Automatic Intramyocardial Stem Cell Injection Device

Team Heartthrob
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Motivation

- Cardiovascular disease is the leading cause of death
  - 696,962 deaths in the U.S in 2020 [Prevention, 2019]
  - ~5 million people experience heart failure annually with over 250,000 deaths [Tomaselli et al., 2004]
- Treatment via Novel Approach
  - Intramyocardial Stem Cell Injection

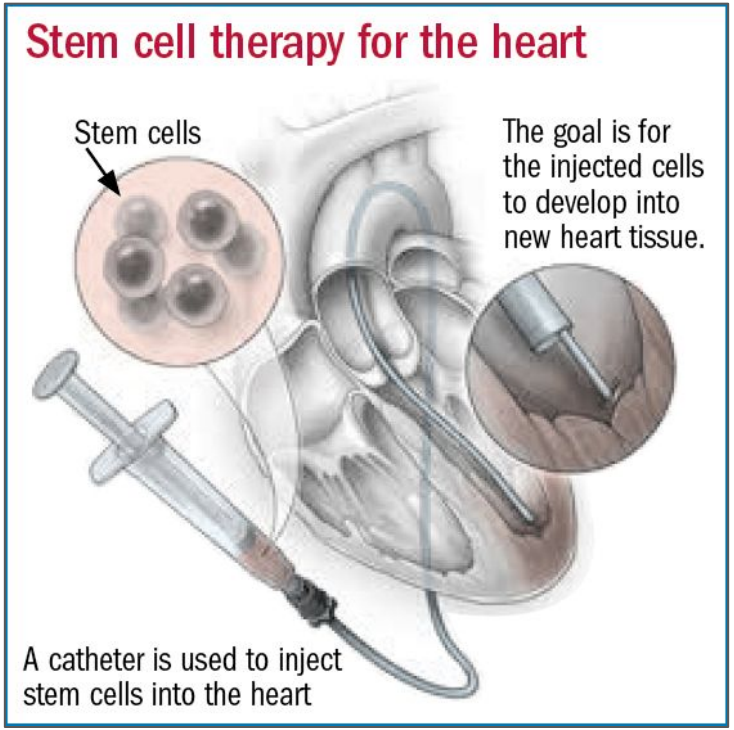


Figure 1: Stem cell therapy in the myocardium
Source: [Health.Harvard].

Problem Statement

- No automated injection device designed for stem cell delivery to the myocardium
  - Operations are performed manually
  - Lack of efficacy
  - Susceptible to hand fatigue
- Need a force sensor feedback system specific to stem cell injection in the myocardium
  - Catheter placement and blockage assistance

Solution: Automatic controlled flow rate of the cells to the heart

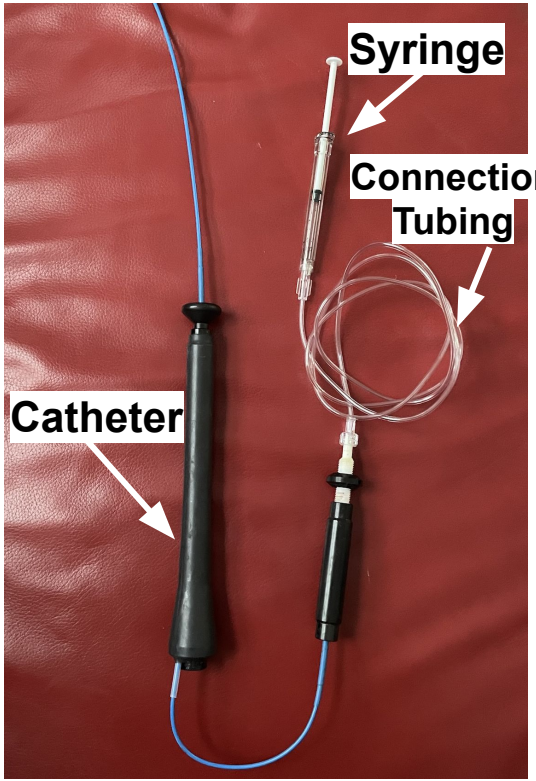


Figure 2: Set-up of the catheter, connection tubing and syringe.

