Institute of Robotics and Intelligent Systems

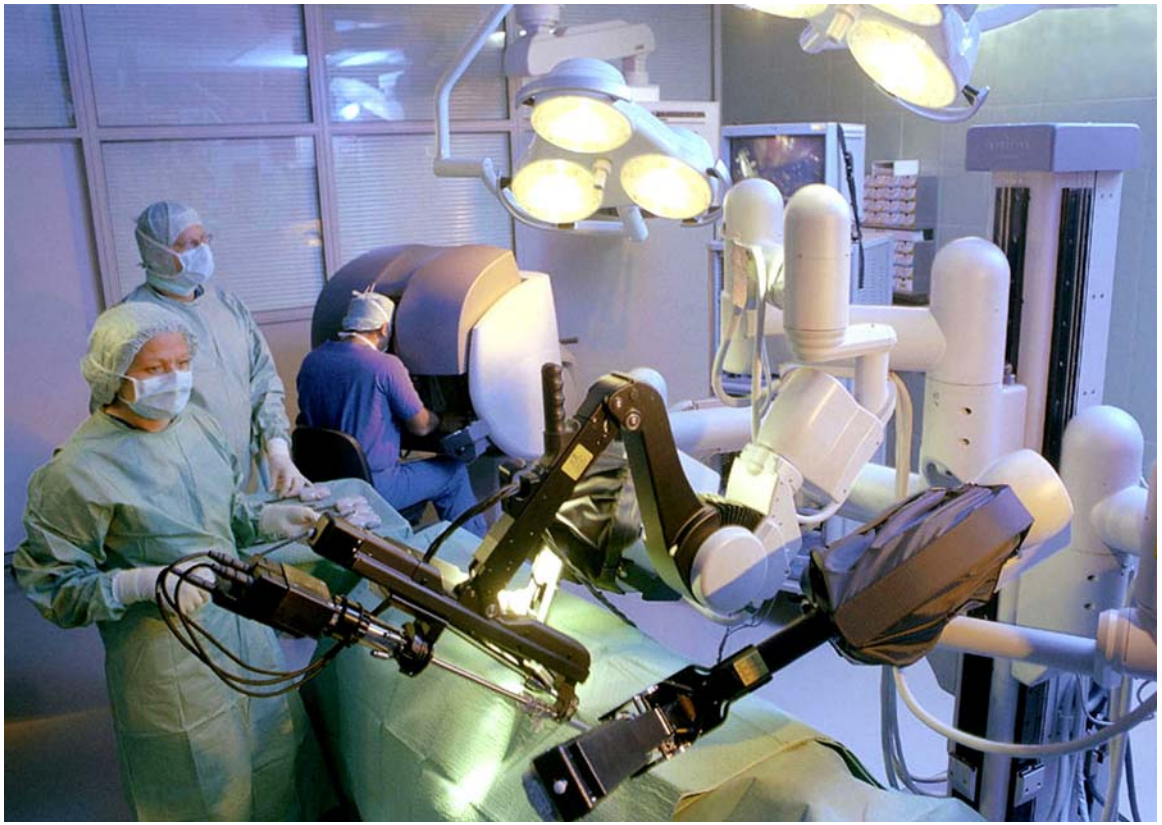
Advanced Instruments for Surgical Interventions

Brad Nelson

Institute of Robotics and Intelligent Systems
ETH Zürich

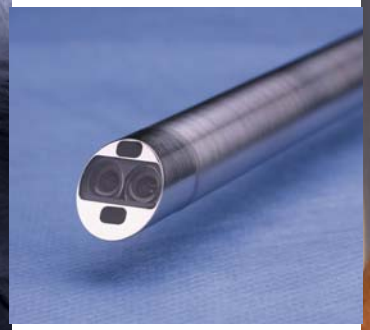
Robotic Minimally Invasive Surgery

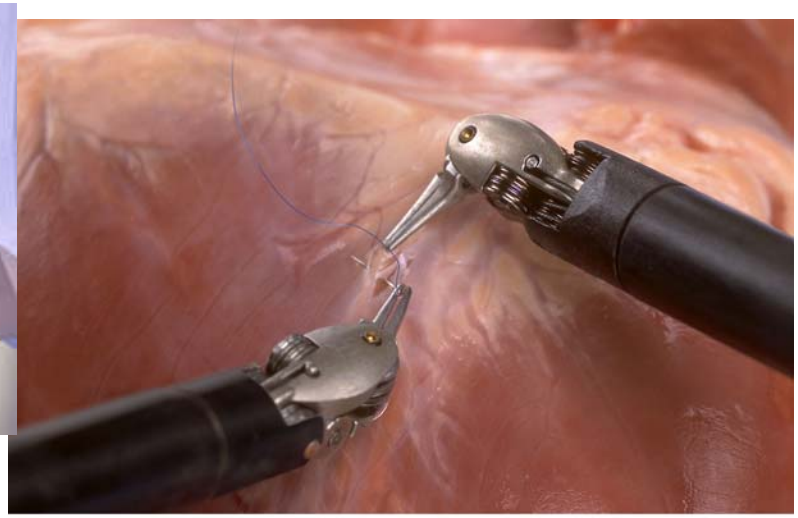
- Intuitive Surgical, Inc.
  - daVinci Surgical System



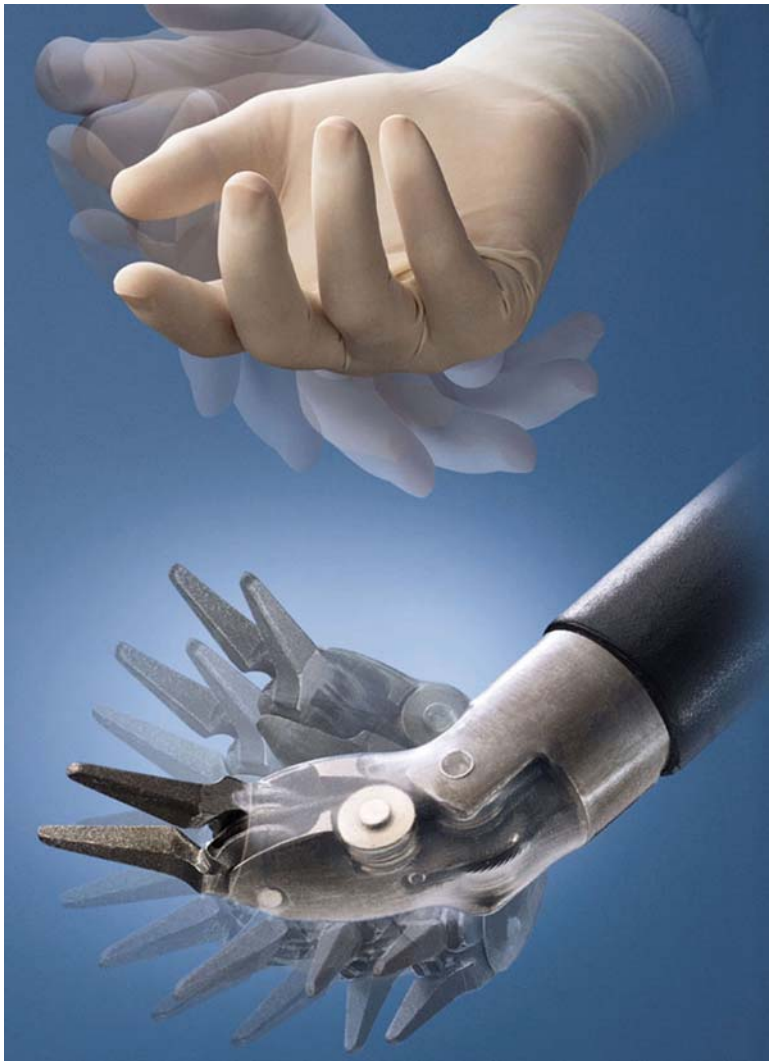
Robotic Teleoperated Surgery

Surgeon's Interface





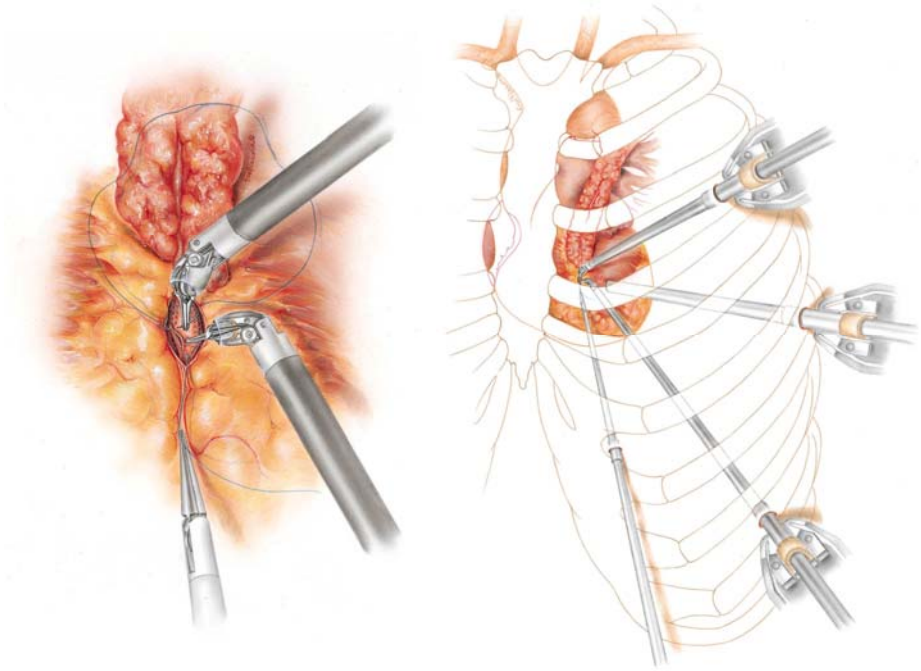
Teleoperated Surgery



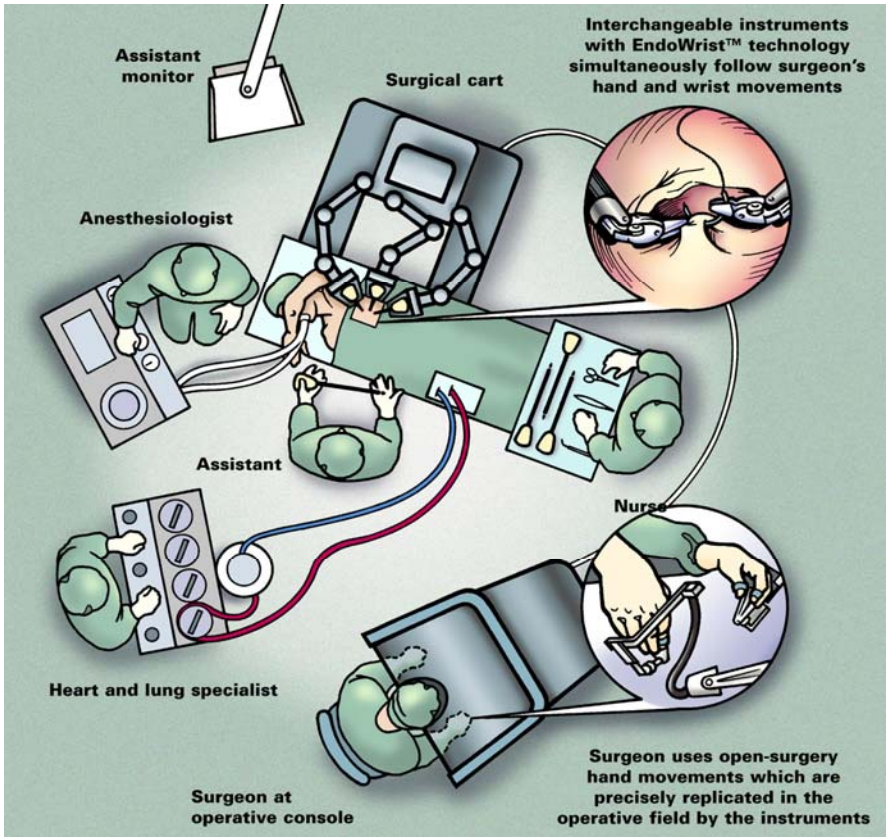
Dexterity
7DOF
wrists

Explicit Control by Surgeon

- Minimally Invasive Procedures
  - Direct control of tools vs. **Teleoperation**

