Carnegie Mellon University
Pittsburgh, Pennsylvania, USA

THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

4TH BIENNIAL NORTH AMERICAN SUMMER SCHOOL ON SURGICAL ROBOTICS

ENDOLUMINAL SURGICAL ROBOTICS

Prof. Paolo Dario
with many contributors as outlined on closing slide

The BioRobotics Institute, Scuola Superiore Sant'Anna
Pisa, Italy

July 21, 2014

MICCAI

National Institute of Biomedical Imaging and Bioengineering

BLUE BELT TECHNOLOGIES, INC

Medtronic

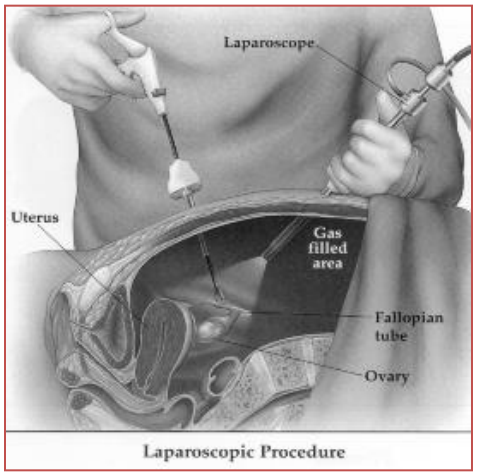
INTUITIVE SURGICAL

IEEE Robotics & Automation Society

Modern Surgery results from the "convergence" and integration of many scientific discoveries and technological advancements

- Anesthetics
- Antiseptics
- Anticoagulants
- Antibiotics
- Analgesics
- Endoscopic instruments

Modern surgery



Laparoscopic Procedure

Minimally invasive surgery

Modern Surgery results from the "convergence" and integration of many scientific discoveries and technological advancements

Anesthetics

Antiseptics

Anticoagulants

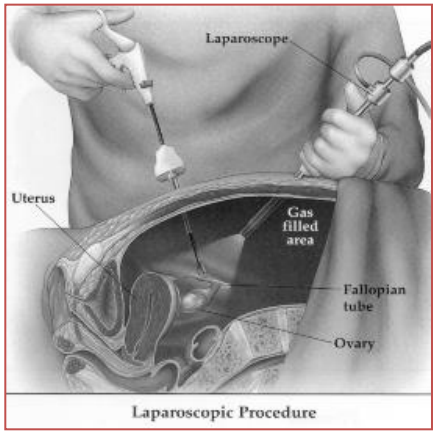
Antibiotics

Analgesics

Endoscopic instruments

Imaging and robotics

Modern surgery

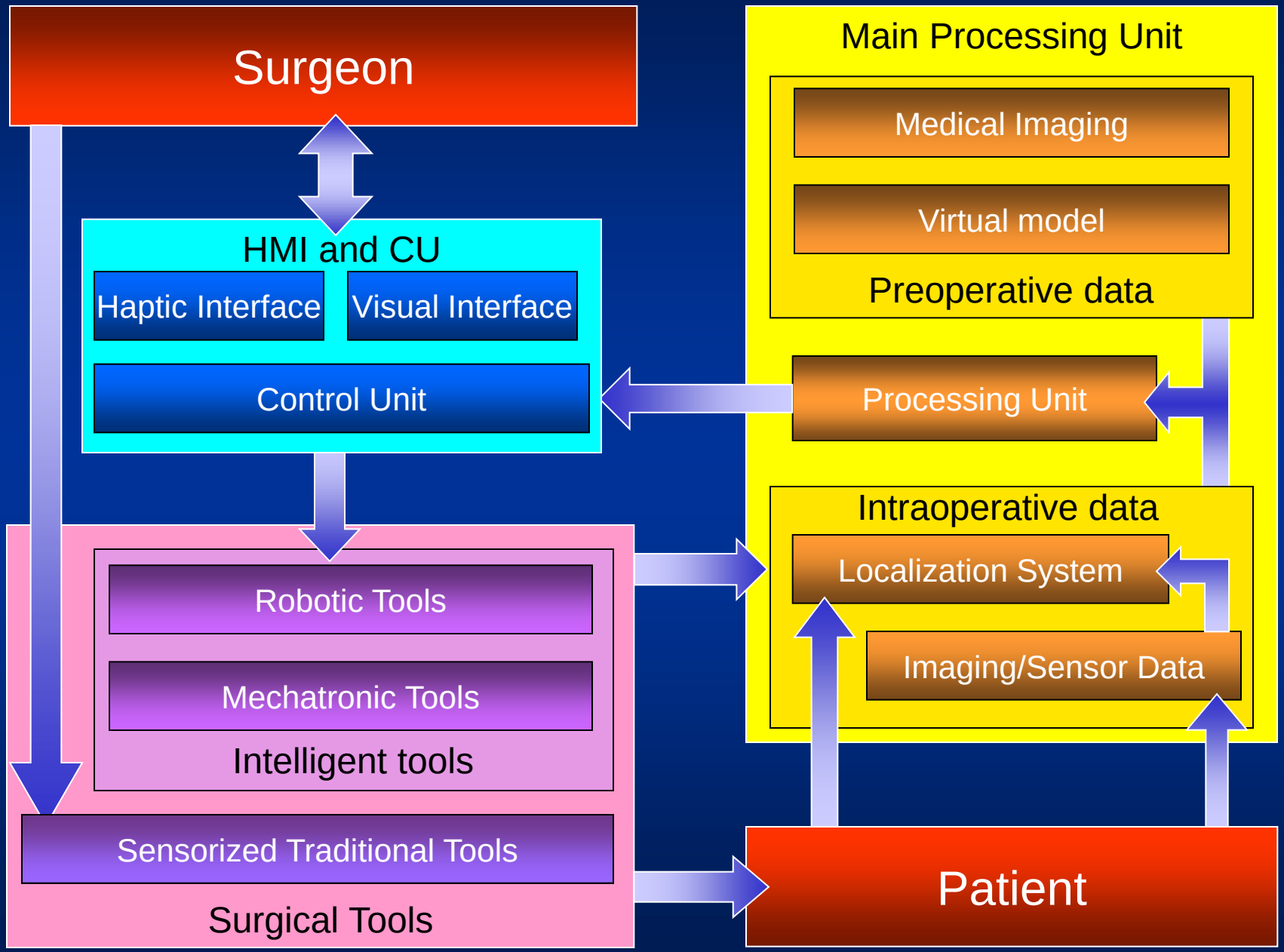


Laparoscopic Procedure

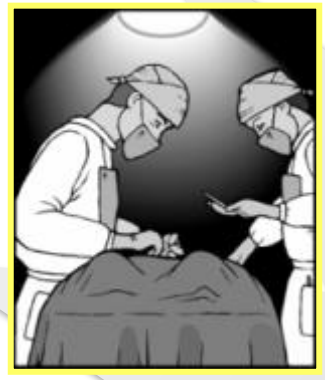
Minimally invasive surgery

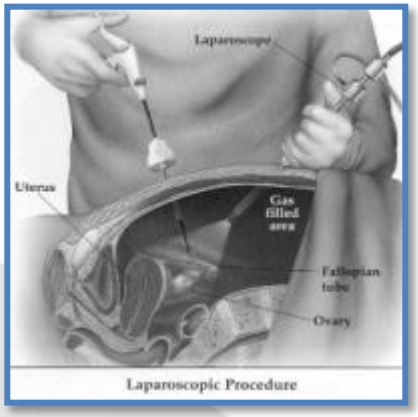
Computer-assisted surgery

Computer Assisted Surgery: Functional Scheme

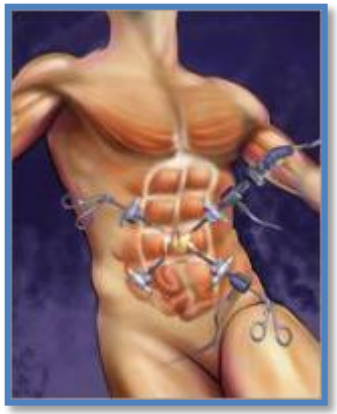


The Evolution of Surgery





Laparoscopic Procedure



TRADITIONAL TECHNIQUES

LAPAROSCOPIC SURGERY

Access Trauma Reduction & Increased Internal Dexterity

+ Accuracy
+ Predictability
+ Repeatability

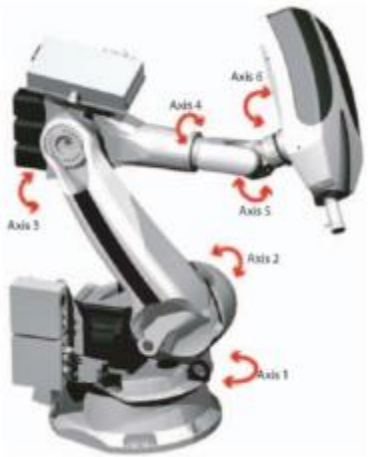
= Quality

ROBOTICS SURGERY

The two most successful surgical robots so far:

- DaVinci (teleoperated)
- CyberKnife (autonomous)

adopt solutions based on the above lessons



Robotics Surgery: Lessons Learned in 25 years

- **Real application domains** and procedures that benefit
- **Cost/benefit** clearly proved
- **Time of intervention** kept short
- **Time and complexity for set-up** to be **minimized**

52. Medical Robotics and Computer-Integrated Surgery

2008 and 2013

Russ Taylor, Arianna Menciassi, Paolo Dario,

Surgeon's Opinion

- External surgical master-slave manipulators (robots) are here to stay and robotic assistance will become the preferred approach, but only for advanced certain operations
- Operations which involve intra-corporeal anastomosis of small vessels and ducts (3mm) & operations where the operative space is restricted benefit from Robotic Assisted Surgery
- In these operations robotic assistance increases 'effectiveness' = reduces the level of difficulty and thus increases the number of surgeons who can perform these operations well and with safety (not just the very gifted master surgeons)
- Cost efficacy will increase with competition and increased multi-disciplinary usage in high volume centres
- Internal **mini-robots** are predicted to replace flexible endoscopy as we know it

Professor Sir Alfred Cuschieri, MD

Director of the Institute of Medical Science and technology in Dundee and St Andrew's Universities

Pioneer of endoscopic surgery

What's next?

- **Consolidating** the success story of Robotics Surgery by addressing the still many open research issues and technical/clinical/ industrial limitations
- **Simplifying** the complexity and **reducing the cost** of procedures
- **Exploring new avenues and paradigms** (one more '**game change**' in surgery with robots?)

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Why a Change of Paradigm is INEVITABLE

Professor Sir Alfred Cuschieri, MD

Director of the Institute of Medical Science and Technology in Dundee and St Andrew's Universities. Pioneer of endoscopic surgery

The operating room of the year 2030 will be a totally different environment than today

MASS Screening and EARLY diagnosis will have a major impact on the type and invasiveness of required surgical procedures

The combination of micro/nano/bio technologies, molecular biology, chemistry, physics, robotics/microrobotics, etc. will be key technologies enabling future high quality (accurate and repeatable), early and minimal invasive surgery

Prevention: the challenge of modern medicine

Treat ASYMPTOMATIC pathologies!

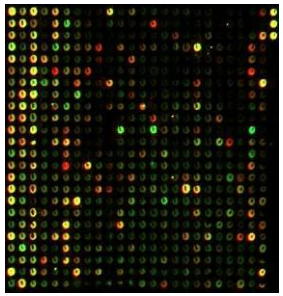
Symptoms

Clinical symptoms

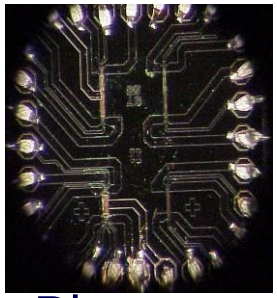
Diagnosis

Predisposition | Focused screening | Therapy | Follow-up

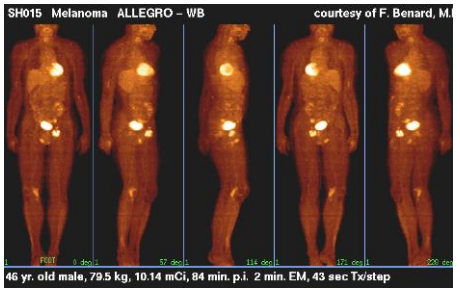
time



Gene Chip



Biosensor



PET-CT
Molecular Imaging

Molecular Diagnostics

Courtesy by Philips

Trends in Surgical Robotics Research

Ultra-low access and endoluminal robotics surgery

Da Vinci-like robots

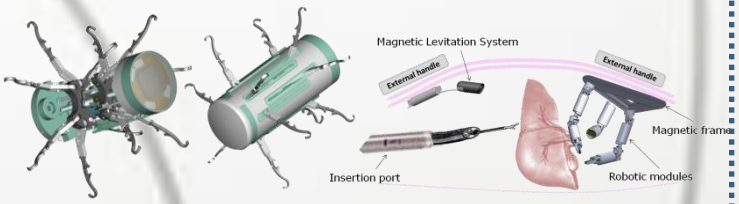
Ultra-low access surgery

OUTSIDE: large robot

INSIDE: very small access and tools inside the body

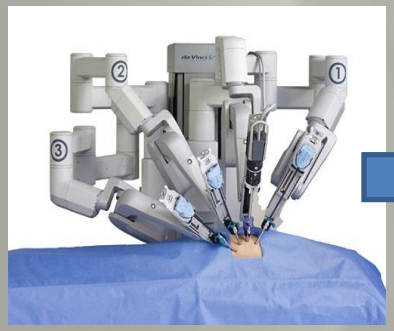
Capsule-like robots

Endoluminal surgery



OUTSIDE: no robots or small control platform

INSIDE: small or modular robots



Ultra-low access robotics surgery

Ultra-low access and endoluminal surgery

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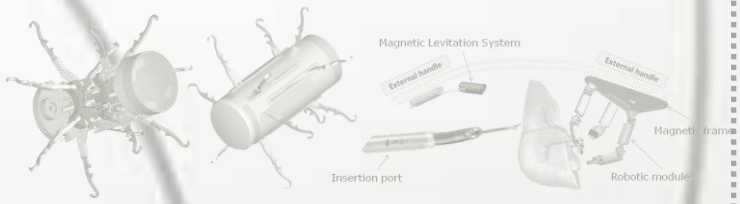

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Surgical Robots

daVinci Surgical System
(Intuitive Surgical Inc., CA, USA)

In 2010 approximately **276,200** procedures were performed worldwide with a **40%** increase over 2009

THE PRESENT: ONE SUPPLIER

Amadeus Maestro
(Titan Medical Inc., Canada)

Alf_X
(Sofar S.p.A., Italy)

daVinci Surgical System
(Intuitive Surgical Inc., CA, USA)

Approved for Human Clinical Trials

THE NEAR FUTURE: MORE SUPPLIERS

Titan Medical & KUKA LWR

April 19, 2010

Titan Medical Inc. (Canadian public company (TSX VENTURE:TMD) http://www.titanmedicalinc.com/) is pleased to announce that **it has selected KUKA Robotics Corporation to supply its Lightweight Robot (LWR) to be integrated with Amadeus*** , a next generation robotic surgical system currently under development by the Company.

Dr. **Reiza Rayman**, President of Titan Medical Inc., commented as follows:

"**KUKA's Light Weight Robot represents a significant advancement in medically designed robotic technology**. The intelligence, speed, and accuracy of the LWR are currently unprecedented. We feel confident that this technology will add further advanced capability to Titan's Amadeus platform."

* Amadeus® Robotic Surgical System is the next generation 4-armed robotic surgical platform. The goal is to bring surgery to a completely new level, because technology will give surgeons extraordinary capability.

The ARAKNES Project has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement num. 224565.

Hyundai Heavy Opens New Surgical Robot Lab

2012.02.20

Photo
(from left): Mr. Park seong-wook, President of Asan Medical Center, Mr. Cho Sung-jang, Secretary General of Asan Foundation and Mr. Lee Choong-dong, Senior Executive Vice President of Hyundai Heavy with a 5-axis surgical robot.

Hyundai Heavy Industries, the world's biggest shipbuilder and Korea's largest industrial robot manufacturer, announced today the opening of a laboratory with Asan Medical Center in an effort to step up the development of surgical robots at Asan Institute for Life Science on February 17.

The opening ceremony was followed by the Symposium for Surgical Robots at Asan Medical Center. At the Korea's largest robot symposium, the Company unveiled projects developing a 6-axis surgical robot system for joint repair, ligament reconstruction robot, and interventional robots.

Hyundai Heavy won US FDA approval for main bodies and controllers of the surgical robot ROBODOC with the local robot venture CUREXO last year. Asan Medical Center completed 2,800 clinical tests using surgical robots.

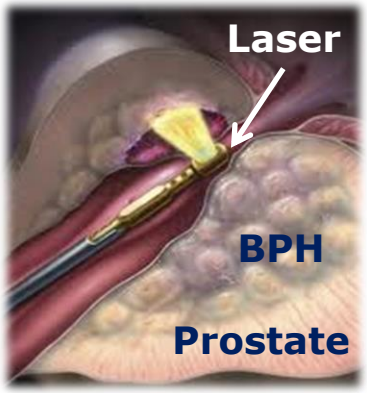
Surgical robots are one of the future growth engines Hyundai Heavy pursue developing. According to Frost & Sullivan, a consultancy, the global surgical robot market is projected to grow to USD 6.6 billion by 2014.

ISTITUTO DI BIOROBOTICA

Scuola Superiore Sant'Anna

Laser assisted robotic surgery in UROLOGY

MILORDS

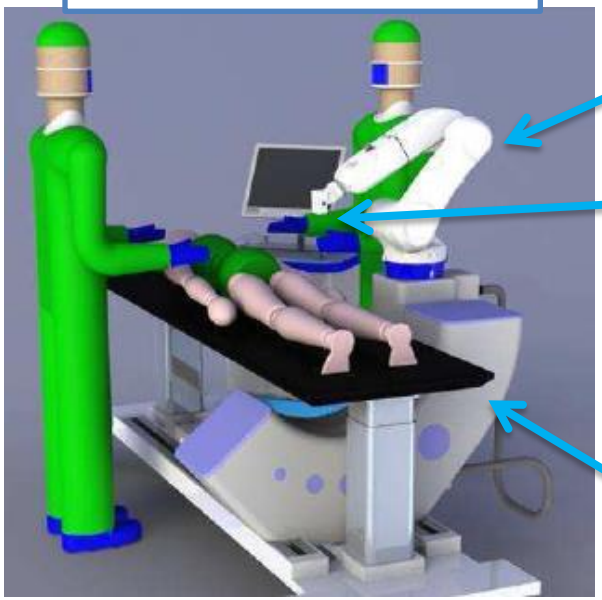


PROBLEM:

- To perform the **laser treatment of benign prostatic hypertrophy** (BPH), by reconstructing the channel of the prostatic urethra in a homogeneous way
- To increase the accuracy of the treatment
- To ensure the contact between the laser fiber and the tissue, thus avoiding thermal damage (carbonization) as much as possible

SOLUTION: a guidance system to provide the surgeon with a 3D visualization and sensor feedback

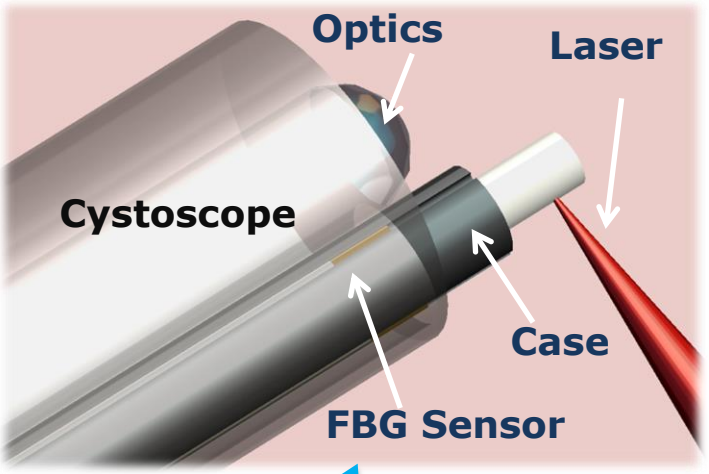
ROBOTIC PLATFORM



6 DOF ADEPT Robot

<u>Shared control:</u>
Cystoscope is mounted on the robot's end effector and moved by surgeon

Imaging system (3D RX)



<u>Strain sensor</u> for detecting contact with tissue

Regione Toscana

A new EU Project
Coordinator: Prof. Arianna Menciassi, SSSA

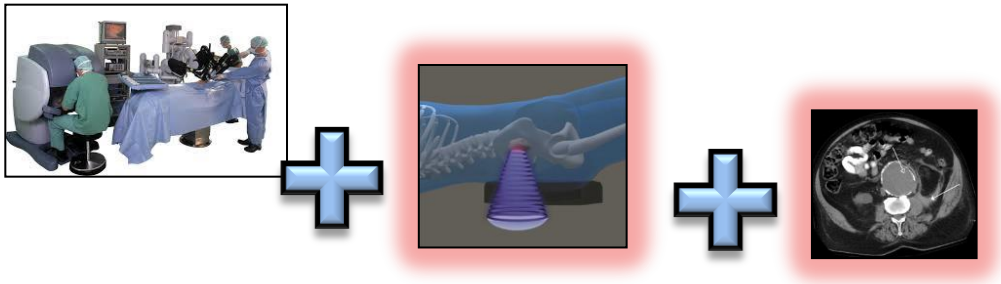
FUTURA

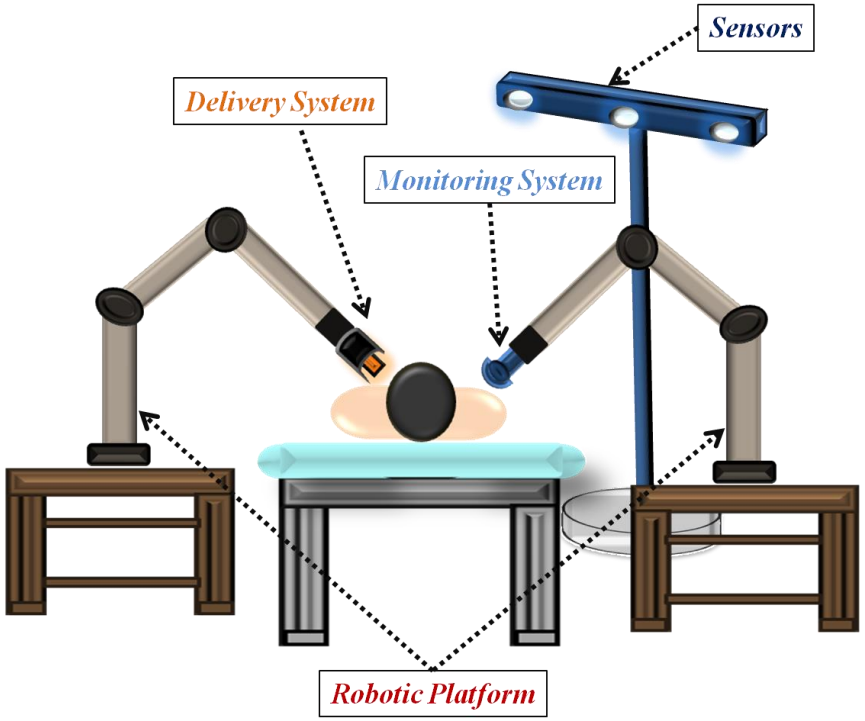
Focused **U**ltrasound **T**herapy **U**sing **R**obotic **A**pproach

SEVENTH FRAMEWORK PROGRAMME

Merging surgical robotics, non-invasive therapy (e.g. focused ultrasounds) and machine learning for medical imaging

- ***Robotic platform:*** two serial commercial manipulators
- ***Monitoring system:*** 2D US confocal probe + 3D US probe
- ***Delivery system:*** custom made HIFU transducer
- ***Sensors:*** Smart environmental sensors + Human-Robot Interaction (HRI) monitoring





Start: November 1, 2013

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Ultra-low access and endoluminal surgery

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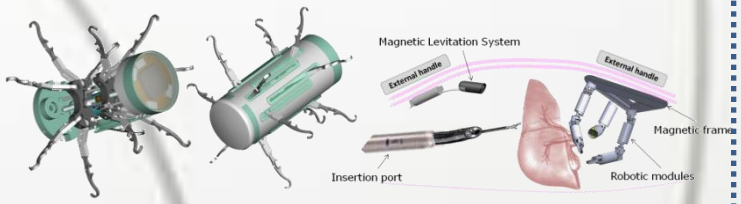
Endoluminal surgery



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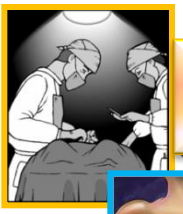
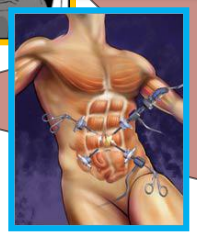
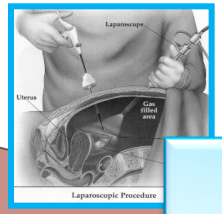
The Evolution of Surgery



TRADITIONAL TECHNIQUES



Access Trauma Reduction in Surgery



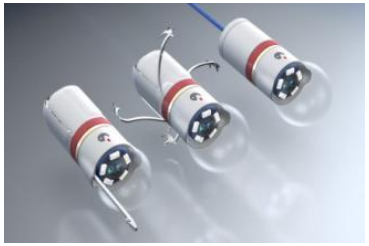
LAPAROSCOPIC SURGERY

SURGICAL ROBOTICS

Size: in the ≤ 1 mm range

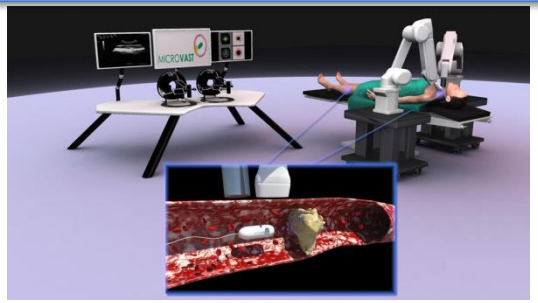
Interventional platforms in the meso scale

ACTIVE (ROBOTIC) ENDOSCOPIC DEVICES AND CAPSULES



SCARLESS ROBOTIC SURGERY

VASCULAR ROBOTIC SURGERY



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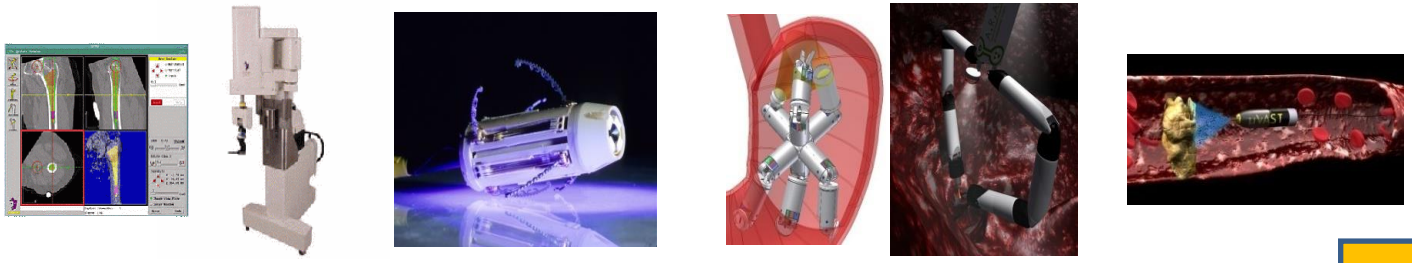
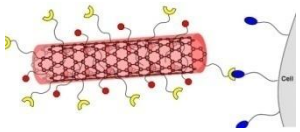
Robotics Surgery: Our Vision & Our Roadmap

$1=10^0$ [m] 10^{-1} 10^{-2} 10^{-3}

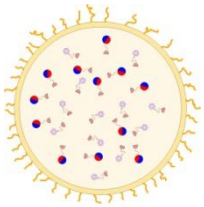
Surgical Robotics | **Capsular Endoscopy** | **Reconfigurable endoluminal platforms** | **Intravascular robotics**



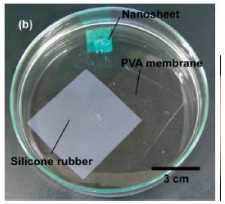
Interventional platforms in the meso scale



Nano-particles, nano-tubes, nano-shells

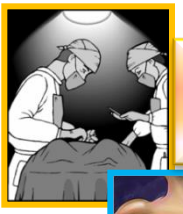


Functionalized nano-carriers, advanced drugs

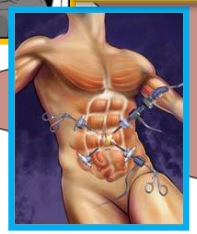


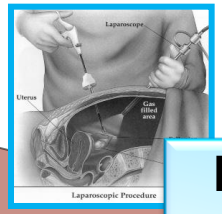
Smart structures

10^{-9} [m] 10^{-6} **Advanced Photonics** 10^{-3}



TRADITIONAL TECHNIQUES





LAPAROSCOPIC SURGERY

Access Trauma Reduction in Surgery

SURGICAL ROBOTICS

Size: in the ≤ 1 mm range

Interventional platforms in the meso scale

Combining **robotic technologies**, "wireless" actuation and biotech **for** transforming **systemic** therapeutic approaches into **targeted, local and precise** therapeutic approaches

An endoluminal robot could also be seen as a carrier of micro/nano therapy agents (i.e. a SHUTTLE)

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Passive and Active Endoscopic Devices

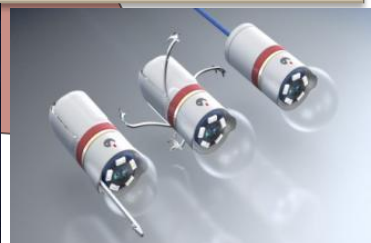
TRADITIONAL TECHNIQUES

FLEXIBLE ENDOSCOPY

Invasiveness Reduction in GI Endoscopy

PASSIVE ENDOSCOPIC CAPSULES

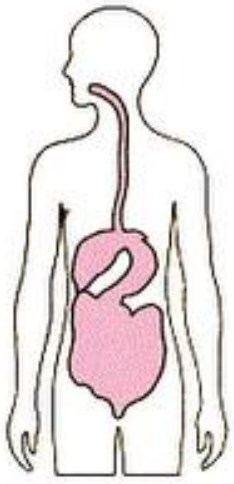
ACTIVE (ROBOTIC) ENDOSCOPIC DEVICES AND CAPSULES



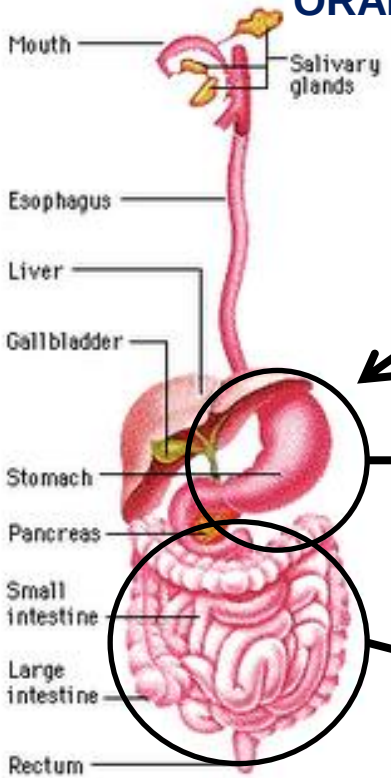
Endoluminal endoscopy and therapy in the gastrointestinal tract: different possible accesses

Gastrointestinal Tract (from esophagus to rectum) : Ø = 10 to 30 mm

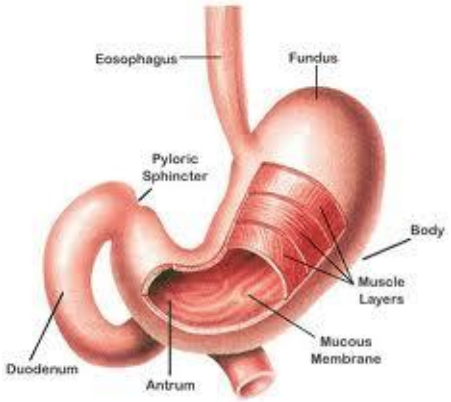
Small diameter → Miniaturization
Physiological curvature → Dedicated/Conformable shape
Collapsed tissues → Active mechanism needed for locomotion



