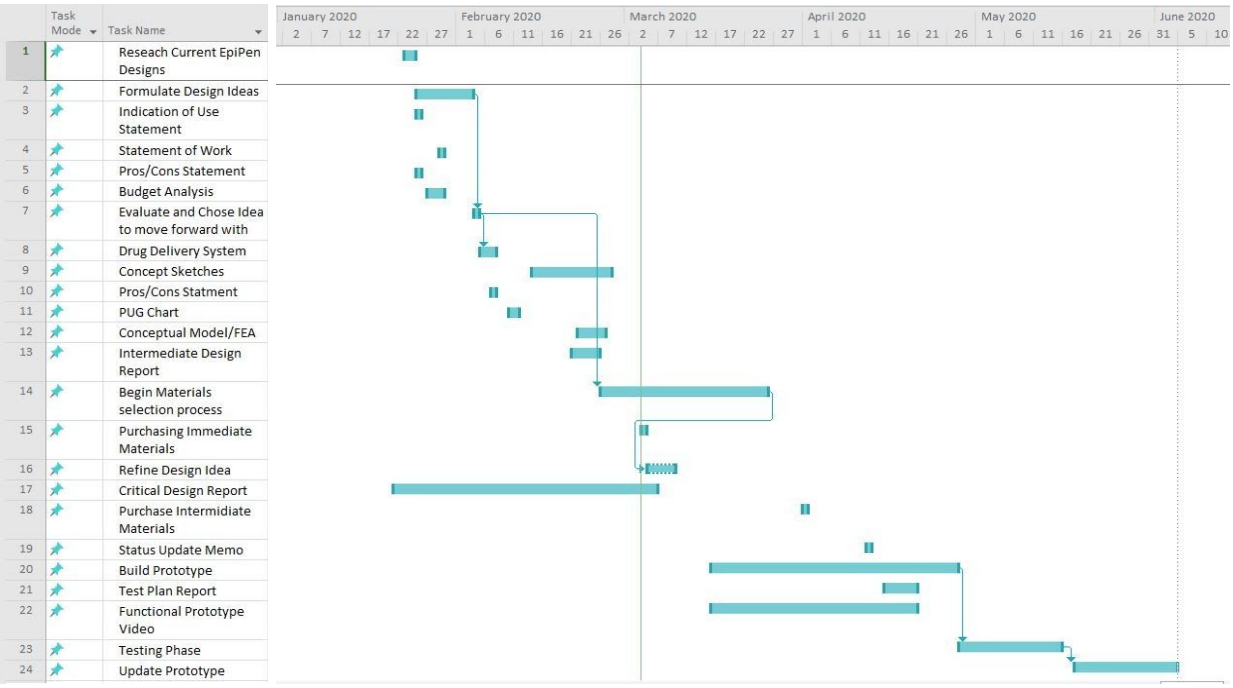


Figure 1b. Network Diagram and Critical Path

Indications for Use

Our product is indicated for the relief of symptoms in patients who are experiencing life-threatening anaphylactic shock due to consumption or exposure to allergens or any other known or unknown triggers as judged by the patient themselves. The intended use of this product is for immediate emergency procedure only. Further medical help should be sought and notified right away.

Budget

Our materials list for our budget is a living document that we will make alterations to as we continue this project. Currently, our total project budget is $700; however, we aim to stay well below this amount. It is presumed that the main allocation of our budget will be to 3D printing materials to design the casing/housing of our auto-injector. The amount of filament needed may fluctuate due to how many prototypes are printed.

Below is our current, non-exhaustive list for budgeting the materials necessary to complete our project.

Item Description	Product Number	Company	Purpose	Associated Task	Units Included	Planned Quantity	Planned Cost/Unit	Planned Total Cost
16 Gauge Injection Needle for T	TDN1520		To inject epinephrine	TBD	3	1	$10.67	$32.00
Gray 3D Printing Filament	727559904978	Keene Village Plastics	To create housing for syringe and medication	TBD	EA	4	$14.00	$56.00
Compression Spring	54NJ95	Grainger	To push needle into leg	TBD	10	2	$2.12	$21.17
0.5 mL Plastic Syringe Plunger	19G346	Grainger	To push medication out	TBD	100	1	$0.39	$38.76
Tranquilizer Dart	TD01		To inject epinephrine	TBD	5	1	$10.31	$51.54
							Total Cost:	$199.47

Figure 2: Preliminary list of materials along with the quantity and cost of each material to finish our prototype device.