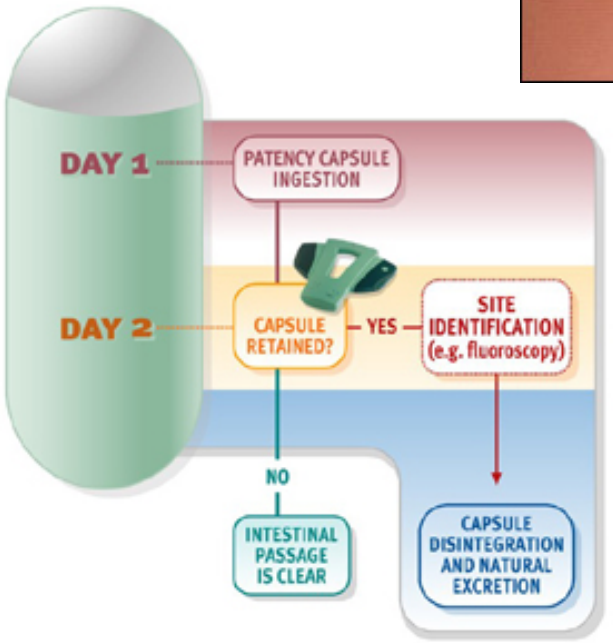


Coronary Artery Bypass Grafting




FOUR MEN AND ONE WOMAN ON
THE MOST FANTASTIC, SPECTACULAR
AND TERRIFYING JOURNEY
OF THEIR LIVES . . .
FANTASTIC VOYAGE
A
COLOUR BY DE LUXE
STEPHEN BOYD · RAQUEL WELCH
EDMOND O'BRIEN · DONALD PLEASENCE
ARTHUR O'CONNELL · WILLIAM REDFIELD
and ARTHUR KENNEDY
SAUL DAVID · RICHARD FLEISCHER
HARRY KLEINER · DAVID DUNCAN
OTTO KLEMENT and JAY LEWIS BIXBY
LEONARD ROSENMAN

Given Imaging M2A Camera Pill



Locomotion: Crawling

Objective

- To understand motion and perception systems of lower animal forms
- To design and fabricate mini- and micro-machines inspired by such biological systems.

Long term goal

A new generation of autonomous smart machines with:

- life-like interaction with the environment
- performance comparable to the animals by which they are inspired.

Potential application

The "inspection" problem in medicine (microendoscopy).

CRIM

Dario and Menciassi

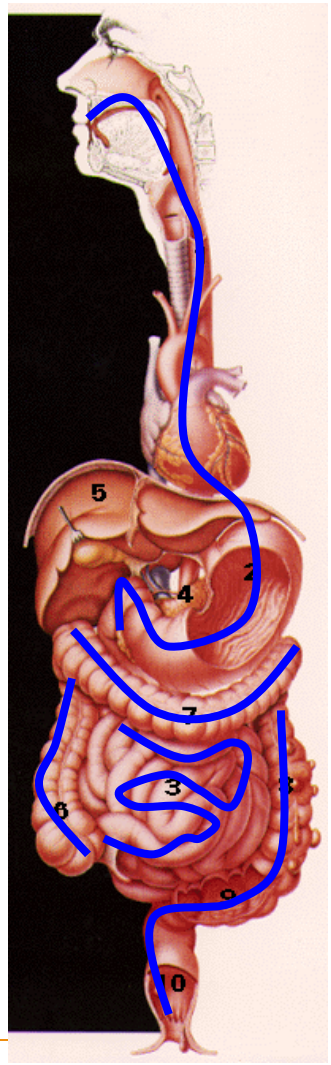
The Emil Project

Smoothly…

…from inchworm to leg locomotion

Dario and Menciassi

Potential possibility to perform FULL endoscopy



Locomotion: Flying

1/ 255 real time

Wing beat frequency:

~200Hz


Picture Mattias Moser

How do Fruit Flies (*Drosophila*) Fly?

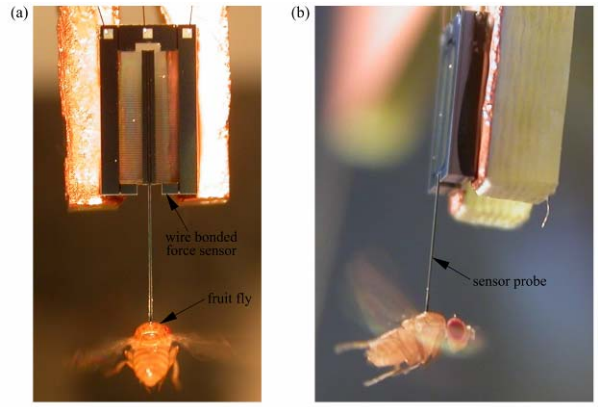
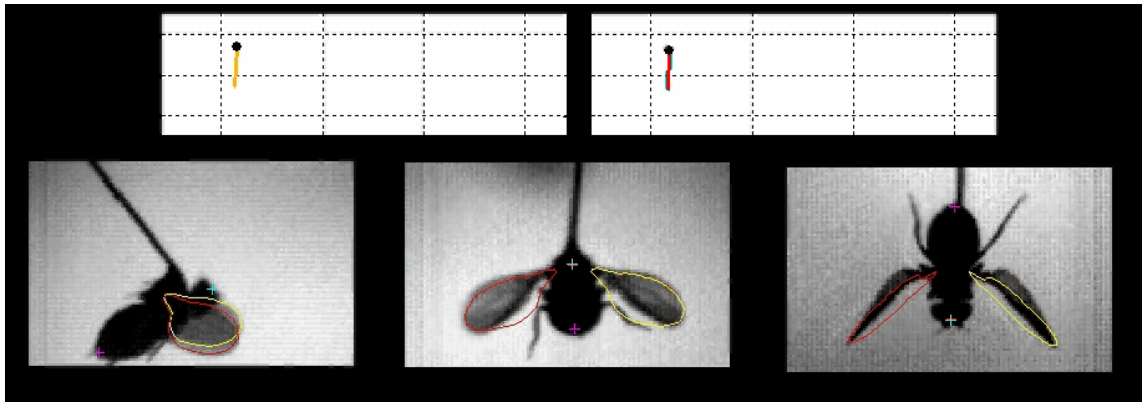
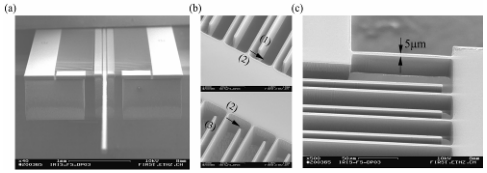


Figure 1. Force sensing of Drosophila tethered to the sensor probe. (a) Front view. (b) Side view.





5000 frames/sec

Wing beat frequency of 200Hz

Lift forces as high as 35μN

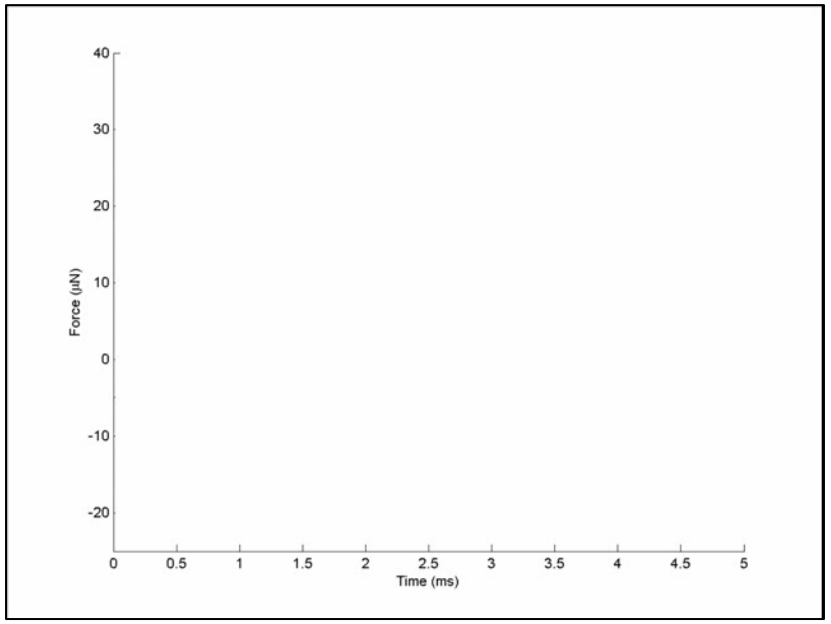


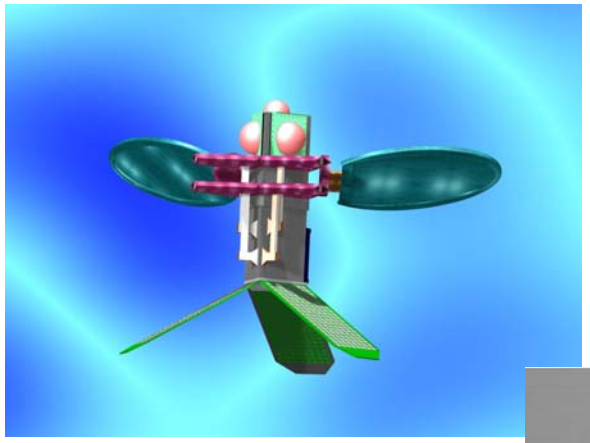
Table I. Device specifications.

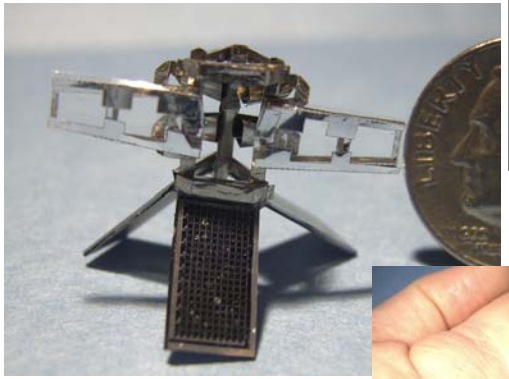
resolution		0.68μN
sensitivity		1.35μN/mV
measurement range		+/- 1mN
bandwidth		7.8kHz
dimensions	base	3.6mm×2.1mm×0.5mm
	probe	3mm×50μm×50μm
	cap. gap (d_1, d_2)	5μm
	cap. spacing (d_3)	20μm
	cap. plates	500μm×5μm×50μm
	springs	125μm×5μm×50μm

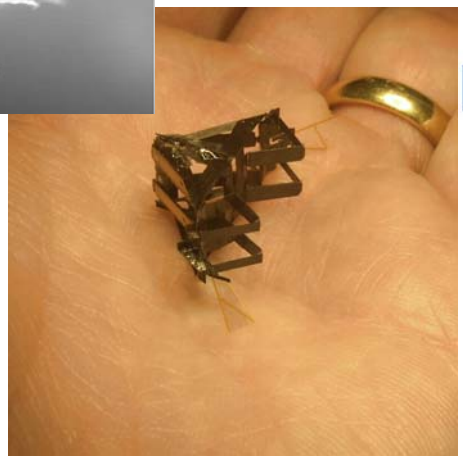
Fry, Sayaman, and Dickinson, *Science*, 2003
Sun, Potasek, Bell, Fry, and Nelson, *JMEMS*, 2004

Micromechanical Flying Insect (MFI)