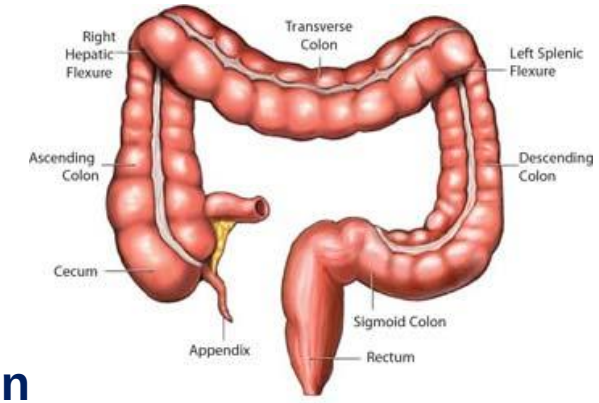
ORAL ACCESS



ABDOMINAL AND UMBILICAL ACCESS



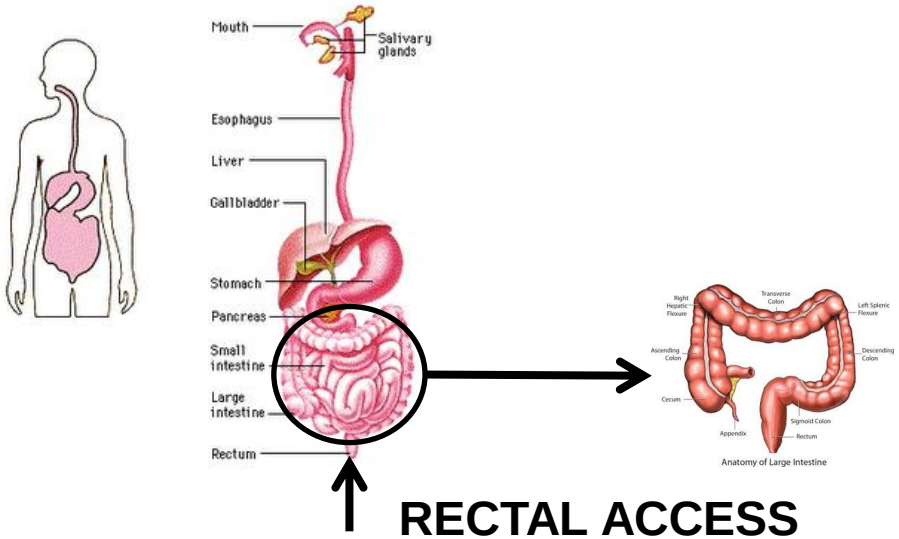
Stomach

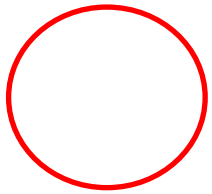


Anatomy of Large Intestine

RECTAL ACCESS

Colon





Gastrointestinal Tract: Ø = 20-30 mm

Case Study #1

Developing a system for **painless** gastrointestinal endoscopy

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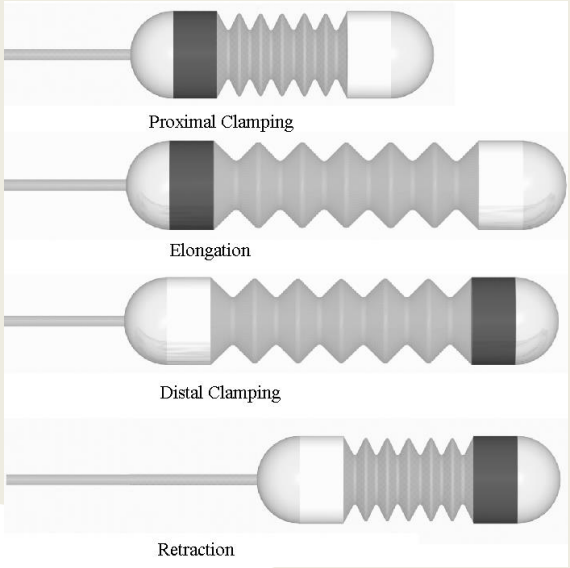
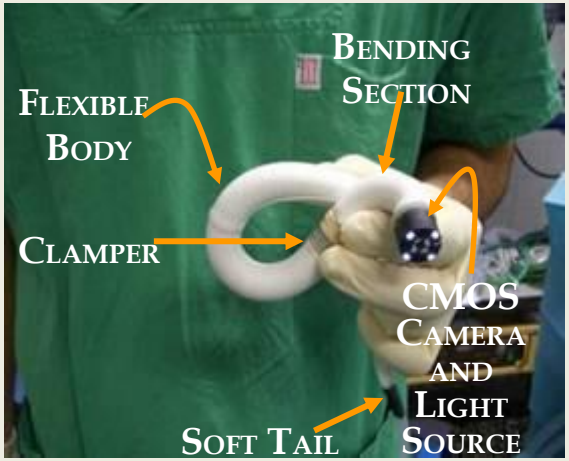
From **bio-inspiration** to **bio-application**
(the EU FET BIOLOCH and the EMIL IMC Projects)

Problems in colonoscopy: pain, difficult maneuverability…



Semi-autonomous inchworm-like locomotion

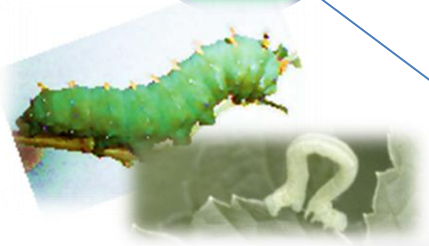
…like a worm in the gut…



The E-WORM Painless Colonoscopy System

From bio-inspired design to industrial design and clinical application (≈ 10 years)

Bio-inspiration



Engineering design

In vitro and in-vivo (animal) validation

Research (IMC EMIL Project@ SSSA)

Industrial design

Clinical application

Industrial and Clinical application (Endotics®) (more than 600 patients)

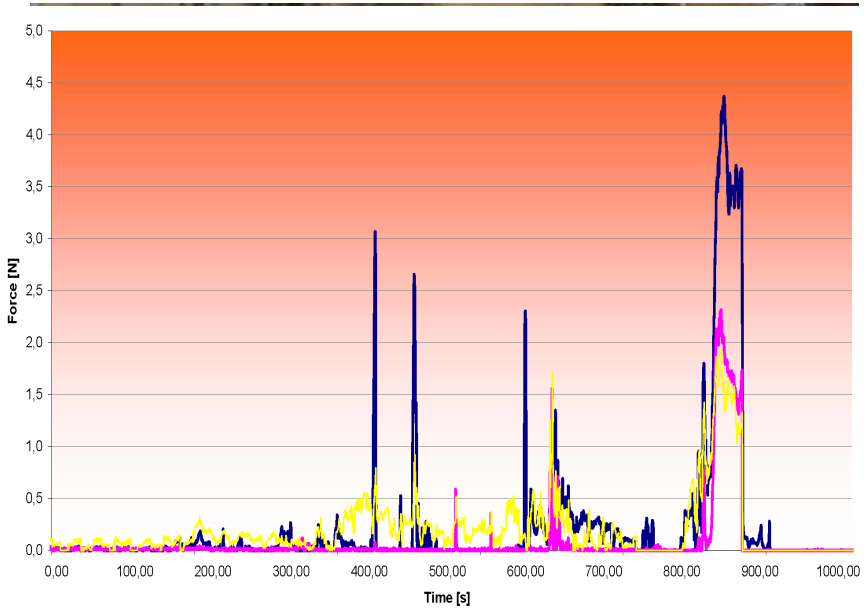
Self propelling, inchworm-like painless colonoscopy system

In-Vitro Tests

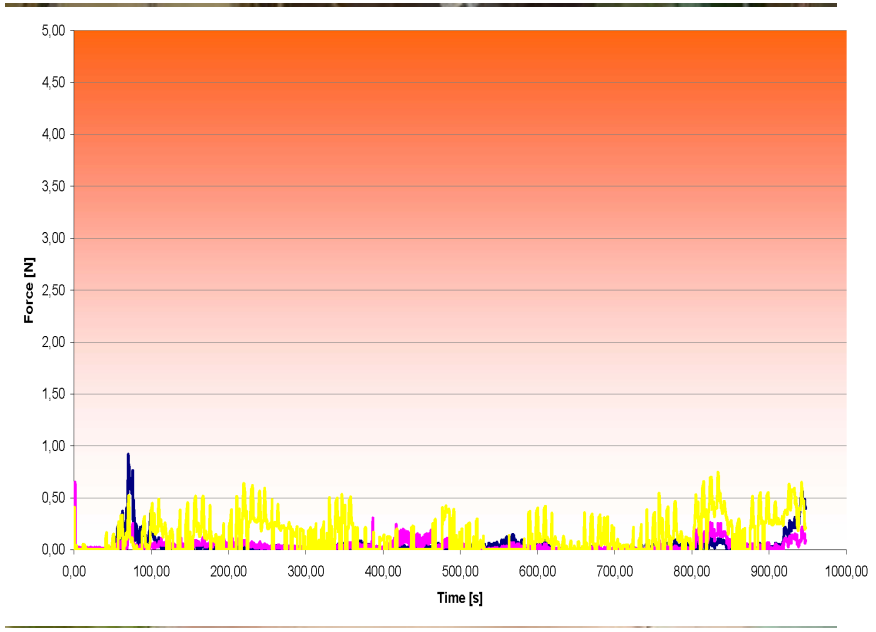
Conventional Colonoscopy Vs worm-like colonoscopy

scuola superiore Sant'Anna di studi universitari e di perfezionamento

E2 produces visibly less deformation to the geometry of the sigmoid. The pictures show how the conventional colonoscope is forcing the bowel to stretch (red arrows).



Conventional Colonoscopy



E^2 endoscopy

Int J Artif Organs. 2009 Oct 21;32(8):517-527. [Epub ahead of print]

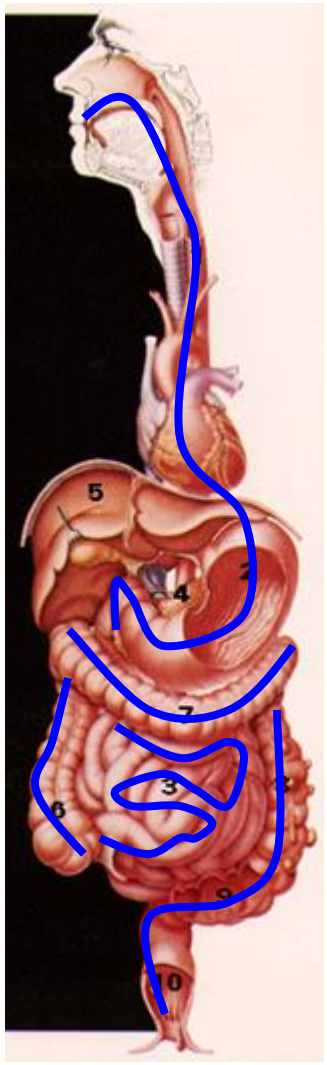
Functional evaluation of the Endotics System, a new disposable self-propelled robotic colonoscope: in vitro tests and clinical trial.

Cosentino F, Tumino E, Rubis Passoni G, Morandi E, Capria A.
Gastroenterology and Digestive Endoscopy, San Giuseppe Hospital, Milan - Italy.

Abstract

Objective: Currently, the best method for CRC screening is colonoscopy, which ideally (where possible) is performed under partial or deep sedation. This study aims to evaluate the efficacy of the Endotics System, a new robotic device composed of a workstation and a disposable probe, in performing accurate and well-tolerated colonoscopies. This new system could also be considered a precursor of other innovating vectors for atraumatic locomotion through natural orifices such as the bowel. The flexible probe adapts its shape to the complex contours of the colon, thereby exerting **low strenuous forces during its movement**. These novel characteristics allow for a painless and safe colonoscopy, thus eliminating all major associated risks such as infection, cardiopulmonary complications and colon perforation. Methods: An experimental study was devised to investigate stress pattern differences between traditional and robotic colonoscopy, in which **40 enrolled patients underwent both robotic and standard colonoscopy within the same day**. Results: The stress pattern related to robotic colonoscopy was **90% lower than that of standard colonoscopy**. Additionally, the robotic colonoscopy demonstrated a **higher diagnostic accuracy**, since, due to the lower insufflation rate, it was able to visualize small polyps and angiodysplasias not seen during the standard colonoscopy. **All patients rated the robotic colonoscopy as virtually painless compared to the standard colonoscopy, ranking pain and discomfort as 0.9 and 1.1 respectively, on a scale of 0 to 10, versus 6.9 and 6.8 respectively for the standard device**. Conclusions: The new Endotics System demonstrates efficacy in the diagnosis of colonic pathologies using a procedure nearly completely devoid of pain. Therefore, this system can also be looked upon as the first step toward developing and implementing colonoscopy with atraumatic locomotion through the bowel while maintaining a high level of diagnostic accuracy.

From "**wired**"painless colonoscopy to "**wireless**" GI endoscopy

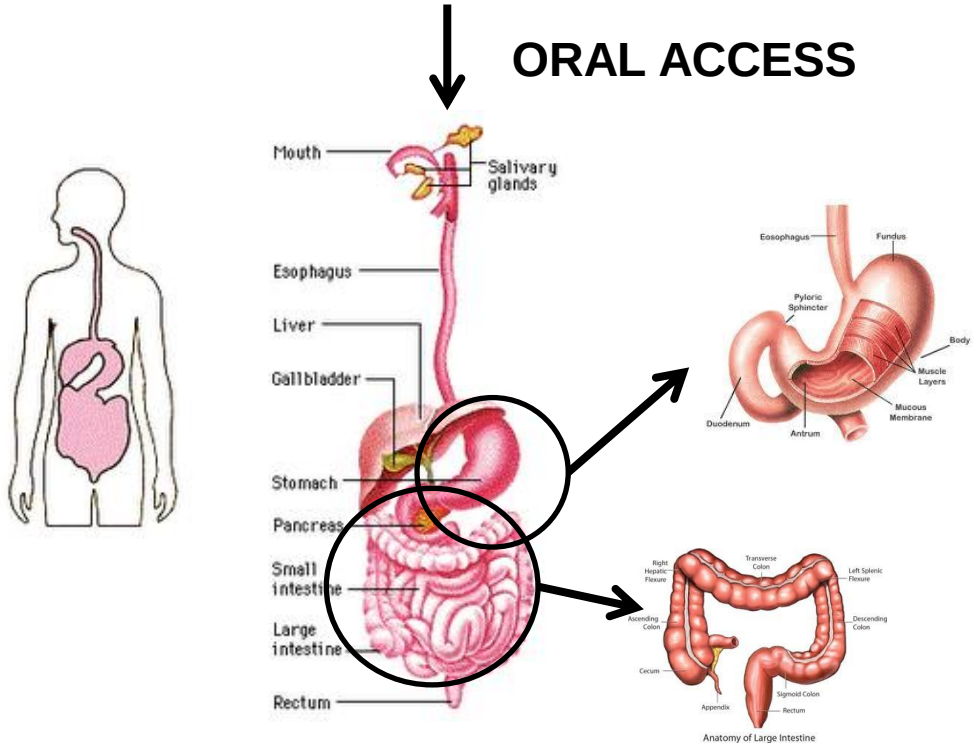


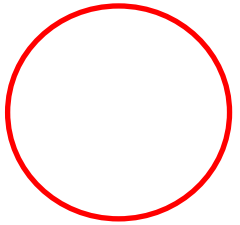
Lessons learned

Reasons for smooth implementation:

- Easy access (Φ= 20÷60mm)
- Two-ended openings
- Sterilization not required (just disinfection)
- **External energy source available**

P. Dario and A. Menciassi Scientific American, August 2010





Oesophageal Tract:
Ø = 10 to 15 mm

Case Study #2

Swallowable Endoscopic Capsules

Passive commercially available wireless capsule endoscopy

G. Iddan, and P. Swain, "History and development of capsule endoscopy", *Gastrointest. Endos., vol. 14, pp. 1-9, 2004.*

The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Capsule Endoscopy versus Colonoscopy for the Detection of Polyps and Cancer

André Van Gossum, M.D., Miguel Munoz Navas, M.D., Iñaqui Fernandez-Urien, M.D., Cristina Carretero, M.D., Gérard Gay, M.D., Michel Delvaux, M.D., Marie Georges Lapalus, M.D., Thierry Ponchon, M.D., Horst Neuhaus, M.D., Michael Philipper, M.D., Guido Costamagna, M.D., Maria Elena Riccioni, M.D., Cristiano Spada, M.D., Lucio Petruzziello, M.D., Chris Fraser, M.D., Aymer Postgate, M.D., Aine Fitzpatrick, M.D., Friedrich Hagenmuller, M.D., Martin Keuchel, M.D., Nathalie Schoofs, M.D., and Jacques Devière, M.D.

Low sensitivity for detecting colonic lesions (64% for lesions 6 mm or bigger, compared with the use of standard colonoscopy)

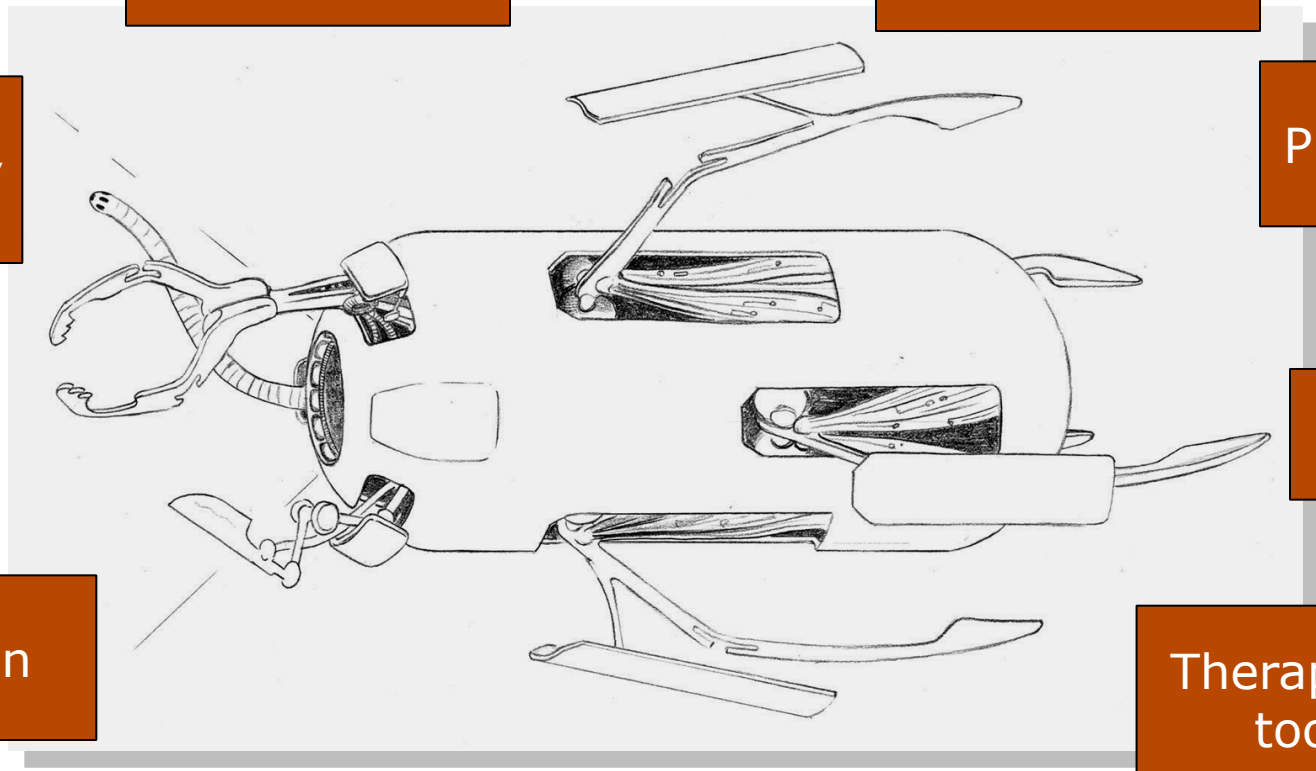
Benefits:

- Small system dimension
- Low invasiveness procedure
- Access to small bowel

Limitations:

- **Passive locomotion**
- **False negative results**

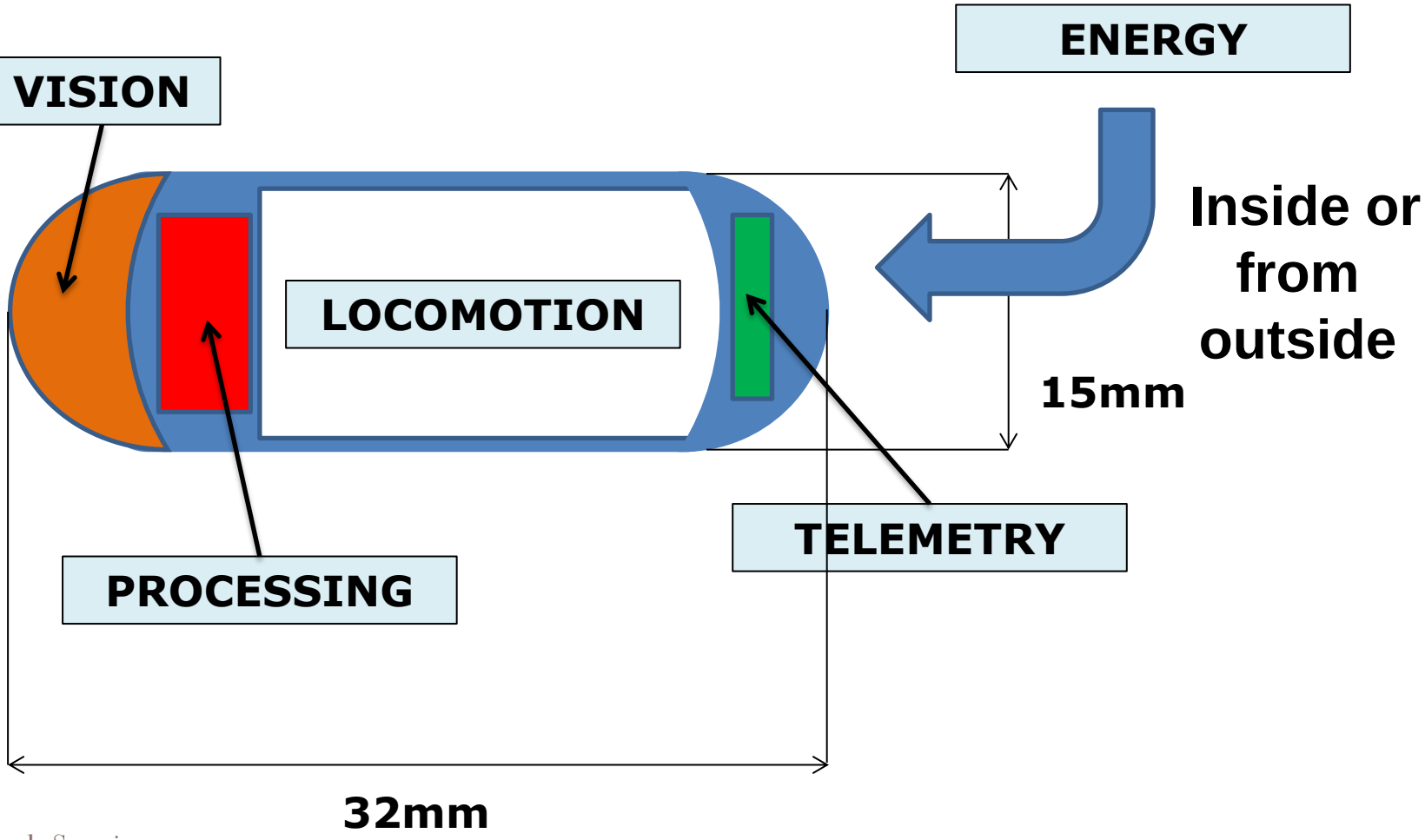
ACTIVE CAPSULE: a **wireless endoscopic 'SHUTTLE'**



The engineering design challenge: all components MUST fit in a **swallowable** size (**Ø ~12 mm x L~ 32 mm**)

Case Study #2 Swallowable Endoscopic Capsule

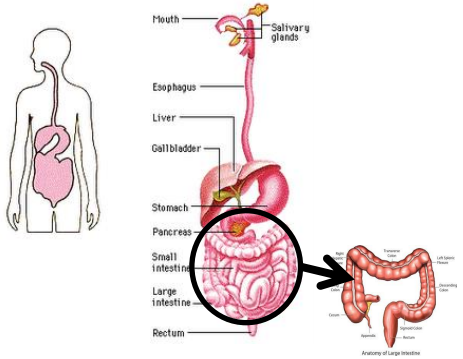
Oesophageal Tract:
Ø = 10 to 15 mm



Attempt #1: Legged capsule

Oesophageal Tract:
Ø = 10 to 15 mm

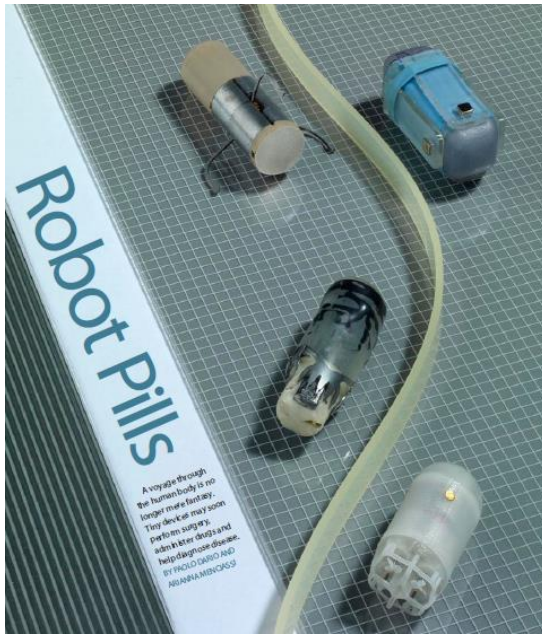
ORAL ACCESS



M. Quirini, et al.
GASTROINTESTINAL ENDOSCOPY
Vol. 67, No. 7, 2008

***SCIENTIFIC AMERICAN - A voyage through the human body is no longer mere fantasy. Tiny devices may soon perform surgery, administer drugs and help diagnose disease.* -By Paolo Dario and Arianna Menciassi**

A. Moglia, et al. THE LANCET, Vol 370 July 14, 2007, pp. 114-116



Scuola Superiore Sant'Anna

Bioinspired design of an **active** endoscopic capsule

Problem: pain, difficult maneuverability…

Solution: inchworm locomotion, self-adaptability

Problem: slow, not adequate for different gut diameters…

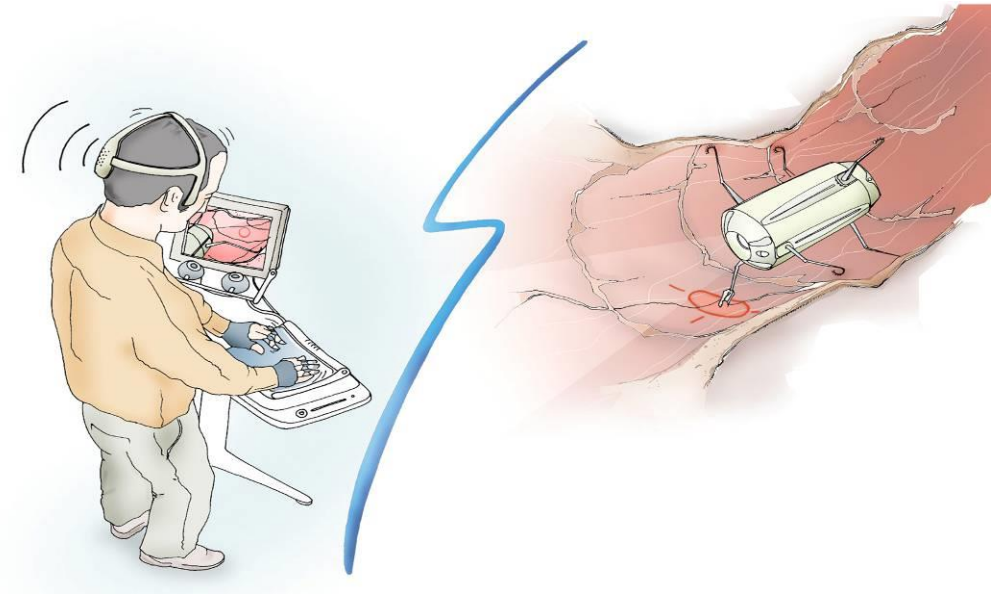
Solution: legged locomotion, insect-like capsular endoscopy

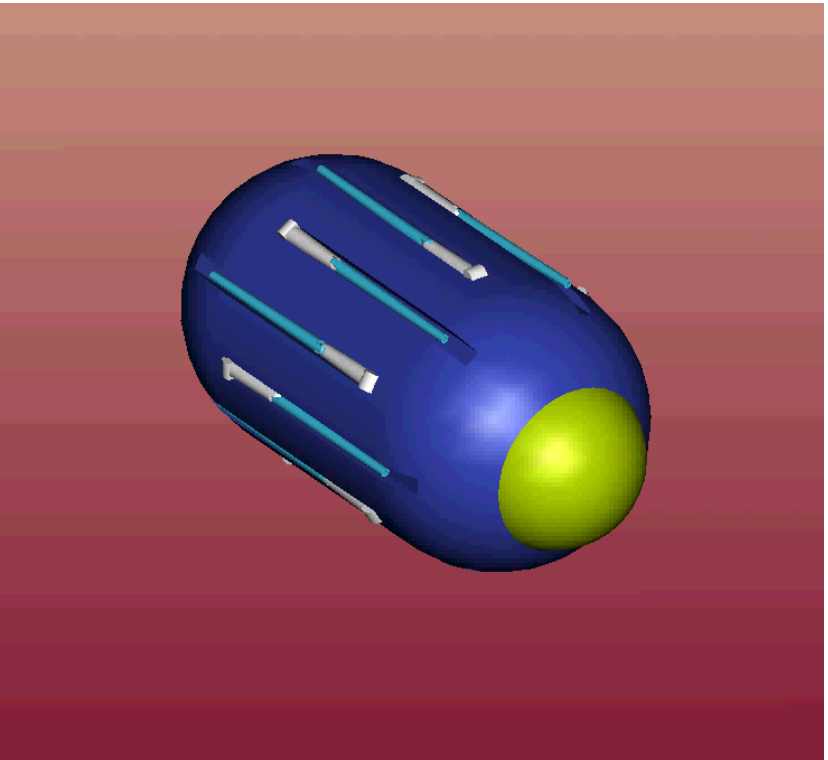
…like a worm in the gut…

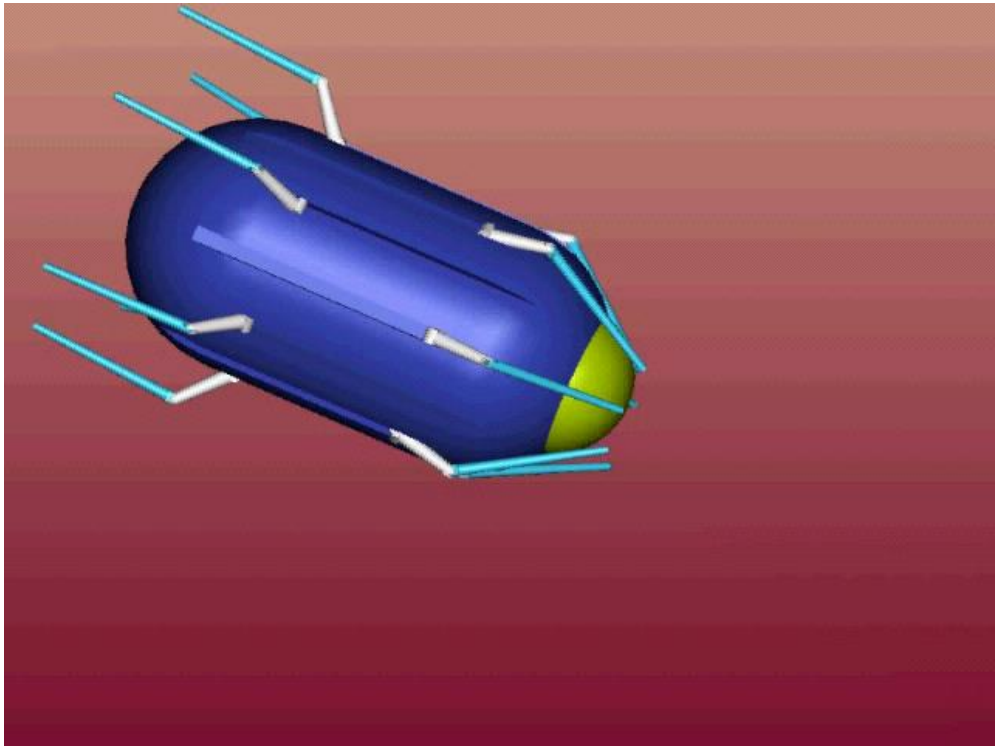
THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

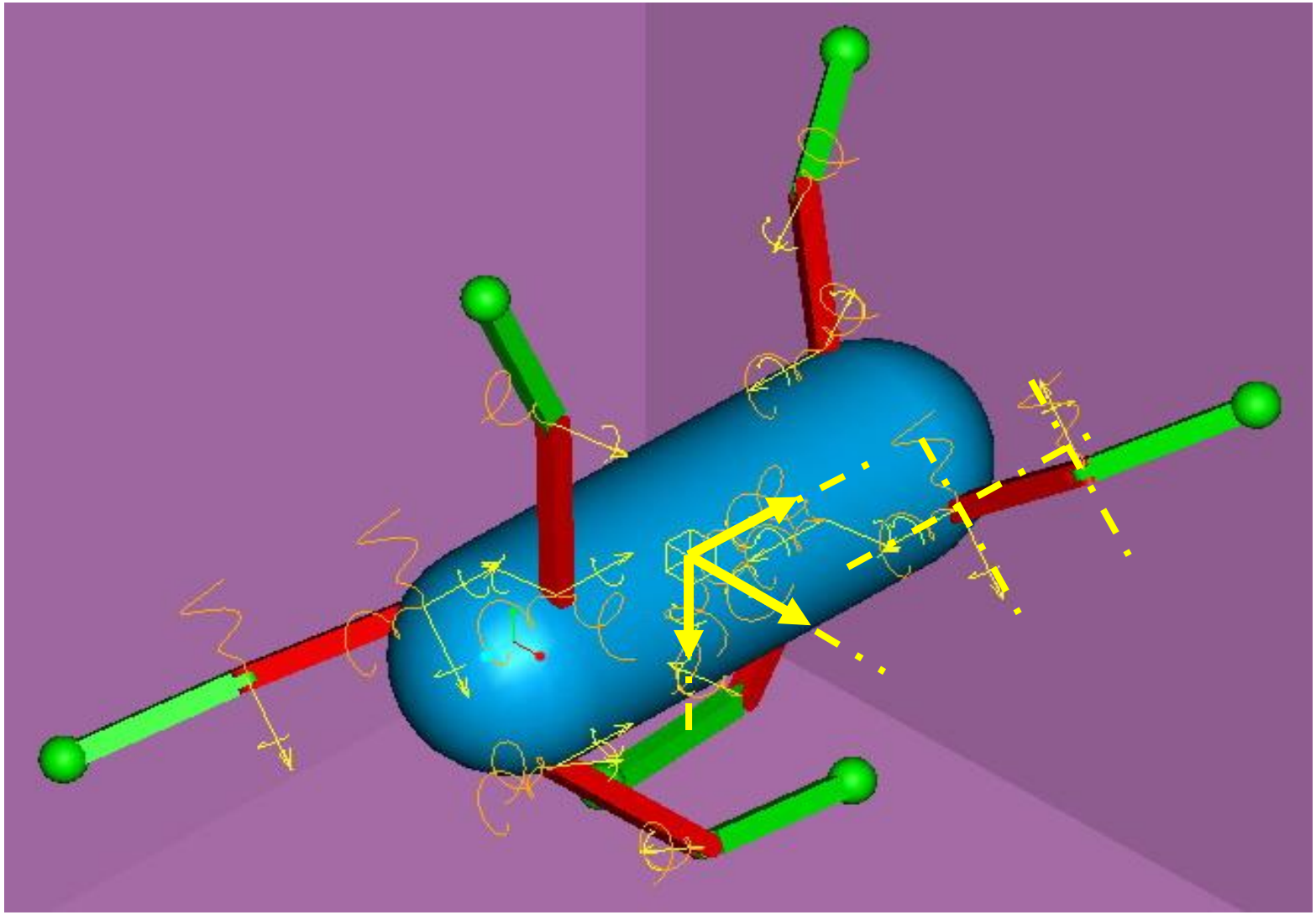
Active, wireless, miniature capsule for endoscopy in the tubular GI tract