Customer Requirements

In order to define our customer requirements, we interviewed current carriers of similar products, EpiPen and Auvi-Q, to determine what features of an auto-injection device were necessary for our product. The customer requirements were portability, production cost, and ease of use.

These three requirements can further be broken down into the following sub-categories:

1. Portability
    a. Shape
    b. Weight
    c. Dimensions
2. Production Cost
    a. Material Composition
    b. Method of Manufacturing
    c. Complexity of Device
3. Ease of Use
    a. Design Efficiency
    b. Design Efficacy
    c. Affordability

Specification Development

Before applying quantitative measurements to each of our customer requirements, we must first define our specifications.

Shape - The two most seemingly desirable shapes are a cylindrical shape and a rectangular box shape.

Weight: Our product must not exceed .15 pounds.

Dimensions- No larger than 3.4” x 2.3” x .5” for a rectangular box design. No larger than R.5” x 7” for a cylindrical design.

Material Composition: 3D-printing filament, adhesive, plastic, stainless steel, and glass. Additional materials may be incorporated with further manufacturing.

Method of Manufacturing: The current method of manufacturing is to 3D-print a designed apparatus shell to house the internal components of our device. The first devices will then be assembled by hand.

Complexity of Device: To be reviewed.

Design Efficiency: Yield at least four products with the current budget provided.

Design Efficacy: Full dosage of medicine should be administered 100% of the time used.

Affordability: Each unit should be able to be manufactured in less than $60.

TAM and Competitive Advantage

In the United States, 3.6 million people are prescribed EpiPens, and 300,000 emergency room visits are reported per year for children under the age of 18 due to food allergies [8]. In 2018, the U.S. market for EpiPens alone reached approximately US $750 million per year, and the entire epinephrine auto-injector worldwide market is estimated to reach US $2.4 billion per year by 2024 [4]. The Total Available Market for our product, if 100% of the available market is achieved, would be equal to the worldwide market, and thus be very vast.

Our competitive advantage over the two top-selling epinephrine auto-injectors includes our product having a less bulky, more user-friendly, and more practical design. As well, while Mylan (the owner of the EpiPen brand) had a near monopoly on the market and thus continuously increased their prices, we would pledge to not flagrantly pad our profit margins at the expense of patients' ability to have access to the product. While it would take time to switch lifetime users of EpiPens and Auvi-Qs over to our product, we believe all users who struggle to afford the highly expensive auto-injectors would make an immediate switch.

Intellectual Property Assessment

In order to not infringe on any pre-existing patents regarding the design of our auto-injection device, it is important to be knowledgeable of exactly what patents are currently on the market. Below in Table 2 is a list of three current patents and three patent applications which have some claims which we could have potentially infringed upon had we not known them.

Table 2: List of patents and current claims on the market.

Patent Name	Patent No.	Patent(P)/ Applicant(A)	Claim	Claim Addressed
Delivery mechanism for an autoinjector	10,406,288	P	**Dual drive injection mechanism wherein two drives are configured to each load their own mechanism to 1) drive the needle into the leg and 2) drive medicine through the needle.**	Design Change necessary. Perhaps a three drive composition or a way to manufacture two components to be driven by the same mechanism.
Medical Device Case	10,320,439	P	**A two pocket smartphone case where an epinephrine injection mechanism can be easily inserted into one and medication tablets can be stored within the other.**	Either do not incorporate a smartphone case into our design or instead make the auto injector inseparable from the phone case.
Syringe plunger assemblies	10,369,292	P	**A specific design for an integrated plunger and plunger rod which can propel fluid as well as a stopping mechanism for the plunger itself.**	Do not incorporate this plunger design within our device.
Autoinjector carrier	20190381236	A	**A certain housing design for an autoinjector within which the autoinjector can be easily removed via pushing up from the bottom.**	Design a different housing case for our product. Perhaps one that uses the force of gravity to slide our device out of--no human forces necessary.
Wearable Medication Delivery Device	20190374714	A	**A method, comprising: maintaining a needle driver of a needle actuator under load of a spring by mating a first key with a first notch in the needle**	Design our product with a manual stimulation necessary for needle release.

			driver and mating a second key with a second notch in the needle driver; and deploying a needle coupled to the needle driver into skin of a person.	
Methods, Systems and Devices for administering medication	20180078710	A	**A medication delivery device comprising of a syringe, flange, syringe barrel, and plunger.**	Inhibit the withdrawal of blood via the needle during its removal from the patient.