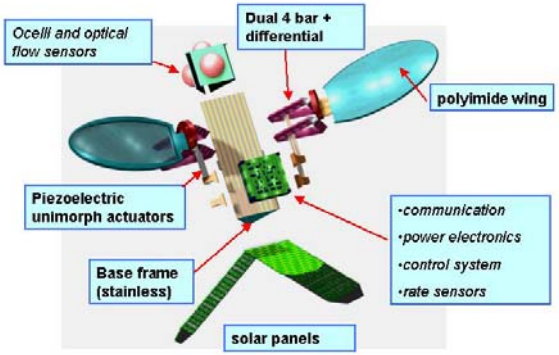
Ron Fearing UC-Berkeley





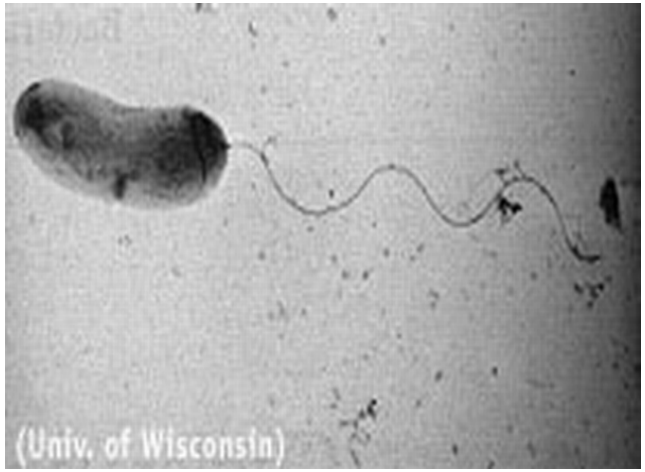


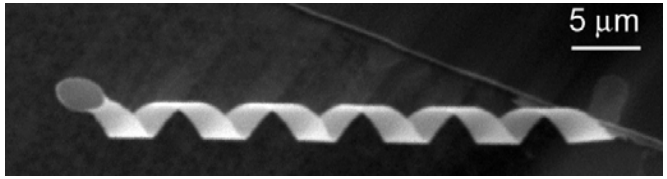
parameter	blowfly	MFI
actuator	muscle	piezoelectric
Actuator mass (mg)	50	50
Actuator power (mW)	10	12
Wing power (mW)	5	10
Wing inertia (mg-mm^2)	20	20
Quality factor Q	1-3	2
Resonant frequency (Hz)	150	150
Wing stroke/rotation (degrees)	160/120	120/90
Wing length (mm)	11	10
Mass (mg)	100	100

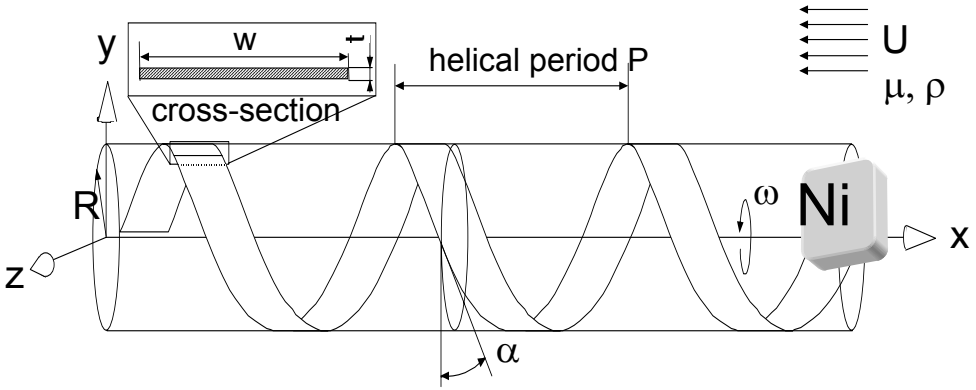


Locomotion: Swimming

- Imitate helical baterial flagella motion for propulsion on the nano- and micro-scale
- Energy source: external electromagnetic field
- Stokes Equation accurate: $\nabla p = \mu \Delta \vec{u}$
  - Justification: $Re_{max} = \frac{u \cdot L}{\nu} \approx 1 \cdot 10^{-4}$
- Existing models for flagella motion only valid for circular cross-sections
- Here: high aspect ratio rectangle

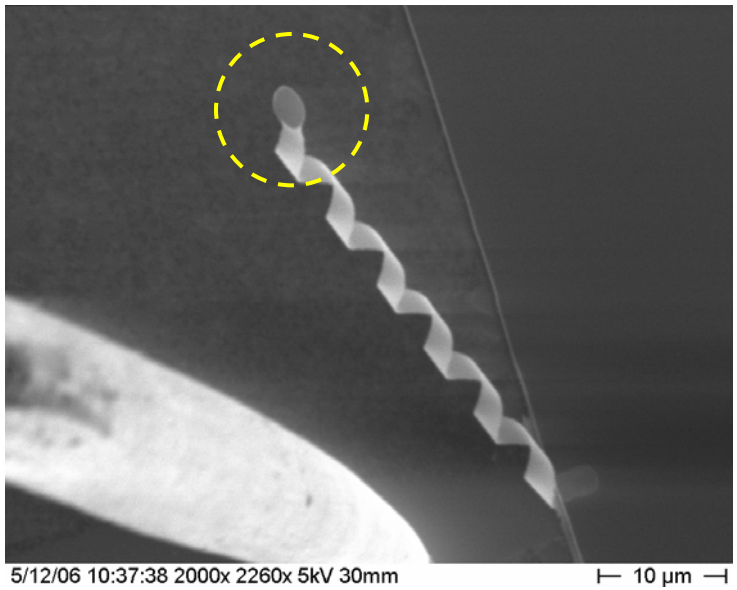


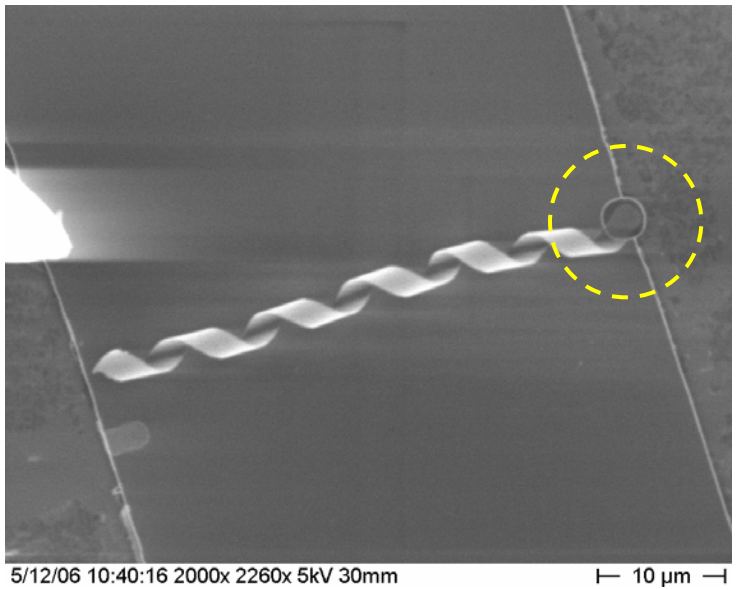




Microswimmer

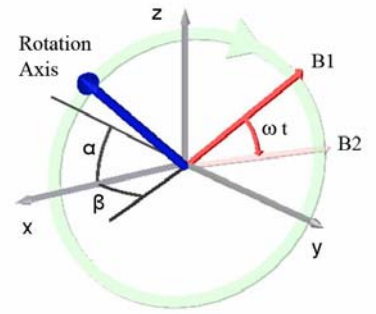
- InGaAs/GaAs nanocoil, 11nm/16nm thick
- Ni „head“
- Placed in paraffin oil or water



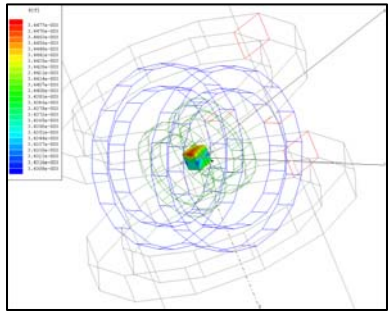


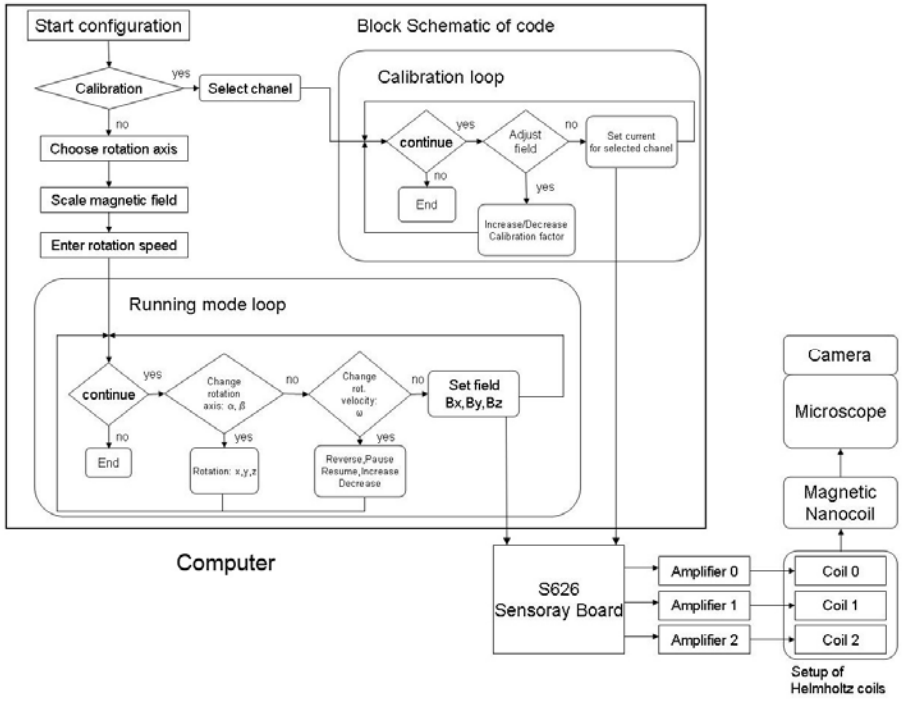
Three-Axis Helmholtz Coil

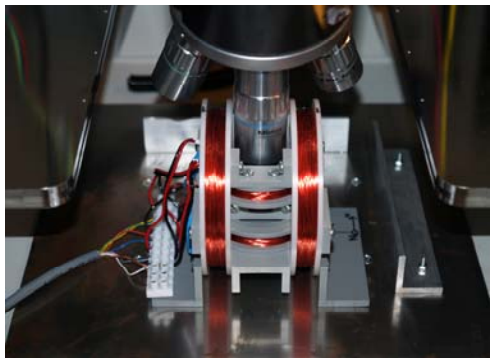
- Rotation of field around any direction

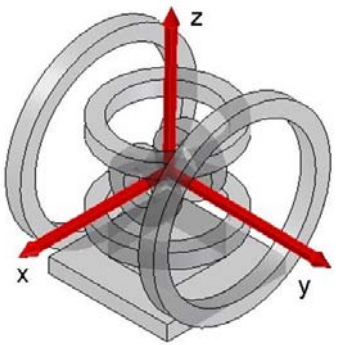


- Homogeneous fields with negligible gradients (< 0.5%)



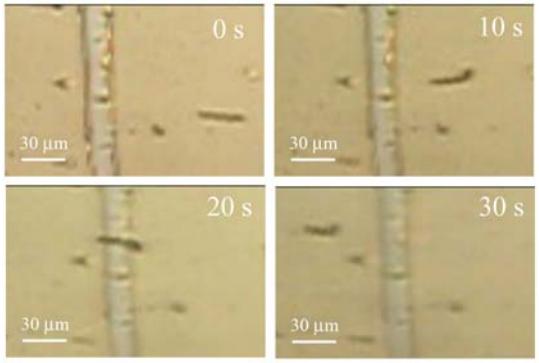




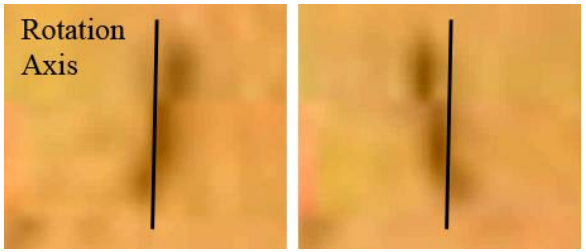


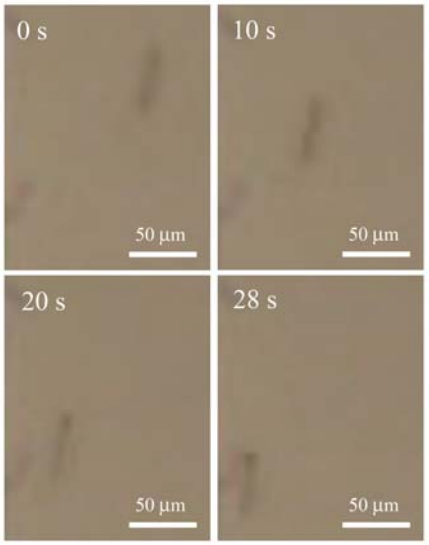
Results from Micropropulsion

- Paraffin Oil
  - Easier experimental procedure
  - 55 to 158 rpm resulted in axial velocities between 2.3 and 3.9 µm/s

