Automatic Intramyocardial Stem Cell Injection Device

Team Heartthrob
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Background

- Cardiovascular disease is the leading cause of death
  - 696,962 deaths in the U.S in 2020 [Prevention, 2019]
- Current Cardiovascular Disease Treatment
    - 25 - 50% mortality rate within 5 years [Rheault-Henry et al., 2021]

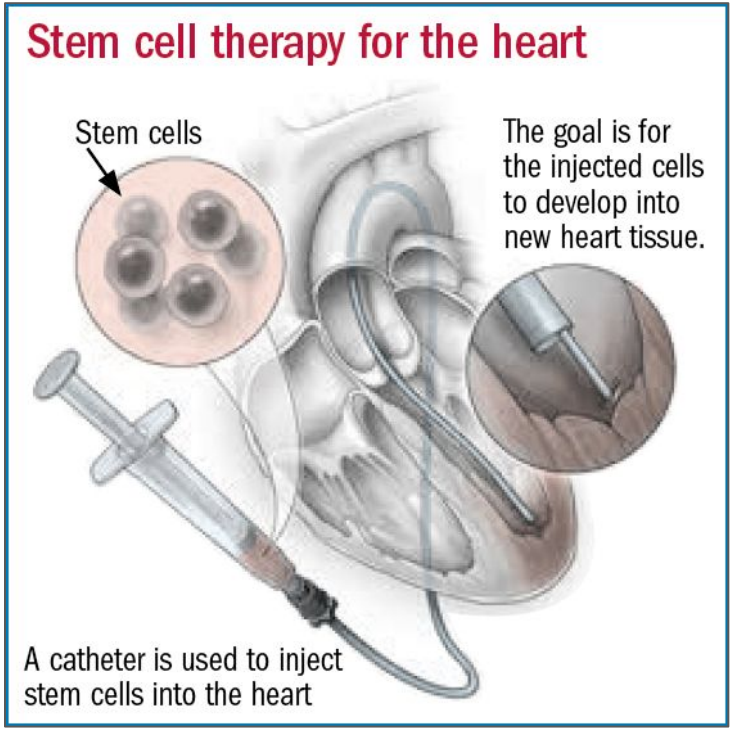


Figure 1: Stem cell therapy in the myocardium [Health.Harvard.edu].

Background

- Treatment via Novel Approach
  - Intramyocardial Stem Cell Injections have therapeutic potential [Hmadcha et al., 2020]
    - Derived from bone marrow [Boyle et al., 2010]

Key Consideration:

- Flow rates
  - Too fast, slow, or inconsistent
    - Damaging to cells [White, 2016]
    - Off-target effects
- Force / Shear Stress

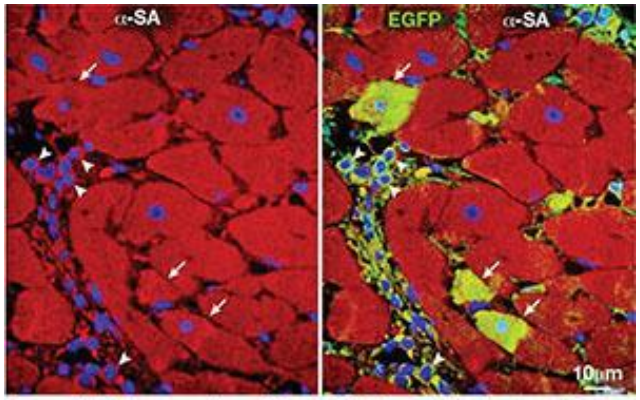


Figure 2: Successful stem cell therapy for heart failure [Wilburnmedicalusa.com].