Conjoint Analysis

Table with your Factors and Levels

Factor	**Level 1**	**Level 2**
Cost (w/o insurance / w/ insurance)	$360	$650
Dimensions	Cube 3.37” x 2.125” x .5”	Cylinder R .5” x 6”
Injection Mechanism	Gas-powered	Spring-powered

Listing of Conjoint Cards

Card #	**Cost**	**Dimensions/ Portability**	**Injection Mechanism**
1	$360	Cube 3.37” x 2.125” x 0.5”	Gas-powered
2	$360	Cylinder R .5” x 6”	Spring-powered
3	$650	Cube 3.37” x 2.125” x 0.5”	Spring-powered
4	$650	Cylinder R .5” x 6”	Gas-powered

Card #	Cost	Dimensions	Delivery Mechanism
1	0	0	0
2	0	1	1
3	1	0	1
4	1	1	0

Ranking: (Best-to-worst)

1. 2143
2. 2143
3. 2134
4. 3421
5. 2413
6. 2143
7. 2431
8. 2413
9. 2314

Statistical Analysis

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.21659543
R Square	0.04691358
Adjusted R S	-0.0424383
Standard Err	1.15770367
Observations	36

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	2.11111111	0.7037037	0.52504318	0.66821658
Residual	32	42.8888889	1.34027778		
Total	35	45			

	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.11111111	0.38590122	5.47059971	5.051E-06	1.32505604	2.89716618	1.32505604	2.89716618
X Variable 1	0.33333333	0.38590122	0.8637789	0.39413789	-0.4527217	1.1193884	-0.4527217	1.1193884
X Variable 2	0.33333333	0.38590122	0.8637789	0.39413789	-0.4527217	1.1193884	-0.4527217	1.1193884
X Variable 3	0.11111111	0.38590122	0.2879263	0.77525979	-0.674944	0.89716618	-0.674944	0.89716618

A brief discussion on which factors you believe will be important to the success of this product based on the information obtained from your classmates.

a. Which factors matter to my customer (at given confidence).

As the p-values are greater than .05, we fail to reject the null hypothesis indicating that the result is statistically insignificant.

b. How much those factors affect my customer attraction to using my product (via the coefficients given).

Both cost and dimensions affect our customer attraction equally at a coefficient of .333 each. However, the method of injection mattered the least to our customers with a coefficient of .111.

c. How much those factors that matter explain the customer attraction (via r-squared or coefficient of determination)

As our r-squared value is .047, this indicates that there is a very weak 3relationship between the dependent variables and independent variables.

Morphology

Morphology						
Product: Alternative Epinephrine Injector		Organization Name: Group 10				
Function	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Safety Mechanism	Safety Cap – second stage of safety that prevents accidental injection of epinephrine	Locking engagement lever – third stage of safety where lever prevents the needle from injecting	Rubber stopper – third stage of safety that prevents needle from releasing epinephrine	Environmental Casing – first stage of safety as it surrounds the autoinjector		
Penetration of Mechanism	Pressurized gas gradient – penetrates skin	Elasticity Powered – penetrates skin	Mechanical Spring-Powered – penetrates skin	Manual Injection – penetrates skin		
Delivery of Medication	Pressurized gas gradient – injects epinephrine as a result of a gas gradient	Elasticity Powered – injects epinephrine as a function an elastic powered medium	Mechanical Spring-Powered – injects epinephrine as a function of spring force			
Retraction of needle	Pressurized gas gradient – retracts the needle as a function of gas pressure	Elasticity Powered – retracts needle as a function of an elastic medium	Mechanical Spring-Powered – retracts needle as a function of spring force	Manual Removal – retracts needle by means of human interaction		
Team member: Tara E. Howard		Team member: Uriel Nieves-Cruz		Prepared by:		