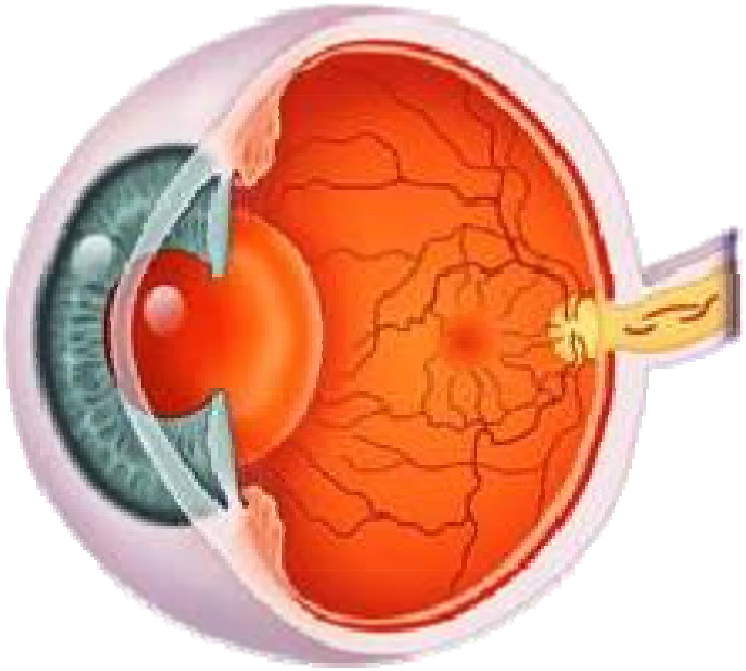


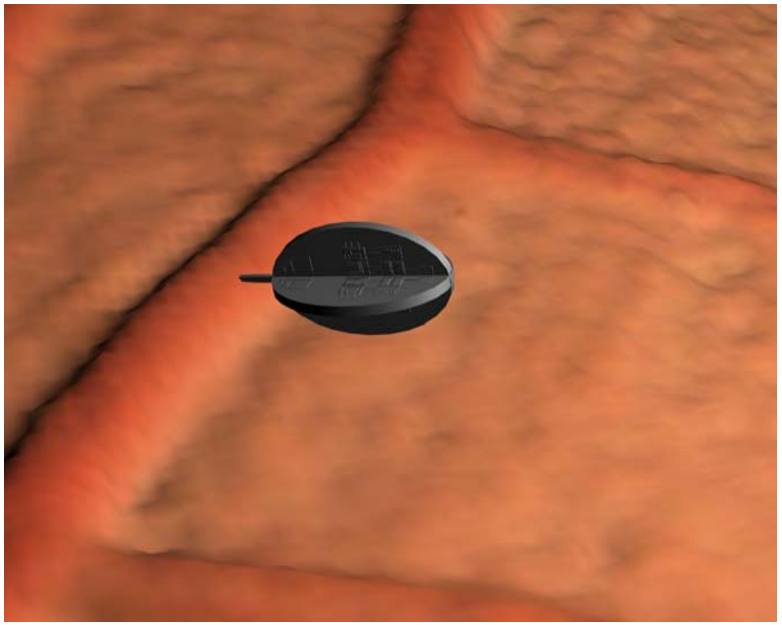
- Water
  - 60 rpm resulted in an axial velocity of 4.6 µm/s





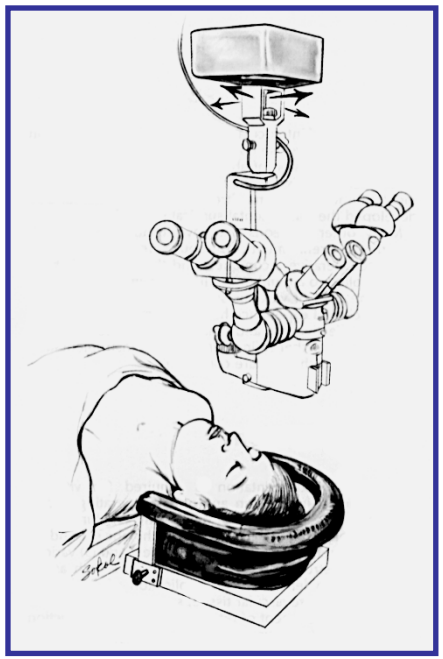
Microrobots for Intraocular Surgery and Diagnosis

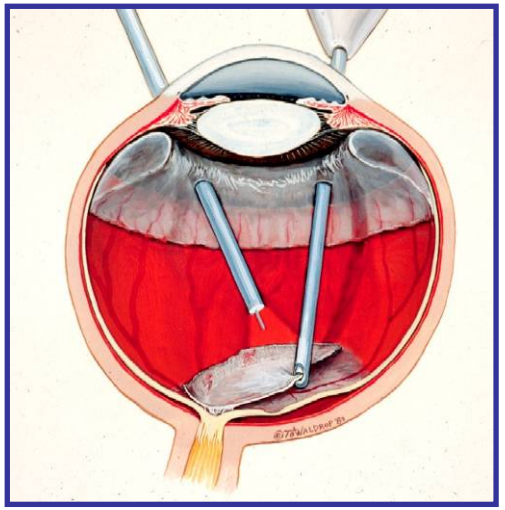




Vitreoretinal Surgery

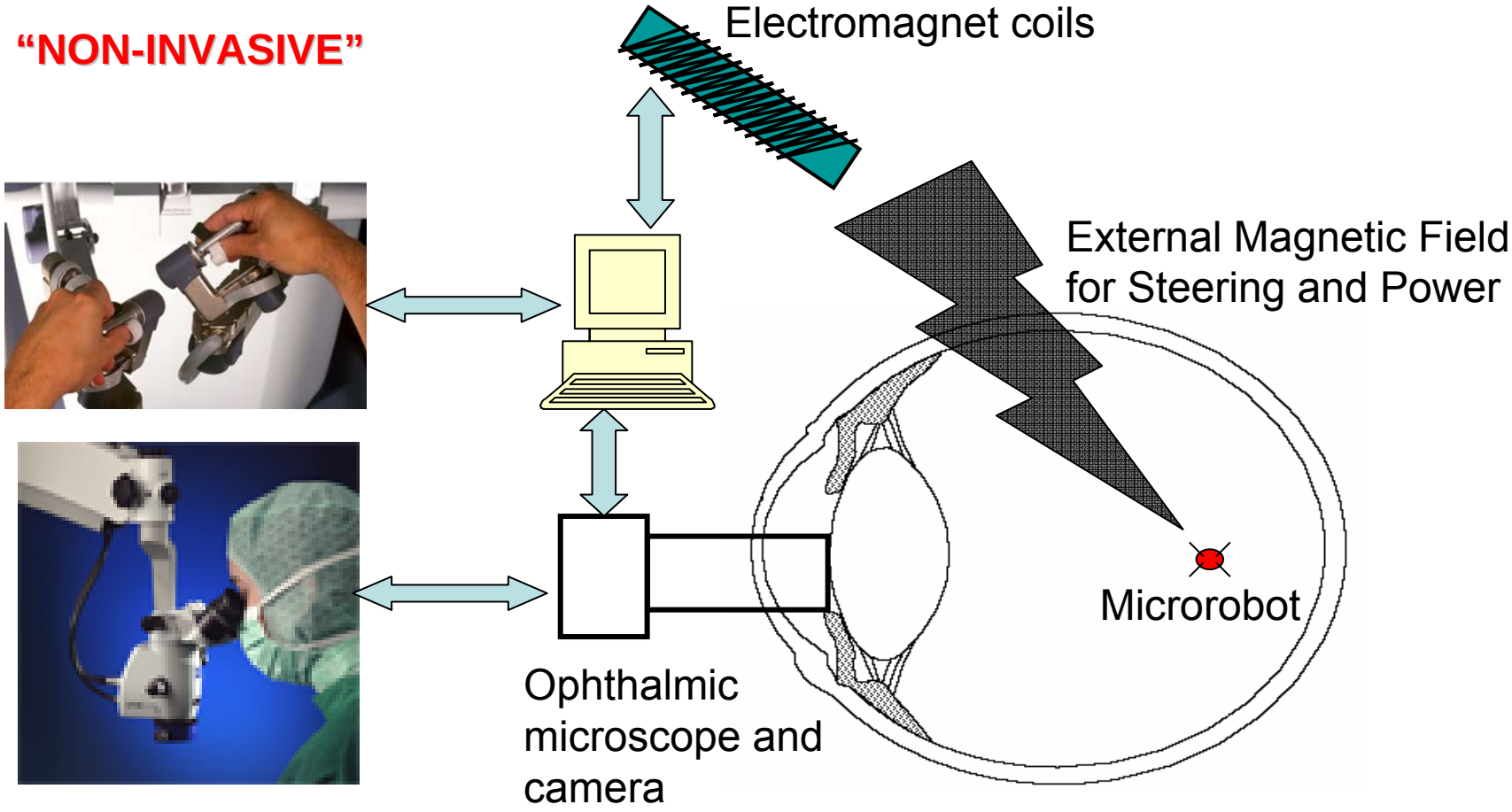
Hager and Taylor
Engineering Research Center for Computer
Integrated Surgical Systems and Technology