Problem Statement

- Automated injection device designed for stem cell delivery to the myocardium
  - Eliminate manual operations
  - Improve efficacy
  - Reduce issues such as hand fatigue
- Force Detection Feedback System specific to stem cell injection in the myocardium
  - Catheter placement and blockage assistance
- Research tool for stem cell injection therapies

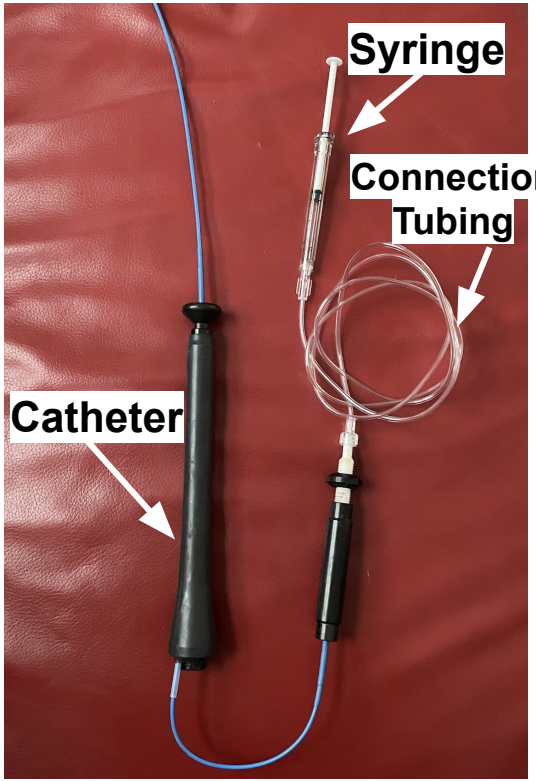


Figure 3: Set-up of the catheter, connection tubing and syringe.

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
- Pressure Sensing Syringe [DeVries, 1988]
  - Pressure sensitive piston between the syringe plunger and the thumb
  - Provides a tactile signal when a specified pressure is applied

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

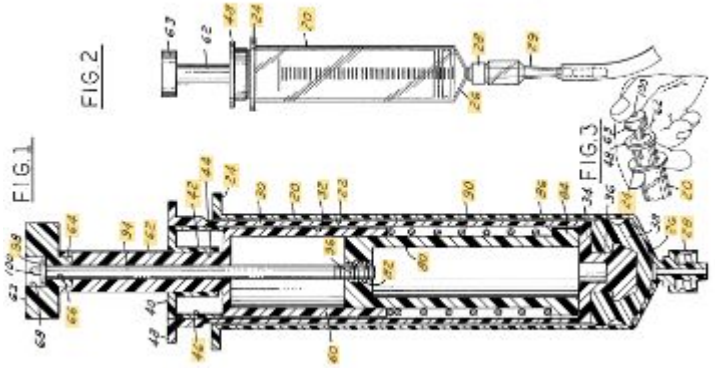


Figure 5: US Patent US4759750A [DeVries, 1988]

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 mL)
- 30 and 60 second injection rates (± 0.5 seconds)
  - Deliver 0.5 mL of solution [Raval et al., 2021]
- Force sensing device and visual feedback
  - Threshold = 2.40 N [Doumit et al., 2016]
- Budget of $3000 and manufacture cost of $500 [Raval, 2022]

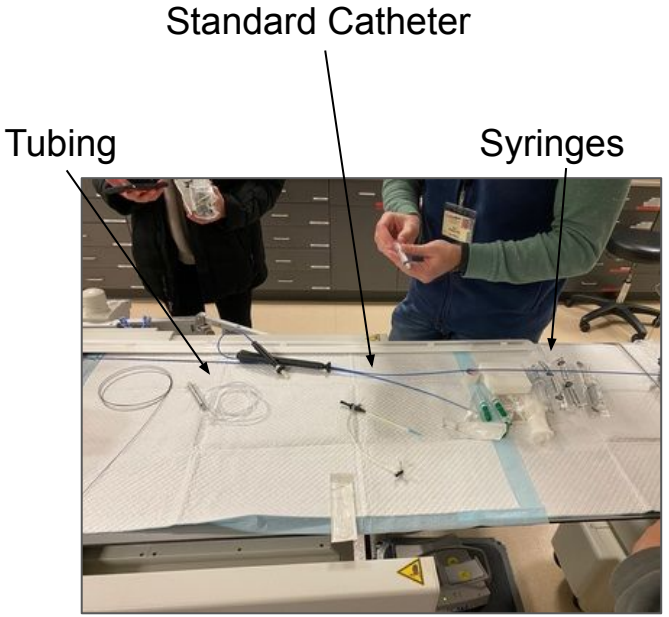


Figure 6: Standard catheters, medical grade tubing and procedural syringes

Current Injection Device Design

- Prototype Features
  - 30 second and 60 second controlled injection rates
    - Start, pause, reset, and adjust functions
    - Regulated via NEMA-17 Stepper Motor
  - Applied force feedback system
    - Detects force via an FSR 400 series force sensor
    - Controlled by Arduino Microcontroller and calibration curve
    - LED threshold light warning and digital display
  - 1 mL syringe mold
- Improve the force detection system