Concept Evaluation

The front runner design we decided upon is a single spring injection mechanism with a button actuator that would deliver the epinephrine into the patient. The injection mechanism delivers the drug through means of a compressed spring that is coiled around the plunger and held in place by the slightly wider top of the plunger which is then released when the button is pressed. After the button has been pressed, the needle is then propelled forward as a result of the spring force within the device and plunges itself into the patient. As the needle pierces the skin, a rubber stopper slides backward revealing the injection hole. Once the injection hole has been exposed, the drug is then injected into the patient as a result of the driving rod that pushes the rubber stopper forward in the direction of the patient and thus driving the drug into the patient.

The model we have developed relies on the following equation for the force needed to inject the solution (epinephrine) into the patient:

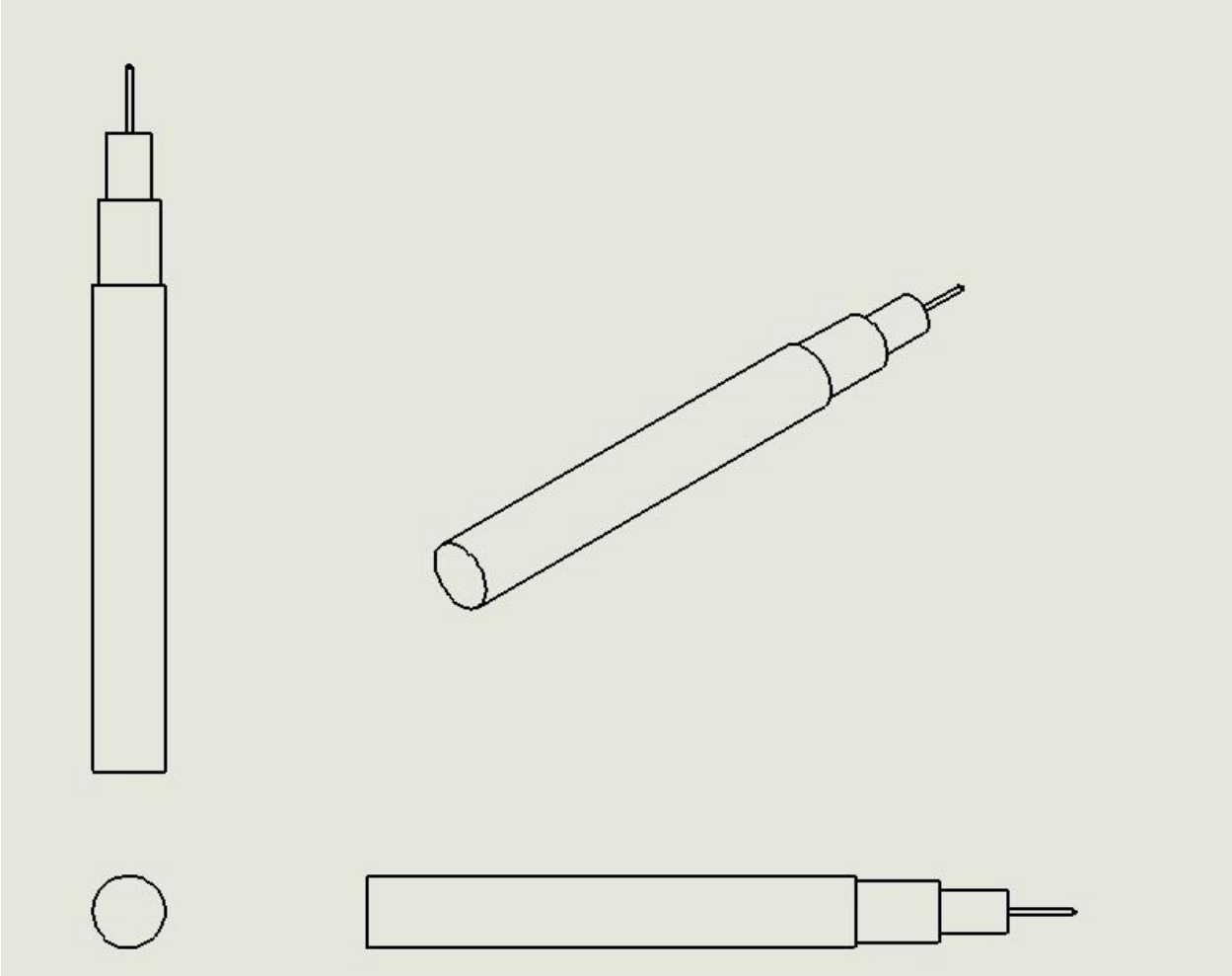
- $F = 32\mu L(\frac{D^2}{d^4})(\frac{V}{T})$
    - F = force required to inject the volume of a solution
    - μ = viscosity of the solution
    - L = length of the needle
    - D = inner diameter of the syringe's barrel
    - d = inner diameter of the needle
    - V = volume of the solution
    - T = duration of time