Background Information

- Current Cardiovascular Disease Treatment
  - 25 - 50% mortality rate within 5 years [Rheault-Henry et al., 2021]
- Mesenchymal stem cells (MSCs)
  - Derived from bone marrow [Boyle et al., 2010]
  - Therapeutic potential [Hmadcha et al., 2020]
- Flow rate
  - Too fast or too slow
    - Damaging to cells [White, 2016]
    - Off-target effects
  - Rate inconsistency

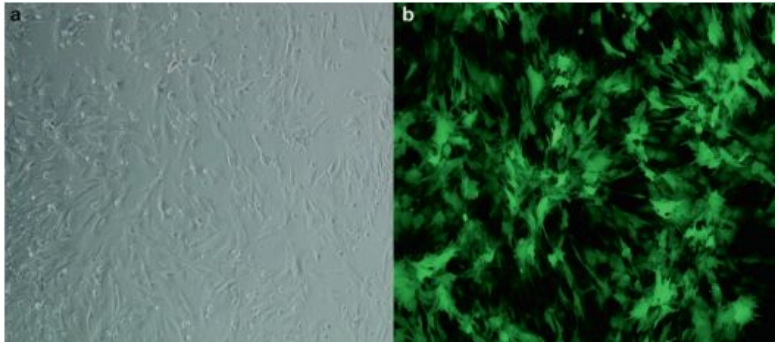


Figure 3: Mesenchymal stem cells in culture [Boyle, et. al, 2010].

Competing Designs

- Baxter Infus OR Syringe Pump ABC 4100 [Wilburn, 2020]
  - Controlled volume of anesthesia
  - Syringe is loaded, flow rate set, clicking start
  - Sense syringe plunger force and movement
- Syringe Pump [Apparatus, 2020]
  - Simplified System
  - Controlled flow rate system
  - Client has one in the lab
  - No force sensor

Figure 4: The "Baxter Infus OR Syringe Pump ABC 4100" [Wilburn, 2020].

Figure 5: Automatic Harvard syringe pump.

Product Design Specifications

- Electronically inject MSCs into the myocardium
  - Maintain cell viability - 5% variance
- Compatible with standard catheters, medical grade tubing, and procedural syringes (1 - 20 mL)
- Withstand sterilization [CDC, 2019]
  - Sterility assurance level of 10^{-3} [FDA, 2013]
- 30 and 60 second injection rates (± 0.5 seconds)
  - Deliver 0.5 mL of solution [Raval et al., 2021]
- Force sensing resistor and visual feedback
  - Threshold = 2.4 N [Doumit et al., 2016]
- Budget of $3000 and manufacture cost of $500 [Raval, 2022]

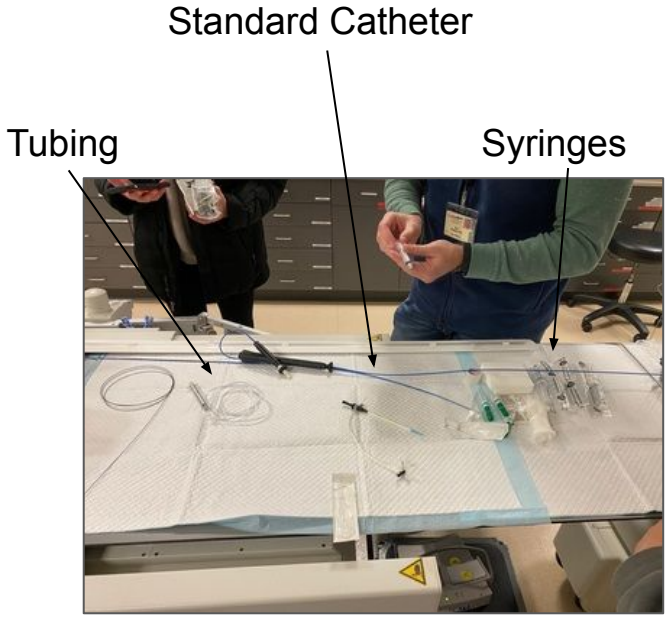


Figure 6: Standard catheters, medical grade tubing and procedural syringes

Force Sensor and Visual Feedback System

- FSR 400 Series Round Force Sensing Resistor [Electronics, 2021]
  - Actuation force - 0.1 N
  - Force sensitivity range - 0 N - 10 N
- Four Signal Feedback System
  - Arduino IDE - Constant force output [Arduino, 2022]
  - Injection LED Signals [Doumit et al., 2016]
    - Blue = Air/Cavity (< 0.6 N)
    - Green = Healthy Tissue
    - Orange = Diseased Tissue
    - Red = Threshold Force (2.4 N)

Figure 7: FSR 400 Force Sensing Resistor highlighting its two prong connectors that allow breadboard and circuit integration [Electronics, 2021].