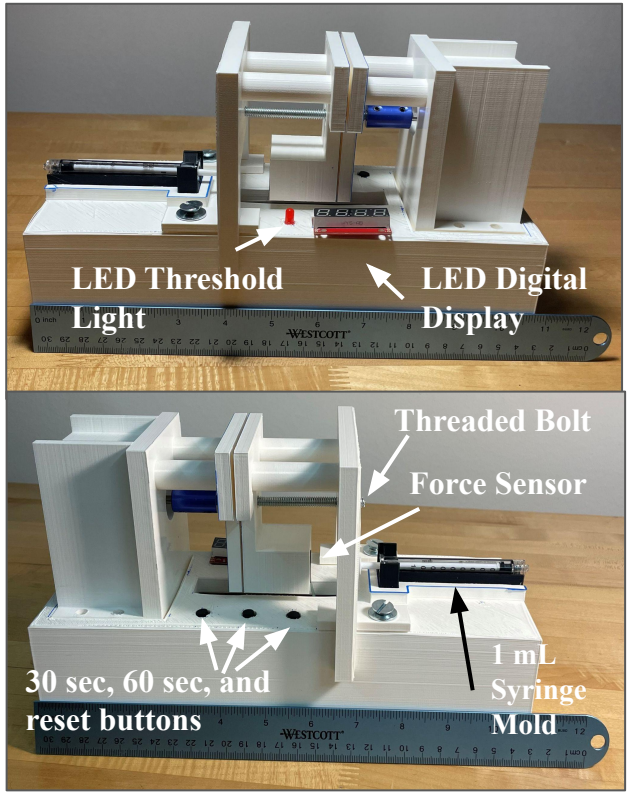


Figure 7: Right and Left end view of the injector prototype displaying the threaded bolt force system, injection buttons, and feedback system.

FSR 400 Series Round Force Sensing Resistor

- Design Features [Electronics, 2021]
  - Actuation force - 0.1 N
  - Force sensitivity range - 0 N - 10 N
  - Circuit Compatibility
- Advantages
  - Feasibility of Fabrication
  - Cost Effective
- Disadvantages
  - Accuracy
  - Sensitivity

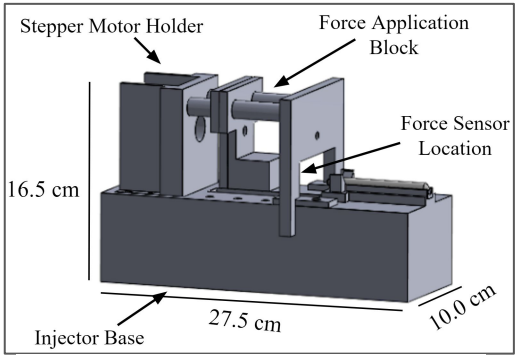


Figure 8: SolidWorks drawing of the current automatic injector, labeling key features.

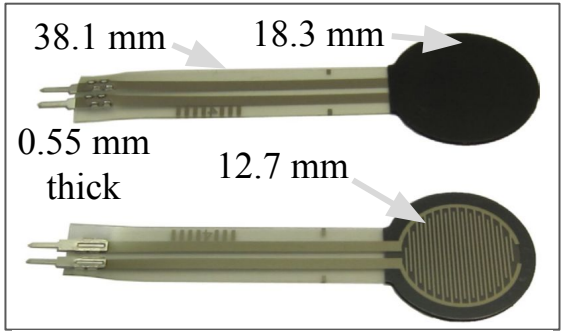


Figure 9: FSR 400 Force Sensing Resistor highlighting its two prong connectors that allow breadboard and circuit integration [Electronics, 2021].