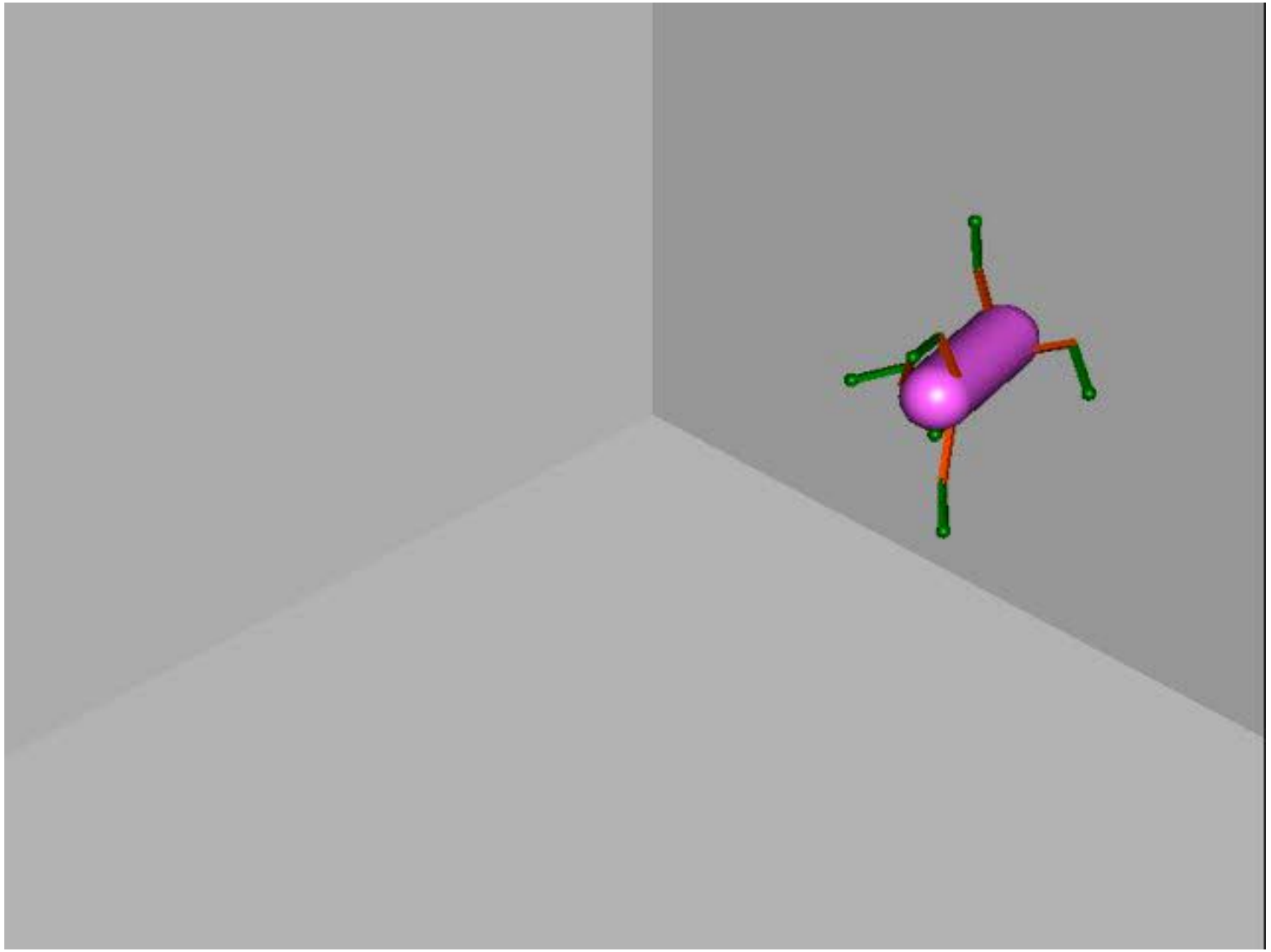


Free body kinematics



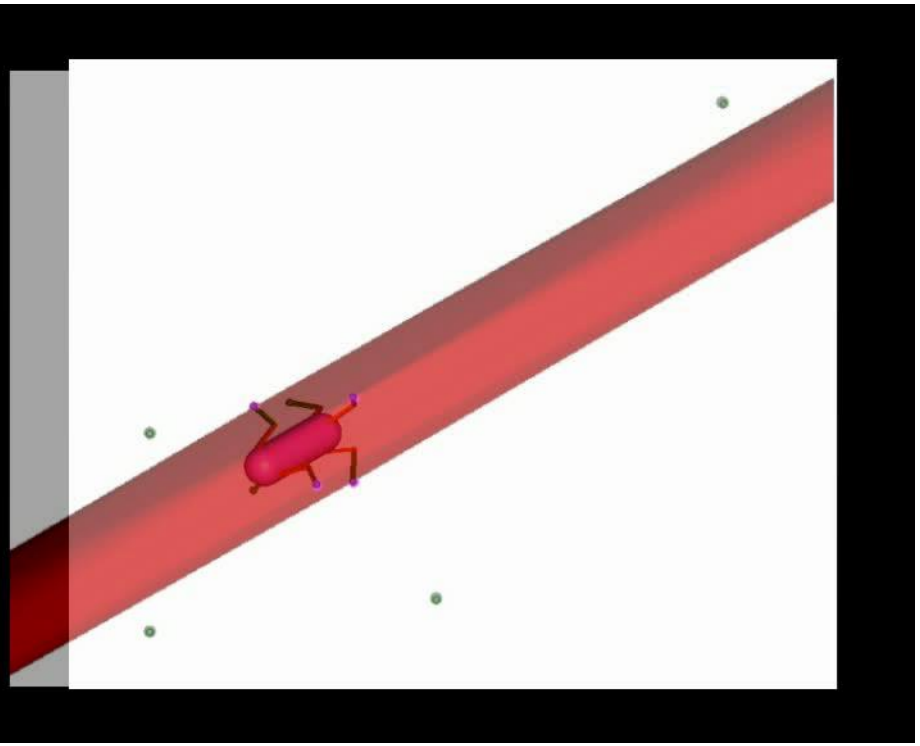
Modeled degrees of freedom: 3 (body trans.) + 3 (body rot.) + 3n (legs)

Free body kinematics



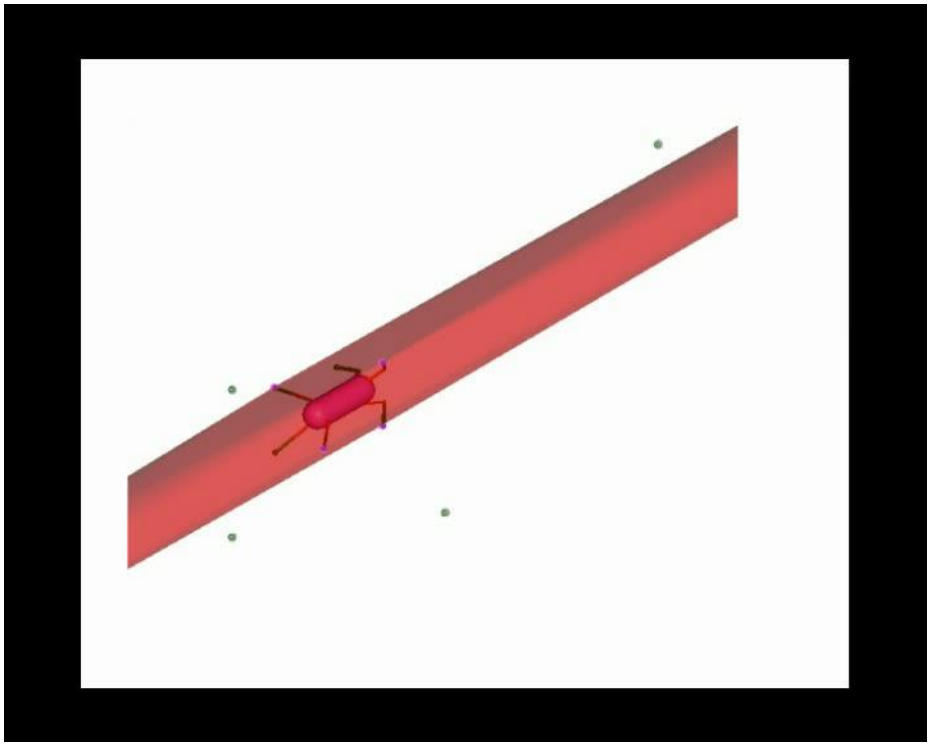
Modeled degrees of freedom: 3 (body trans.) + 3 (body rot.) + 3n (legs)

Comparing different gait patterns



Front/rear phase:	**0°**
Period:	**3 s**
Full interval:	**12 s**
Traveled distance:	**23 mm**

"Rower Gait"

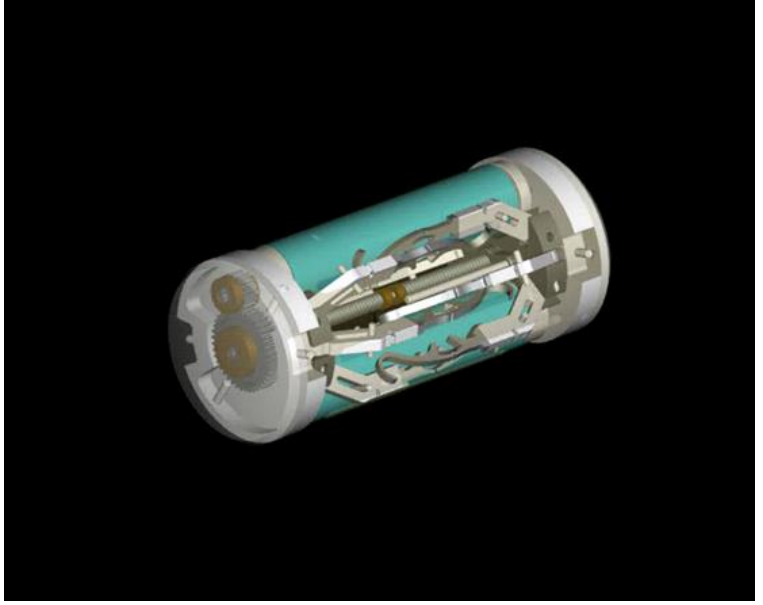


Front/rear phase:	**180°**
Period:	**3 s**
Full interval:	**12 s**
Traveled distance:	**144 mm**

"Out of phase rower gait"

mean cycle power: 30 mW
energy / distance: 2.5 J/m

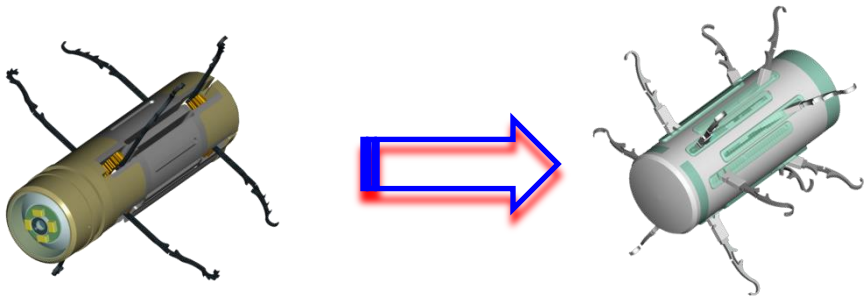
Legged capsule for tubular organs. From 4 to 8 and 12 biomimetic legs, with the aim of improving locomotion

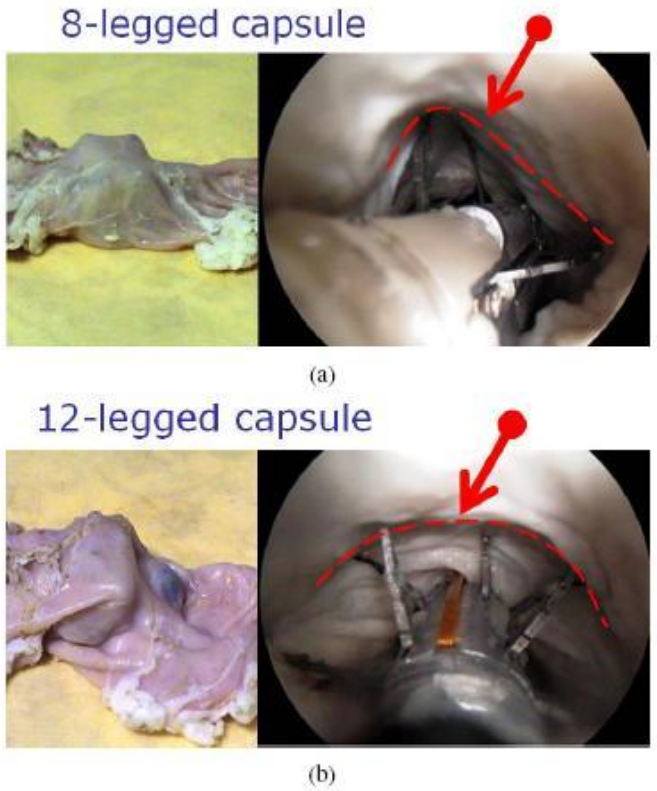


Features: 12 legs (6 in the front and 6 in the rear part)
Dimensions: Φ11 mm; L30 mm
Average speed: 5 cm/minute
Pulling force: 3.8 N → 0.66 N per leg

1. P. Valdastri, R. J. Webster III, C. Quaglia, M. Quirini, A. Menciassi, P. Dario, "*A New Mechanism for Meso-Scale Legged Locomotion in Compliant Tubular Environments*", **IEEE Transactions on Robotics**, 2009, Vol. 25, No. 5, pp. 1047-1057.
2. C. Quaglia, E. Buselli, R. J. Webster III, P. Valdastri, A. Menciassi, P. Dario, "*An Endoscopic Capsule Robot: A Meso-Scale Engineering Case Study*", **Journal of Micromechanics and Microengineering**, 2009, Vol. 19, No. 10, 105007.
3. E. Buselli, P. Valdastri, M. Quirini, A. Menciassi, P. Dario, "*Superelastic leg design optimization for an endoscopic capsule with active locomotion*", **Smart Materials and Structures**, Vol. 18, No. 1, January 2009.

4-8-12 legs for a capsule





Increasing the leg number aims at two main goals:

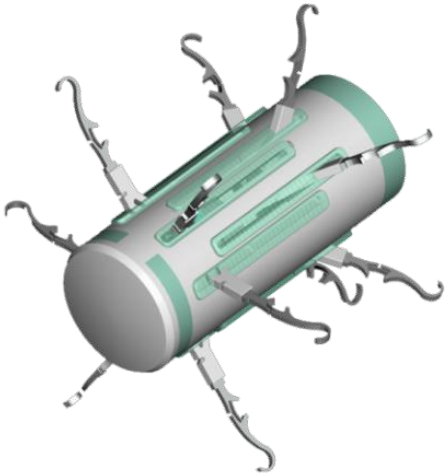
1) **more legs distribute the force necessary to propel the capsule over more points of contact, thus reducing the individual foot force and tissue irritation;**

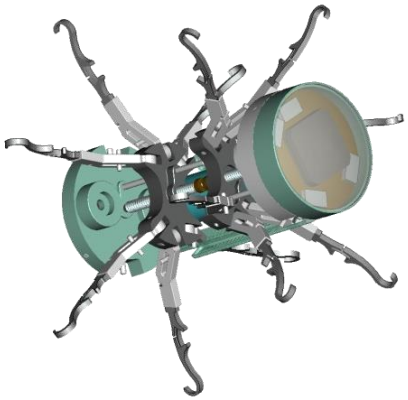
2) **more points of contact improve the propulsion of the capsule in the folded, loose, highly deformable, unstructured environment of the colon.**

Optimization of capsule legs in terms of degrees of freedom, number and friction enhancement areas

1. Diameter: 11.1 mm;
2. Length: 28 mm (38.5 mm with camera);
3. 12 legs;
4. 2 DC brushless motors (NAMIKI);
5. Force at the leg's tip of about 1N;
6. No frontal latex balloon required;
7. On board electronics drivers;
8. Power consumption: 0.66 W.

The 12-leg capsule main features



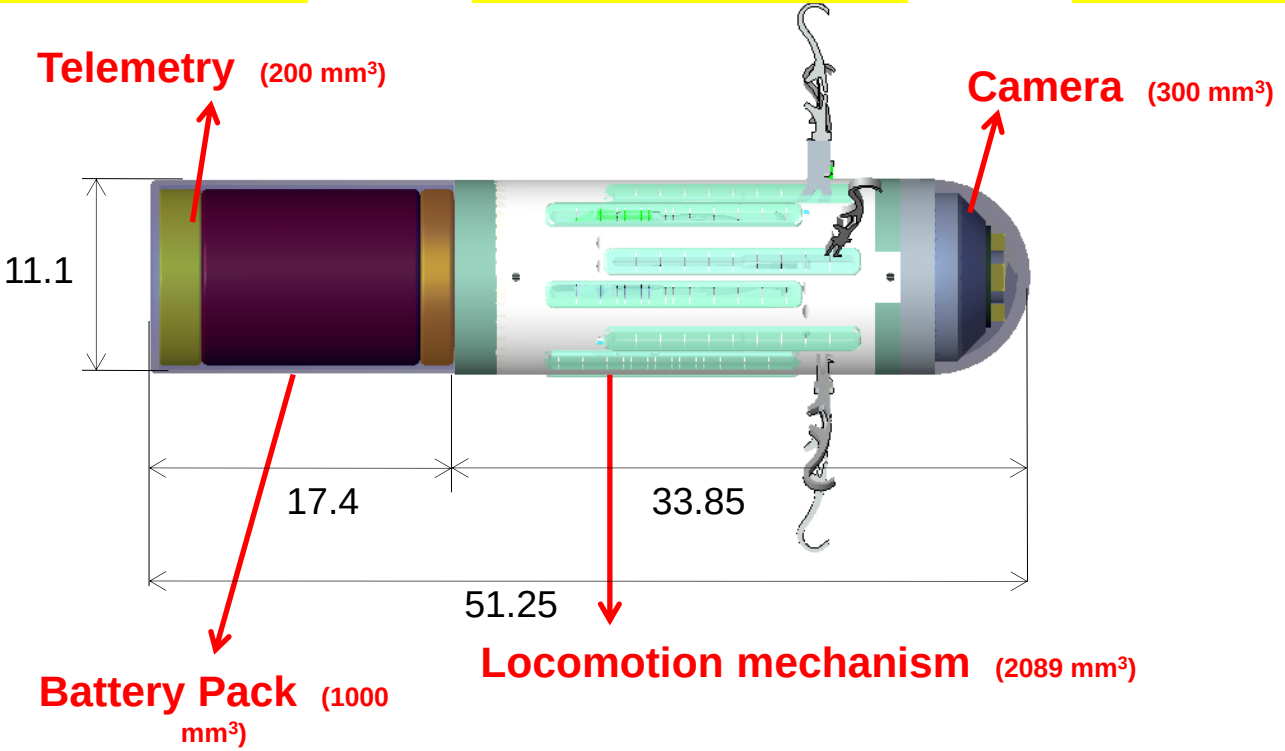


The capsule includes more than 70 high precision components

Wireless Legged Capsule: The Energy Problem

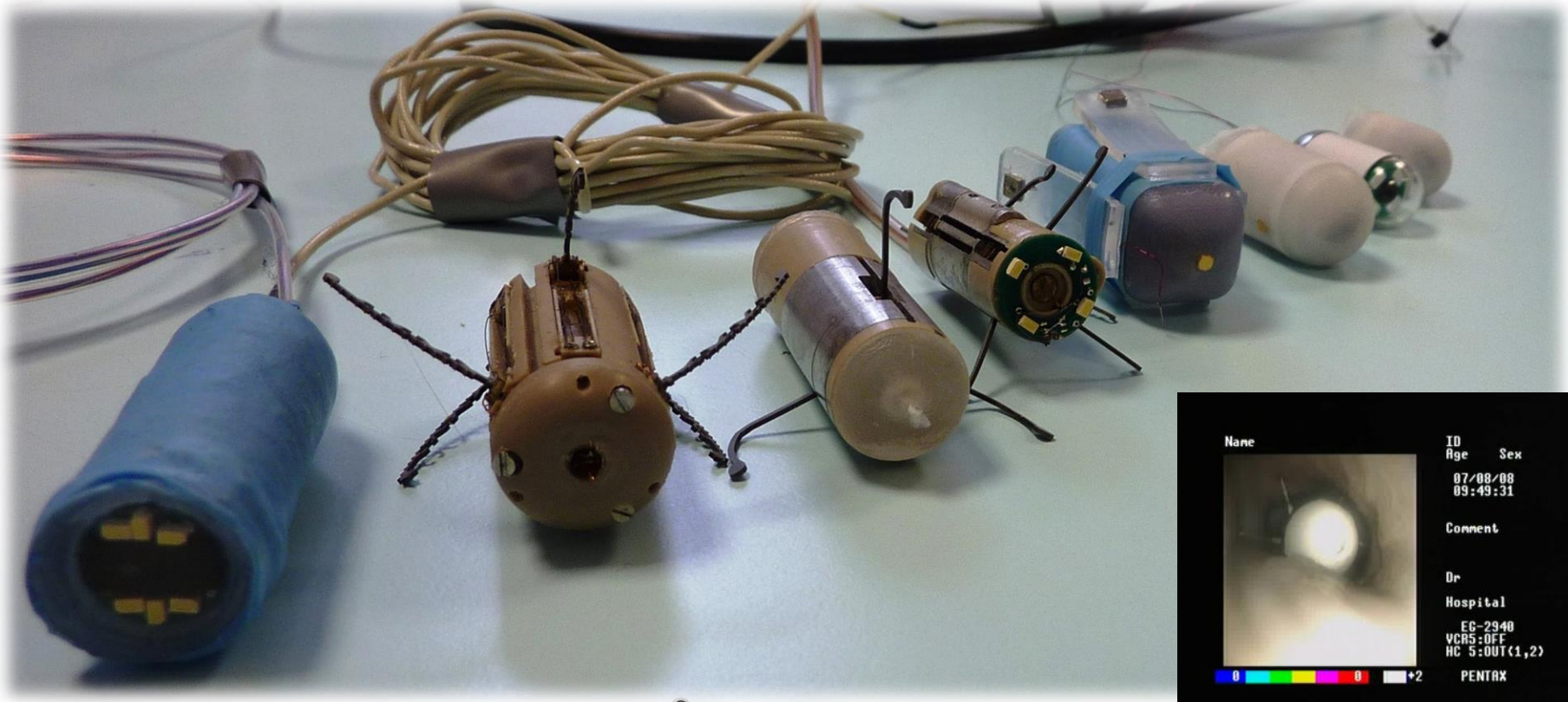
- Spatial constraints
- Locomotion system volume

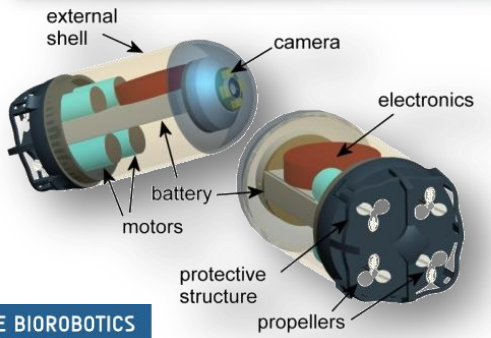
→ Add telemetry, drivers and batteries on board → The pill becomes too long to be swallowed

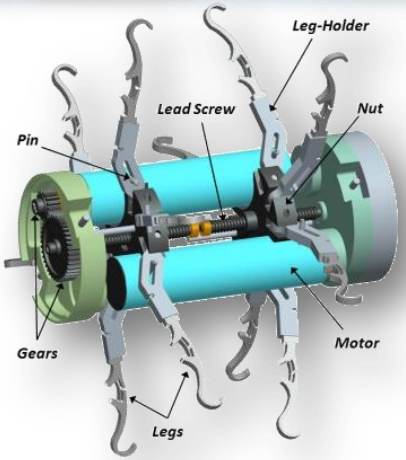


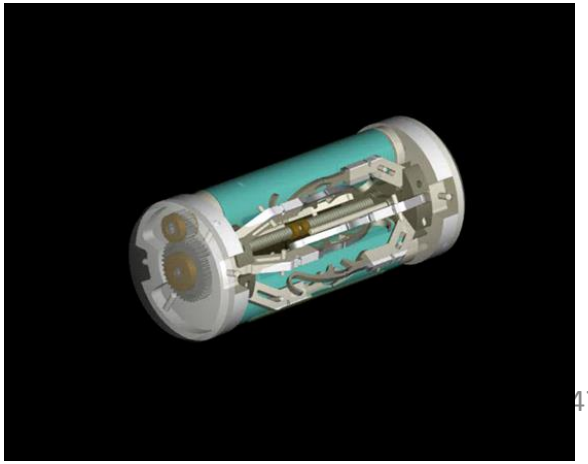
Total volume: 3789 mm³

ACTIVE capsules developed at The BioRobotics Institute



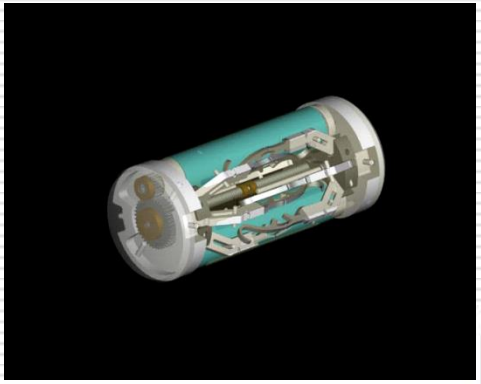


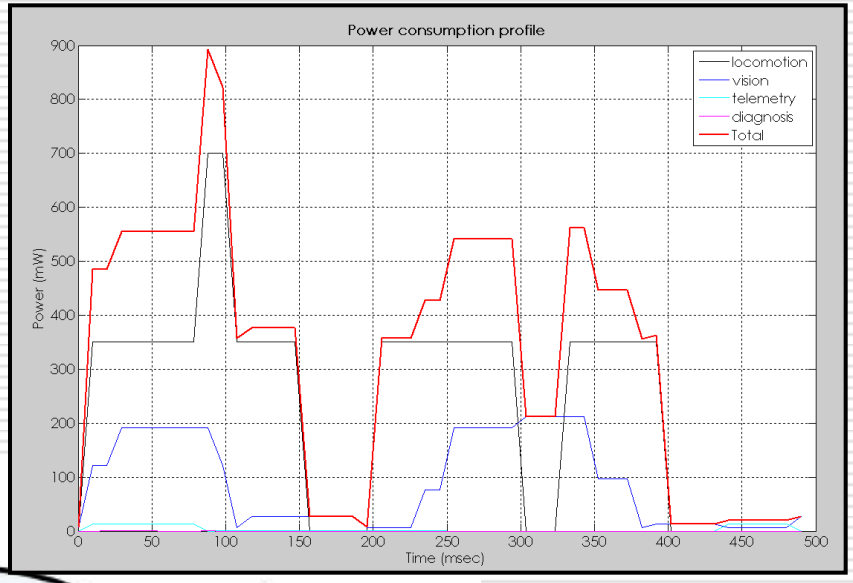


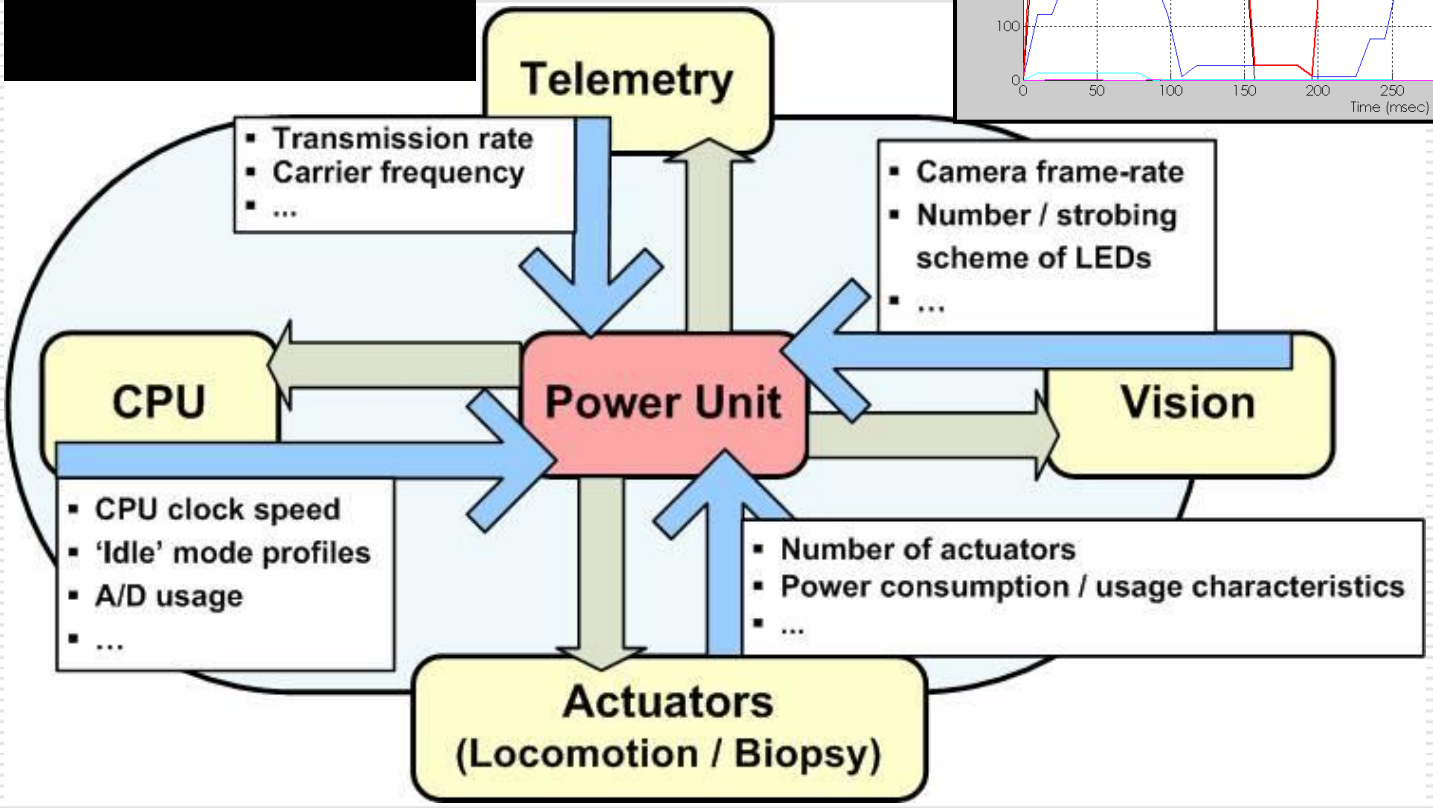


The MAJOR problem for active, legged endoscopic capsules

POWER!