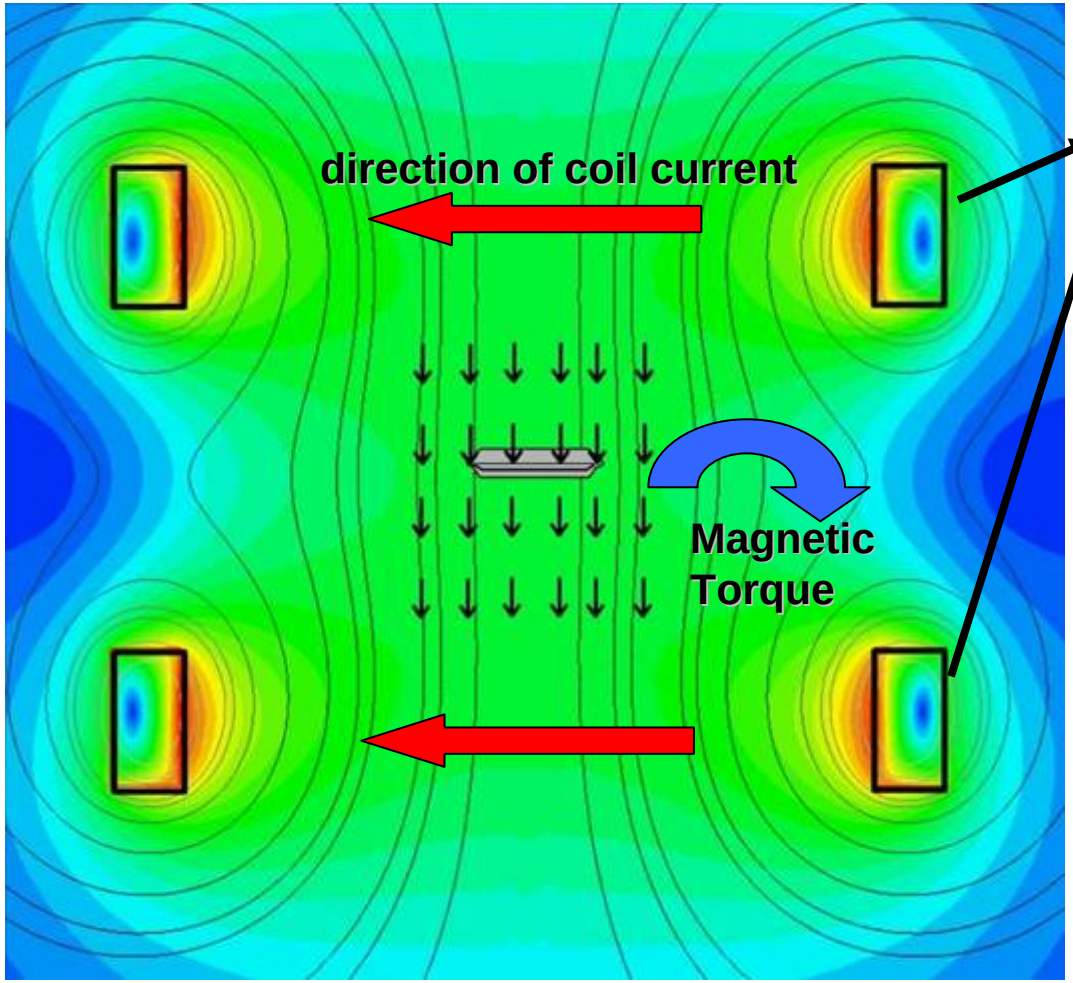


From “Ophthalmic Surgery” by The Wilmer Ophthalmological Institute

Microrobotic Surgery in the Eye

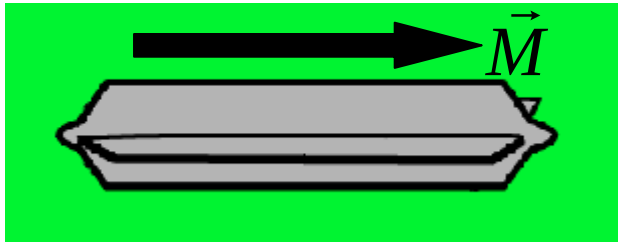


Locomotion: Magnetic Steering



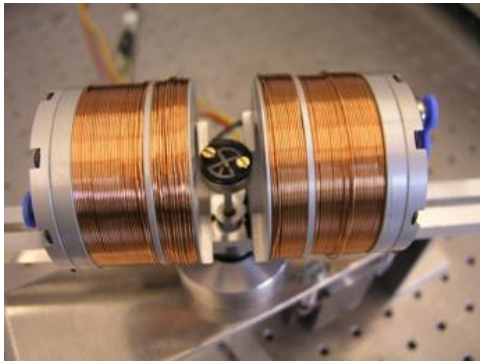
$$\tau_{magnetic} = V\vec{M} \times \vec{B}$$

Helmholtz Coil pair provides uniform magnetic field at the center

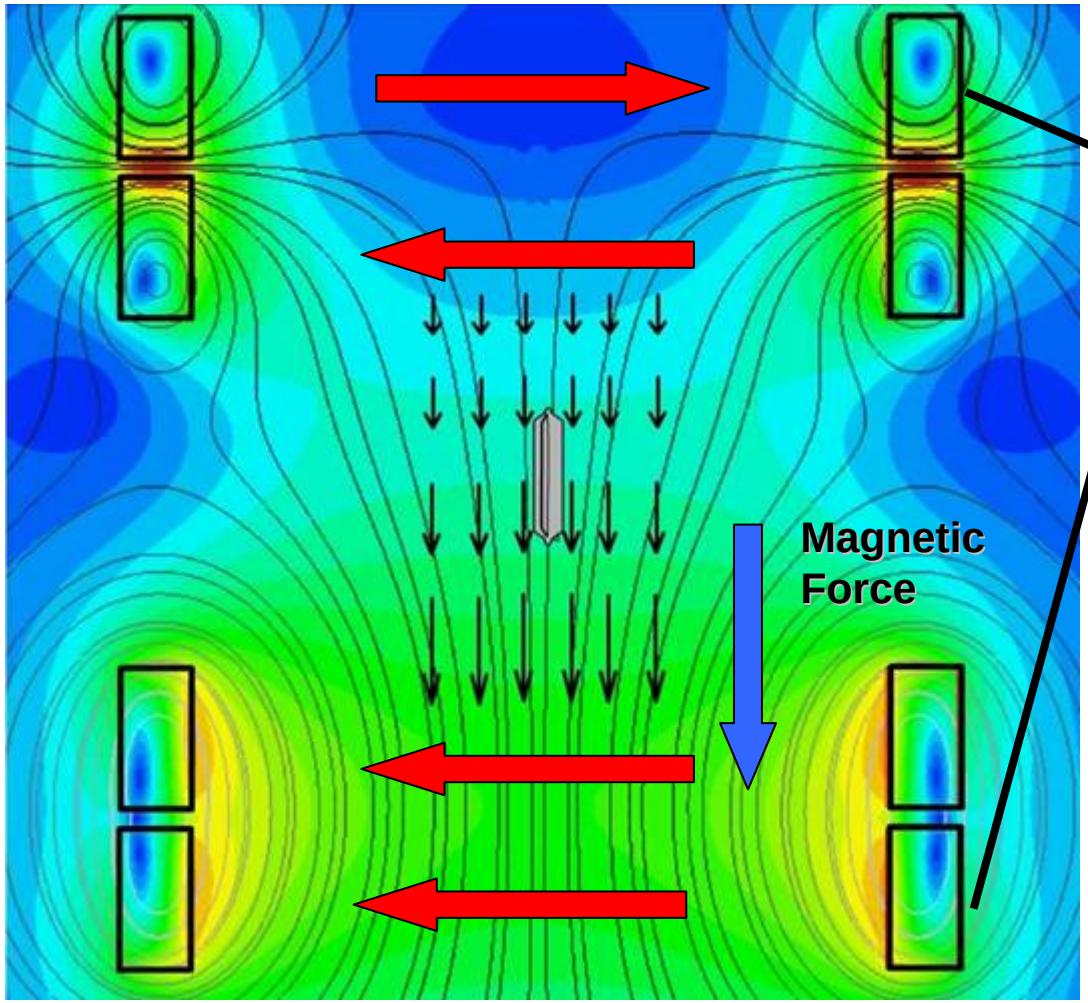


Direction of Magnetization

- Shape Anisotropy
- Permanent Magnets

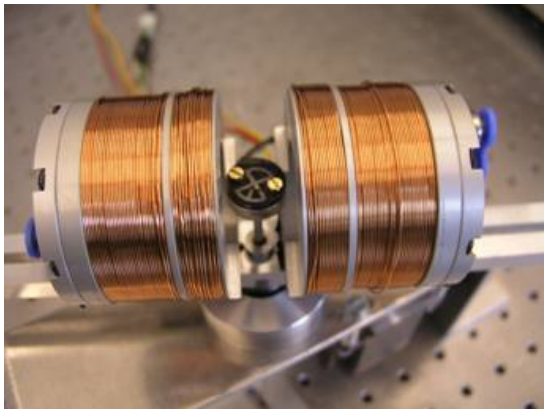


Magnetic Steering

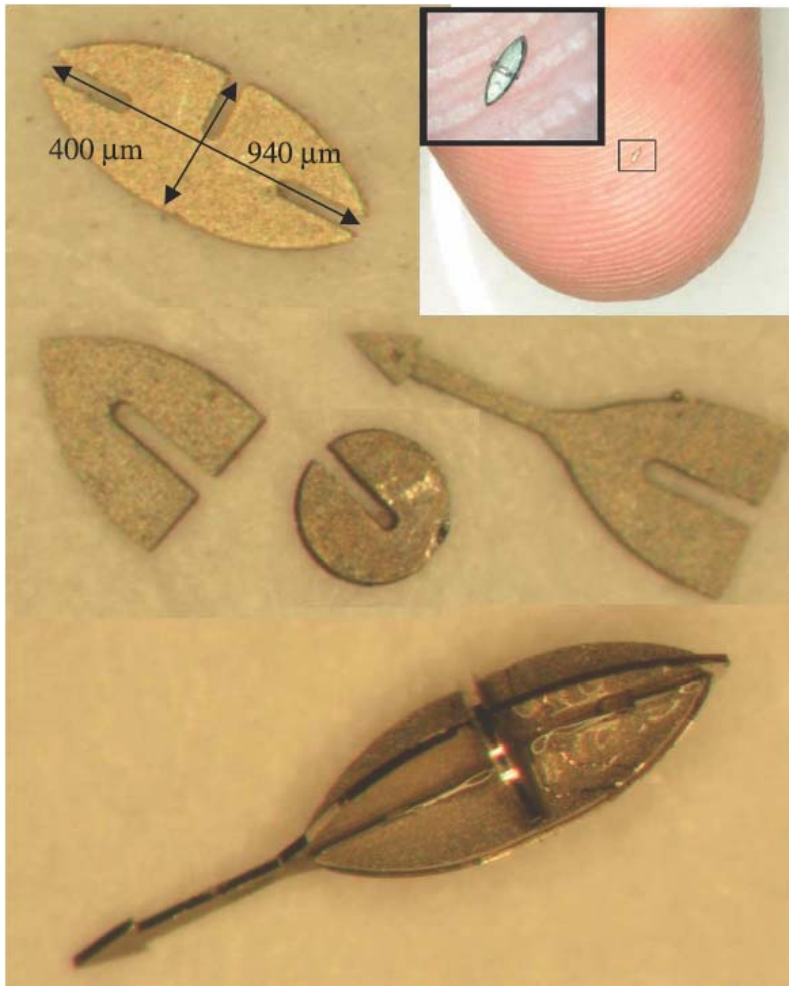


$$F_{magnetic} = V\vec{M}\nabla\vec{B}$$

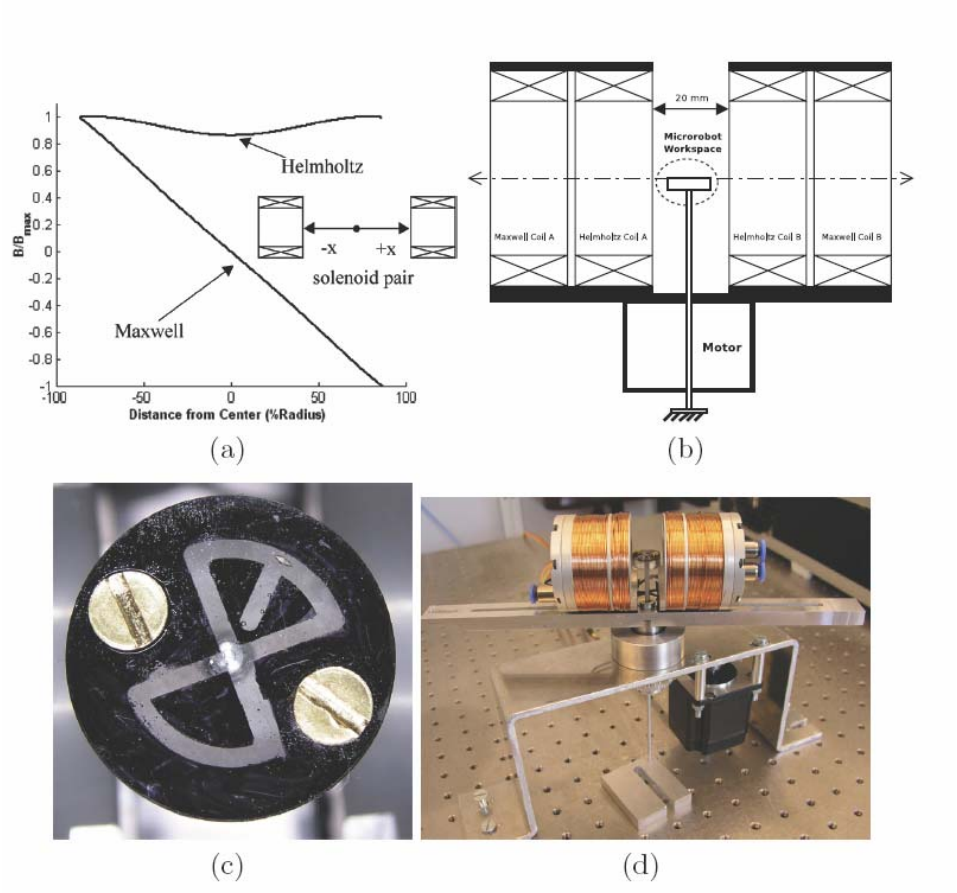
Maxwell Coil pair provides uniform field gradient at the center