FSG Series Force Sensor

- Design Features [Digi-Key, 2022]
  - Force range - 0 N - 5 N (0.0098 N Resolution)
  - Sensitivity - 7.2 mV/V/N
  - Accuracy - ± 0.5%
  - Repeatability - ± 0.2%
- Advantages
  - Sensitivity
  - Safety
- Disadvantages
  - Circuit Integration
  - Cost

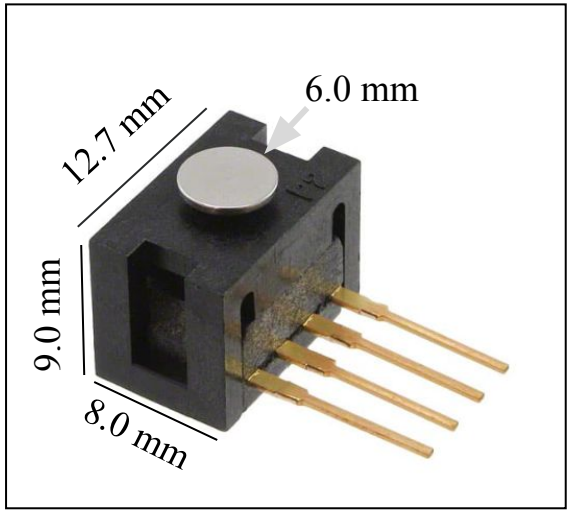


Figure 10: FSG020WNPB Series Force Sensor highlighting its elevated sensor (promotes complete force reception) [Digi-Key, 2022].

LCMKD-10N Load Cell with NanoShield

- Design Features [Omega, 2022, Electronicos, 2022]
  - Force range - 0 N - 10 N
  - Sensitivity - 2 mV/V/N
  - Accuracy - ± 0.25%
  - Repeatability - ± 0.1%
- Advantages
  - Accuracy
  - Safety
- Disadvantages
  - Fabrication Feasibility
  - Cost

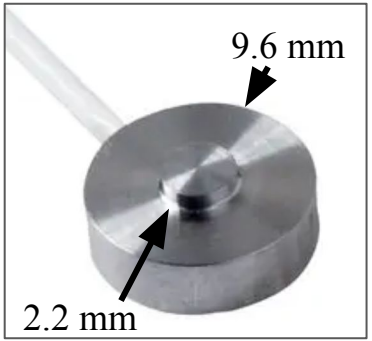


Figure 11: LCMKD-10N Load Cell highlighting its compression plate and nanoshield integradable cable [Omega, 2022].

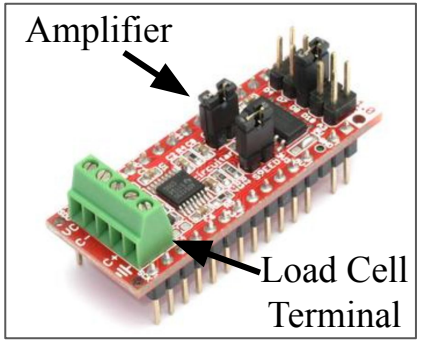


Figure 12: Load Cell Nanoshield containing a load cell connector (green terminal), integrated amplifier, noise filtering circuit, and a high-resolution ADC converter [Electronicos, 2018].

P30 Non-Invasive Pressure Sensor

- Design Features [Devices, 2017]
  - Pressure range - 0 kPa - 207 kPa
  - Disposable flow module
  - Reusable pressure sensor
- Advantages
  - Accuracy
  - Procedural integration
- Disadvantages
  - Safety
  - Durability

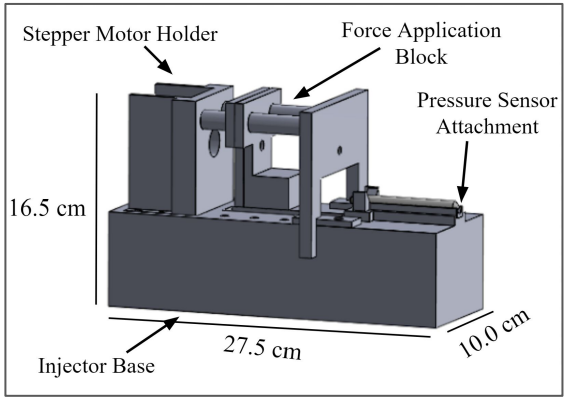


Figure 13: SolidWorks drawing of the current automatic injector, labeling key features.

