# Non-Operative Correction for Long-gap Esophageal Atresia


Laboratory for Manufacturing and Productivity
30 YEARS OF ENGINEERING THE REAL WORLD

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Boston Children's Hospital
Until every child is well


## 1. Introduction

About 1000 infants a year in the US are born with their esophagus disconnected, which is called Esophageal Atresia (EA). There have been some methods developed for EA as following:

***Foker et al.***

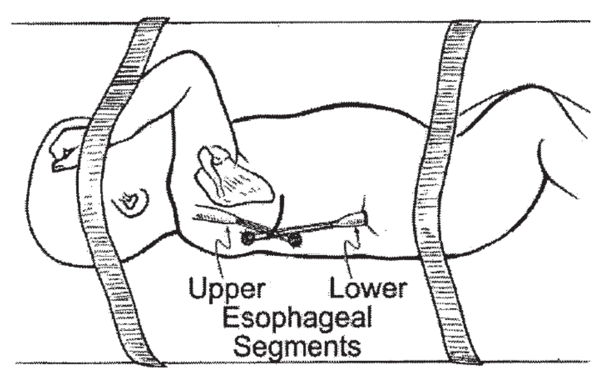
- The standard operative method for EA.
- Requires thoracotomy and paralyzation (1-2 weeks).

***Hendren et al.***

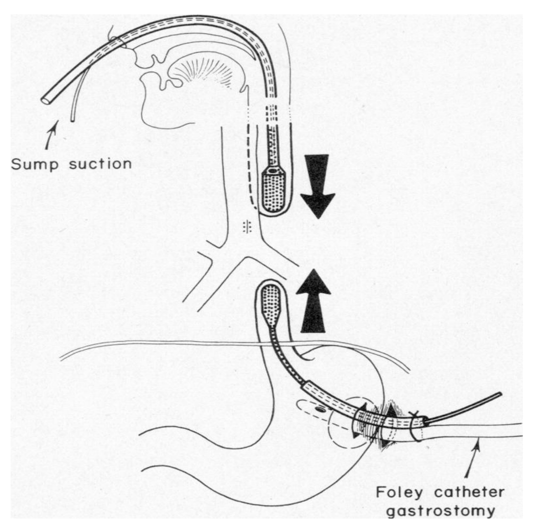
- Putting two ferromagnetic "bullets" into esophageal pouches.
- Appling external magnetic fields to generate magnetic force.

***Zaritzky et al.***

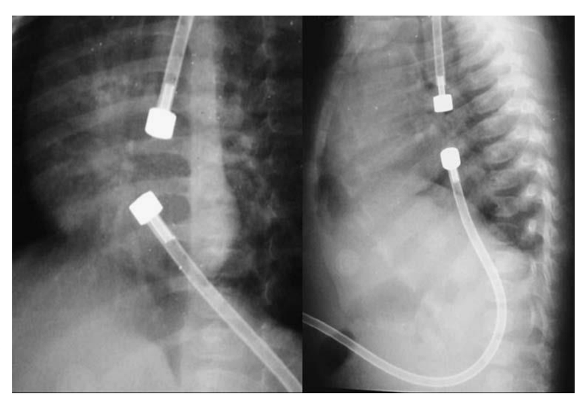
- Putting two permanent magnets into esophageal pouches.
- Permanent magnets generate sufficient force for short-gap EA.




Foker et al. (2005)




Hendren et al. (1975)



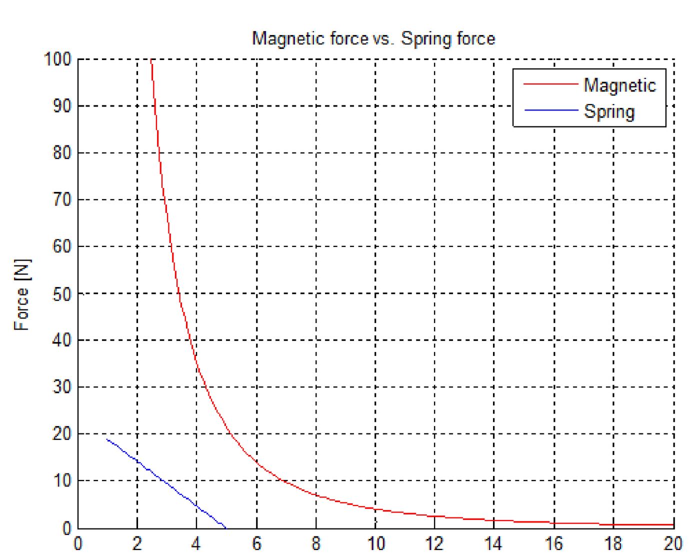
Zaritzky et al., (2009)