This equation will assist us in determining the proper spring constant we need, and thus, the spring we will utilize in our design. The needle selected is 1.5 millimeters in diameter, and it is hypothesized that the exposed needle length will be approximately 16 millimeters. The diameter of the barrel is 11 millimeters. A common concentration for epinephrine in solution is 1mg/1mL. With the auto-injectors, even though 2mL of solution is stored, only 0.3 mL, and thus 0.3 mg of epinephrine, are actually injected. Each 0.3 mL of solution contains 0.3 mg epinephrine, 1.8 mg sodium chloride, 0.5 mg sodium metabisulfite, hydrochloric acid to adjust pH, and water for injection. The pH range is 2.2 - 5.0.

The solution, if produced commercially, would be compressed with nitrogen to avoid oxidation, but due to constraints we have, oxygen will be used to compress the solution for our prototype.

Conceptual Model

The following CAD drawing models our design:

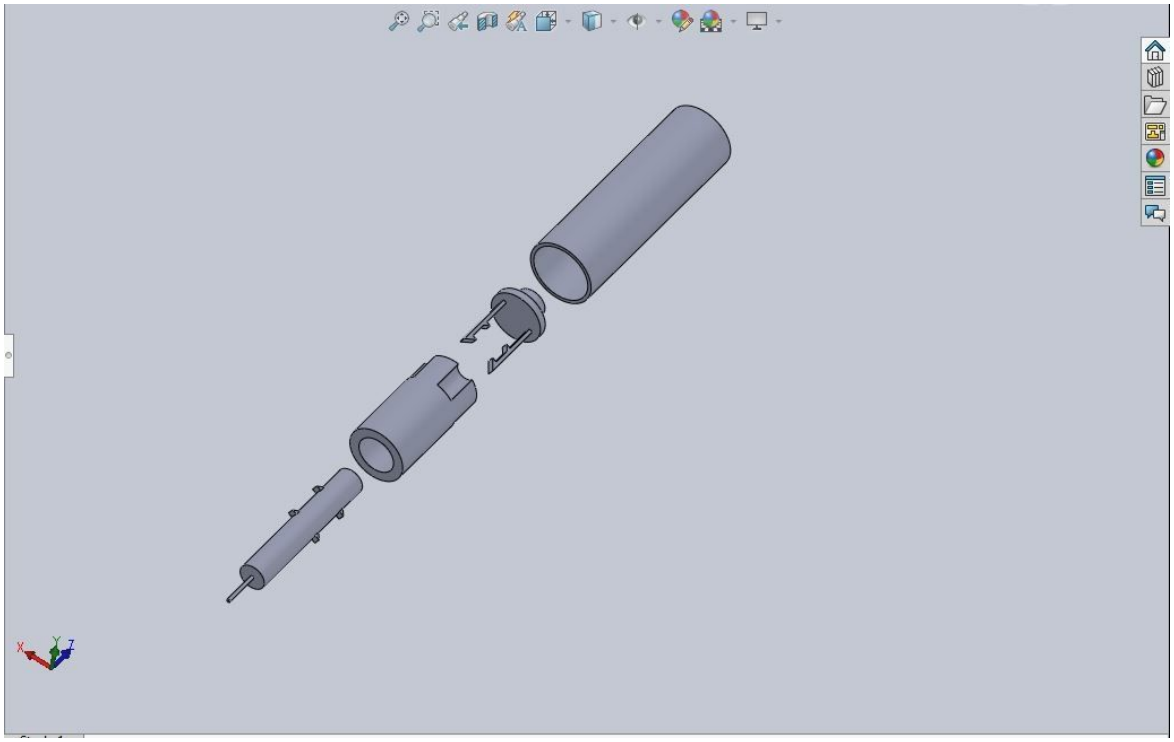


In developing the model, we determined that a double-spring epinephrine auto-injector would be more complicated and introduced more modes of failure than a single-spring auto-injector. Furthermore, in looking at the inspirations of different designs, it was made more apparent that the Auvi-Q auto-injector would be more difficult to model as well due to the shape of the auto-injector. A credit card-sized injector is much more compact of a design than a linear model. The linear model can be most accurately related to that of an EpiPen or an AdrenaClick.

Further development would be impacted by the design/product that makes up the needle and injection mechanism. The model can only be as small as the needle and its casing.

Detailed Design

The following CAD assembly drawing shows further improvements upon our conceptual model:



Our design is made up of five main parts – the outer cylinder case, the button/locking mechanism, the inner cylinder guard, the syringe, and the springs. Seen first here is the outer cylinder case. This is one of our 3D printed parts and serves as a protective casing for the auto-injector, as well as holds the button firmly in place. This piece is the largest of all of the parts. The next part is the button/locking mechanism. When in place, the button sticks through a hole in the top of the outer casing, while the “legs” attach to the pegs on the syringe. The legs serve as a locking mechanism. When the button is depressed, the legs pan out slightly, releasing the syringe from being “locked”. The inner cylinder guard is seen below, which prevents the button from moving. Both the guard and the button will be 3D printed. The syringe will be purchased, along with a needle. We will affix the pegs onto the syringe. Through displacement of the spring a small amount of pressurized oxygen will be engaged to push on the distal end of the drug compartment, pushing the drug through the needle and into the patient. The needle will need to be manually removed from the leg. Lastly, compressed springs not seen in this model are to be affixed