Cellicopter: Propeller Controlled Injections

- Design Features
  - Speed Control DC Motor [Motor, 2020]
  - Ultimaker PLA Force Application Rod
  - Syringe Clamp Molds
- Advantages
  - Portability
  - Durability
- Disadvantages
  - Injection Rate Efficacy
  - DC Motor Cost

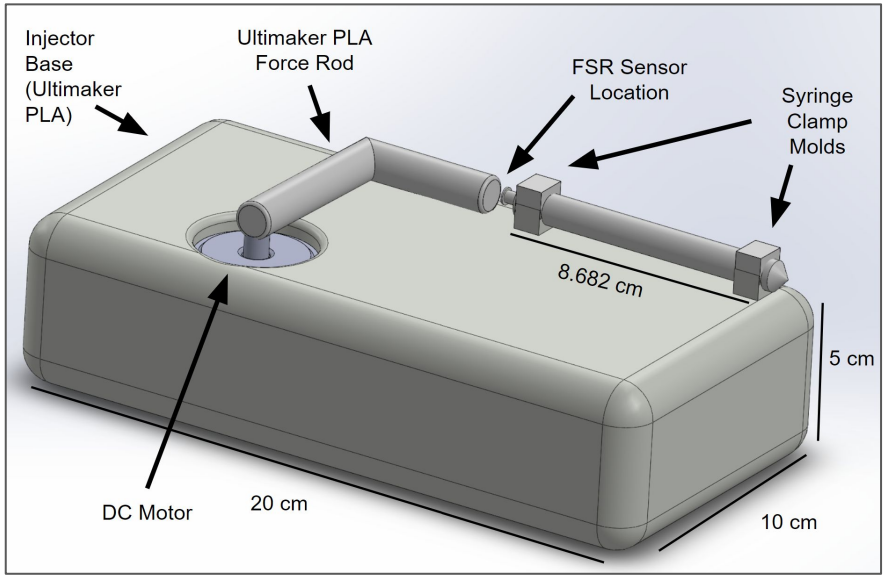


Figure 8: Cellicopter SolidWorks design, highlighting key features and scale.

Cellringe Pump: Thread Regulated Injections

- Design Features
  - Stepper Motor [Industries, 2022]
  - Force Application via a Threaded Screw
  - Syringe Clamp Molds
- Advantages
  - Cell Viability and Injection Rate Efficacy
  - Ease of Fabrication
- Disadvantages
  - Durability

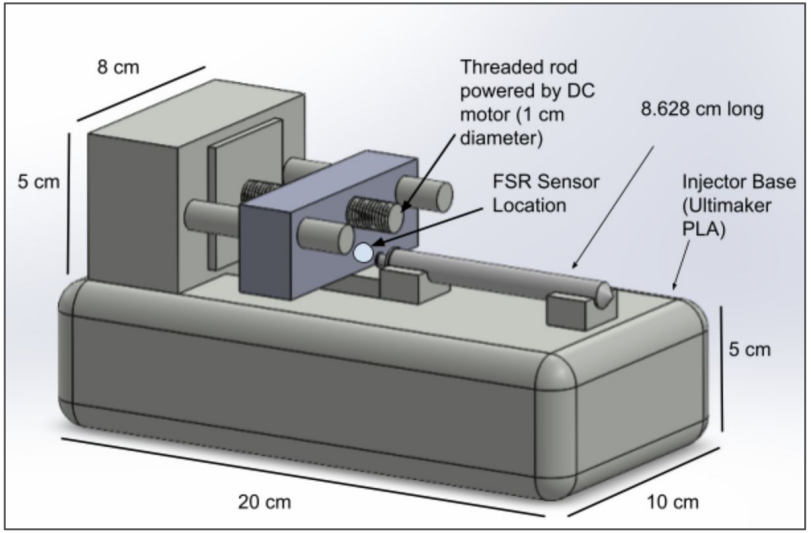


Figure 9: Cellringe Pump Sketch, highlighting key design features and scale.

Cellvolver: Fully Automatic Dual Motor Injections

- Design Features
  - Two DC Motors [Motor, 2020]
  - Fully Automatic Injection Procedure
  - Threaded Screw Force Application
- Advantages
  - Ease of Operation
  - Controlled Force Application
- Disadvantages
  - Fabrication Feasibility
  - Safety