## 2. Long-gap Esophageal Atresia (LEA)

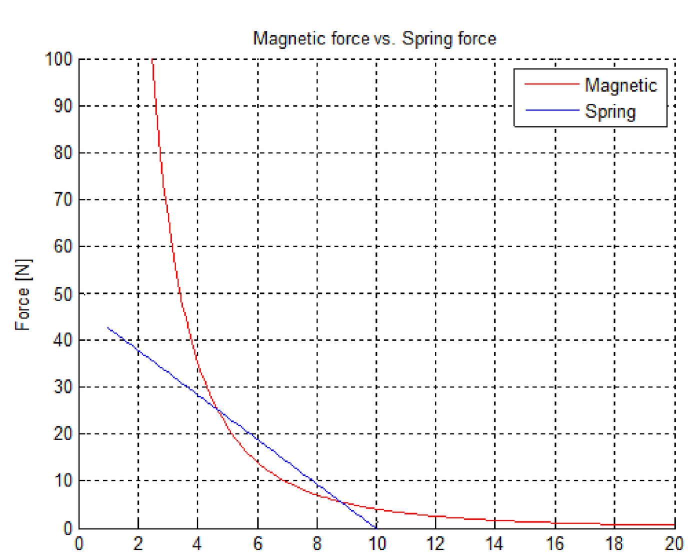
When the gap size is larger than certain value, permanent magnets cannot generate sufficient force during the whole operation. This is called long-gap esophageal atresia, which requires additional pushing mechanism to assist the magnetic pulling force.

$$F_S = kx \qquad \text{(Spring force of Esophagus)}$$

$$F_M = \frac{\pi {B_r}^2 R^4}{4\mu_o}\left[\frac{1}{x^2}+\frac{1}{(x+2t)^2}-\frac{1}{(x+t)^2}\right] \qquad \text{(Magnetic force)}$$