to the back sides of both the syringe and the button, which will provide the force necessary to puncture the skin. When the button releases the syringe, the spring is capable of forcing the syringe to its full length which allows the needle to be exposed, then forces the oxygen to push the drug out of the syringe. Small changes to the overall design of our product can be made as we move forwards with the testing of our project, but the overall function or our auto-injection device will remain the same.

Prototype Manufacturing Plans

We hoped to begin our manufacturing in early April, but due to the COVID-19 crisis, we were forced to change our project into a more formal research project, developing future manufacturing and testing plans for the product. The majority of our prototype will be 3D-printed based off of the solidworks designs which we have made. The parts manufactured in this way will be the outer cylinder case, inner cylinder guard, the safety cap and the button/locking mechanism. A series of springs and glue will be purchased to combine and assemble each of the pieces of our device into one cohesive product. The actual needle and syringe of our auto-injector is being purchased from a vendor and will be inserted within our device.

Our prior plan was that once we had manufactured our first prototype, we would test our product for design flaws and failures. Upon reflection, the details of our design might change, but the method of manufacturing will remain the same, 3D-print or purchase the parts that we need. This process would be repeated until we have created a reliable, working device.

Test Plans

Design of Experiments

We plan on testing our product in three key areas of the design: the needle, the syringe, and the efficacy of the device. The first and most important test that we will perform will be to determine the strength and failure points of the needle that we are using. Using the provided bend-stress testing and shear stress equipment we plan on testing the limits which our needle can experience before failure. This is important as we need to know if there will be any danger of the needle shearing or bending upon insertion of the leg as that could lead to failure of medicine injection or increased physical injury.

Our syringe portion will be tested by submerging the body of the syringe underwater. The syringe should be air-tight, as it needs to hold pressurized air within it for a pressure gradient to be used for administering our medication. If we see air bubbles leak from our syringe then we know we will need to find a different syringe body to use.

The next test we are going to perform is to validate the effectiveness of our device as a whole. We are planning on purchasing ballistic gel and testing our completed model on the gel. When we can consistently achieve the correct drug dosage and ejection mechanism function then we will be ready to submit a final product. An aqueous solution will be mixed to the same viscosity as epinephrine during these tests as that will most closely model real life function.