A legged capsule incorporating state-of-art batteries could only walk for less than 30 minutes along the GI tract

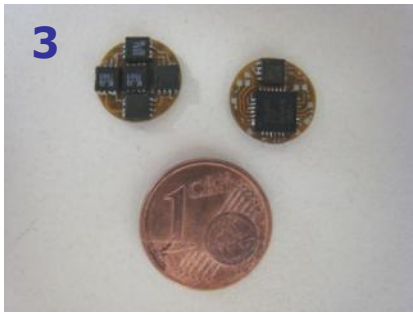
Attempt #2: adding modules ("tenders") containing energy sources

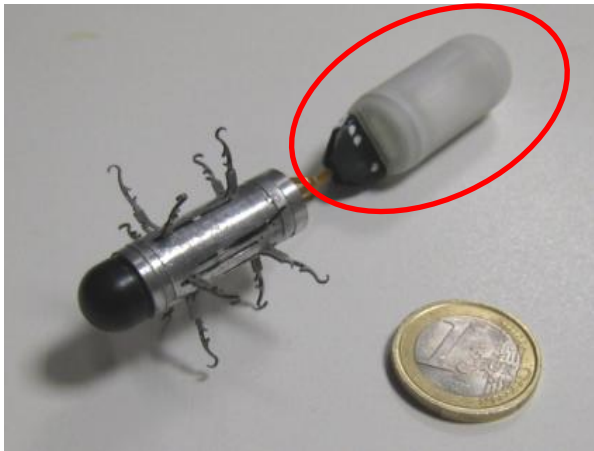
The capsule has an additional module containing the transceiver unit (for control and telemetry), two batteries and the miniaturised motor control board

Tender size: D = 15 mm; L = 35 mm

1. **2 batteries**: LP20, *Plantarco Ltd.-Canada*, 20mAh, 3.7V, 12x9x3.2mm
2. **Wireless transceiver** RC2300, 12x25 mm
3. **Motor driver board**, D = 10 mm; h = 2.5 mm

   Duration = 13 locomotion cycles

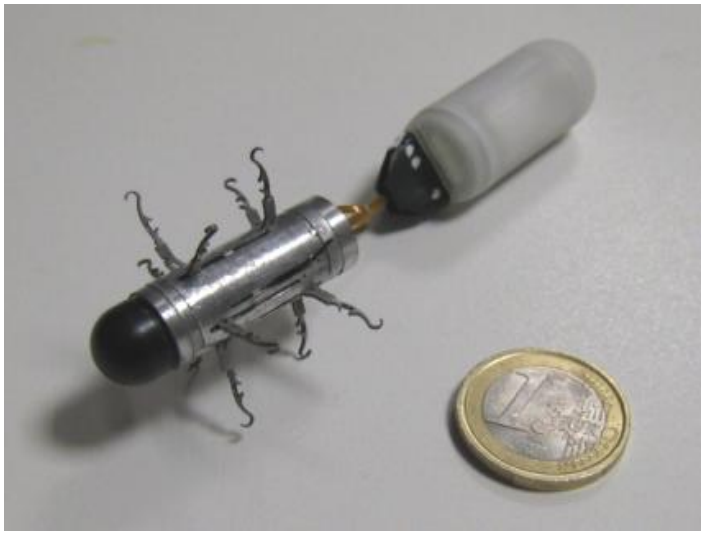




Tender solutions have been also considered by gastroenterologists. E.g.: C. P. Swain, "Method, system and device for in vivo biopsy", WO2005112460

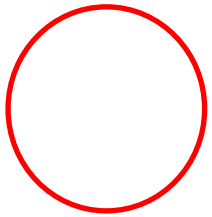
Limitations of the "tender" approach

- *Swallowability*
- *Safety and comfort*
- *Steerability*

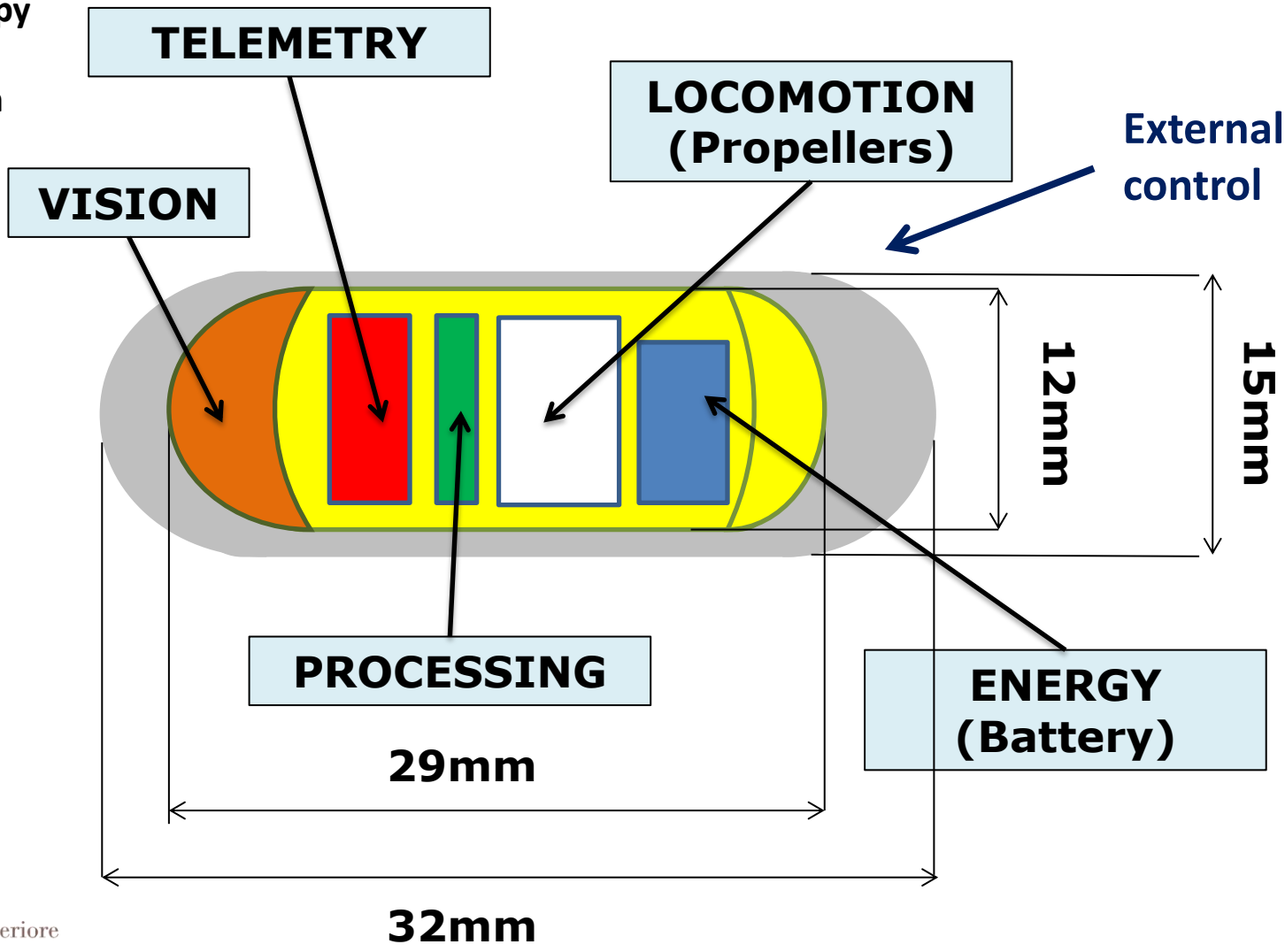


Attempt #3: Wireless Electromagnetic Guidance

Attempt #3: Wireless Electromagnetic Guidance

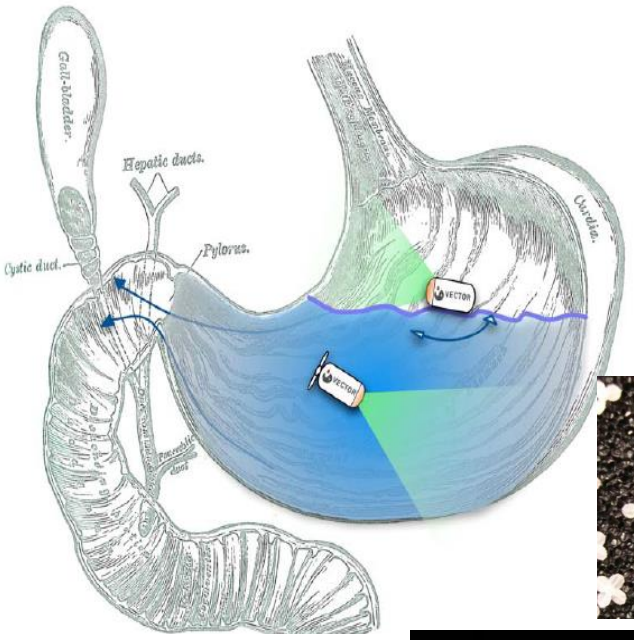


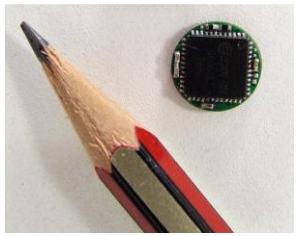
Stomach Endoscopy (Gastroscopy) :
Ø = 10 to 15 mm

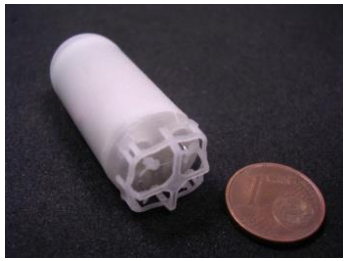


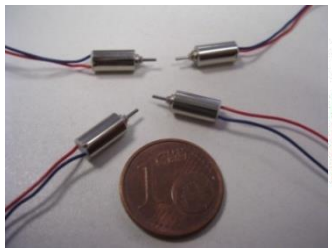
Wireless Capsule for PAINLESS GASTROSCOPY

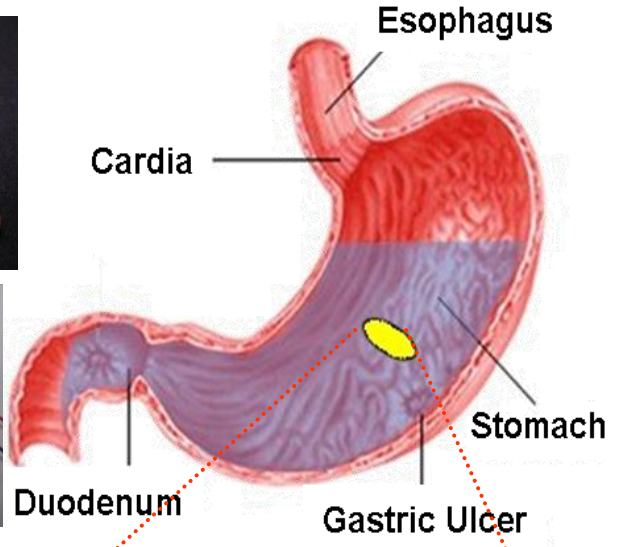
Ingestion of liquid in context with the examination allows to obtain organ distension, thus making possible a low power 3D locomotion in the stomach

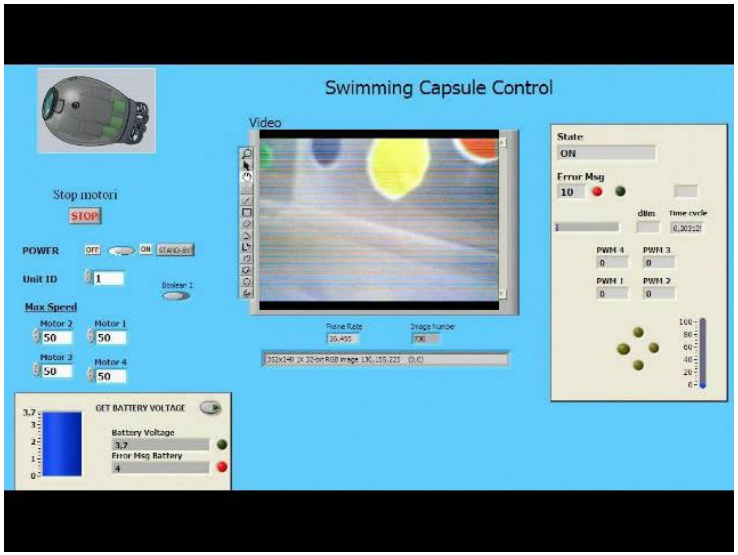


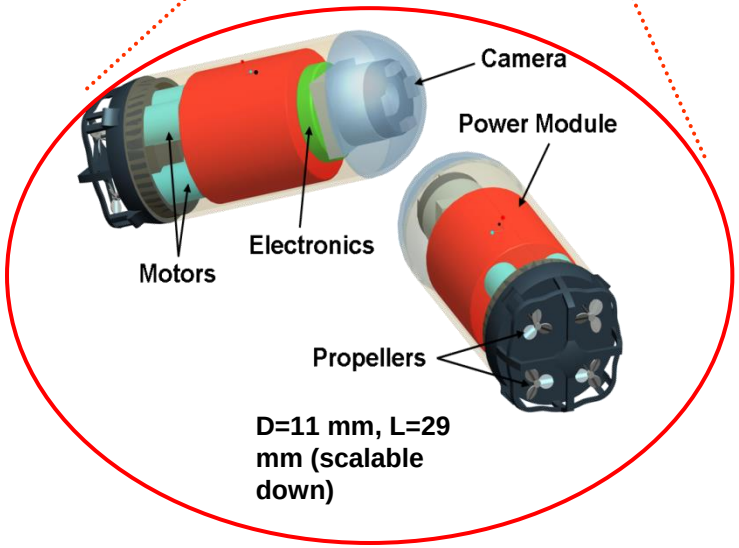




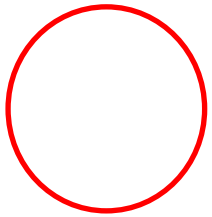




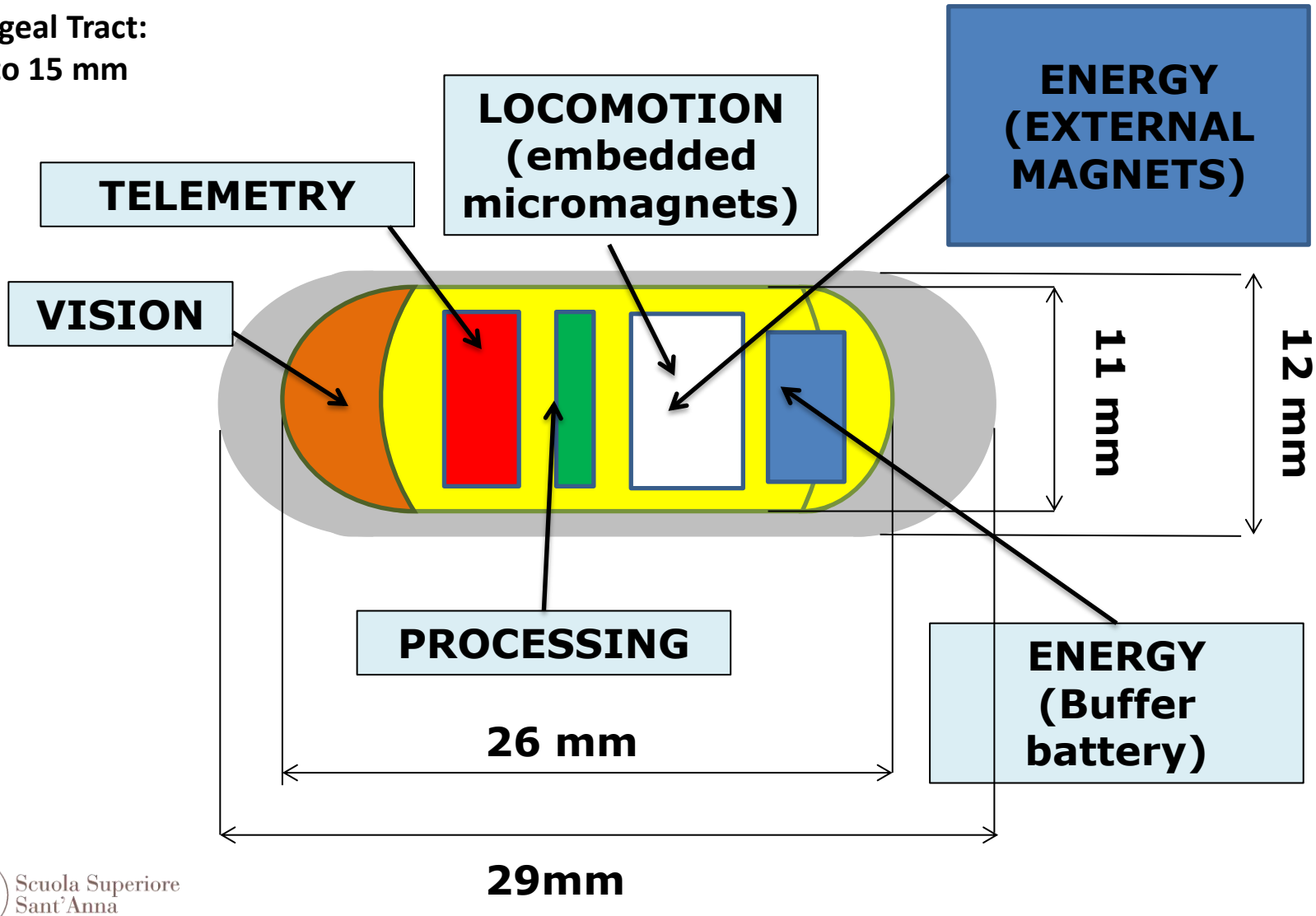




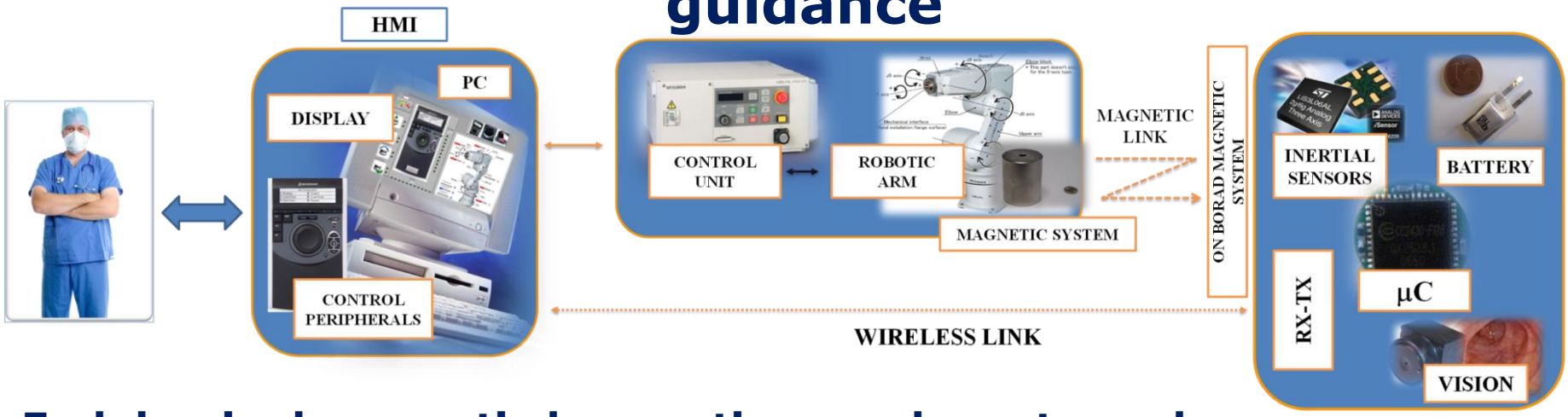
Attempt #4: Wireless Magnetic Guidance



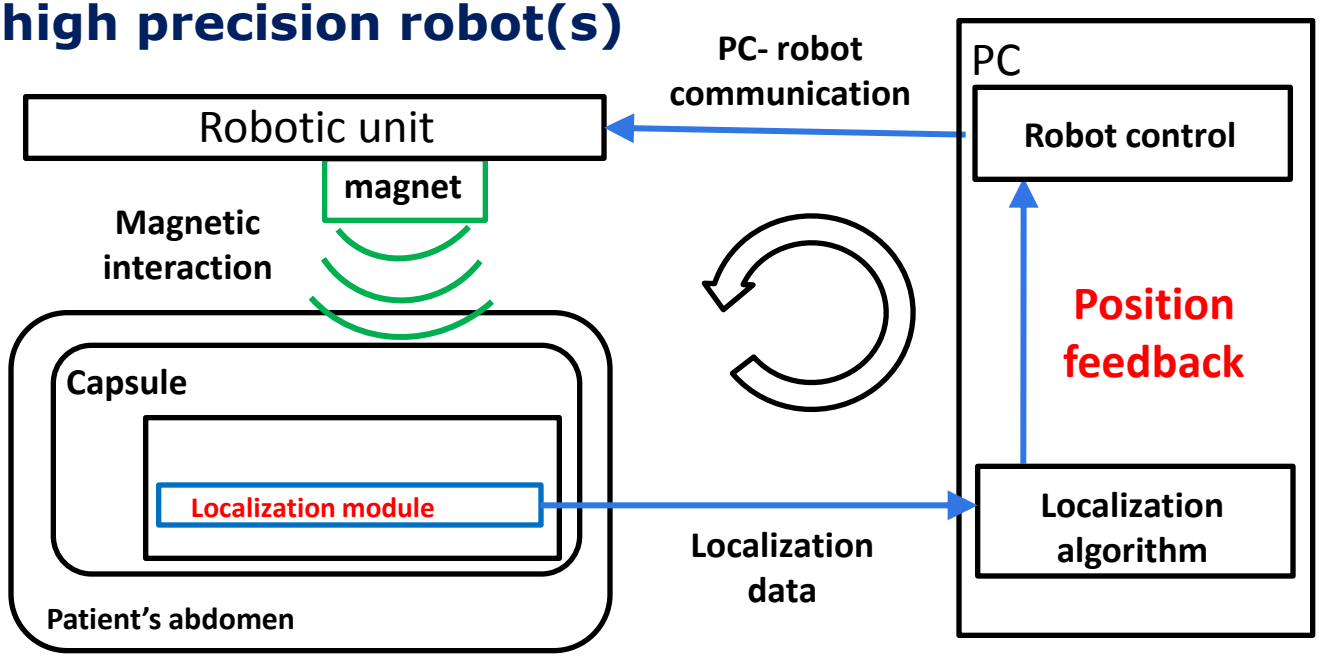
Oesophageal Tract:
Ø = 10 to 15 mm



A solution to overcome the energy problem in active capsular endoscopy: **robot-assisted wireless magnetic guidance**



Endoluminal magnetic locomotion can be extremely precise when the external magnet (s) is/are moved by means of high precision robot(s)



Screening Capsule: low-rate image capsule without telemetry with remote diagnostic purpose to be proposed as a pharmaceutical device

Diagnostic Capsule: high-rate image real time capsule with diagnostic capabilities and active locomotion

Therapeutic Capsule: high-rate image real time capsule with the integration of therapeutic tools

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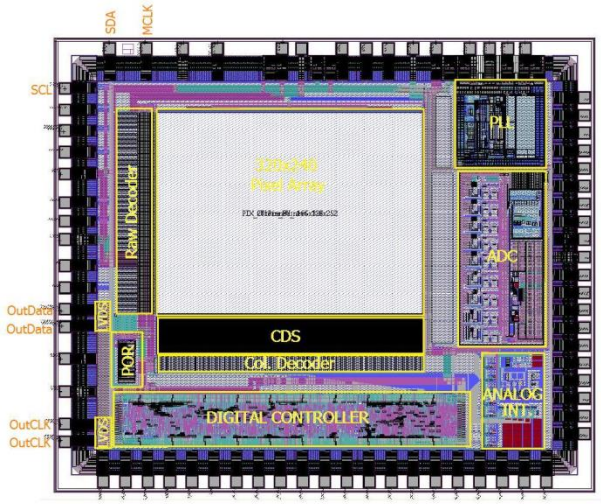
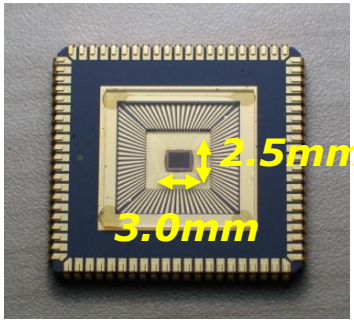
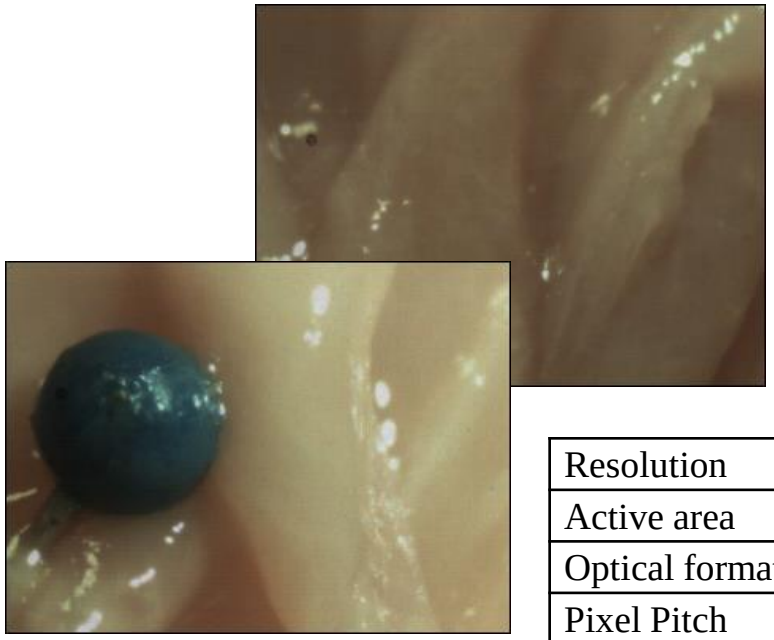
The EU VECTOR and the Korea IMC Projects

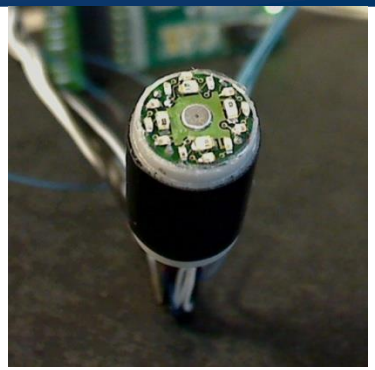
Camera on Chip

Custom image sensor









Multispectral illumination

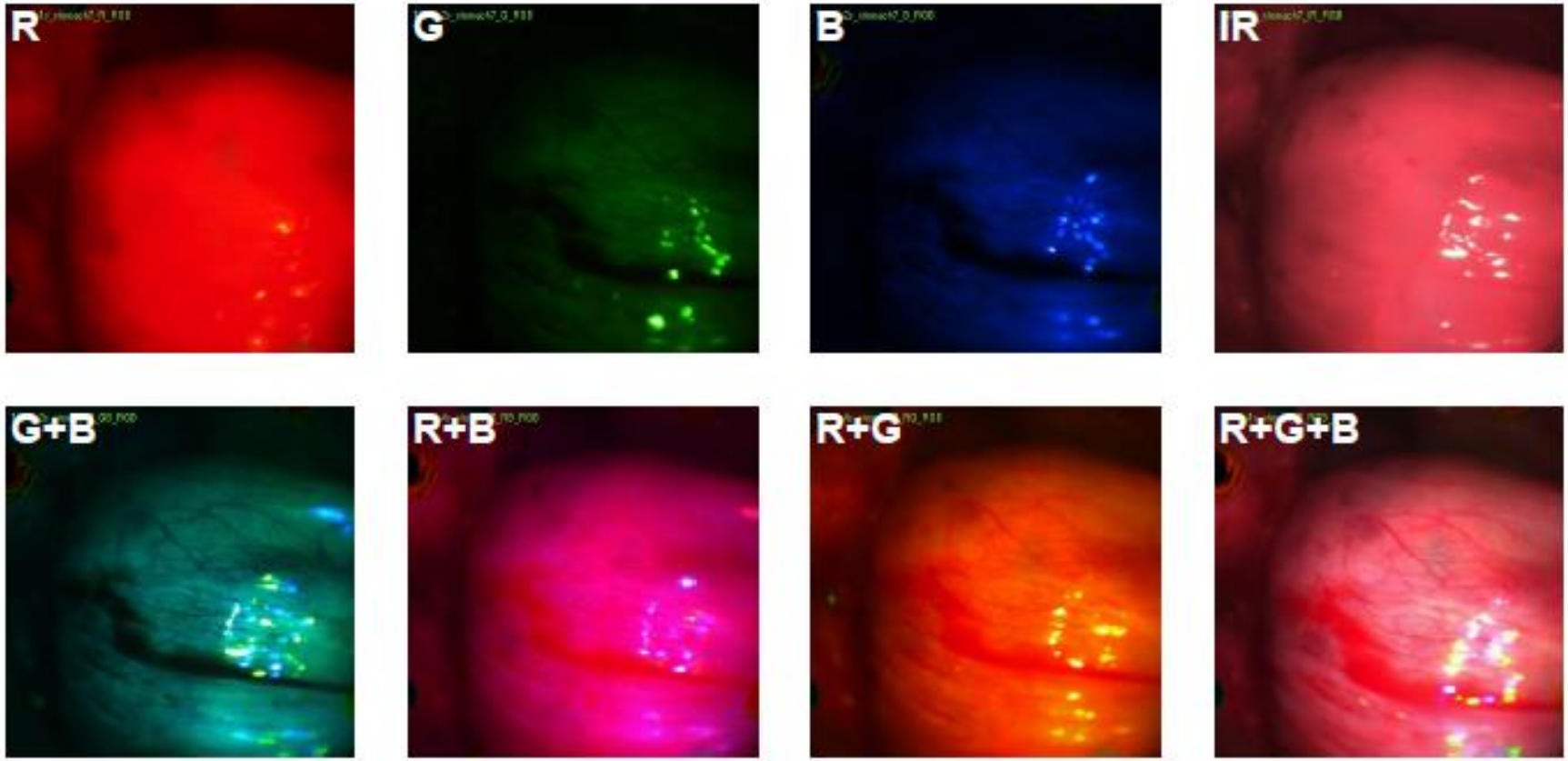
Resolution		QVGA
Active area		320×240
Optical format	inch	1/11
Pixel Pitch	μm^2	4.4×4.4
Shutter type		rolling
Die dimension	mm^2	2.5×3.0

Sensitivity	lux	0.1@555nm,27° C, 30msec.
	W/m^2	1.7×10^{-4}@27° C, 30msec.
Responsivity	V/lux*sec.	0.52@555nm, 27° C
	$V/W/m^2$*sec.	360@@27° C
Dynamic range	dB	50
SNR	dB	46(max)
Pixel Noise	%	0.70
Fixed Pattern Noise	%	0.86

Raw images with multispectral illumination and positive lens

Narrow Band Imaging

In vivo images from pig open stomach



Robot-guided, magnetically actuated endoscopic capsule

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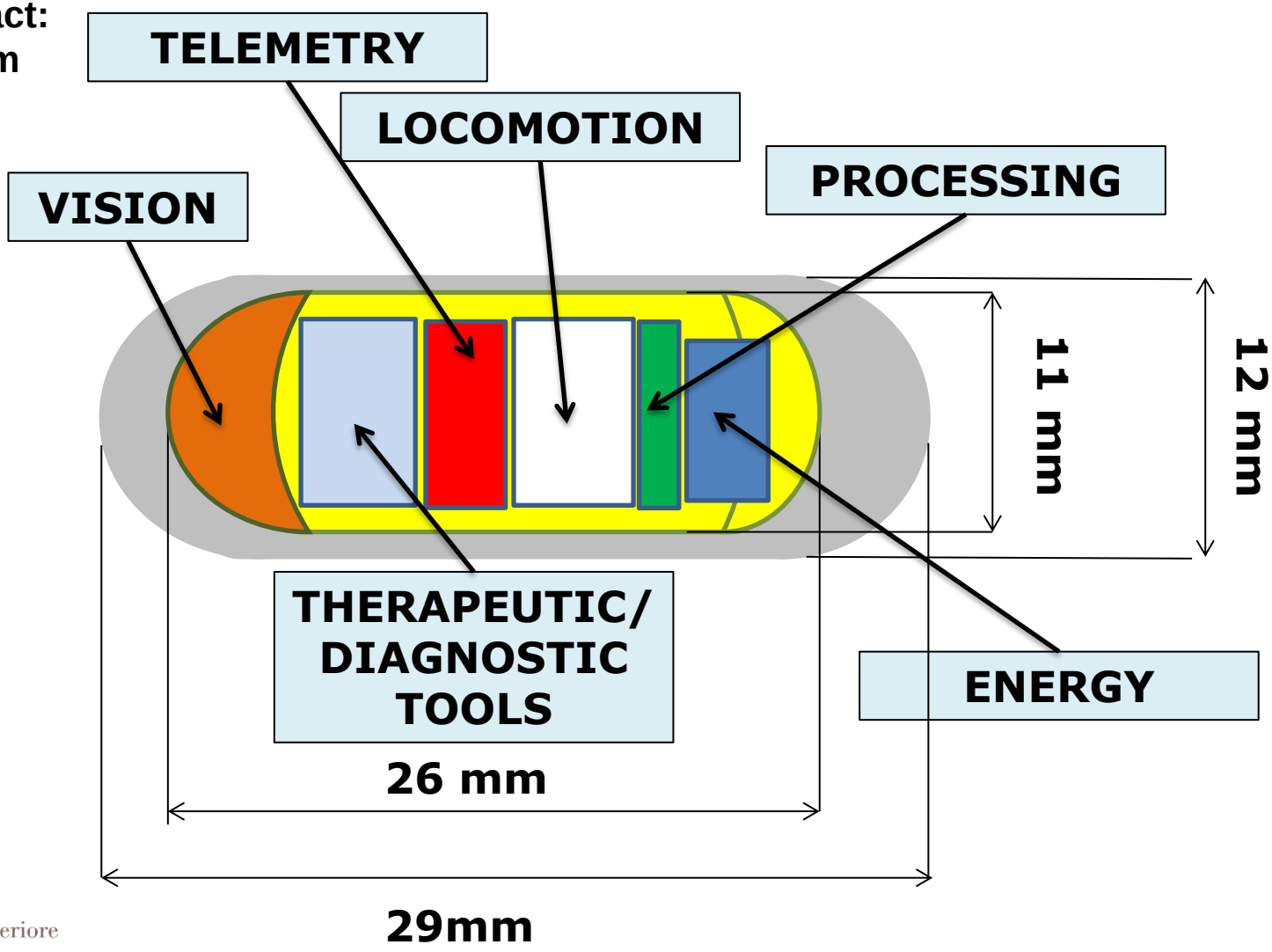
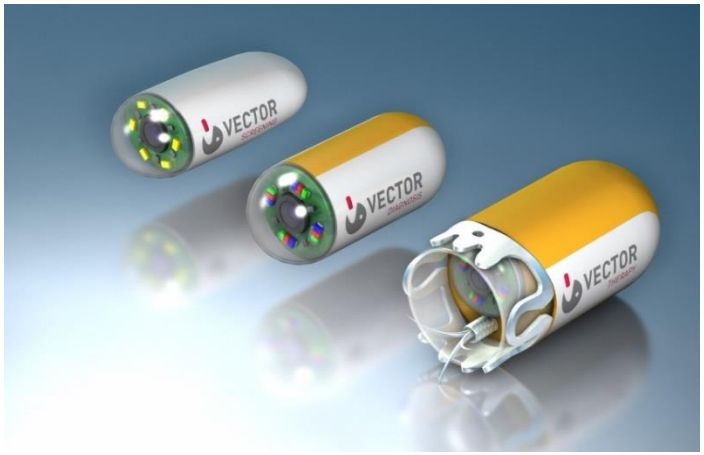
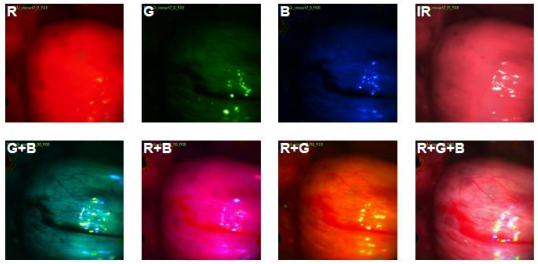
G. Ciuti, R. Donlin, P. Valdastri, A. Arezzo, A. Menciassi, M. Morino and P. Dario: Robotic versus manual control in magnetic steering of an endoscopic capsule. Endoscopy, vol. 42, pp. 148-152, 2010.