**Short-gap EA**: Magnetic force is always larger than spring force of esophagus.



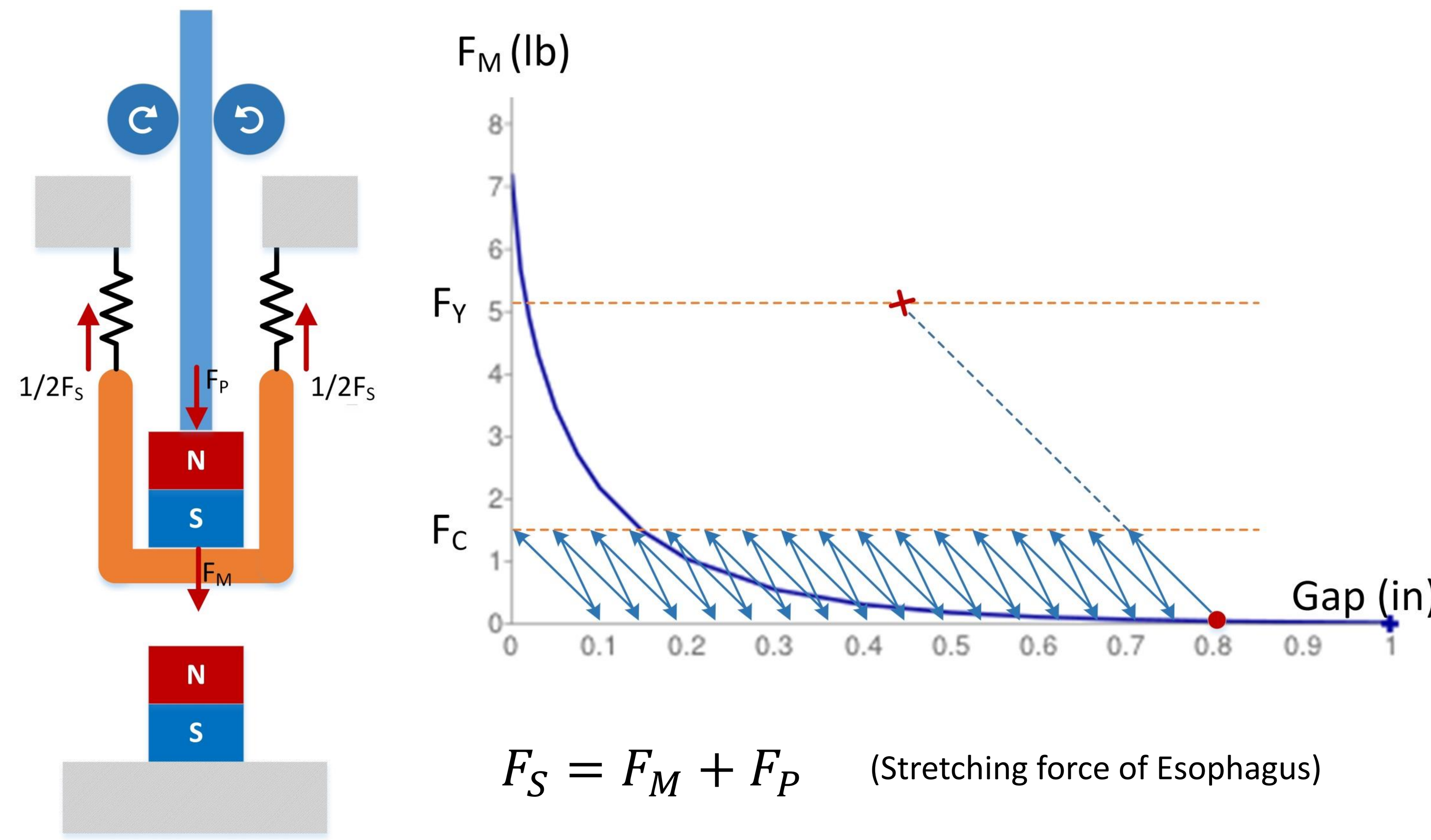

**Long-gap EA**: Magnetic force is *NOT* always larger than spring force of esophagus.

## 3. Process Design

The process of non-operative correction for LEA consists of three steps: bougienage, anastomosis, and retrieval.

### *3.1. Bougienage*

During the bougienage, esophagus gets cyclic stretching force so that it is stimulated to grow.




$$F_S = F_M + F_P \qquad \text{(Stretching force of Esophagus)}$$

Modeling for long-gap esophageal atresia. (Left) Cyclic force to stimulate esophagus to grow. $F_Y$ is the yielding force of esophagus and $F_C$ is the maximum force for operation. (Right)

*Magnetic force ($F_M$)*

- Two permanent magnets generates force attracting each other. While the axial force increases exponentially as the gap size decrease, the radial stabilizing force makes the two magnets orient towards each other (self alignment). This property guide the two devices to meet at one point ultimately, joining the two esophagus pouches together.

*Mechanical pushing ($F_P$)*

- Mechanical pushing force should assist magnetic force when the magnetic force cannot generate sufficient force due to the large gap size.
- The pushing force is generated by friction roller, which is driven by position controlled servo motor.

### *3.2. Anastomosis*

- After the bougienage makes two esophageal ends meet, large squeezing force needs to be applied, so that the sandwiched esophageal tissue gets necrosis. The force generated by permanent magnets exponentially increase as the gap size decrease, which is advantageous for anastomosis.