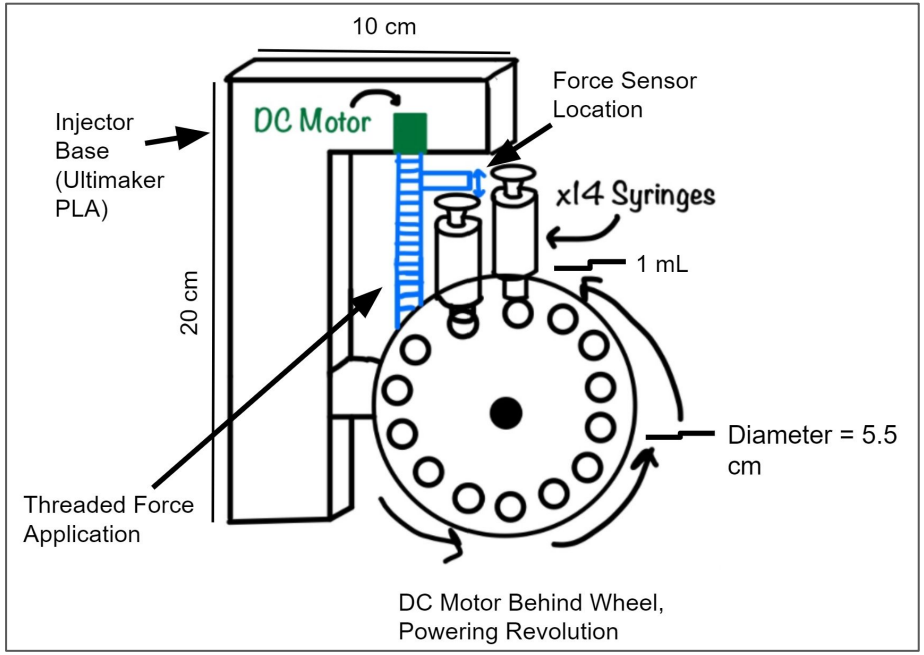


Figure 10: Cellvolver Sketch, highlighting key design features and scale.

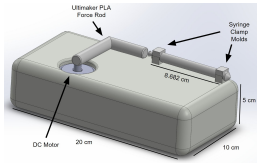
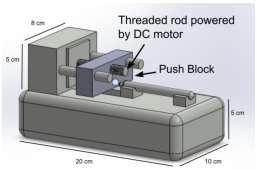
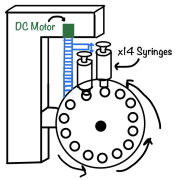
Design Matrix Criteria

Table 1: Design criterion and associated weight values.

Design Criteria	Weight
Ease of Operation	25
Efficacy	20
Feasibility	20
Safety	10
Cost	10
Portability and Maneuverability	10
Durability	5
Total (100)	**100**

Design Matrix

Table 2: Design Matrix evaluating top three designs. The "Cellringe Pump" design won as the top design idea.

Automated Injection System Base Designs							
Design Criteria	**Weight**	Cellicopter: Propeller Controlled Injections 		Cellringe Pump: Threaded Regulated Injection 		Cellvolver: Fully Automatic Dual Motor Injections 	
Ease of Operation	25	4/5	20	4/5	20	5/5	25
Efficacy	20	4/5	16	5/5	20	3/5	12
Feasibility	20	4/5	16	5/5	20	3/5	12
Safety	10	5/5	10	5/5	10	3/5	6
Cost	10	3/5	6	5/5	10	2/5	4
Portability and Maneuverability	10	5/5	10	4/5	8	3/5	6
Durability	5	5/5	5	4/5	4	3/5	3
Total (100)	**100**	**Sum**	83	**Sum**	92	**Sum**	68

Future Work

Prototyping the Cellringe Pump: Thread Regulated Injections

- 3D print injector base using Ultimaker PLA
- Fabricate feedback system and injection automation
- Install FSR 400 series force sensing resistor

Testing using all syringe sizes

- Force gauge testing
- Bovine steak injections
- Mesenchymal stem cell viability
- Correct volume dispensed

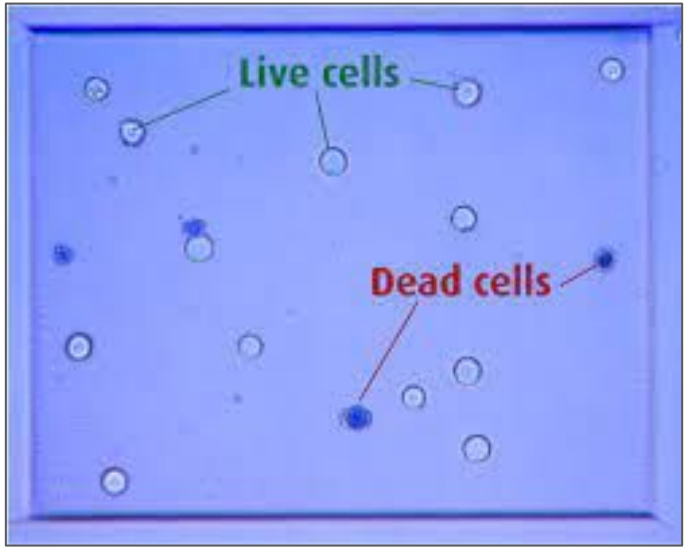


Figure 11: Trypan Blue Staining for Viability [EDVOTEK]

Acknowledgements

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Dr. Melissa Kinney

Figure 12: The team at the UW Health University Hospital after experiencing a intramyocardial stem cell injection demonstration.

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Questions?