Microassembled Microrobots



Steering Tests in a Plane



Publicity

Magnetic MicroRobots

- A MicroRobotic Platform for Investigating
  - MEMS assembly
  - Microfabrication
  - Deposition of hard magnetic materials for MEMS
  - Microsensors and microactuators
  - VisualServoing
  - Ultrasonic Servoing
  - New biomedical applications and procedures

6 DOF Motion and Force Control

Motion Planning

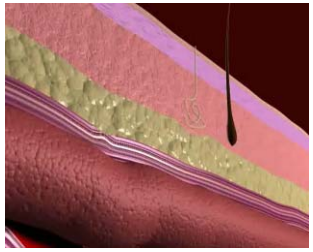
Localization

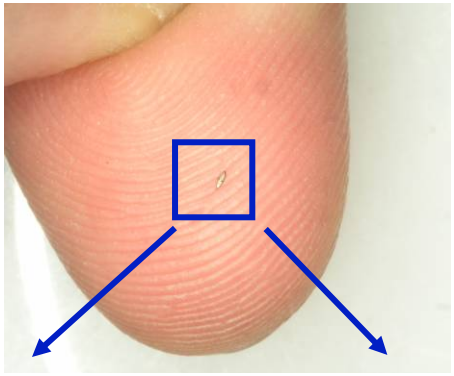
Multi-Sensor Integration

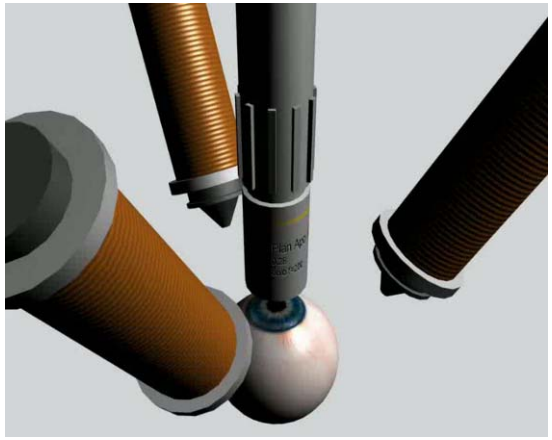
3D Reconstruction

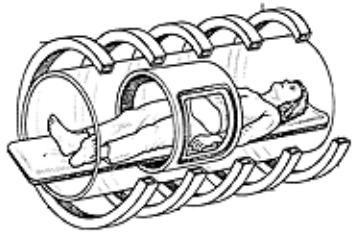
Sensor/Actuator Development

...









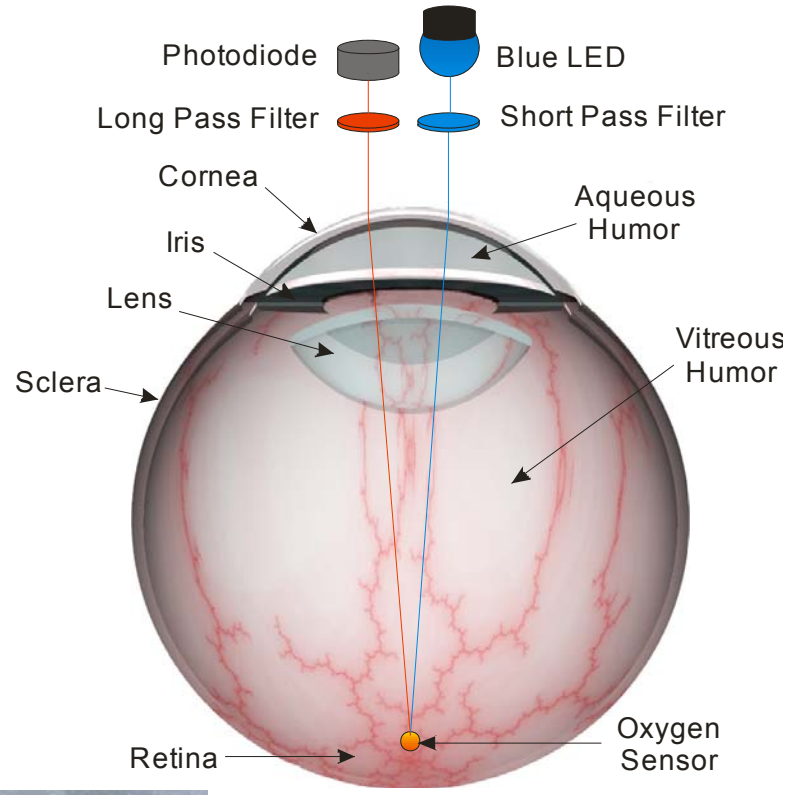
Wireless magnetically guided microrobots

Intraocular Oxygen Sensing

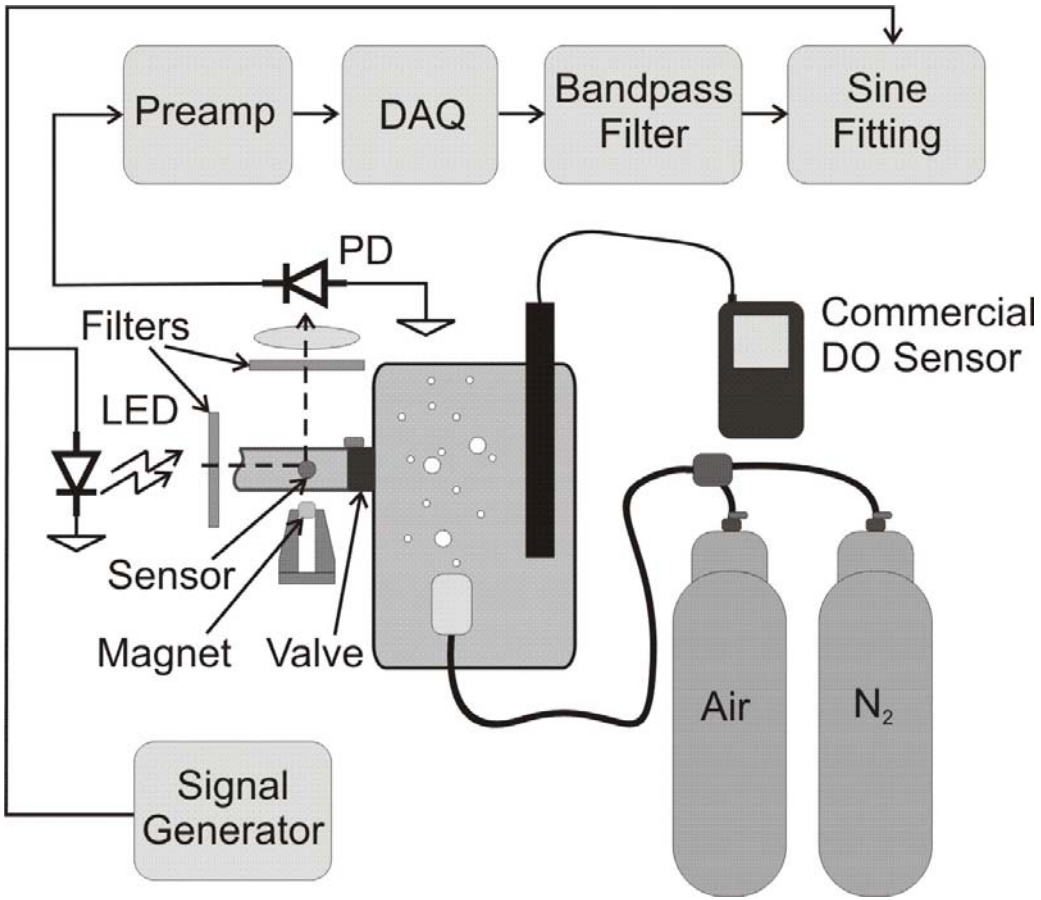
- The retina of the living eye needs sufficient supply of oxygen and other relevant nutrients to perform its primary visual function.

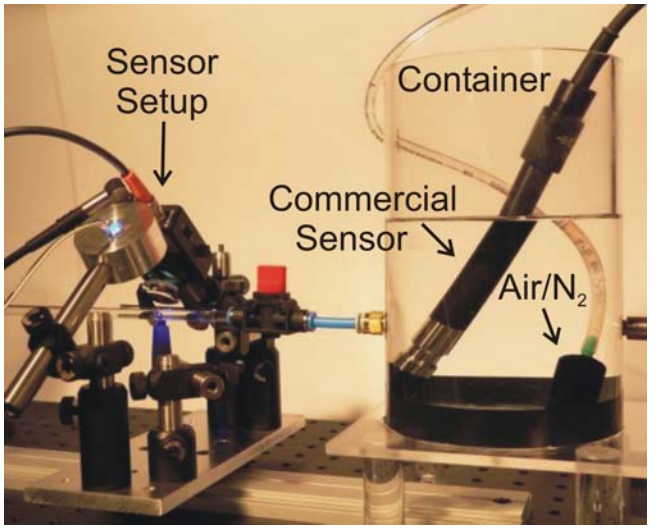
- Inadequate oxygen supply and retinal hypoxia inevitably result in major eye diseases including
  - Diabetic retinopathy
  - Glaucoma
  - Retinopathy of prematurity
  - Age related macular degeneration
  - Retinal vein occlusions

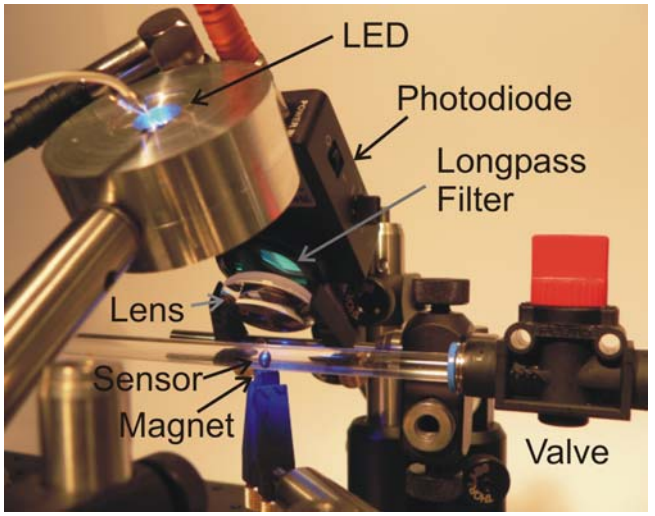
- The influence of oxygen on these diseases is not well understood and *in vivo* oxygen measurements are essential for better diagnosis and treatment.



Experimental Setup

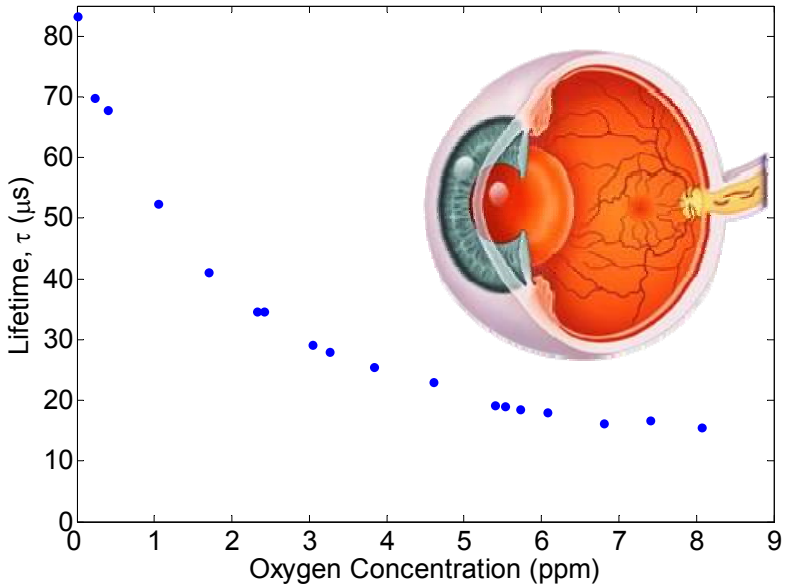




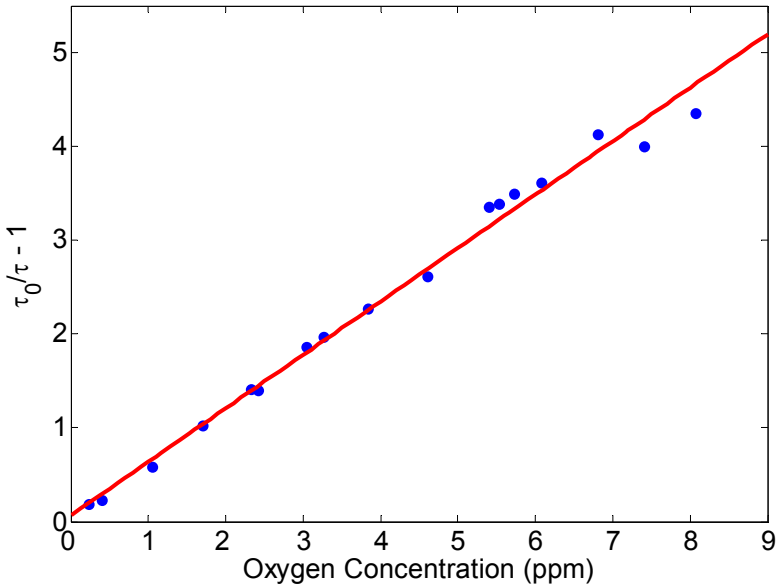


Experimental Results

- Three cycles were made going from the lowest oxygen concentration level (0.25 ppm) to the highest (8.27 ppm) and back to the lowest again. 17 measurements were taken during these cycles.