Performance Metrics

- Needle
    - Flex testing
- Syringe Body
    - Air-tight sealing
- Device Efficacy
    - Delivers full dosage 100% of the time

	Pass Criteria	Fail Criteria
Needle Testing	Elastic modulus of 8 +/- .001 GPa	Elastic Modulus of 8 +/- .002 GPa
Syringe Body	No liquid found within the syringe body	Liquid found within the syringe body
Device Efficacy	Delivers 100% of dosage found within the syringe body	Any dosage found within the syringe body

Sample Sizes

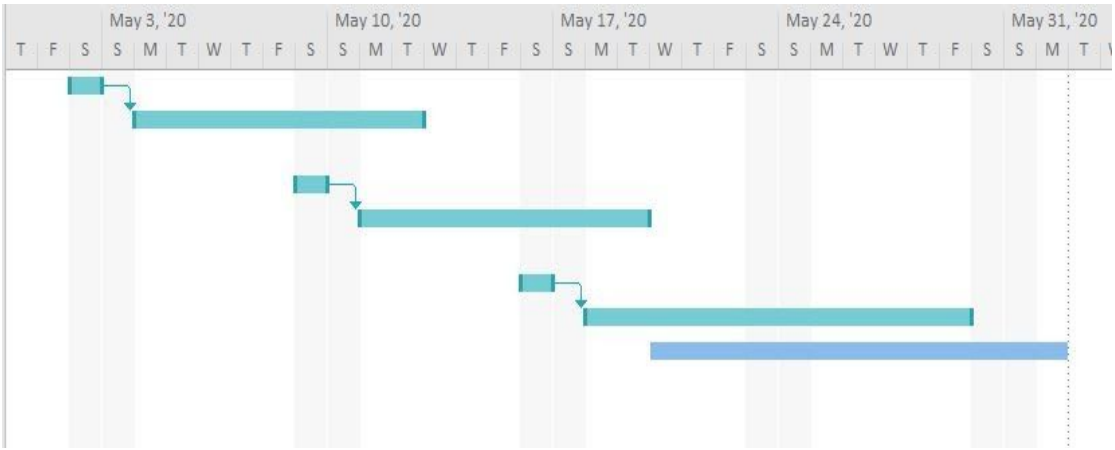
A sample size of 30 samples, n = 30, will be used for every study.

Expected Results

In the three-bend-test, we expect every needle to perform within the given passing parameters. As each needle is made from the same material and size, there would be no difference in this first test. In the second test, we hope that the syringe body is completely sealed off from the surrounding environment. As the syringe bodies are bought from a qualified medical supplier, we expect each body to pass. The hardest test we expect to pass is that of device efficacy. As our fail criteria includes any remaining liquid within the chamber, if any remains, we would have to rethink our design and conduct a revision. We hope for a passing rate greater than 95%.

Network Diagram

Task Mode	Task Name	Duration	Start	Finish
	Syringe Body Testing	1 day	Sat 5/2/20	Sat 5/2/20
	Syringe adjustments/repurchasir	7 days	Mon 5/4/20	Tue 5/12/20
	Needle Testing	1 day	Sat 5/9/20	Sat 5/9/20
	Needle Repurchasing if Necessary	7 days	Mon 5/11/20	Tue 5/19/20
	Device Efficacy Testing	1 day	Sat 5/16/20	Sat 5/16/20
	Time to rework design	2 wks	Mon 5/18/20	Fri 5/29/20
	Repeat Previous Testing	1.8 wks	Wed 5/20/20	Mon 6/1/20



Resources and Contingencies

Test	Materials Necessary	Contingency
Syringe Body Testing	Auto-injection device and a bucket of water, no lab space needed, any one member of the group can perform this test	Repurchase New pressurized air containers
Needle Testing	Needles and a 3 point bend testing machine. This test will need access to the BMED laboratories as well as the entire groups participation	Purchase new needles
Device Efficacy Testing	Ballistic Gel, Completely assembled epinephrine auto-injection device, this test requires no lab space and only one member	Rework design until full dosage of medication is delivered 100% of the time