Attempt #5: Swallowable, active endoscopic capsules with additional therapeutic and diagnostic capabilities

Oesophageal Tract:
Ø = 10 to 15 mm





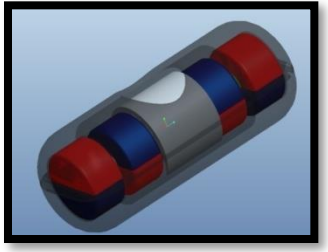


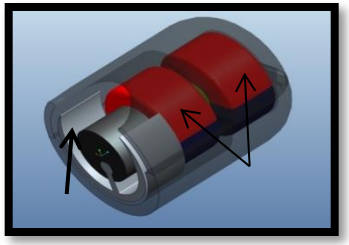
Endoscopic capsules with imaging capabilities AND additional functionalities

- **Biopsy capsules**
- Capsules for painless colonoscopy
- Capsules releasing “components”

Biopsy Capsule

Magnetic actuation

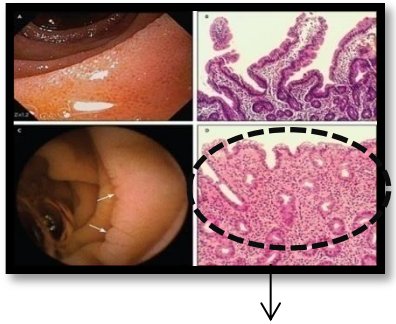




✓**bistable mechanism (**closed capsule without external field**)**

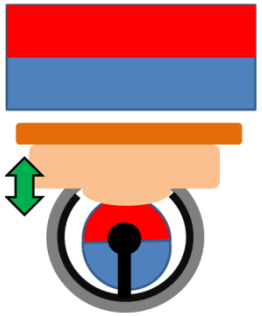
✓**activation by external field** (no internal motor)

✓**effective adhesion to bowel wall** (by magnetic attraction force)

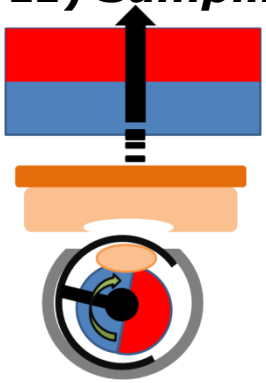


CD (Coeliac Disease) (duodenal biopsy required)

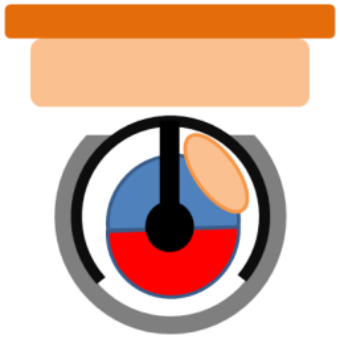
I) ***Adhesion***

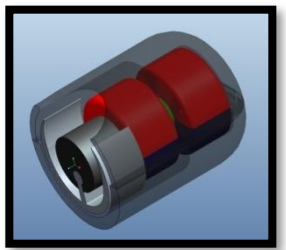


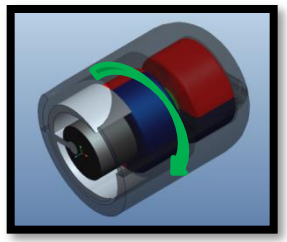
II) ***Sampling***

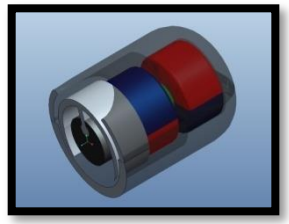


III) ***Storage***









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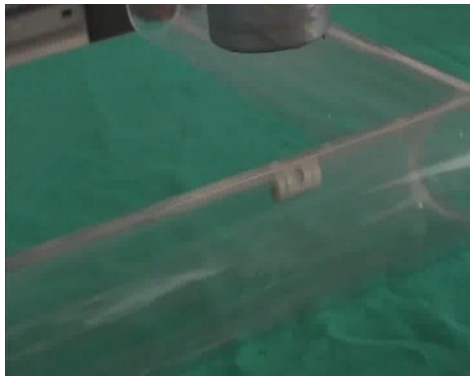
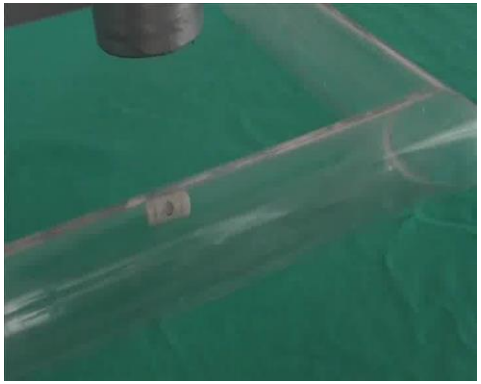
Biopsy Capsule

In-vitro Tests

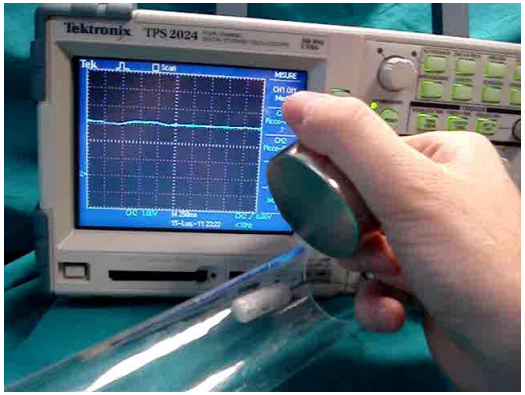
MAGNETIC LOCOMOTION



EXTERNAL ACTIVATION

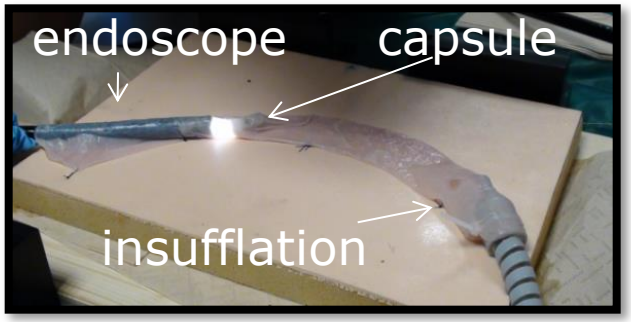


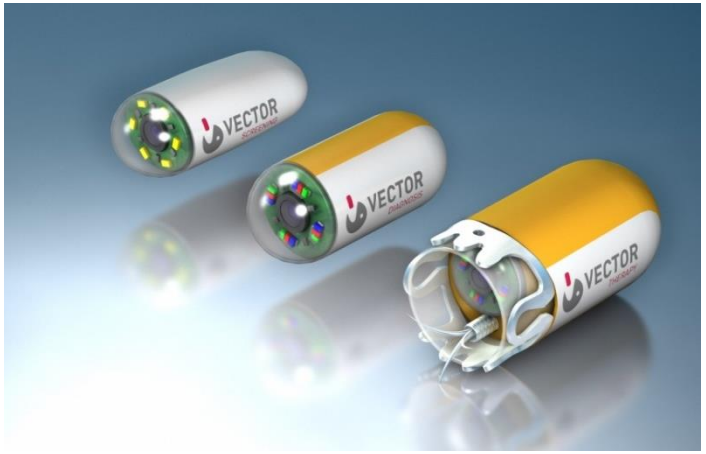
CLOSED LOOP CONTROL (wired capsule)



Ex-Vivo Tests

- *mechanical prototype*
- *section of porcine small bowel*



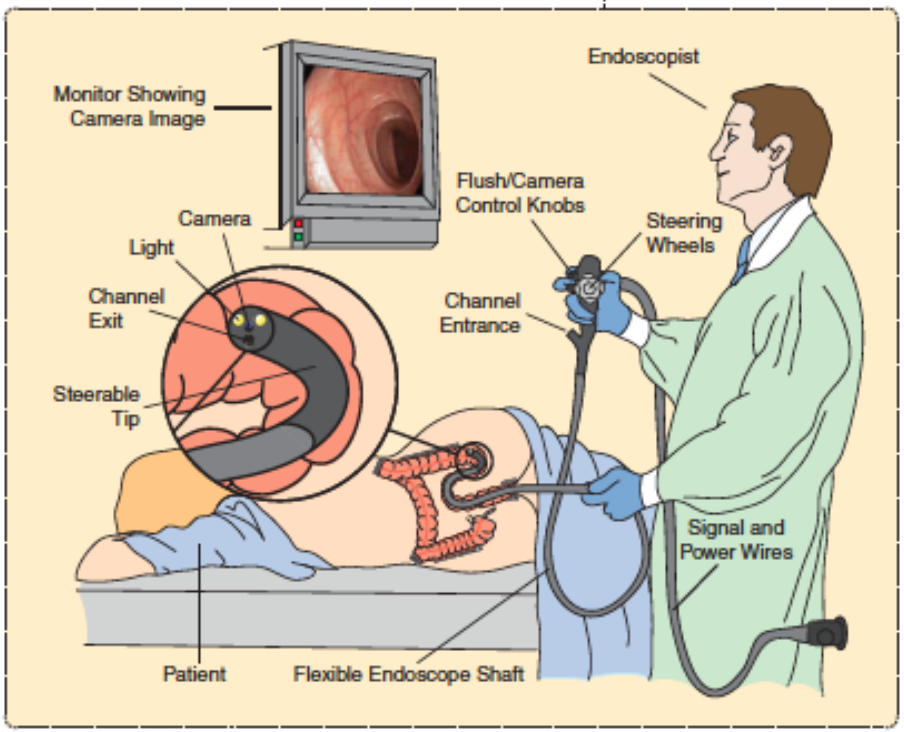


Endoscopic capsules with additional functionalities

- Biopsy capsules
- Capsule for painless colonoscopy
- Capsules releasing “components”

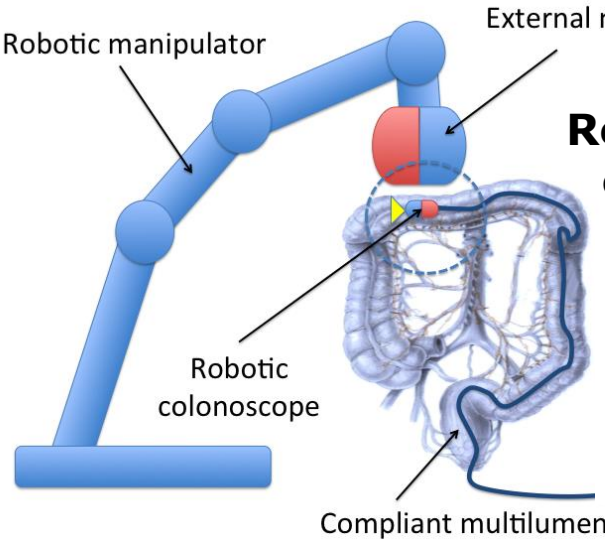
Traditional vs. robotic capsule colonoscopy

Traditional colonoscopy

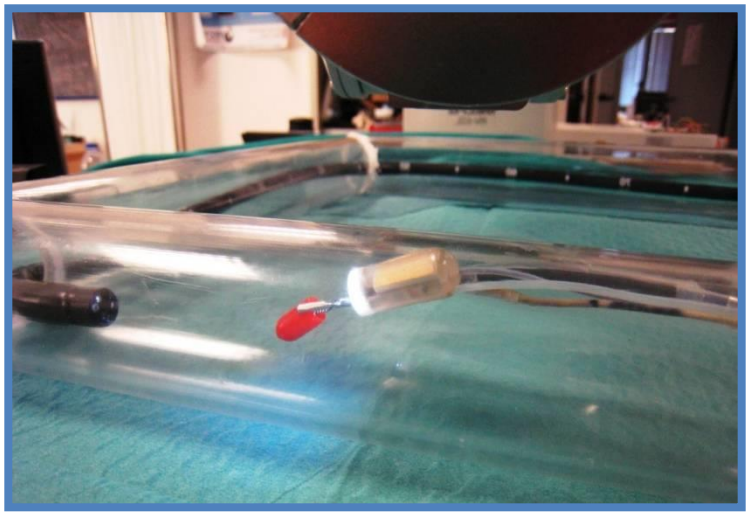


User controller

Robotic capsule colonoscopy

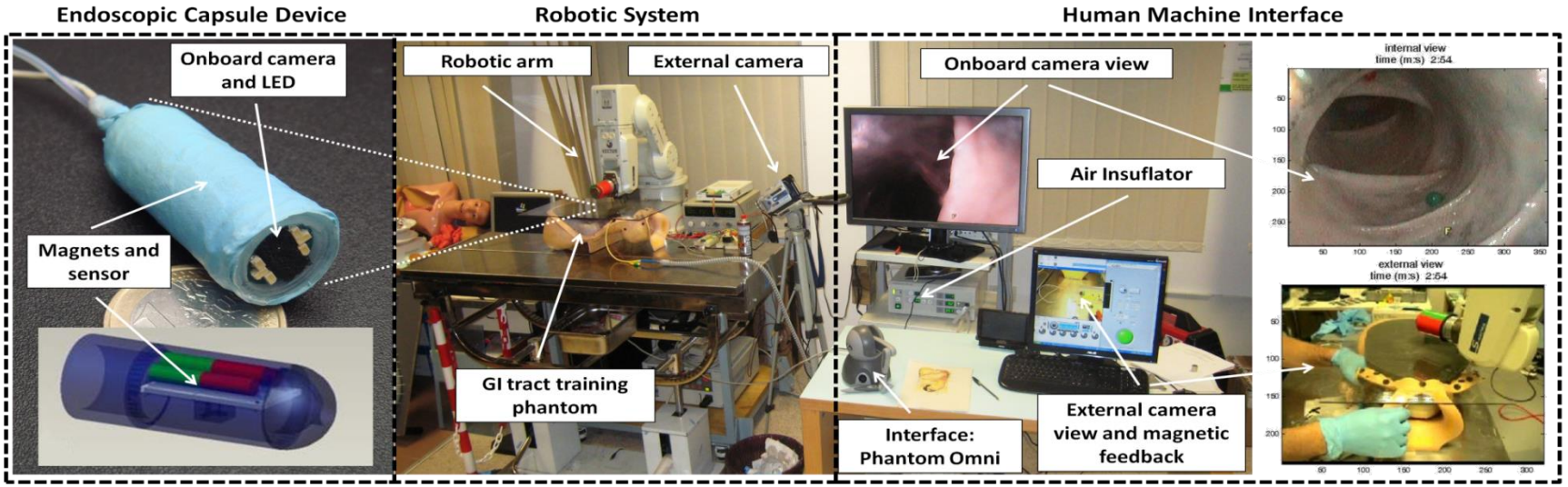


Remote user controller



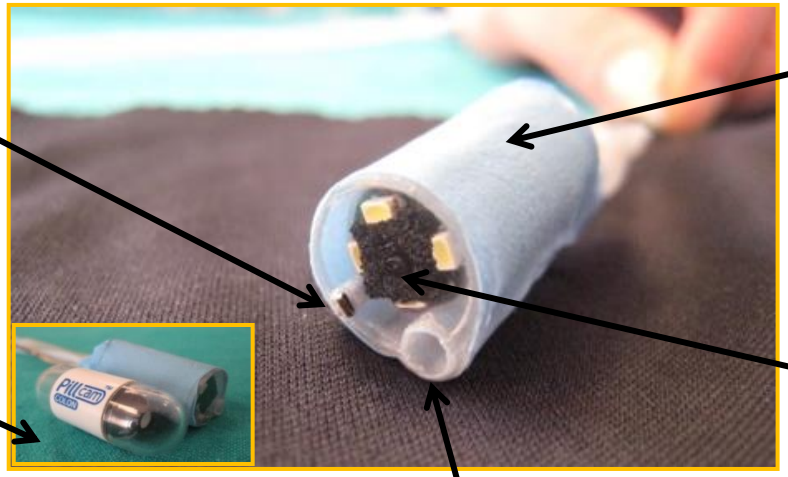
Loeve Arjo, Paul Breedveld, and Jenny Dankelman. "Scopes too flexible... and too stiff." *Pulse, IEEE* 1.3 (2010): 26-41.

Robot-guided, magnetically-actuated endoscopic device for *painless colonoscopy*



Washing system:
injection of water for the glass cleaning from a dedicated channel and nozzle

Capsule shell:
26mm in length and 11mm in diameter, less than the commercial PillCam Colon (11mm × 31mm)



Hall-effect sensor:
on-board magnetic field sensor that provides real-time clues about the magnetic link strength

Video module:
color VGA camera and 4 light emitting diodes (LED)

Operating channel:
air and water injection and endoscopic tools introduction for therapeutic and surgical procedures

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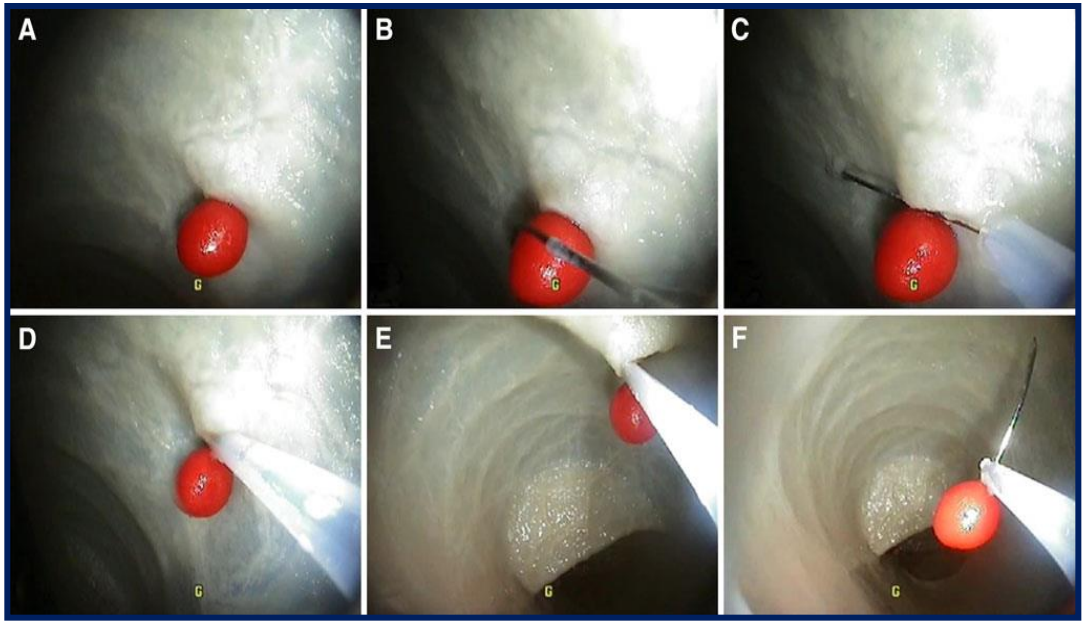
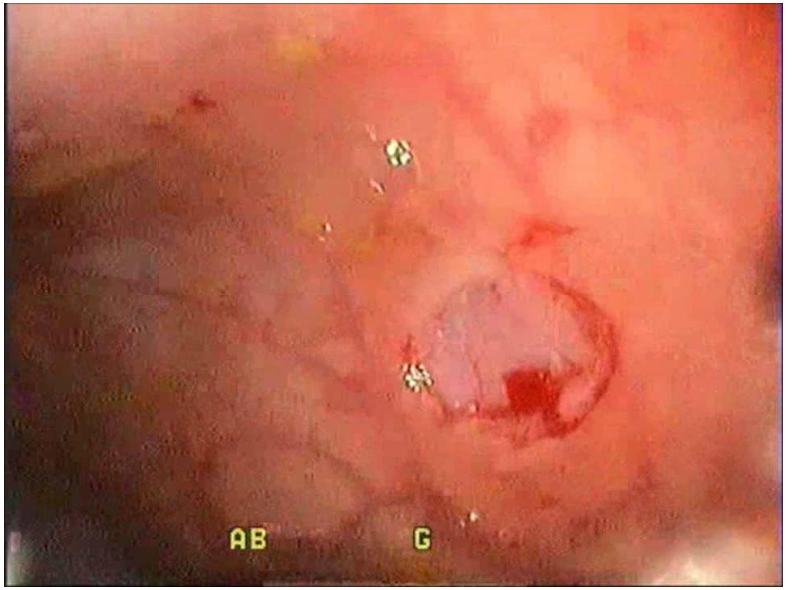
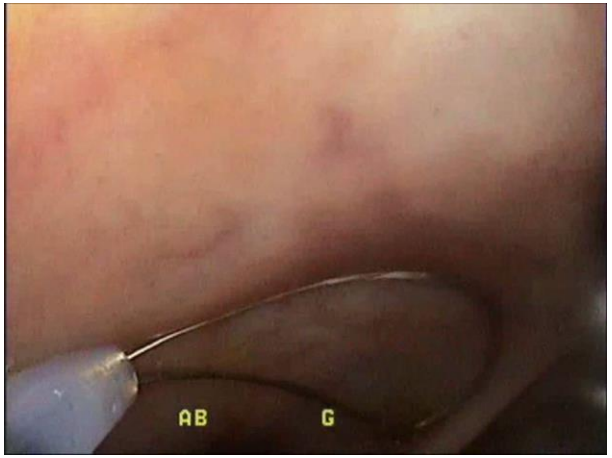
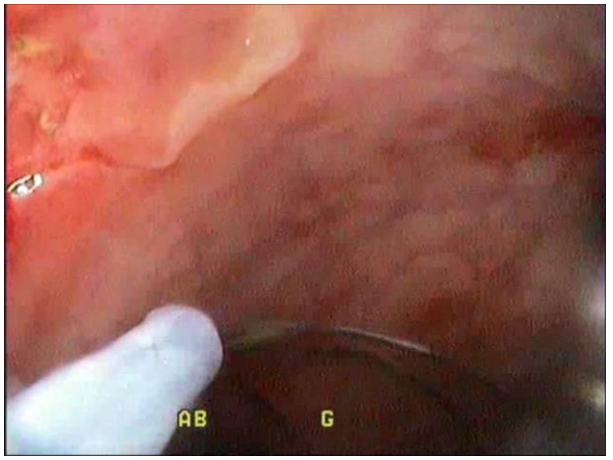
Magnetically-Actuated Capsule for Painless Colonoscopy

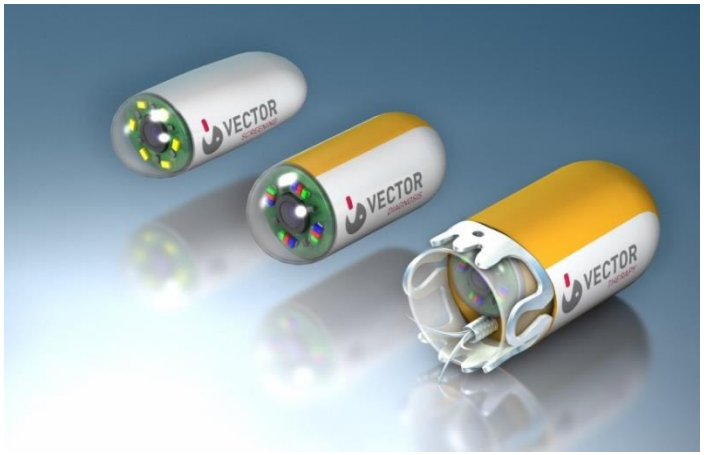
In-vitro, ex-vivo and in-vivo experimental tests







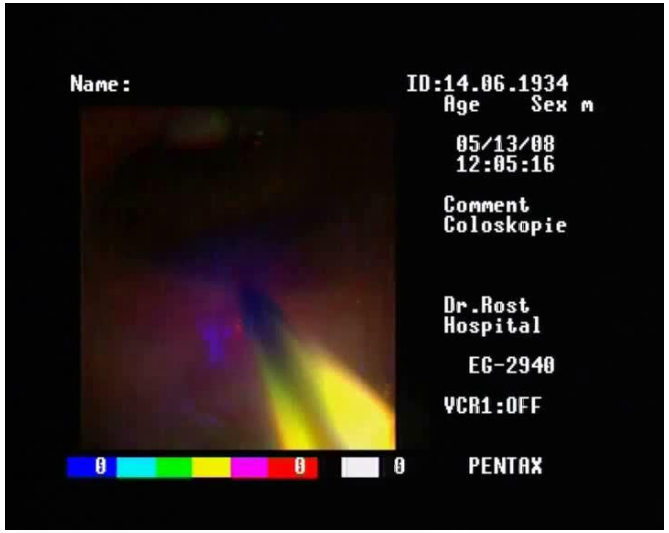




Endoscopic capsules with additional functionalities

- Biopsy capsules
- Capsule for painless colonoscopy
- Capsules releasing “components”

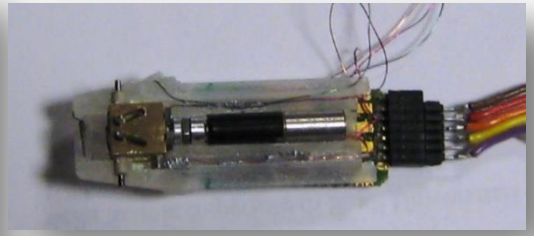
Endoscopic capsule releasing a superelastic clip

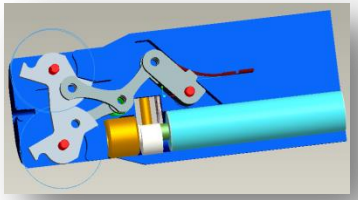


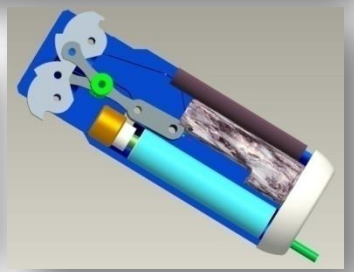
Main Components

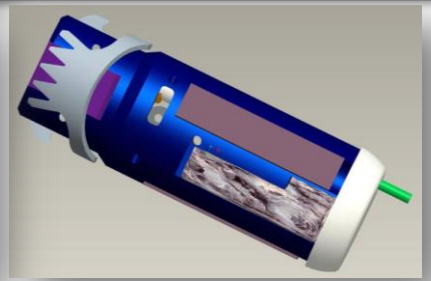
- Magnets for external magnetic steering
- Motor and mechanism for clip releasing
- Wireless motor controller

For the treatment of **gastrointestinal bleeding** and for **endoscopic digestive organ wall closure**.









OTSC CLIP

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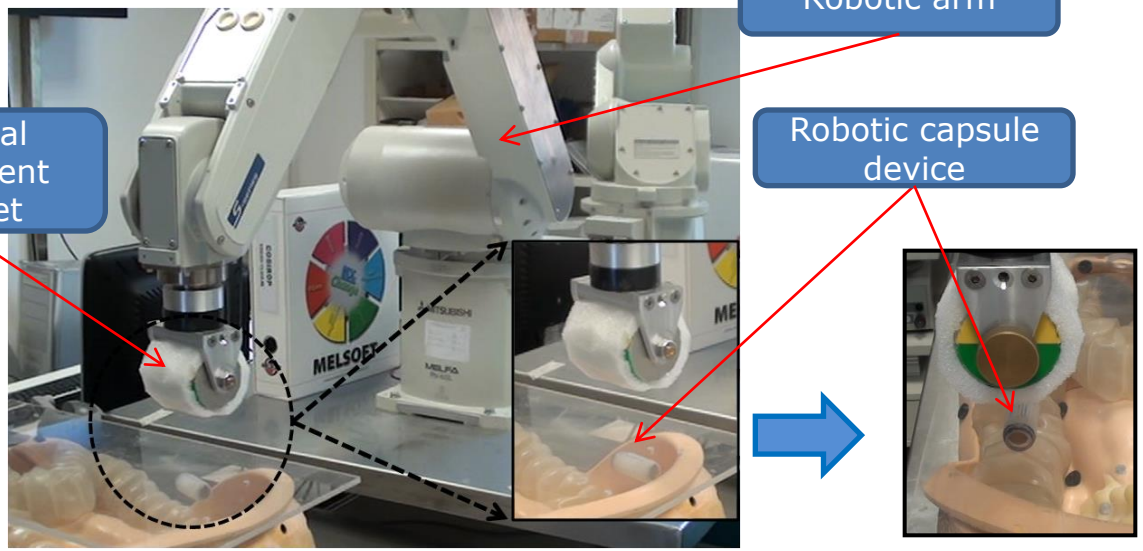
ovesco

Bench testing demonstrated a tear-off force between 2.5 N and 5.3 N

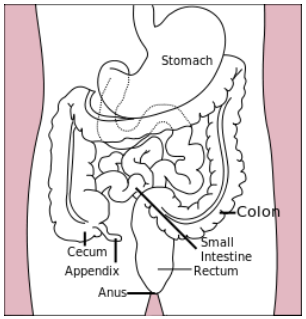
Capsule for medicated μ/n-film delivery

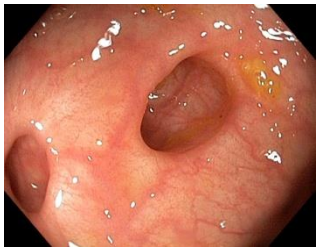
The capsule is magnetically guided to target location

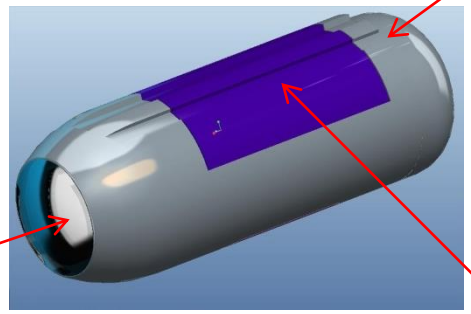
Main Features
Size: ϕ13 x 36 mm (currently)
Locomotion: magnetic
Powering: on-board battery
Actuation: SMA (trigger)
Area for film: ~ 1 cm^2
Can remove mucus from tissue

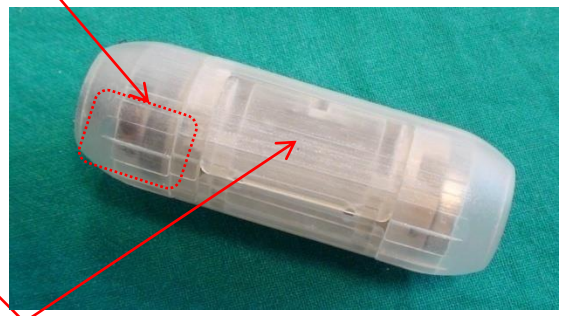


Mucus can be removed from target tissue by capsule scraping (roll motion)









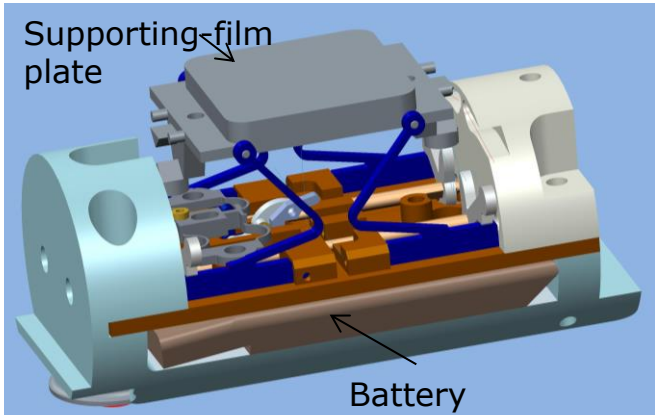
Grooves for mucus displacement

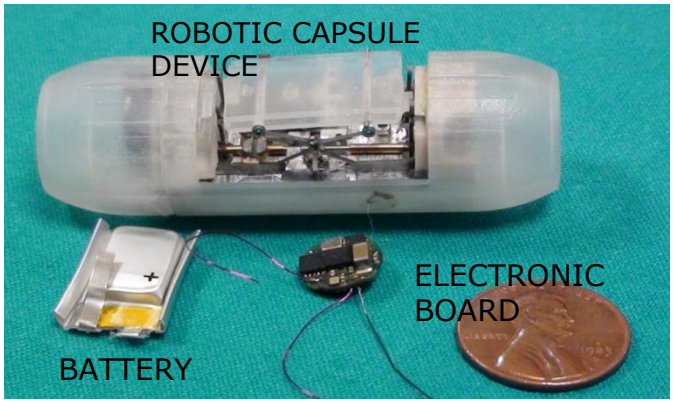
Camera

N.2 mobile covers

Capsule for medicated μ/n-film delivery

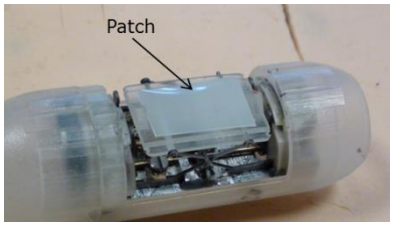
Film is pushed against tissue; capsule (in particular plate) is guided away (yet film sticks)