### *3.3. Retrieval*

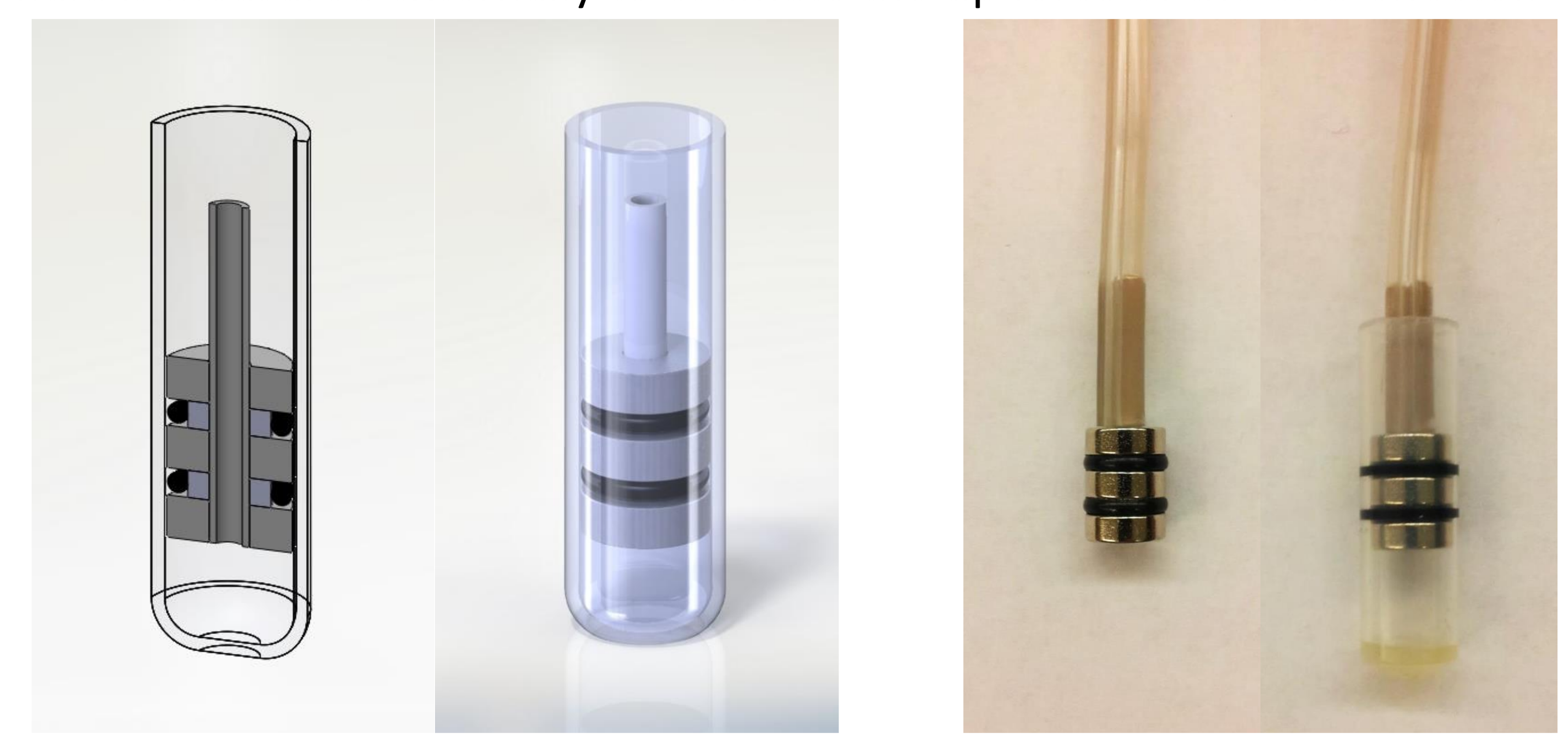
- After the anastomosis is achieved, the device should be retrieved.
- Fluid can be injected into the device through the central hole, which functions as standoff between the two magnets .

## 4. Device Design

The device consists of four modules: end-effector, friction drive, fluidic system, and control system.

### *4.1. End-effector*

The end-effector assembly is designed based on syringe mechanism, in which the plunger is comprised of ring type permanent magnets. Fluid is injected through the hole and fills the region between barrel and plunger. The injected fluid generates displacement of the syringe, while the pressure of the fluid is measured externally to estimate the tip force of the end-effector.



End-effector Assembly consisting of barrel and magnet plunger. Magnet plunger is comprised of ring type NdFeB magnets, O-rings, spacers, and tube for injecting fluid.