Conclusion and Discussion

Current injection-based methods for epinephrine delivery have been proven to be costly, bulky, and frequently improperly used, which showcases the deep need and market for a new method of epinephrine delivery - a spring powered, button operated auto-injector. Using concept morphology and conjoint analysis coupled with a detailed array of customer requirements, our team developed a final detailed 3D computer aided design to present to our peers and to our stakeholders. Our design, while not sleeker than the most popularized device, the EpiPen, would allow for a safer drug delivery mechanism by deferring accidental ‘sticks’ and reducing the costs of manufacturing once in the mass production stage due to the simplicity of the design. From our research, while the size of the injector was important to the patients, they cared more highly about the safety and efficacy of the delivery method; therefore, it became our chief point of improvement we wanted to hit.

Due to the ongoing COVID-19 crisis, after the presentation of our detailed designs, we had to segway our aims for this project from creating a functional prototype to developing future manufacturing and testing plans, all while compiling the information and data into a mock design history file, given that we would no longer be able to 3D print our product, and thus hindering us from producing a prototype. With that being said, the extra time available due to not spending weeks creating a physical deliverable allowed us to develop a far more in-depth understanding and explanation of the necessity, purpose, and desired outcomes of our future testing methods we would use for a product. As well, the dramatic shift in focus of our project taught us hands-on skills for overcoming massive setbacks in engineering settings.

We are confident that patients’ outcomes would increase positively, improper dosings would decrease, and more non-patients would feel comfortable using our product compared to the top competitors if our product was manufactured in the methods we proposed for future manufacturing plans. Our current largest concern is ensuring the needle can be punctured even through the thickest of clothing, but with an increase in gauge size of the needle and higher spring constant, this can be established, Further clinical studies would be required to prove this, but given our presumptions, product specifications, and testing, all of these goals are well within reach. We wish we could have seen our design come into physical fruition; however, the assurance we received from our research led us to feel wholeheartedly comfortable and in support of our product.

References

[1] Food Allergy Research & Education (2020) Facts and Statistics. Retrieved from https://www.foodallergy.org/resources/facts-and-statistics
[2] https://www.webmd.com/allergies/anaphylaxis
[3] Fromer, L. (Dec. 2016) Prevention of Anaphylaxis: The Role of the Epinephrine Auto-Injector. *The American Journal of Medicine, 129(12)*, 1244-1250. Retrieved from https://www.amjmed.com/article/S0002-9343(16)30795-1/abstract
[4] Keown, A. (19 Feb. 2019) Teva Eyes 25 Percent of the $750 Million EpiPen Market by Year's End. Urbandale, IO: Biospace. Retrieved from https://www.biospace.com/article/teva-eyes-25-percent-of-the-750-million-epipen-market-by-year-s-end/
[5] Kessler, C., Edwards, E., Dissinger, E., Sye, S., Visich, T., Grant, E. (Sept. 2019) Usability and preference of epinephrine auto-injectors. *Annals of Allergy, Asthma & Immunology, 123(3),* 256-262. Retrieved from https://www.annallergy.org/article/S1081-1206(19)30437-5/fulltext
[6] Posner, L. S., Camargo, C. A. (21 Mar. 2017) Update on the usage and safety of epinephrine auto-injectors, 2017. *Drug, Healthcare and Patient Safety, 9,* 9-18. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5367766/
[7] Rockoff, J. D. (24 Aug. 2016) Mylan Faces Scrutiny Over EpiPen Price Increases. New York City, NY: The Wall Street Journal. Retrieved from https://www.wsj.com/articles/mylan-faces-scrutiny-over-epipen-price-increases-1472074823
[8] Tunney, K. (26 Aug. 2016) How Many People Use EpiPens In America? Mylan's Price Increase Is Taking Advantage Of Its Users. New York City, NY: Bustle Digital Group. Retrieved from https://www.bustle.com/articles/180800-how-many-people-use-epipens-in-america-mylans-price-increase-is-taking-advantage-of-its-users
[9] Westermann-Clark, E., Pepper, A. N., Lockey, R. F. (20 Jun. 2018) Economic considerations in the treatment of systemic allergic reactions. *Journal of Asthma and Allergy, 11,* 153-158. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6016598/