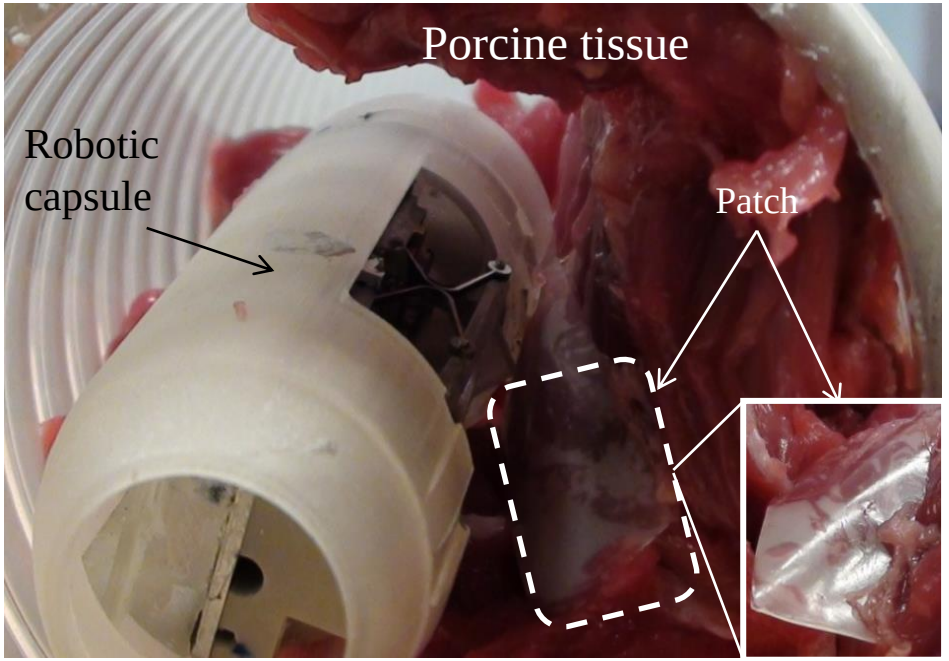




Main Features
Size: ϕ13 x 36 mm (currently)
Locomotion: magnetic
Powering: on-board battery
Actuation: SMA (trigger)
Area for film: ~ 1 cm^2
Can remove mucus from tissue

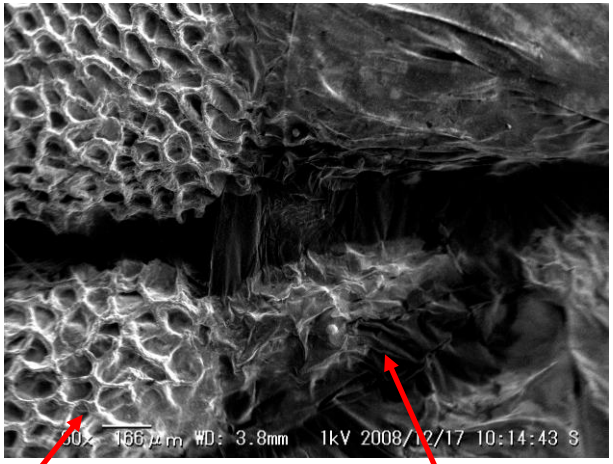
❑ System prototype





Magnetic nanofilms as nanoplaster for endoluminal surgery

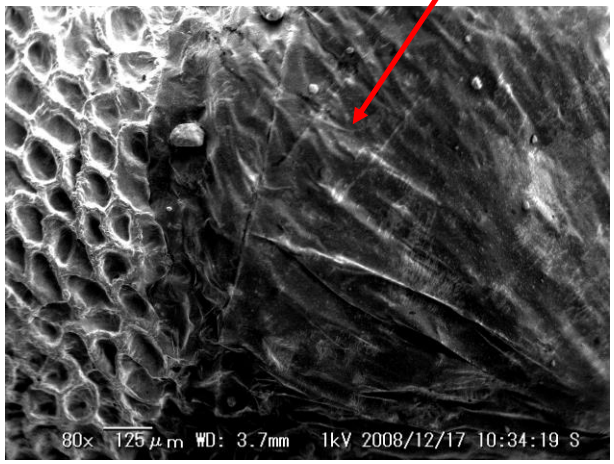
10 mg/ml NP (200 nm) in PLA 20 mg/ml



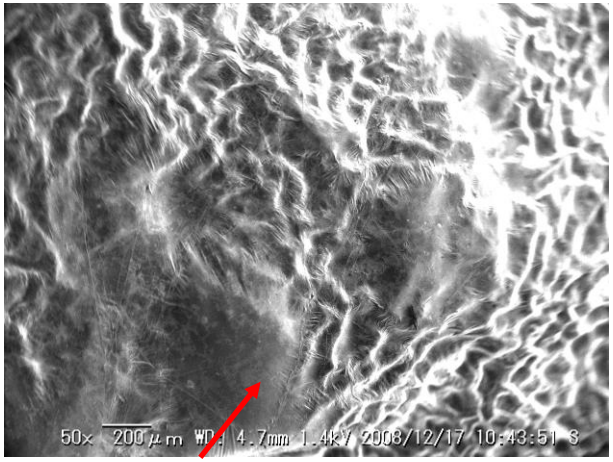
Film covering an incision on the mucosal wall

gastric wall

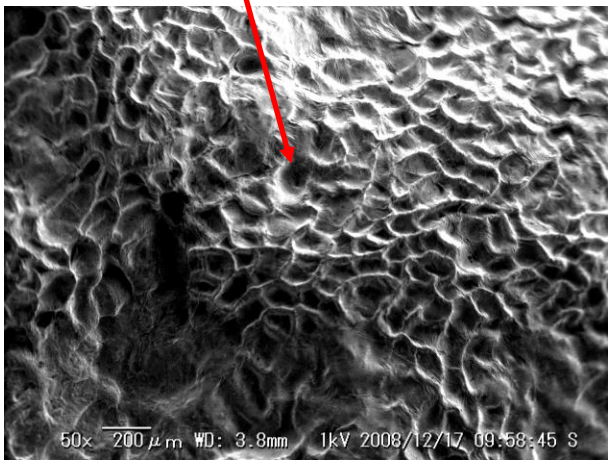
magnetic nanofilm



10 mg/ml NP (40 nm) in PLA 10 mg/ml



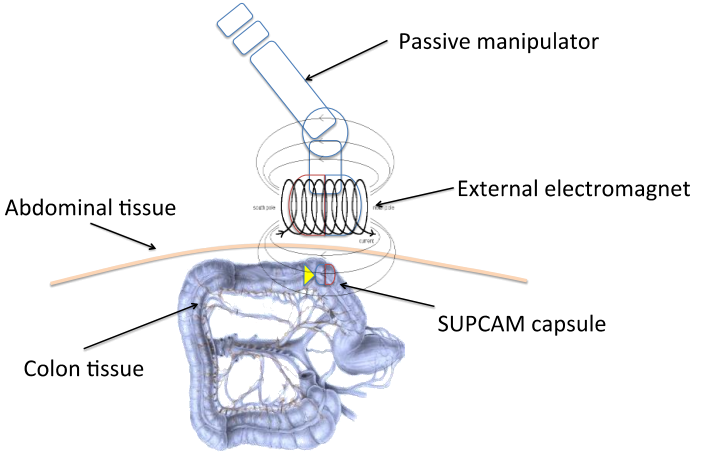
The film follows the folds of the mucosal wall, completely covering it.

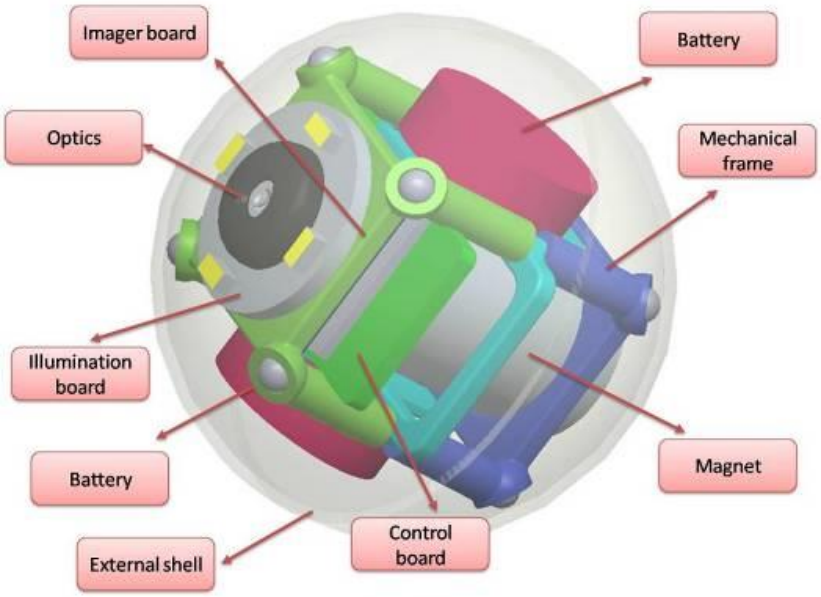


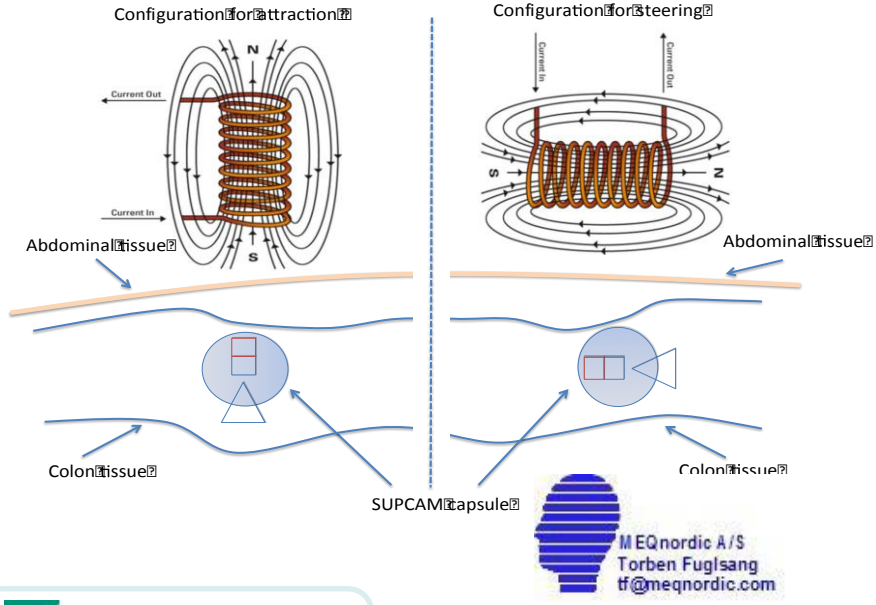
supcam

lorem ipsum dolor

New cost effective and minimally invasive **endoscopic** device able to investigate the colonic mucosa, ensuring a high level of navigation accuracy and enhanced diagnostic capabilities







MEQnordic A/S
Torben Fuglsang
tf@meqnordic.com

Special Electronic Design

THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

AWAIBA

Fraunhofer IOF

D'APPOLONIA

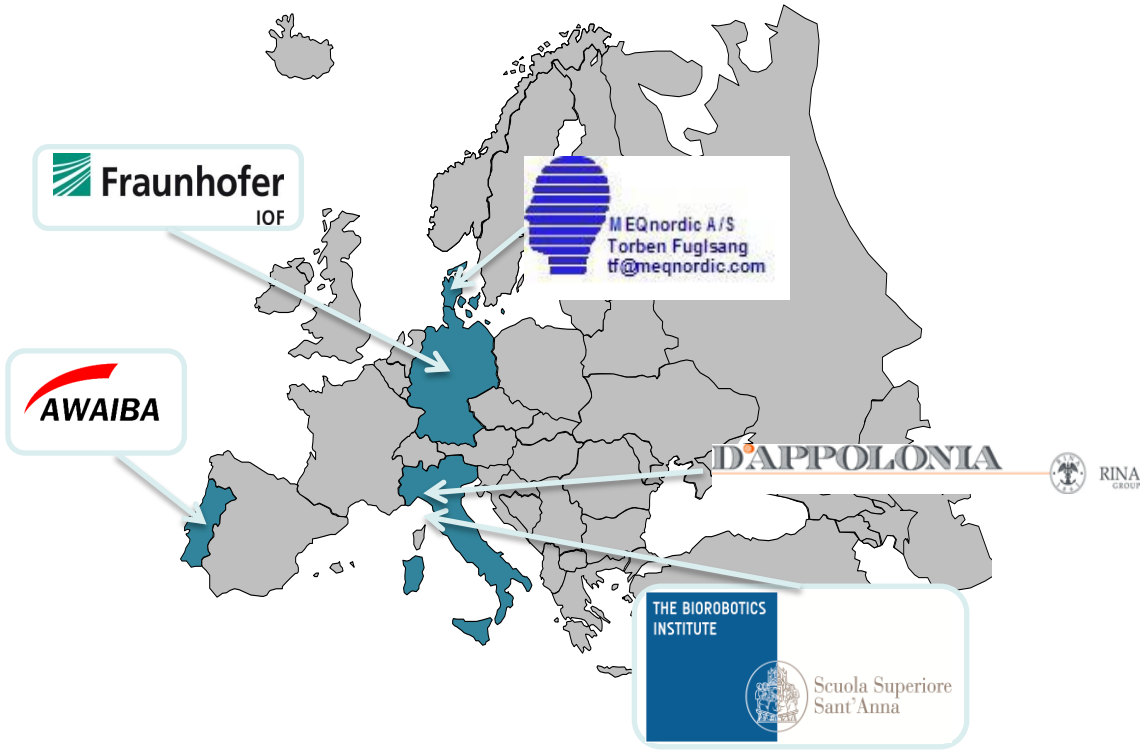
RINA GROUP

The SUPCAM is a project funded under the "Research for SMEs" scheme belonging to the 7th Framework Programme (FP7/2007-2013) under grant agreement No. FP7-SME-315378.c

SUPCAM project

The aim of SUPCAM project is the development of an **endoscopic capsule whose structure and innovative design allow to safely and accurately guide it along the colonic lumen from the outside, through an electromagnet, completely wireless.**

Project consortium



Ministero dello Sviluppo Economico
Direzione generale per la lotta alla contraffazione
Ufficio Italiano Brevetti e Marchi

ATTESTATO DI BREVETTO PER INVENZIONE INDUSTRIALE

N. 0001399340

Il presente brevetto viene concesso per l'invenzione della domanda sotto specificata:

num. domanda	anno	C.C.I.A.A.	data pres. domanda	classifica
000055	2010	FIRENZE	29/03/2010	A61B1 05

TITOLARE/I TOZZI ALESSANDRO
TAVARNELLE VAL DI PESA (FI)
SPECIAL ELECTRONIC DESIGN S.R.L. - S.E.D.
CERTALDO (FI)

MANDATARIO SOLDATINI ANDREA

INDIRIZZO SOCIETA' ITALIANA BREVETTI S.P.A.
CORSO DEI TINTORI 25
50122 FIRENZE

TITOLO CAPSULA ENDOSCOPICA AD AZIONAMENTO E CONTROLLO MAGNETICO.

INVENTORE/I BRUNI CARLO
TOZZI ALESSANDRO

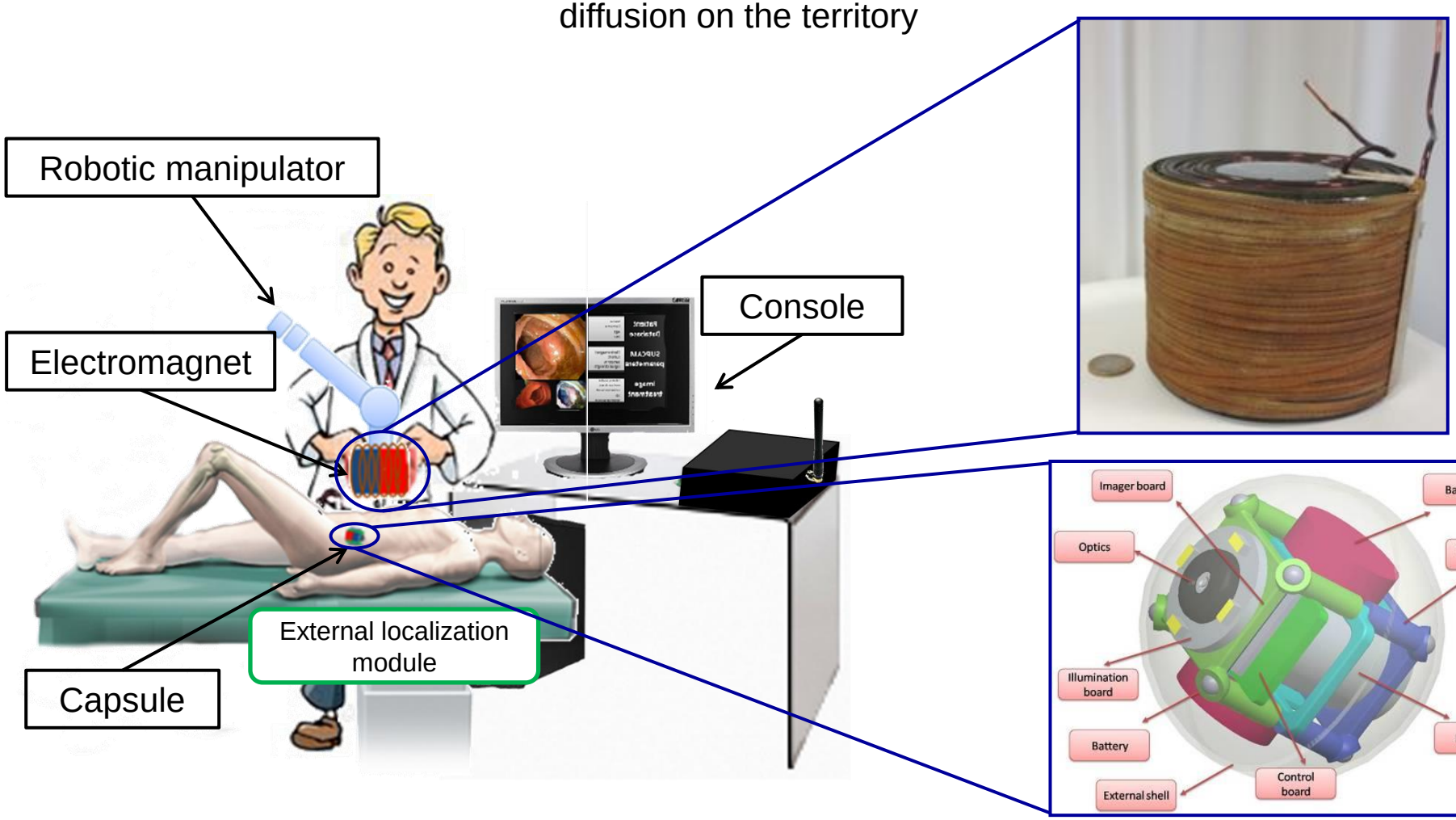
Roma,

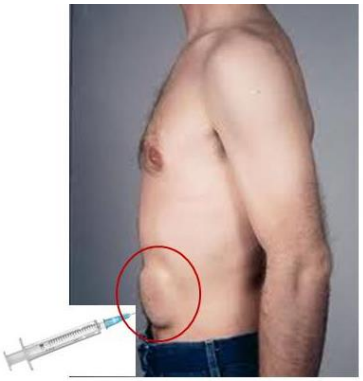
Special Electronic Design

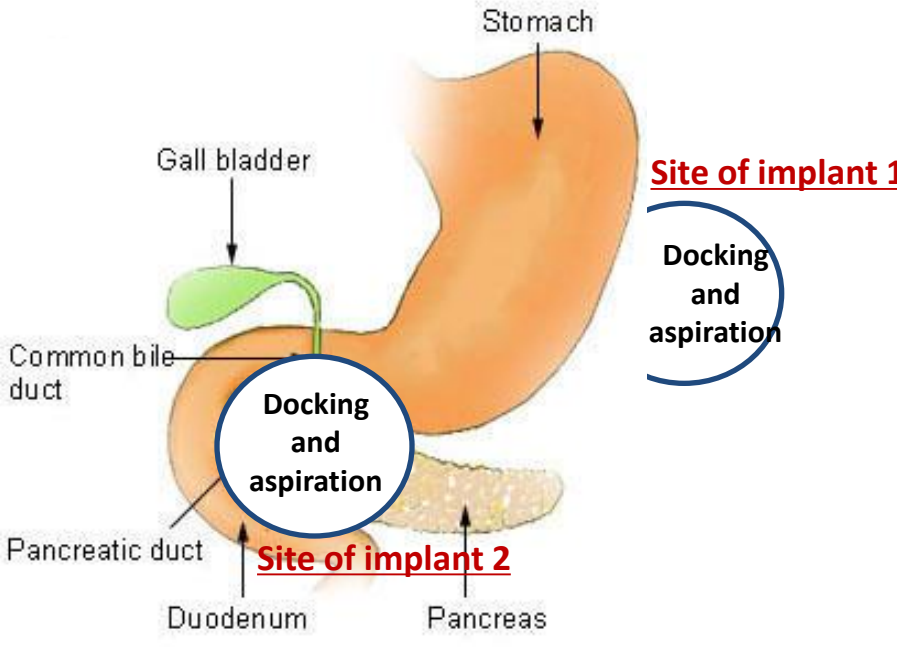
The SUPCAM is a project funded under the "Research for SMEs" scheme belonging to the 7th Framework Programme (FP7/2007-2013) under grant agreement No. FP7-SME-315378.c

SUPCAM project

The SUPCAM platform ensures an accurate vision of the mucosa of the colon, a reduction of clinical risk, and an improvement of acceptability by the patient with a potential wide diffusion on the territory







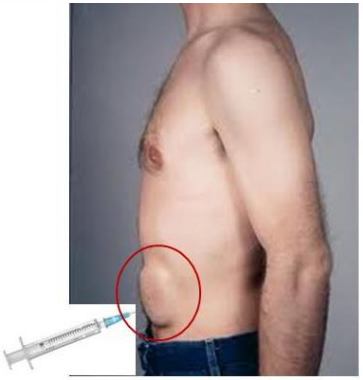
Having learned the techniques to finely control the positioning of an endoluminal capsule by means of an external robot, we can now envisage a wide class of novel applications. For example, **refilling an implanted artificial pancreas by means of oral capsules containing insuline**

A Novel Concept: Magnetically-Controllable Insulin-Filled Capsules as Carriers for Diabetes Treatment

- 347 million people worldwide suffer from diabetes
- diabetes deaths are expected to double between 2005 and 2030
- worldwide diabetes market: from $ 14.9 billion in 2009 to $ 55 billion in 2019
- lifestyle strongly affected by traditional therapy

Multiple daily insulin injections
- The patient is slave of his/her pathology
- Long-term complications
- Non-physiologic insulin profile

Wearable artificial pancreas
- Delays in insulin adsorption
- Common daily activities strongly affected

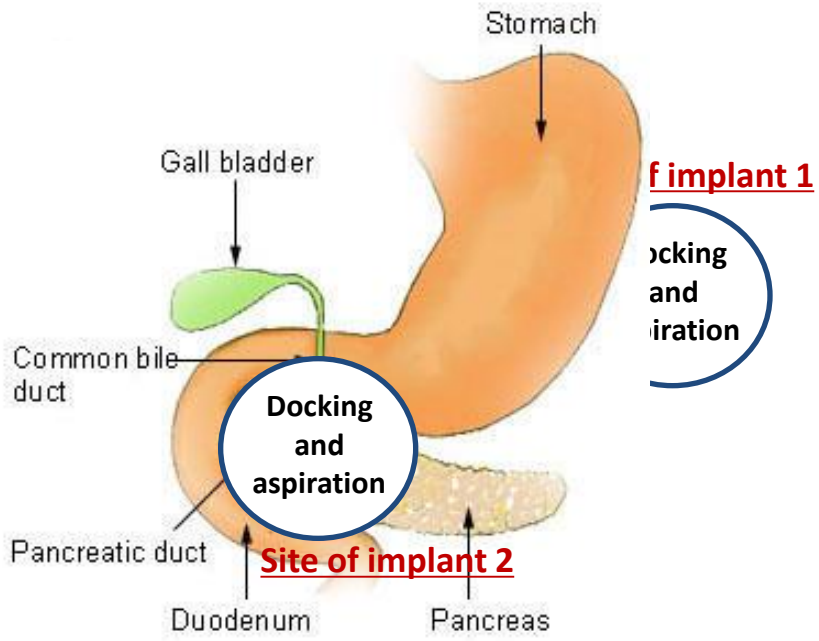


Implanted artificial pancreas
- Limited lifetime
- Need of complicated periodical refilling procedures (surgical operations needed every 3 months)
- Low insulin stability in the implanted device

Holy Grail of diabetes treatment

Long-term totally implantable AP refillable through insulin pills

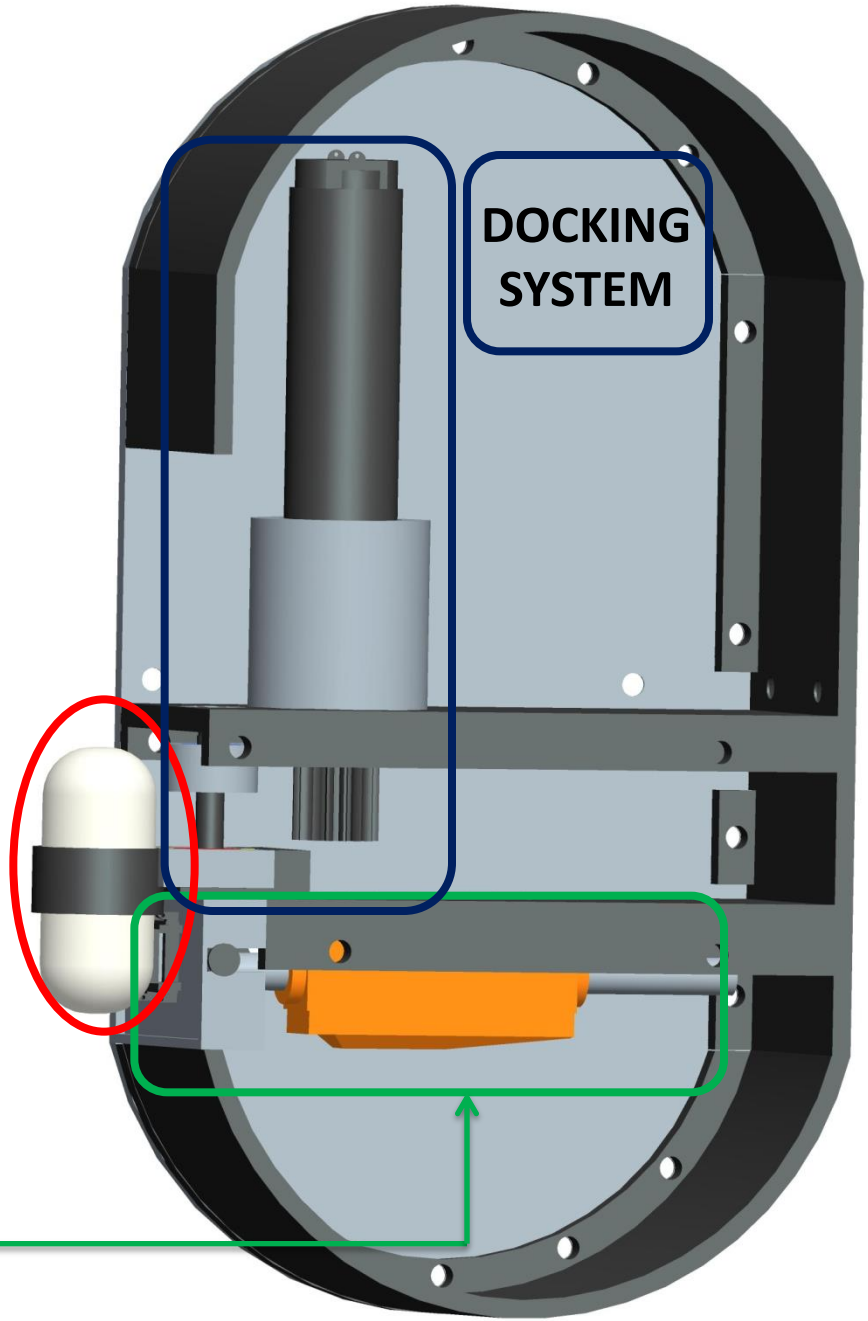
Novel implantable artificial pancreas *



f implant 1

ocking and iration

SENSORIZED SWALLOWABLE CAPSULE



PASSIVE VALVE AND NEEDLE SYSTEM

* Ricotti et al. PCT Patent WO/2012/011132 , Jan 2012

Sensorized Swallowable Capsule

FERROMAGNETIC RING

Φ_{ext} = 14 mm

Φ_{int} = 12 mm

H = 7 mm

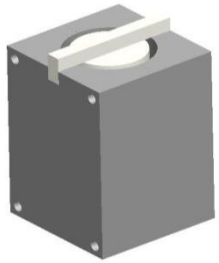
PDMS CAPSULE

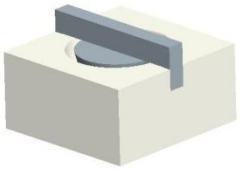
Φ_{ext} = 12 mm

Φ_{int} = 10 mm

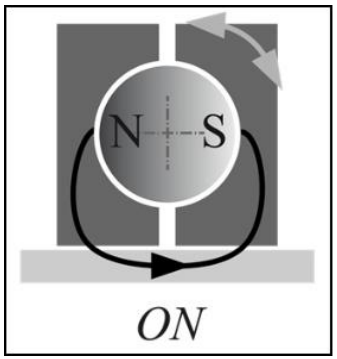
t = 1 mm

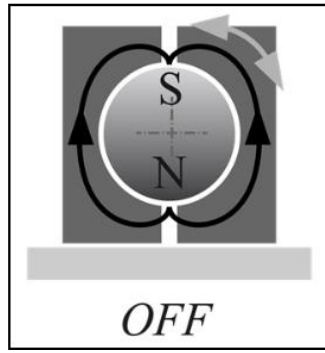
H = 30 mm





TEFLON CAPSULE MOULDS

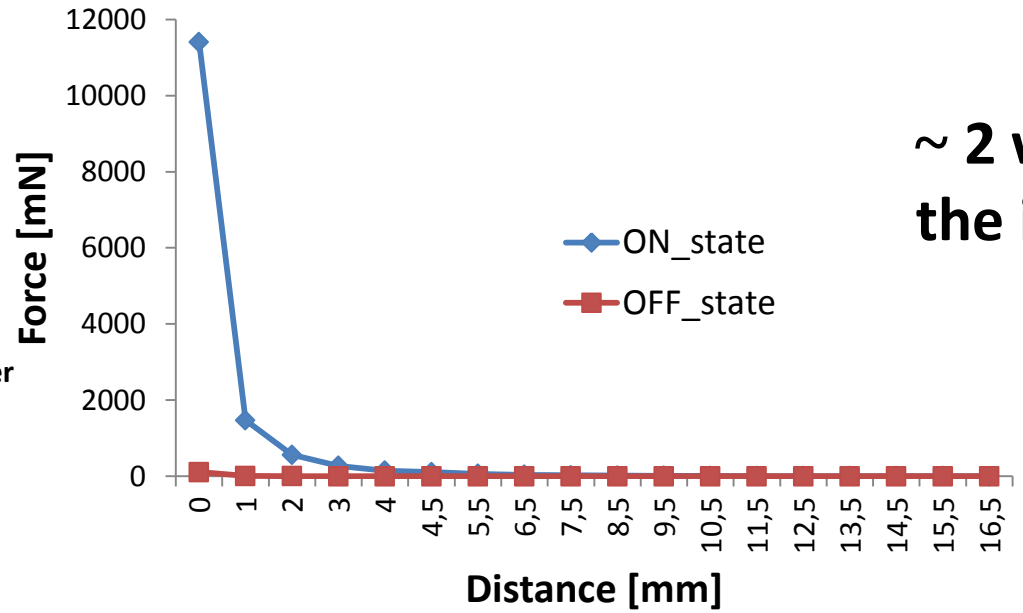




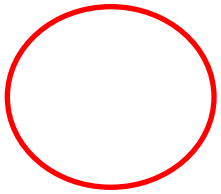
Insulin content for each capsule ≈ 2 ml

~ 2 week autonomy for the implanted Artificial Pancreas

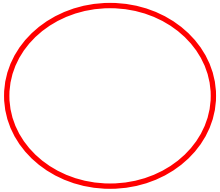
TI Microreader evaluation Module RI-STU-MRD2