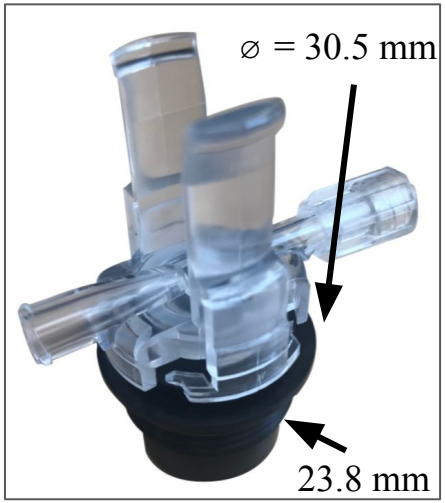


Figure 14: P30 Non-Invasive Pressure Sensor highlighting its flow module and pressure sensor [Devices, 2017].

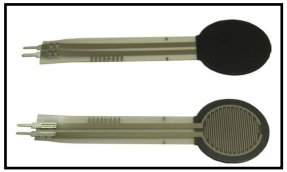
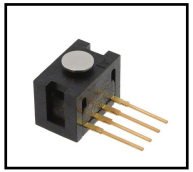
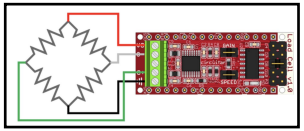
Design Matrix Criteria

Table 1: Design criterion and associated weight values.

Design Criteria	Weight
Accuracy	25
Sensitivity	25
Feasibility	20
Cost	10
Safety	10
Ease of Operation	5
Durability	5
Total (100)	**100**

Design Matrix

Table 2: Design Matrix evaluating top four force detection designs.

Design Criteria	Weight	FSR Force Sensor 	FSG Series Force Sensor 	LCMKD-10N Load Cell with Nanoshield 	Non-Invasive Pressure Sensor 
Accuracy	25	2/5	4/5	4/5	5/5
Sensitivity	25	2/5	5/5	5/5	4/5
Feasibility	20	5/5	4/5	3/5	3/5
Cost	10	5/5	3/5	2/5	3/5
Safety	10	4/5	5/5	5/5	3/5
Ease of Operation	5	5/5	5/5	5/5	4/5
Durability	5	4/5	4/5	4/5	3/5
Total	**100**	**65**	**86**	**80**	**76**

Future Work

- Interface the FSG Series Force Sensor with the current design
  - Detect forces experienced by cells correlating the external force to the force experienced by cells
- Optimize current design
- Extensive force and cell viability testing
  - Various viscosities
  - Mimic aortic shape
  - Catheter obstruction testing
  - Bovine steak and *ex vivo* heart injection testing
  - Clinical validation via porcine models

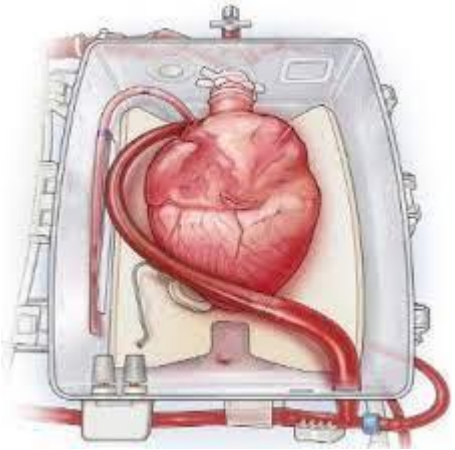


Figure 15: *Ex vivo* heart injection testing [Myast.org].

Acknowledgements

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Dr. Eric Schmuck

Dr. Aviad Hai

Figure 16: The team at the UW Health University Hospital

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Thank You!