- Lifetime of the N948 dyes immobilized in polystyrene film under various oxygen concentrations.



- Stern-Volmer plot of the N948 dyes immobilized in polystyrene film under various oxygen concentrations.

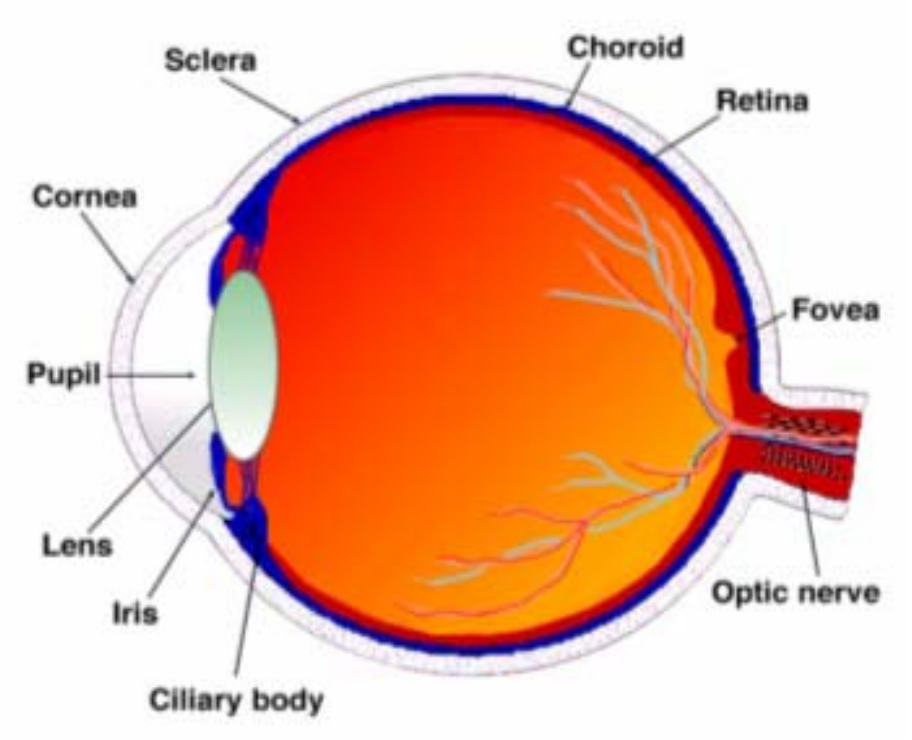
MicroRobotic Drug Delivery

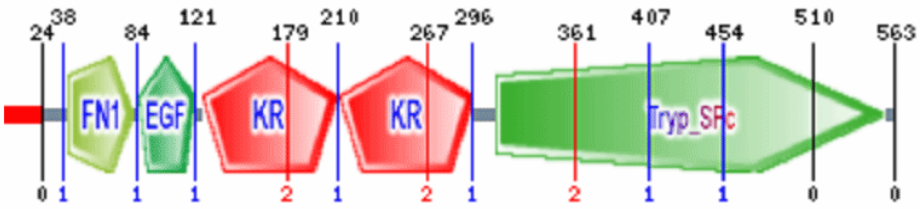
- Retinal Vein Occlusions are one of the most common causes of visual loss cases over the world.
- Obstruction of the retinal venous system by thrombus formation
- May involve the central, hemi-central, or branch retinal vein.
- Treatments are unsatisfactory

- Retinal vein cannulation allows drugs be delivered directly to retinal vein to cause thrombolysis with satisfactory results
- Side effects: Vitreous haemorrhage (bleeding) due to the large size of the needles.

- Conclusions: Vitrectomy with intravenous thrombolysis with t-PA seems to offer the most promising option for CRVO. (Shahid et al., 2006, Journal of Ophthalmology)

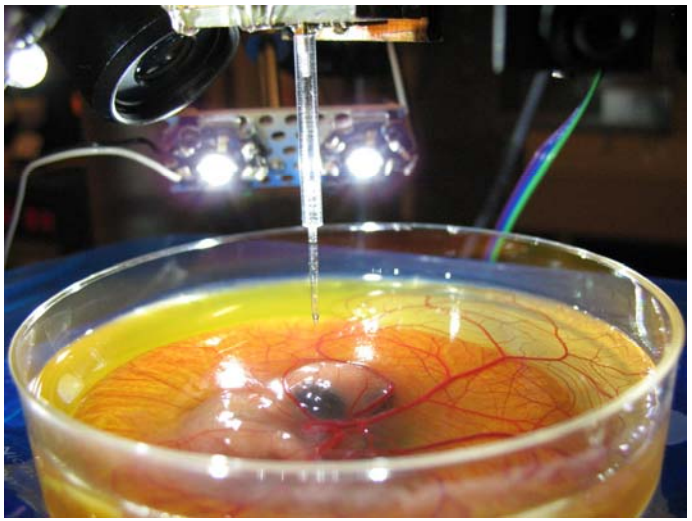
- tPA: Protein based enzyme produced in human endothelial cells. Thrombolytic agent (clot-busting drug).

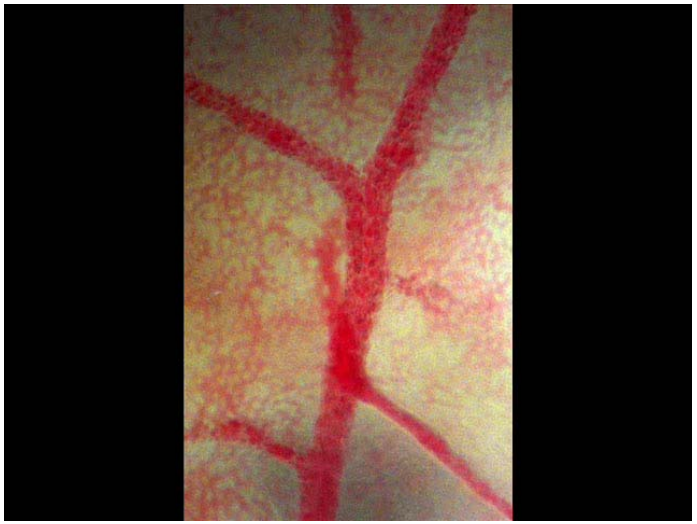




MicroRobotic Drug Delivery

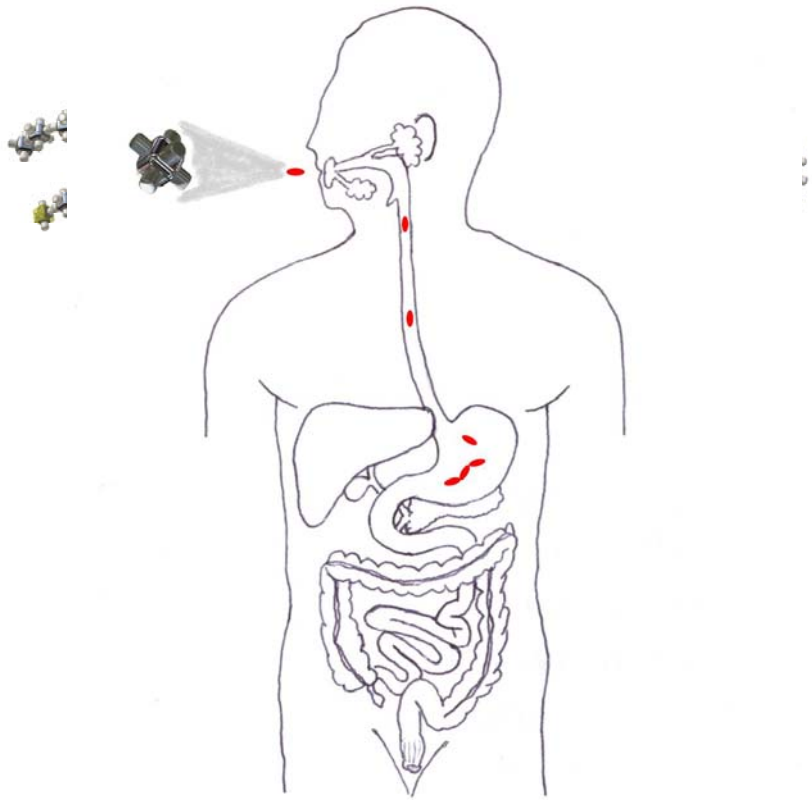
Chicken embryos for modeling retinal veins