From Case Study #2 to Case Study #3



Gastrointestinal Tract:
Ø = 10 to 30 mm

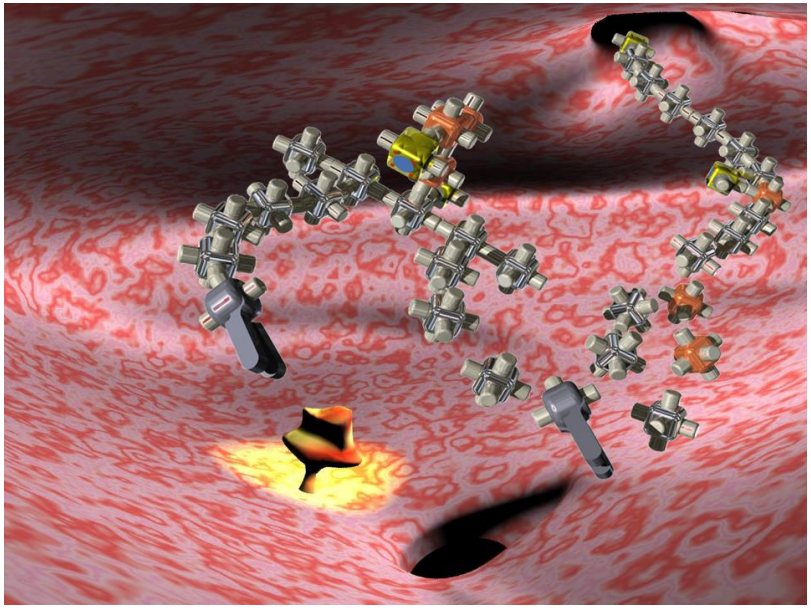


Abdomen by
NOTES/Single Port
Access: Ø = 15 to 32 mm

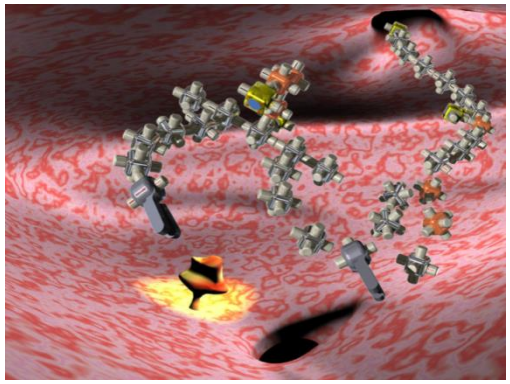
Simple diagnostic robots (capsule-like) with limited therapeutic capabilities

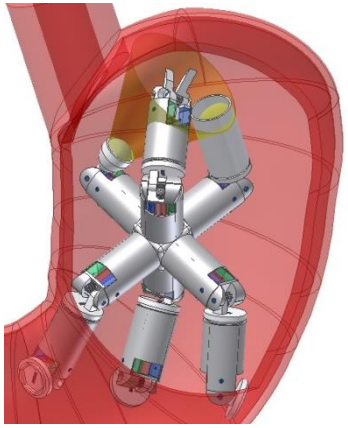
Dexterous endoluminal robots with diagnostic/ therapeutic/surgical capabilities

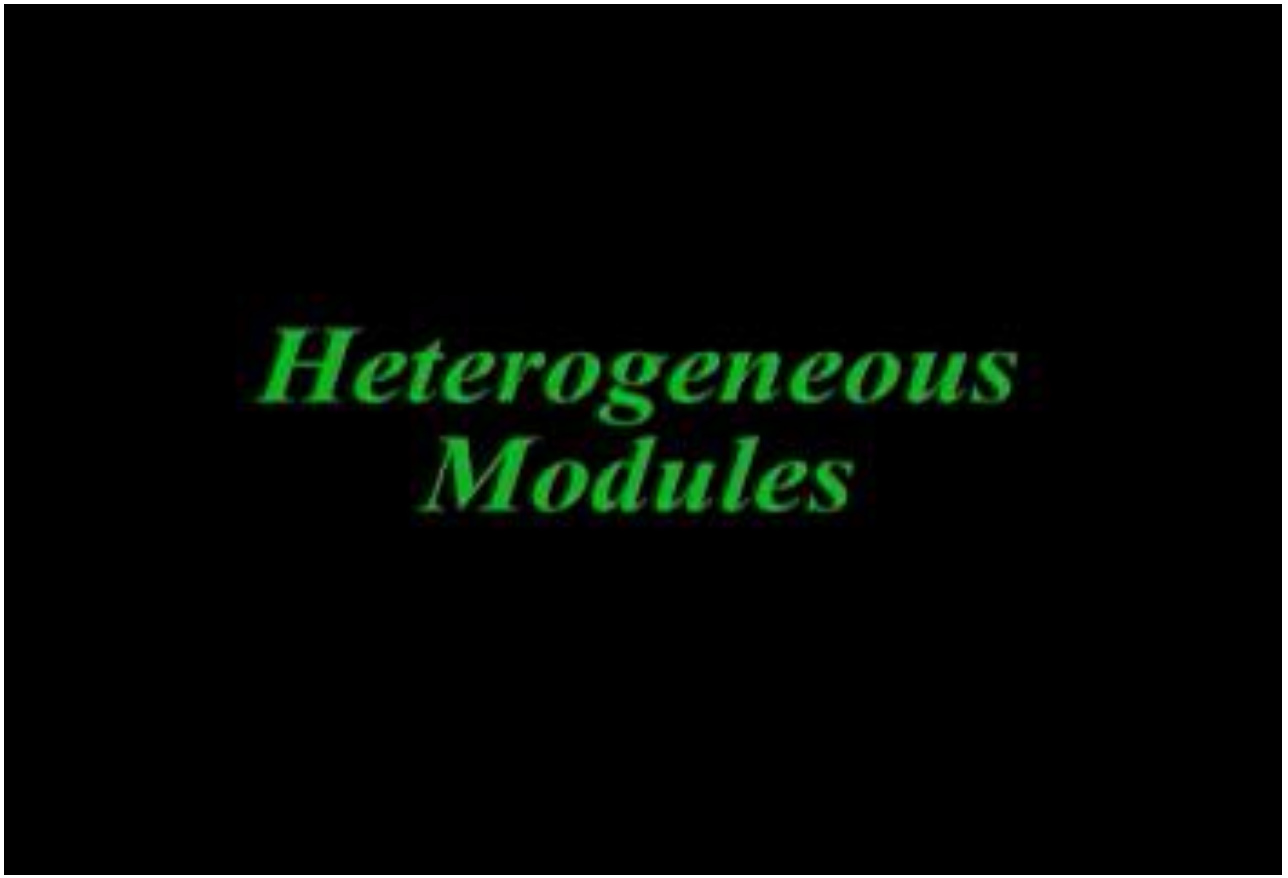
From one to many capsules: reconfigurable robots for the exploration and for real surgery in the human body

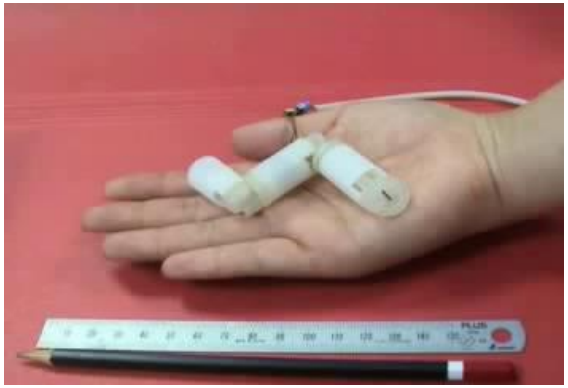


From **Single** Capsules to a **Molteplicity** of Capsules: **Modular** and **Reconfigurable** Surgical Instruments

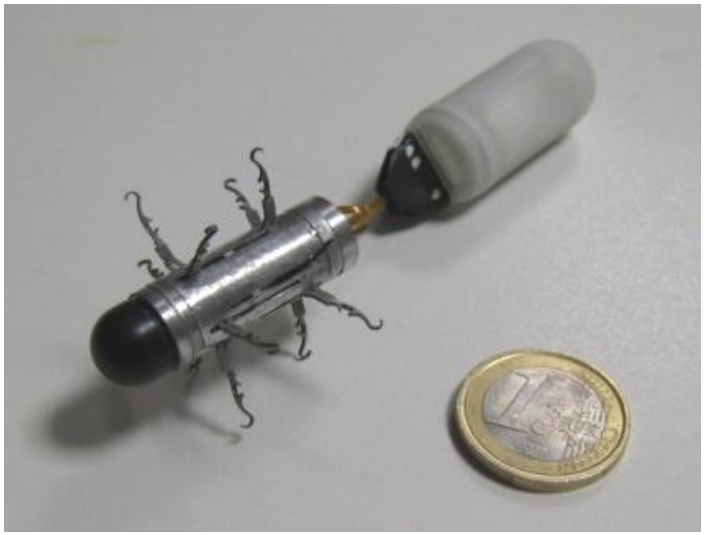




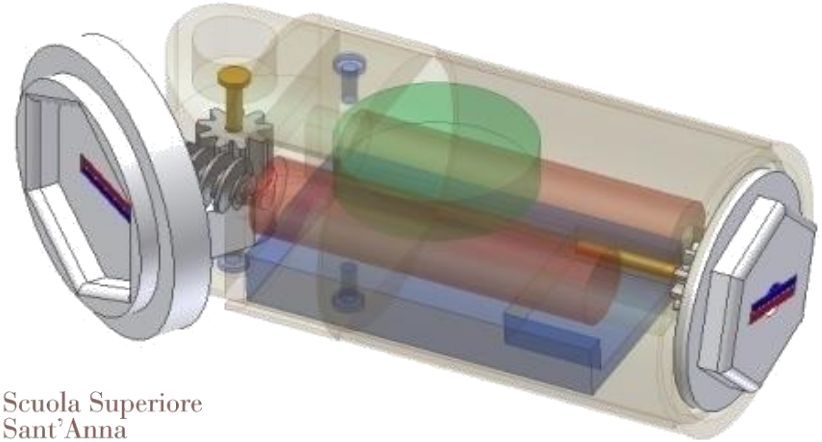




Case Study #3

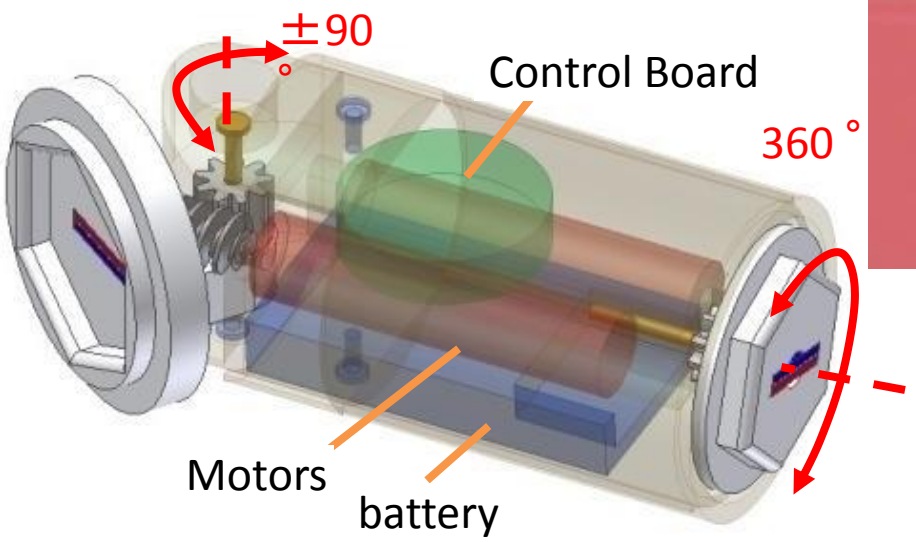


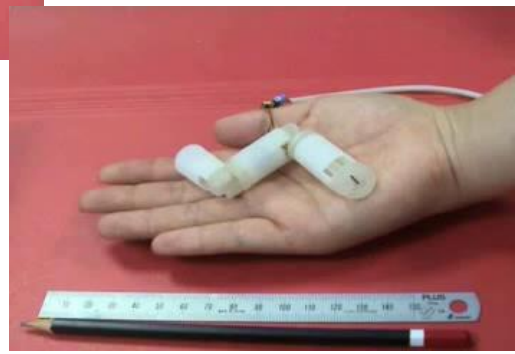
Evolution of the “tender” approach: multiple swallowable modules to be assembled and disassembled inside the stomach

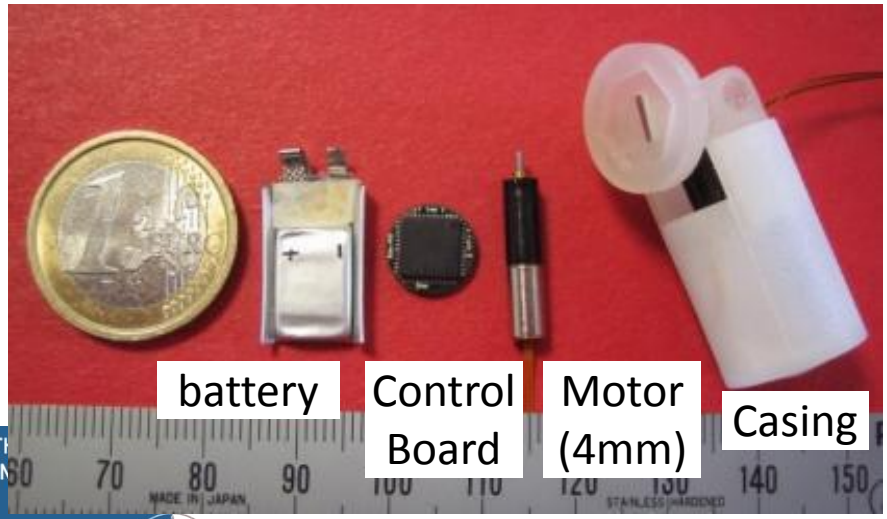


Prototype of a robotic module

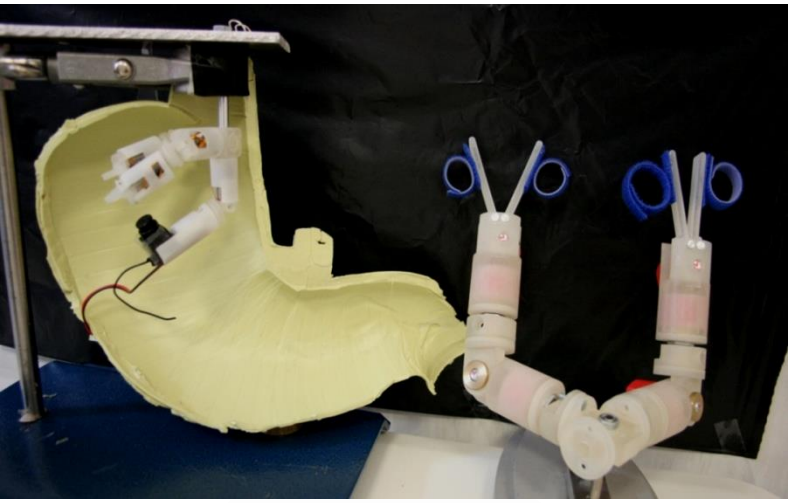
Φ15.4 X 36.3 , 5.6 g, 2 DOF

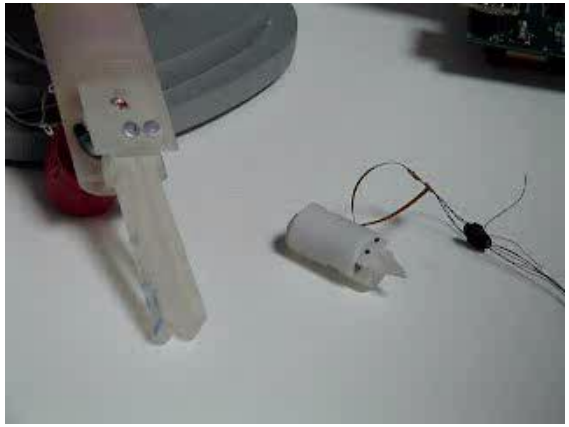


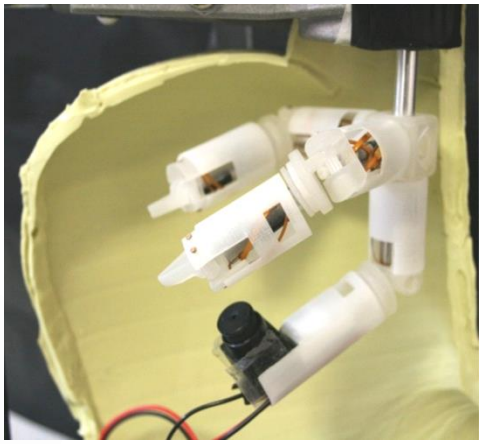


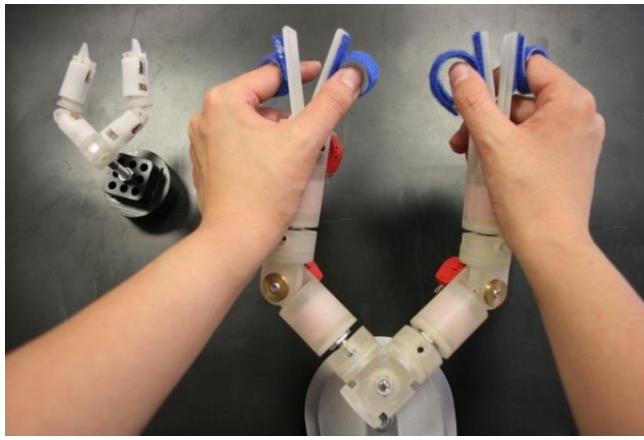


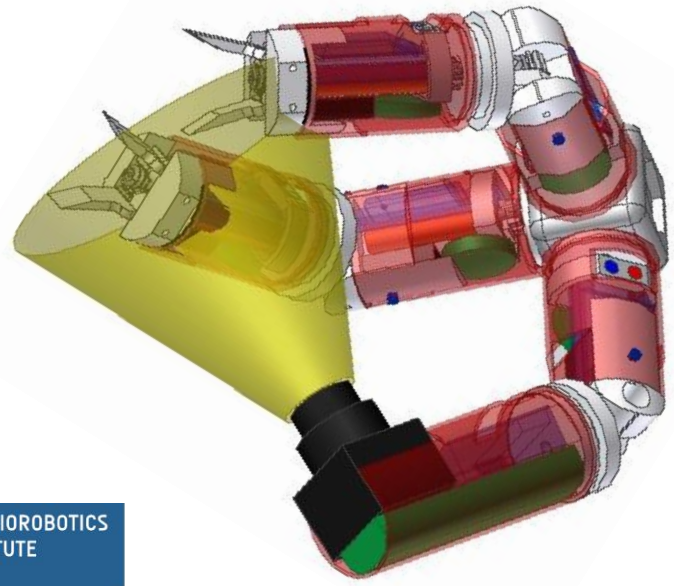
Teleoperation of a module

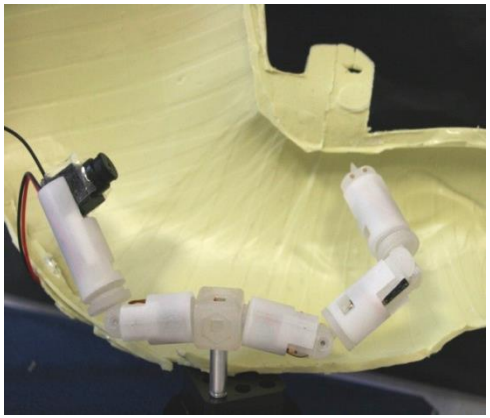


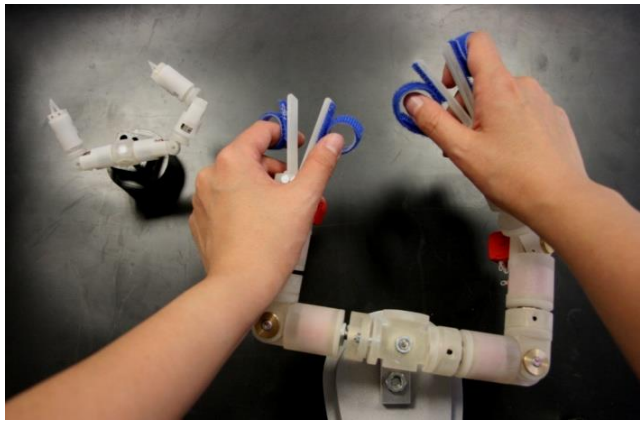










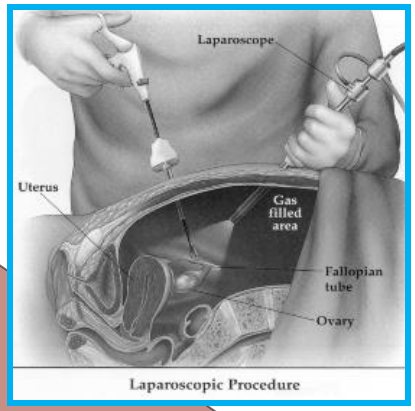


THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

Scarless Robotic Surgery

TRADITIONAL TECHNIQUES



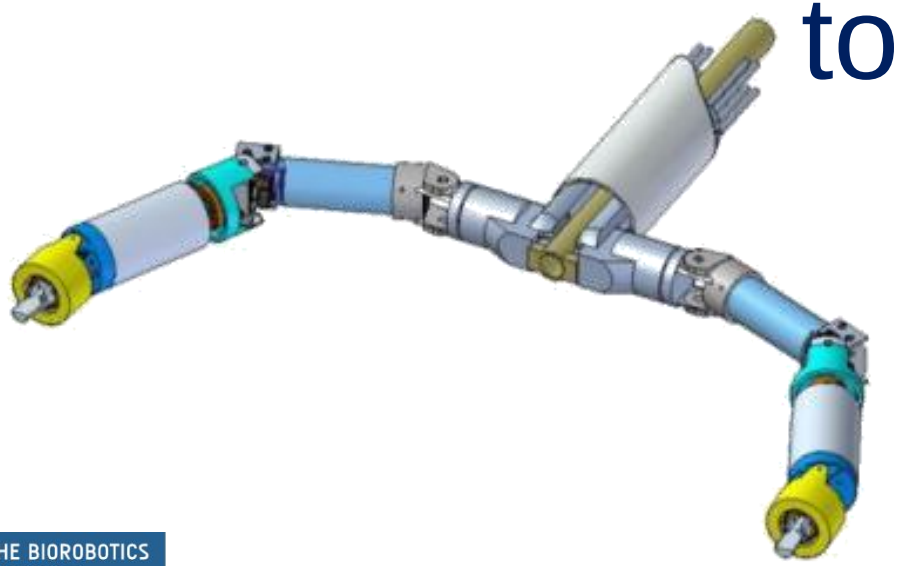
LAPAROSCOPIC SURGERY

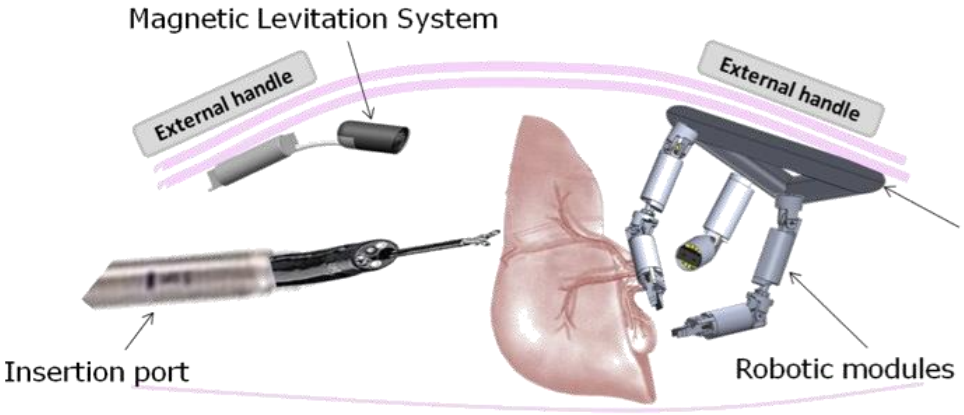
ROBOTIC SURGERY

SCARLESS ROBOTIC SURGERY

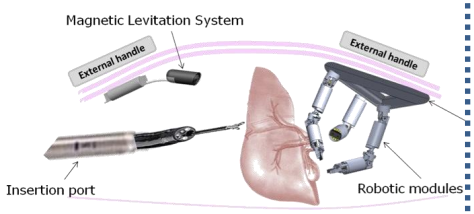
Case Study #4

Evolution of the concept of "modular" approach towards the design of clinically usable surgical tools





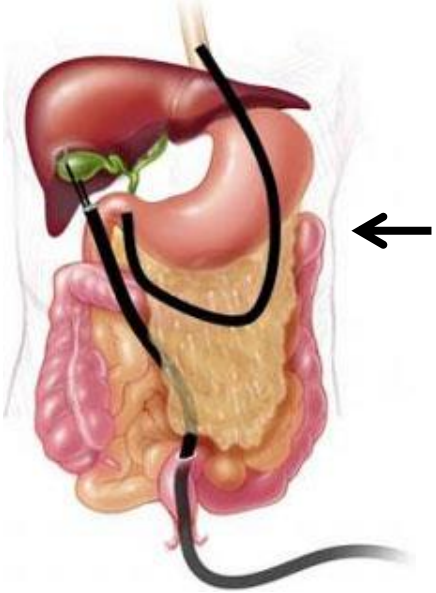
Different Accesses



NOTES (Trans-Oesophageal or Trans-Vaginal

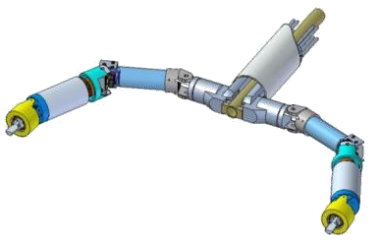
Abdomen by NOTES/Single Port Access access: Ø = 15 to 32 mm

OESOPHAGEAL ACCESS

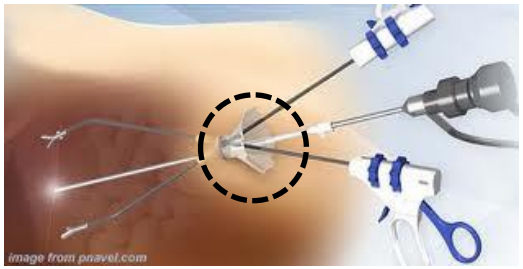


UMBILICAL ACCESS

TRANSVAGINAL ACCESS



SINGLE PORT ACCESS (Trans-Umbilical)



- Small dimension
- Anatomical constraints
- Safety issues

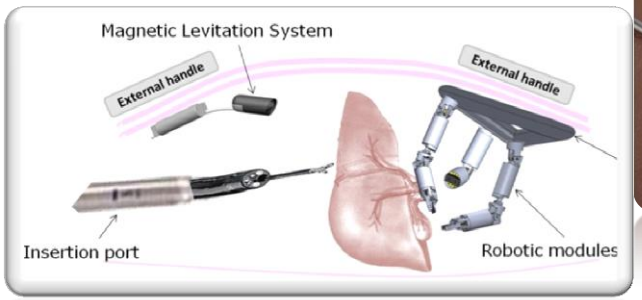
- Totally scarless
- Reduce post-interventional complications

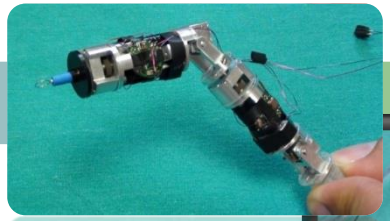
-Fulcrum effect
- Instruments collision
-Triangulation limitation

- Single scarless incision

ARAKNES platforms

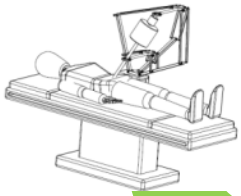
Research Platform (trocar/NOTES access)

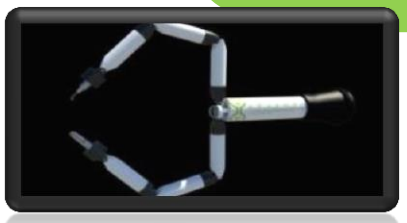


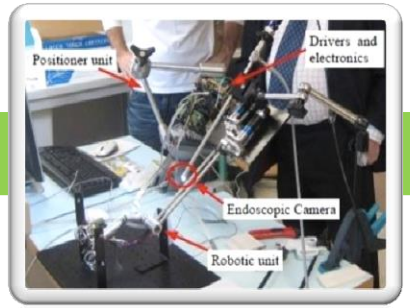


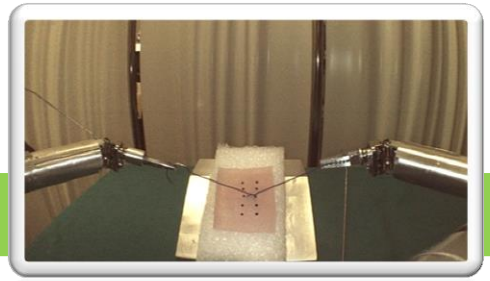
Abdomen by trocar access: D = 10-15 mm

Clinical Platform (umbilical access)