### *4.2. Fluidic System*

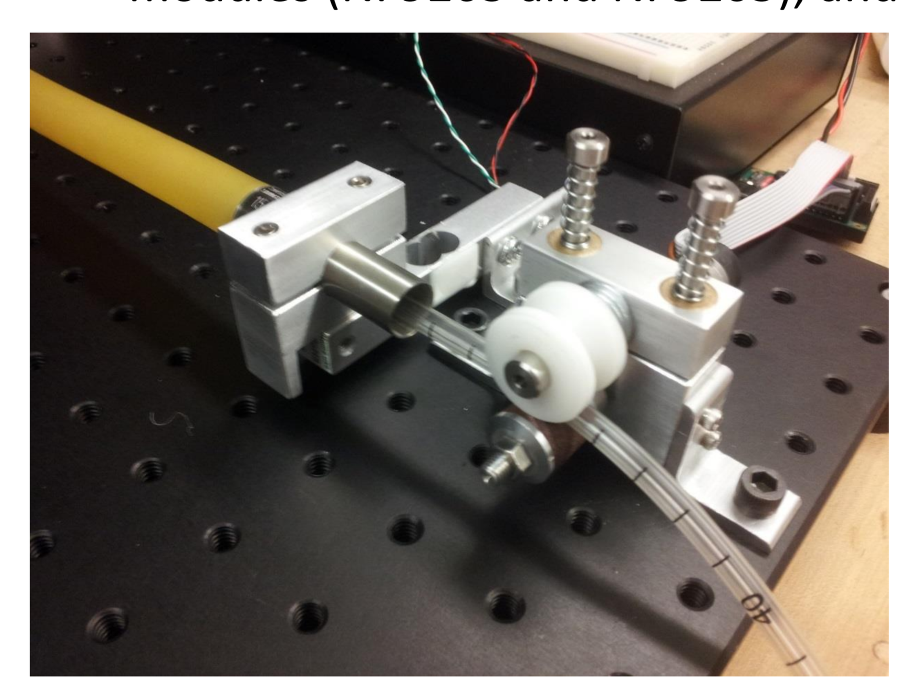
- The fluid tube has a bifurcation at the external end. One end is connected to syringe pump, which can inject fluid into the device. The other end is connected to pressure sensor, which can estimate the force on the esophagus pouch from the measured pressure.

### *4.3. Friction Drive*

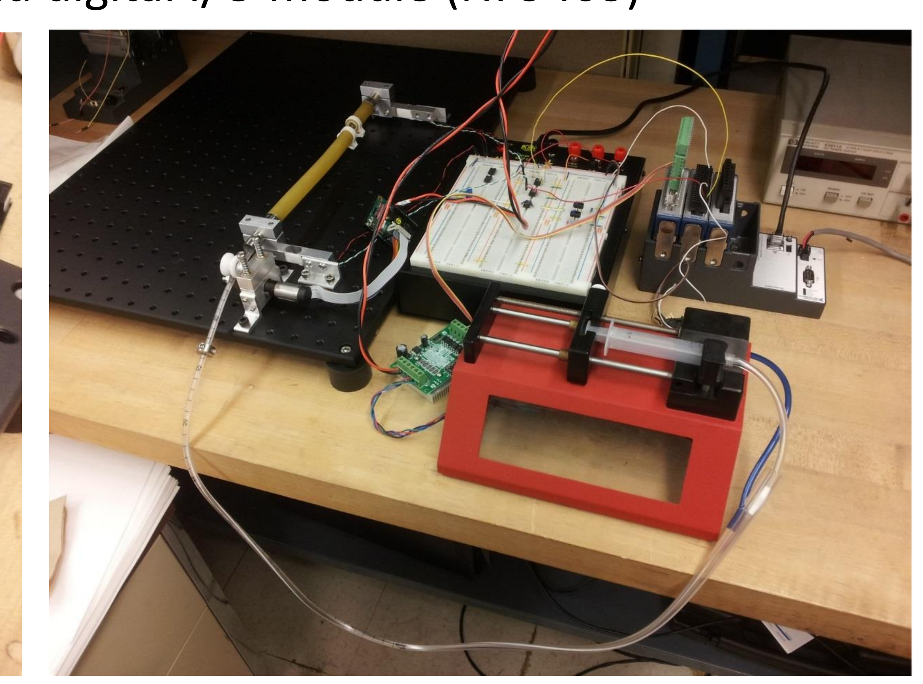
- The friction drive consists of position controlled servo motor, a driving roller, and a idler.

### *4.4. Control System*

- The whole system is controlled using NI cRIO 90786, with analogue I/O modules (NI 9263 and NI 9205), and digital I/O module (NI 9403)



Friction drive



Bench setup