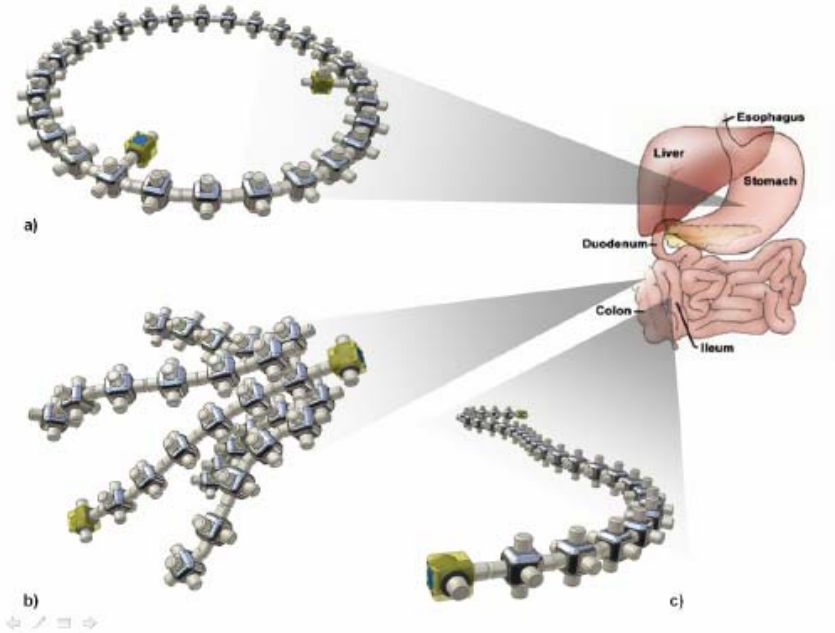


ARES – Assembling Reconfigurable Endoluminal Surigcal System

A cu … d
self

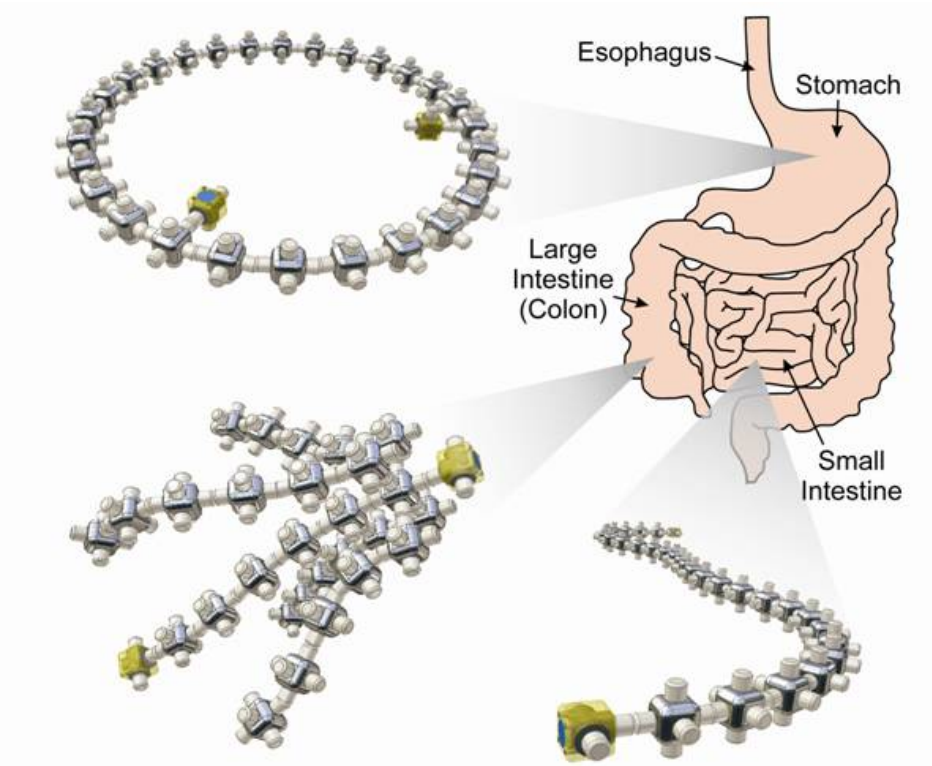


… able to adapt its configuration to the specific site of intervention and to the task that must be executed



ARES

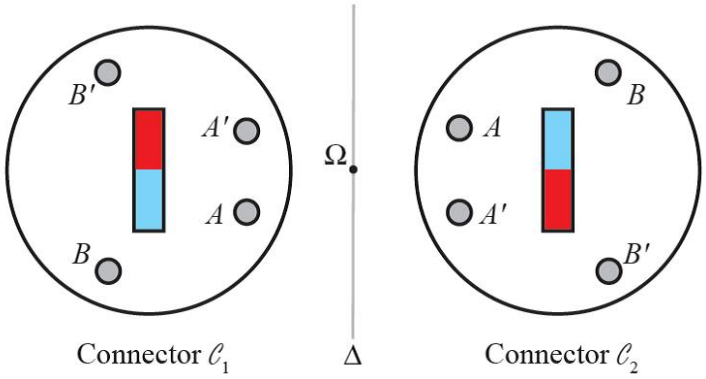
Assembling
Reconfigurable
Endoluminal
Surgical system

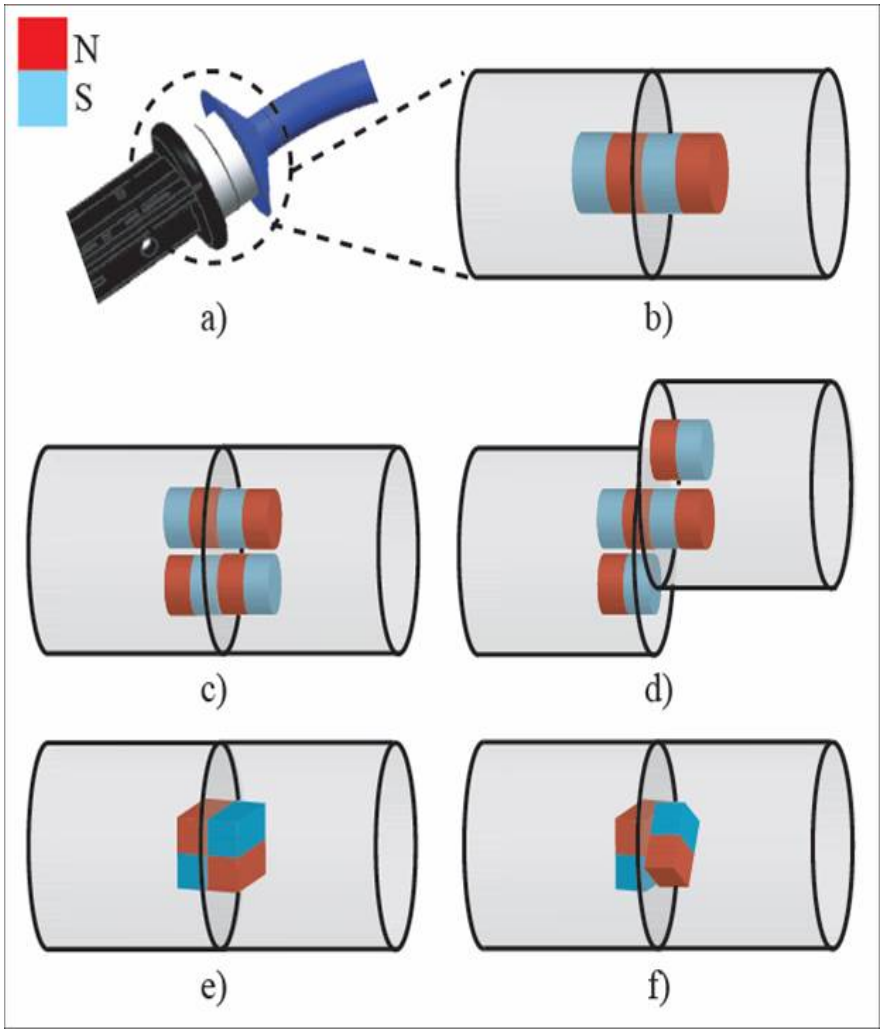


First key requirement:
A passive reversible and robust (dis-)connection mechanism

The MASH Connector

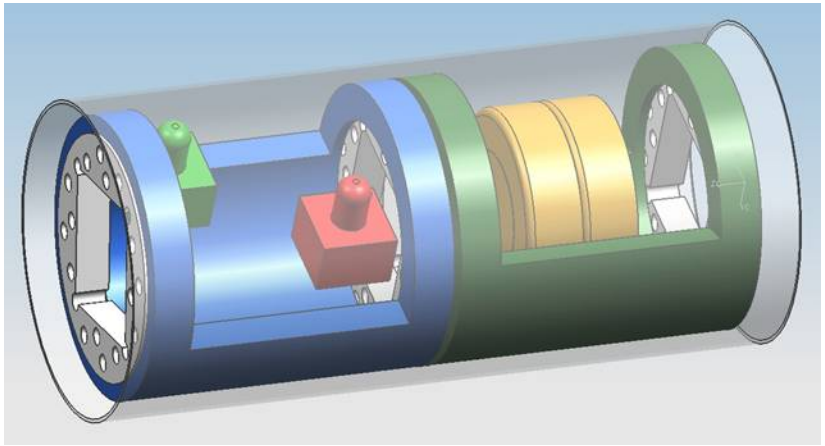
- **MA**gnetic
  - passive
  - robust
  - scalable
- **S**elf-Aligning
  - due to specific magnet configuration
- **H**ermaphroditic





Outlook

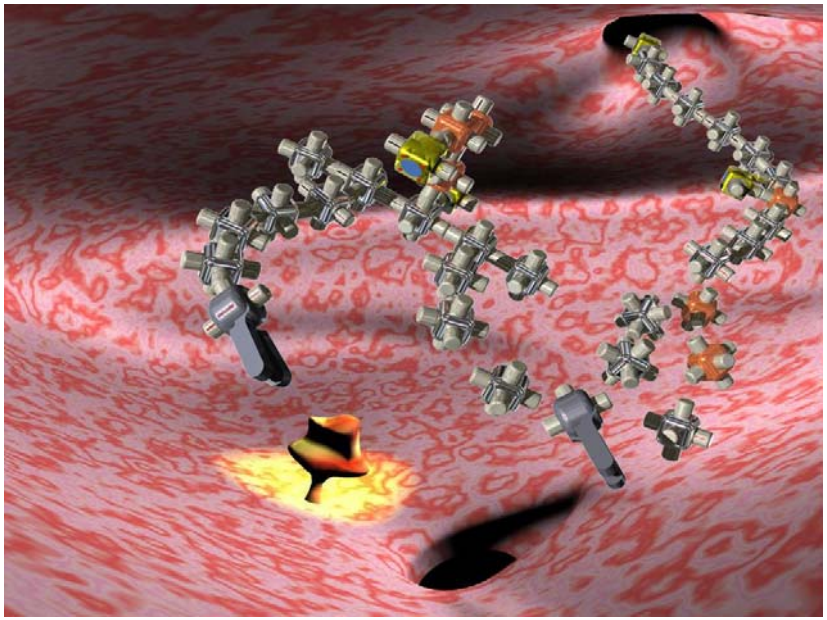
- Design and Fabrication of mMASH
  - microdrilling, micromilling
  - Compression moulding
  - Si etch



- Design of a low-power disconnection mechanism
  - Shape memory alloy based
  - Electromagnetic actuation

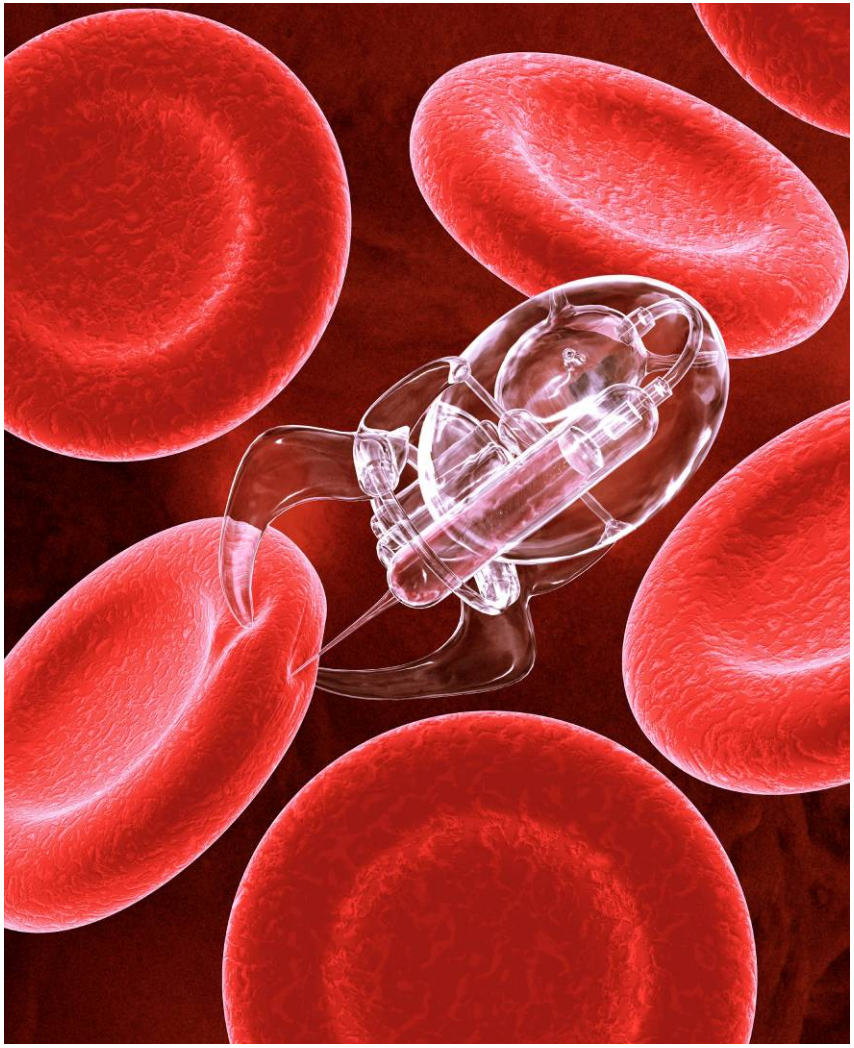
A Revolutionary Idea
(or perhaps just crazy??)

Screening tasks



Surgical and in-site drug delivery tasks

We are just getting started …



Coneyl Jay
2002