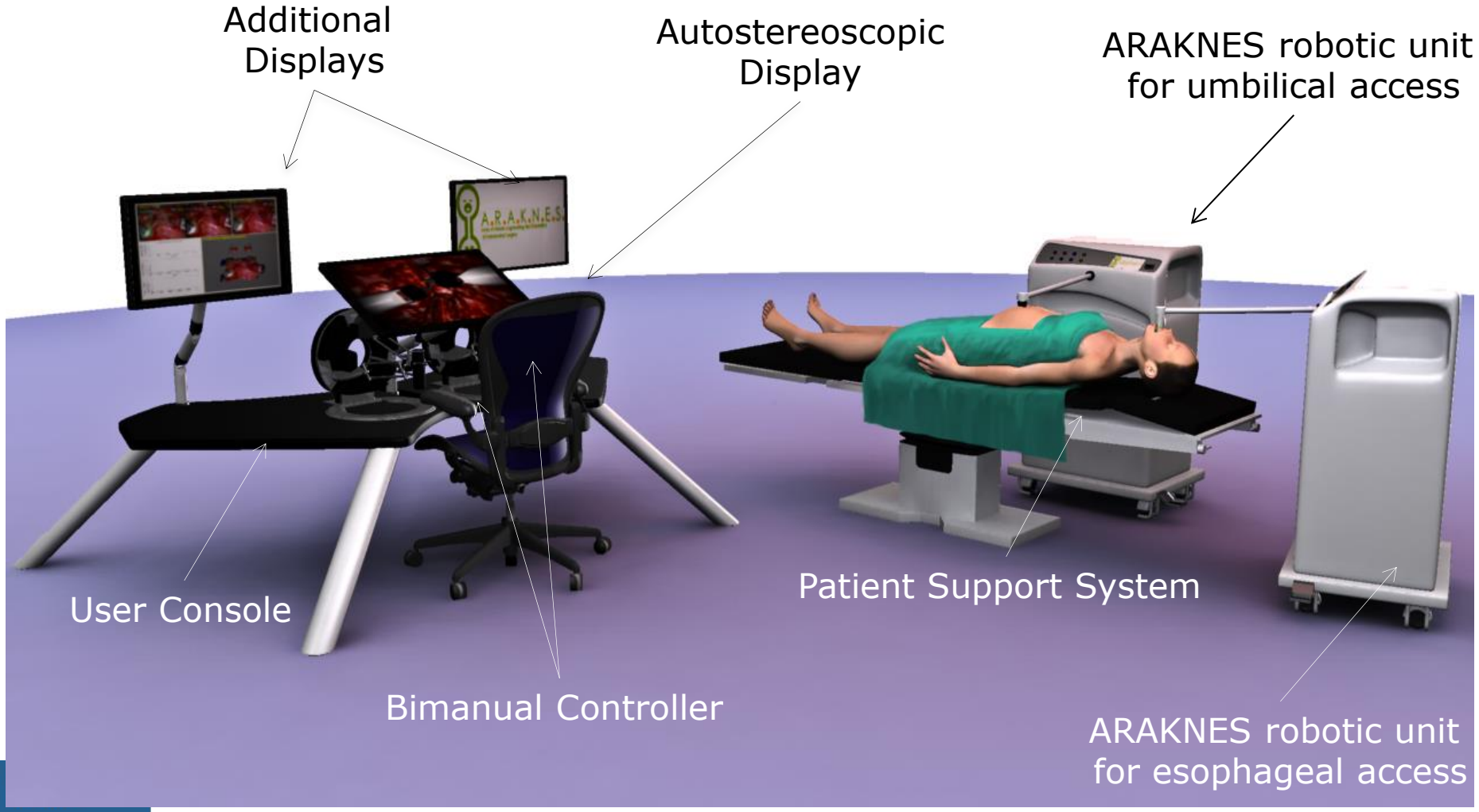




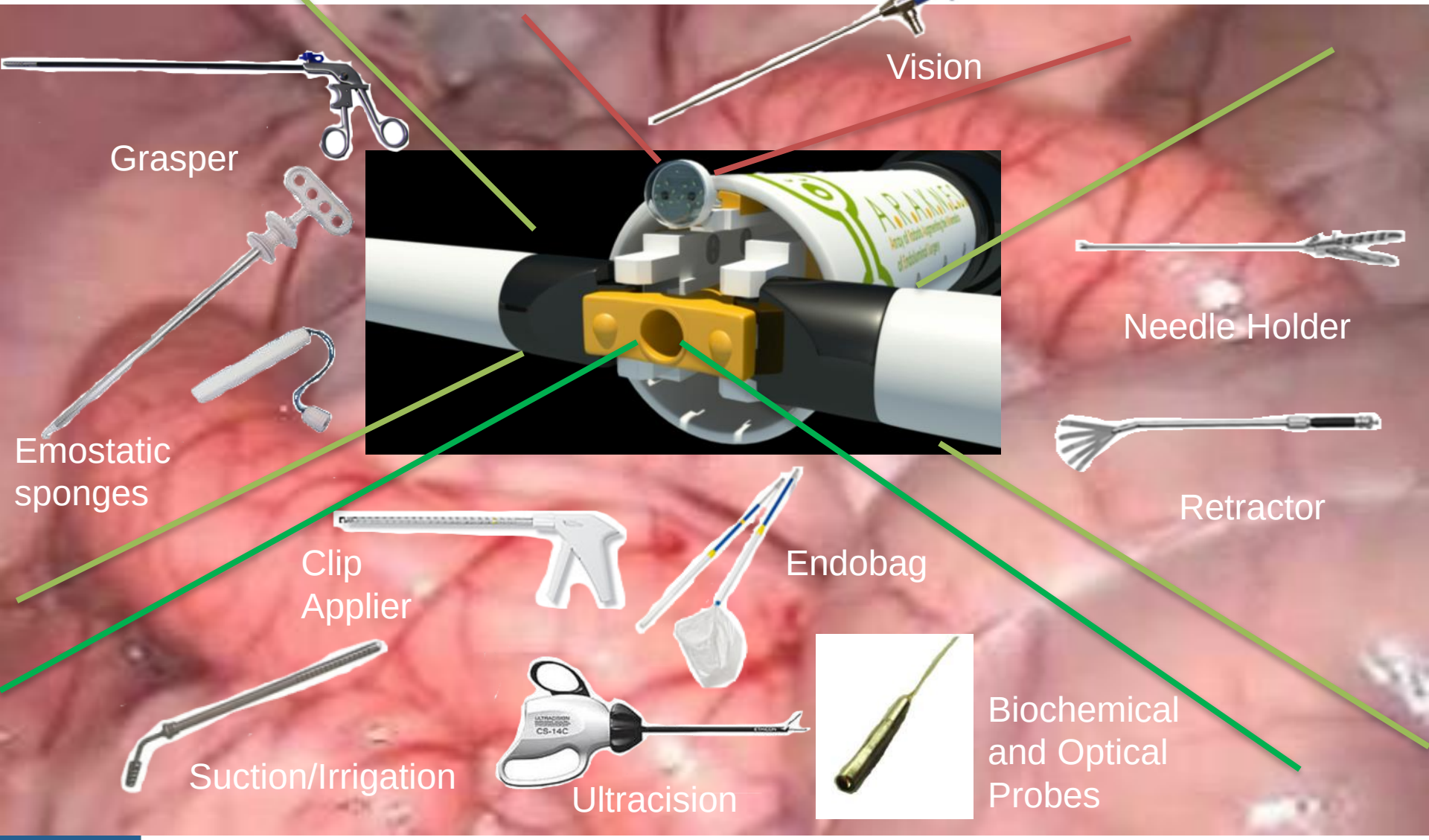


Abdomen by Single Port access: D = 20-32 mm

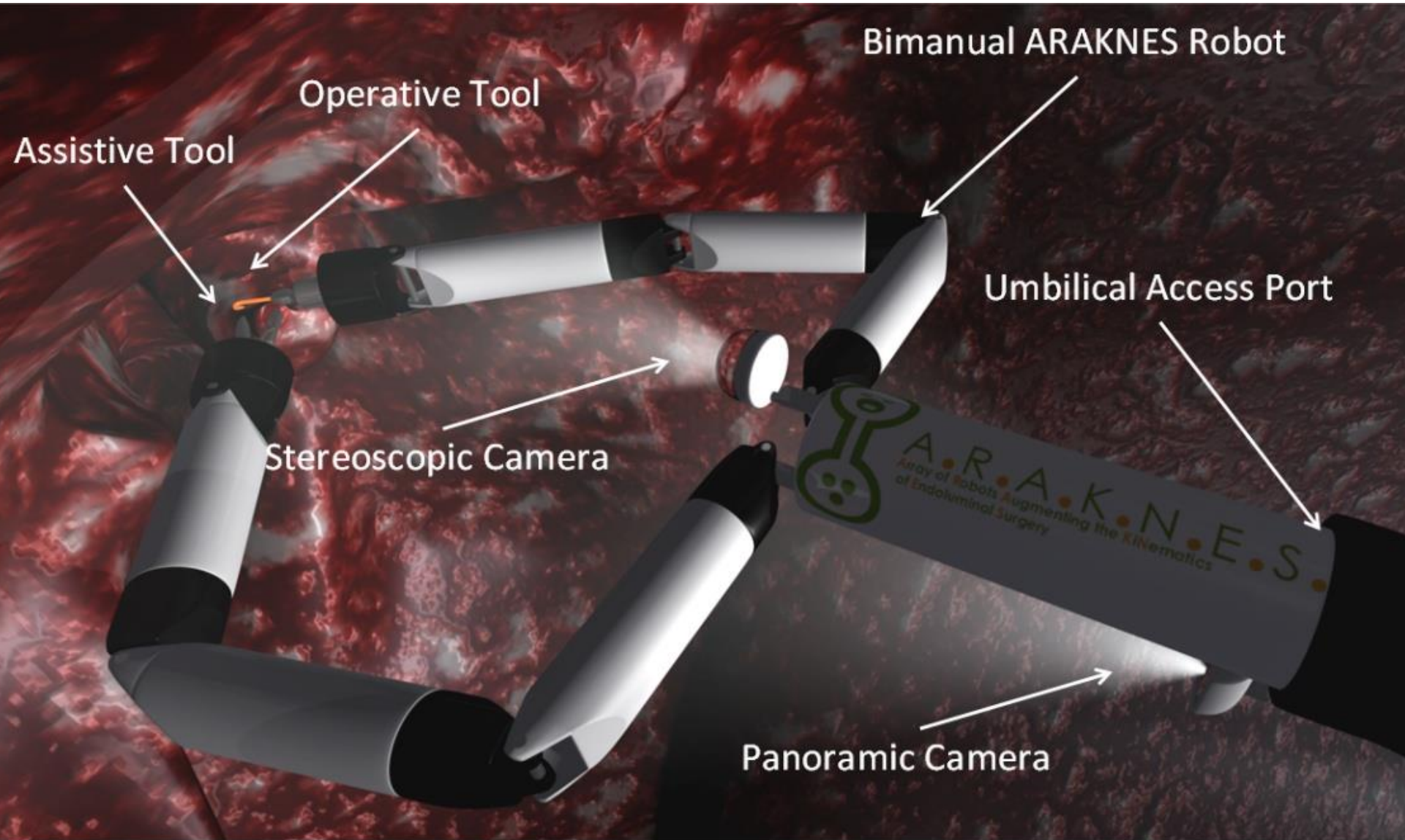
ARAKNES (Array of Robots Augmenting the KiNematics of Endoluminal Surgery) EU Project (2008-2012)



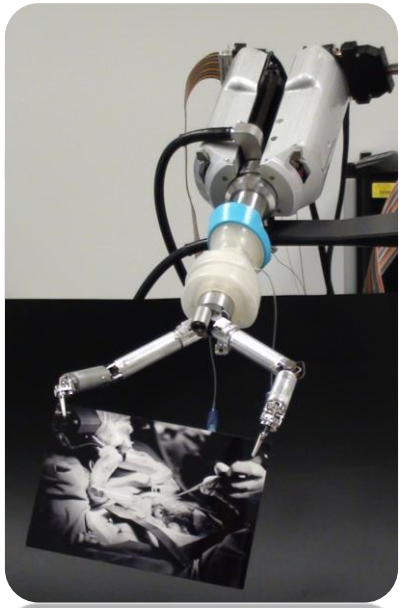
The ARAKNES Vision: Bringing the Operating Room Inside the Patient



SPRINT (Single-Port lapaRoscopy bImaNual roboT) robot

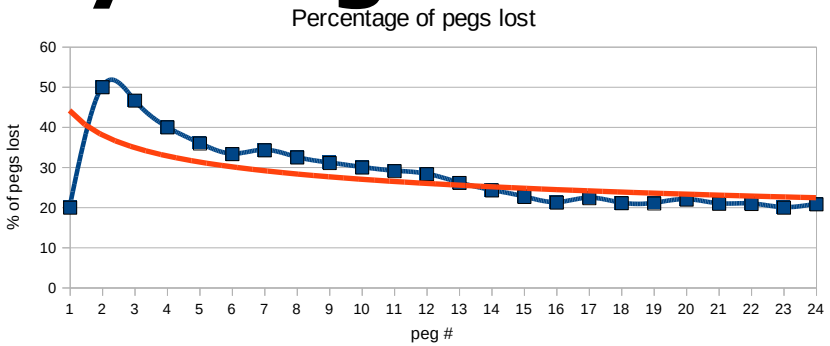


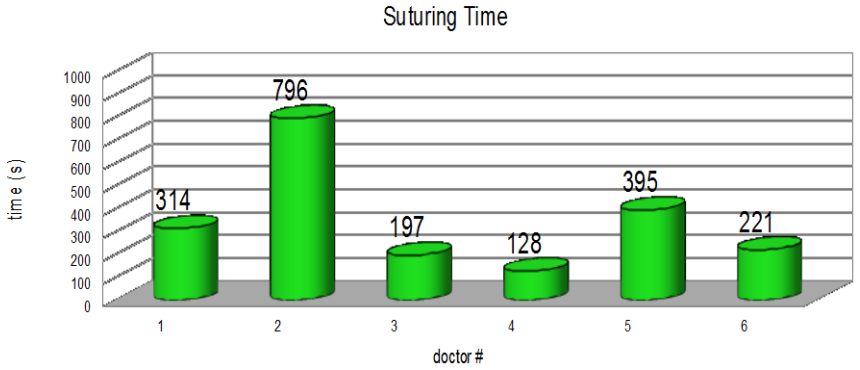
System Delivery Through the Introducer



The SPRINT introducer enables simple changes of tools and the insertion of additional sensors

Characterization by Surgeons





Peg Transfer Task

Suturing Task

SURGEON Background	1	2	3	4	5	6
AGE	46	49	37	51	70	47
SPECIALIZATION	General Surgery	Urology	General Surgery	General Surgery	Laparoscopic Surgery	Gynecology
# OF YEARS OF EXPERIENCE	21	20	12	25	>30	20
EXPERIENCE WITH ROBOTIC ASSISTED LAPAROSCOPY	YES	YES	YES	YES	YES	YES
EXPERIENCE IN SINGLE PORT LAPAROSCOPY	YES	NO	YES	YES	YES	YES

G. Petroni, M. Niccolini, A. Menciassi, P. Dario, A. Cuschieri, *A novel intracorporeal assembling robotic system for single-port laparoscopic surgery,* Surgical Endoscopy, 2012

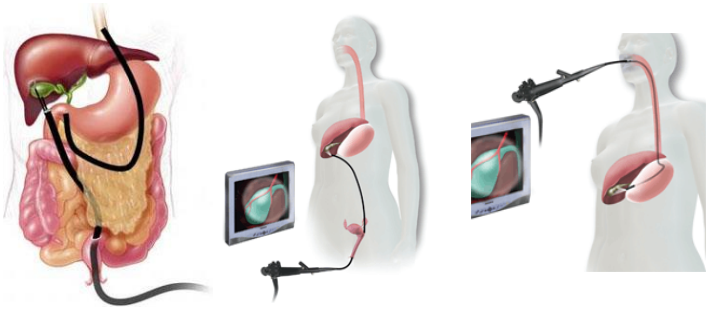
Scuola Superiore Sant'Anna

SPRINT Robot: In-Vivo Tests

G. Petroni, M. Niccolini, S. Caccavaro, C. Quaglia, A. Menciassi, S. Schostek, G. Basili, O. Goletti, M. Schurr, P. Dario, *A novel robotic system for single-port laparoscopic surgery: preliminary experience,* Surgical Endoscopy, 2012

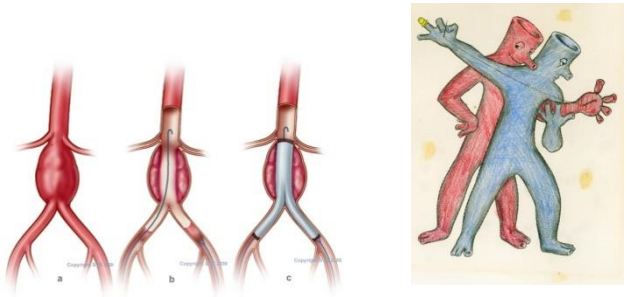
The Quest for Miniaturization

ABDOMINAL SURGERY



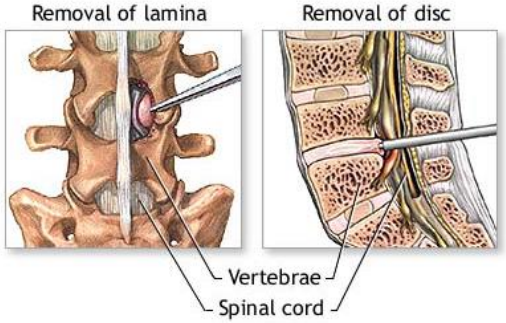
NOTES (Natural Orifice Transluminal Surgery) SURGERY
Reaching the target (esophagus diameter about 14 mm)
Bringing actions to the target

VASCULAR SURGERY



Challenges in vascular therapy:
Reaching the target (Vascular system diameter: **8 to 5 mm**)
Bringing therapeutic actions to the target

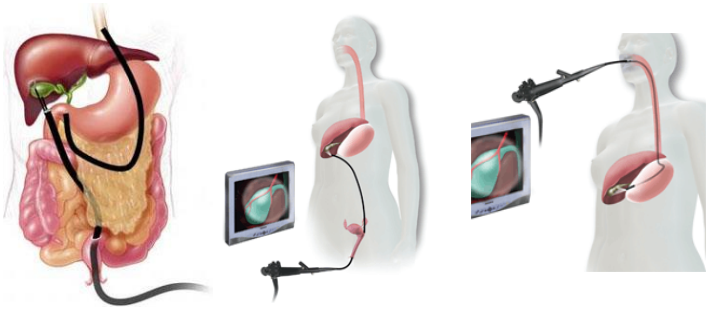
NEURO ENDOSCOPY



Challenges in neuro endoscopy:
Reaching the target (spinal cord diameter: **4 to 1.5 mm**)
Bringing actions to the target

The Quest for Miniaturization

ABDOMINAL SURGERY



NOTES (Natural Orifice Transluminal Surgery) SURGERY
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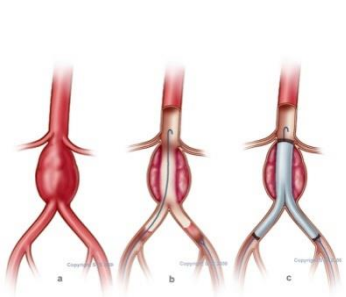
VASCULAR SURGERY



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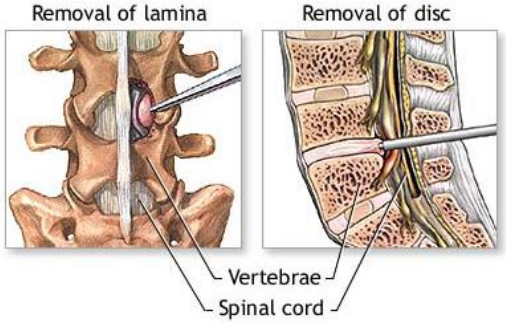


Challenges in neuro endoscopy:
Reaching the target (spinal cord diameter: **4 to 1.5 mm**)
Bringing actions to the target

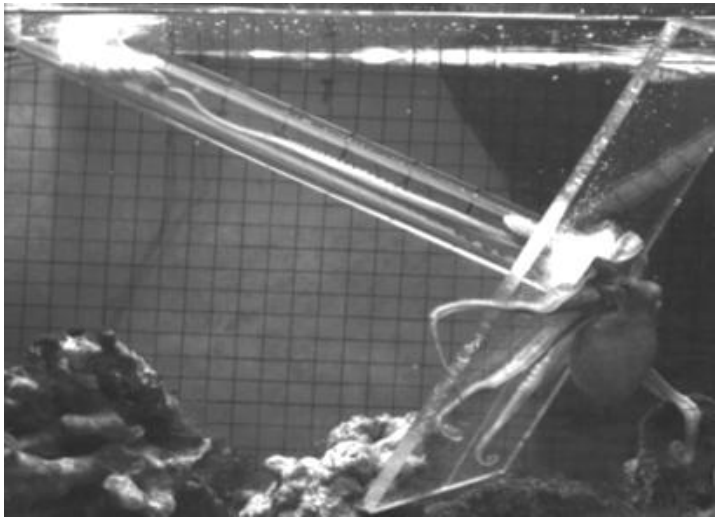
From bio-inspiration to bio-application for endoluminal surgery

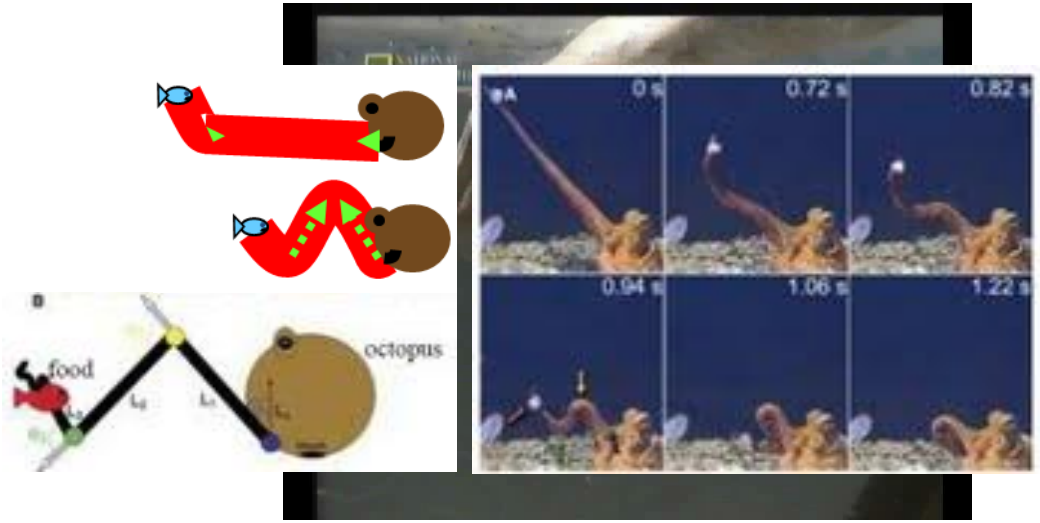
A soft robotic arm that can ***squeeze*** through a standard 12mm diameter Trocar-port, *reconfigure* itself and *stiffen* by hydrostatic actuation to perform compliant force control tasks while facing unexpected situations.

Bioinspiration

Arms Elongation : 70% of arms mean elongation corresponding to 23% of diameter reduction

Fetching movement: from flexible to articulated structure





Margheri L., Mazzolai B., Ponte G., Fiorito G., Dario P., Laschi C. (2010) Methods and tools for the anatomical study and experimental in vivo measurement of the Octopus vulgaris arm for biomimetic design, IEEE RAS / EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob 2010), Tokyo, Japan.

Sumbre G, Fiorito G, Flash T, Hochner B (2006) Octopuses use a human-like strategy to control precise point-to-point arm movements. Curr Biol 16:767-772.

From Biology to Robotics

OCTOPUS proj(OCTOPUS, 012)

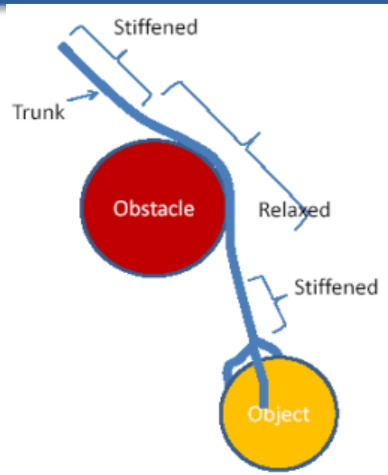
The STIFF-FLOP EU Project

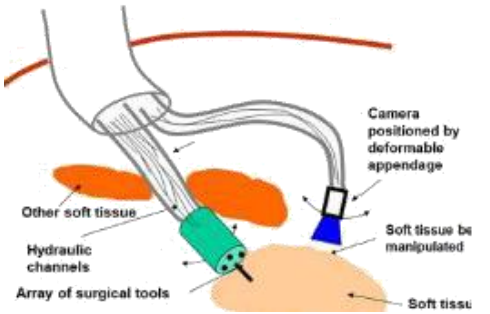
EUROPEAN COMMISSION
European Research Area

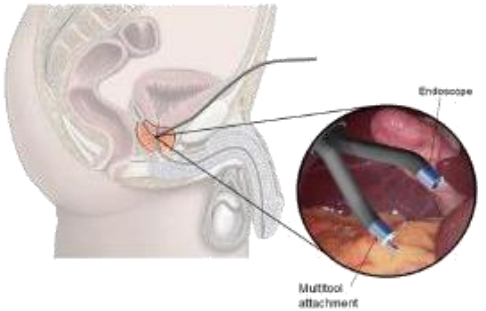
SEVENTH FRAMEWORK PROGRAMME

STIFF-FLOP
STIFFness controllable Flexible and Le
Manipulator for surgical OPerations

- To use **biological inspiration** to create novel, flexible manipulator structures that are inherently capable **of morphing their state from completely soft to entirely articulated,**
- Distributed tactile/pressure sensing to locally adapt to and compensate for changes in the environment
- To **advance learning and cognitive reasoning in a complete embodiment of a hyper-redundant manipulation** system that experiences and learns from physical interactions with its environment,
- **Novel 3D haptic feedback providing surgeon with a "feel"** for the remote environment
- Developing **cognitive behaviour** by learning from human in the loop







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University of London

THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna

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tecnalia
Tecnalia Research & Innovation

PIAP
Przemysłowy Instytut Automatyki i Pomiarów

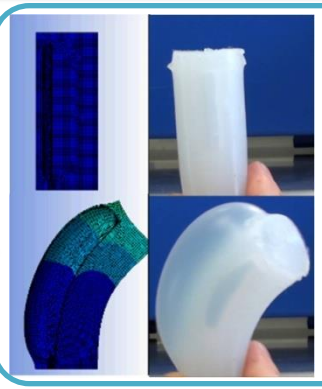
UNIVERSITÀ DEGLI STUDI DI TORINO
ALMA UNIVERSITAS TAURINENSIS

UNIVERSITÄT SIEGEN

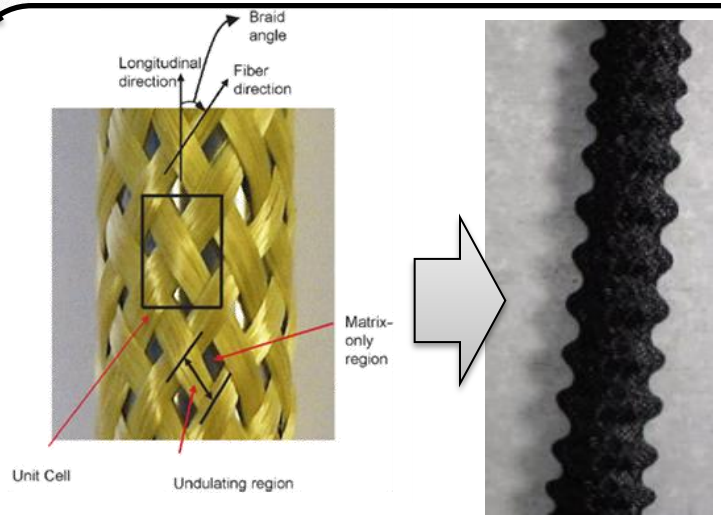
UNIVERSITY OF SURREY

Shadow
Robot Company

Multi-Directional Bending Module

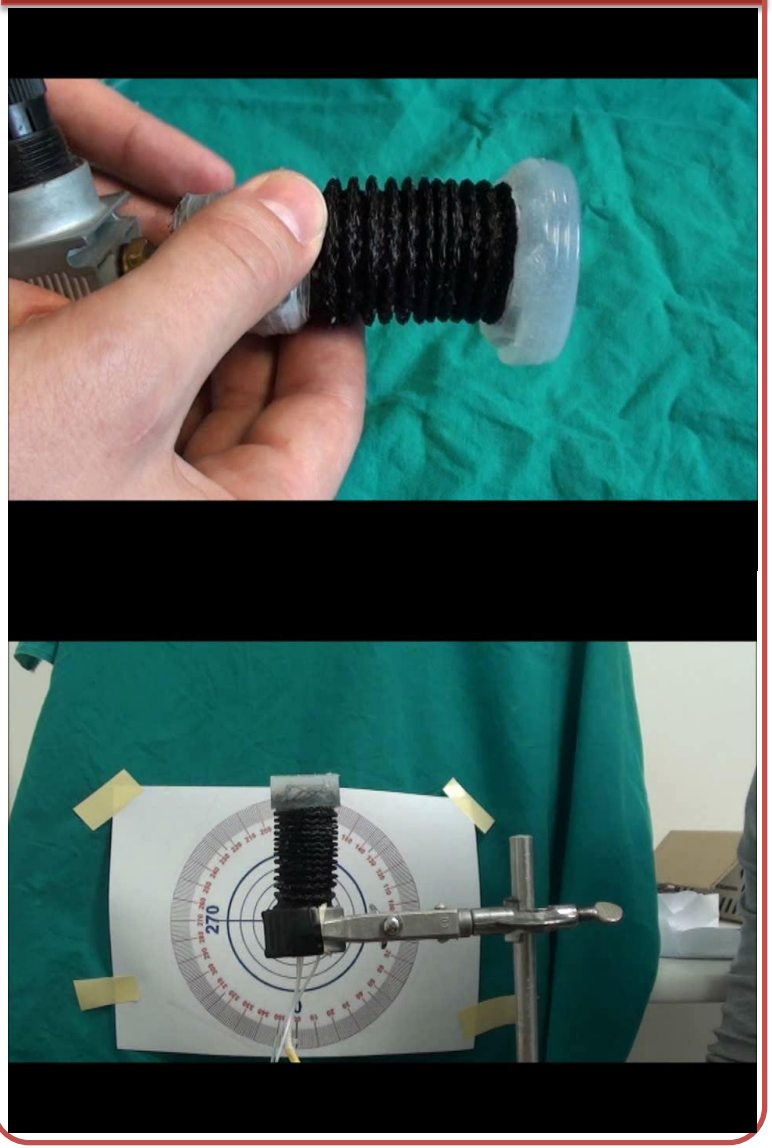


Flexible silicone actuator with three embedded fluidic chambers for multi directional bending



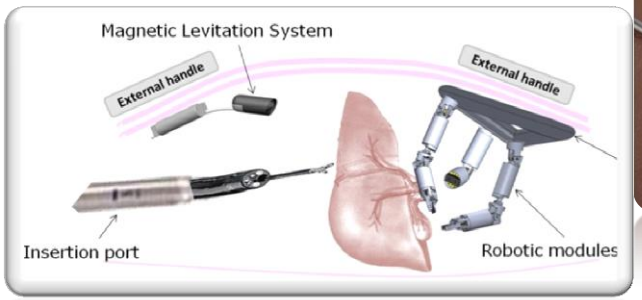
Bellow- shaped braided structure

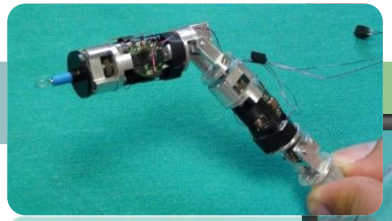
Up to 115° bending, and 66% elongation.



ARAKNES platforms

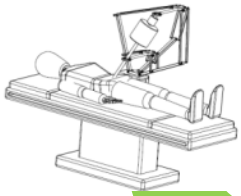
Research Platform (trocar/NOTES access)

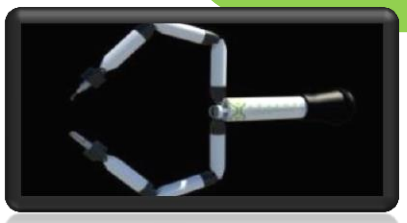


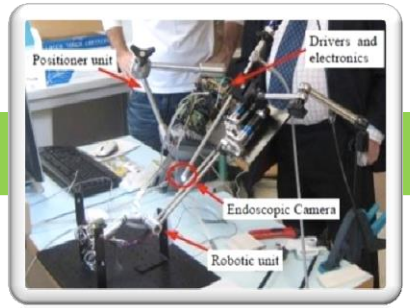


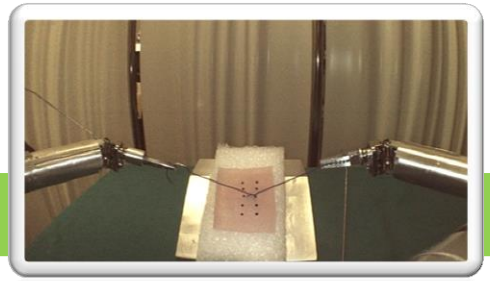
Abdomen by trocar access: D = 10-15 mm

Clinical Platform (umbilical access)



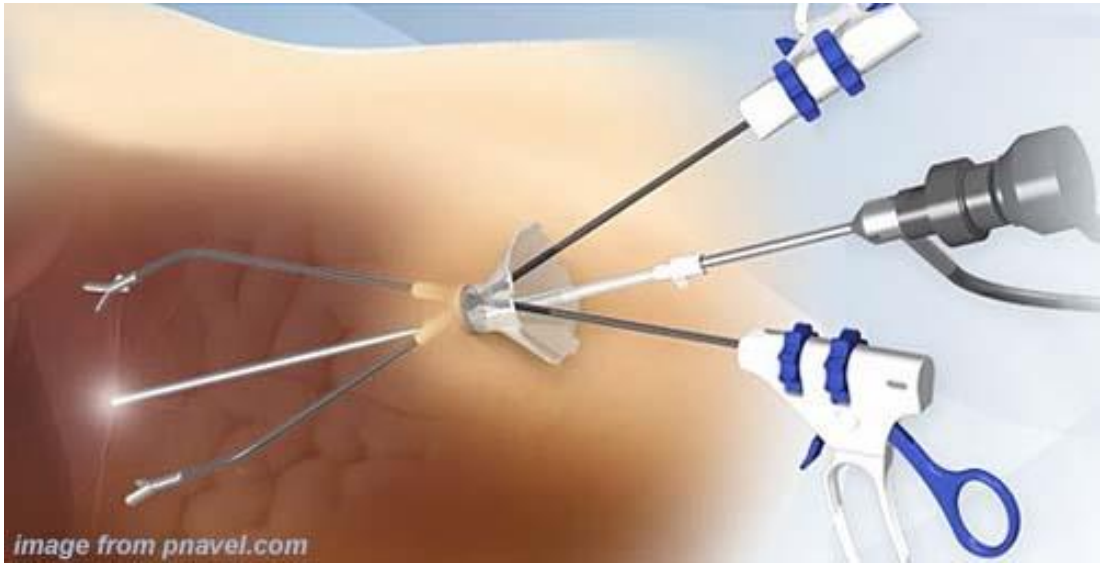




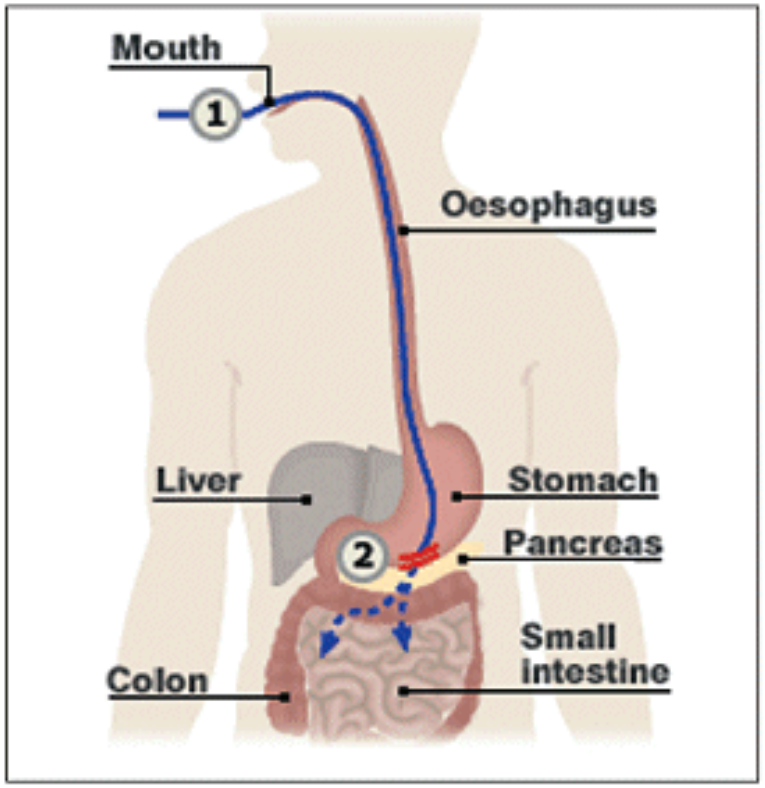


Abdomen by Single Port access: D = 20-32 mm

The Quest for Miniaturization: Endoluminal Robotic Surgery



Single-Port Laparoscopic Surgery



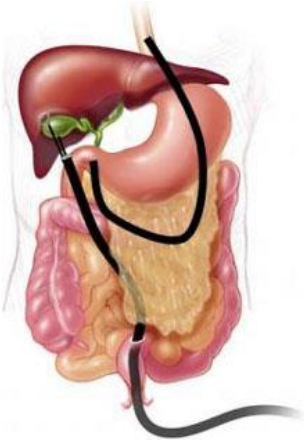
1. The endoscope with incision tools
2. The stomach wall is cut to access the abdominal cavity

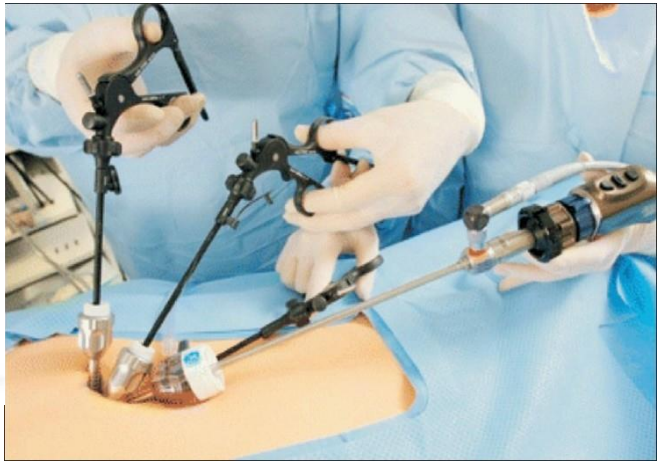
Flexible Endoscopic Surgery (NOTES)

N.O.T.E.S and **Single Port Laparoscopy**: no visible scars!

Open surgery

Abdominal incision **1 year after open surgery**





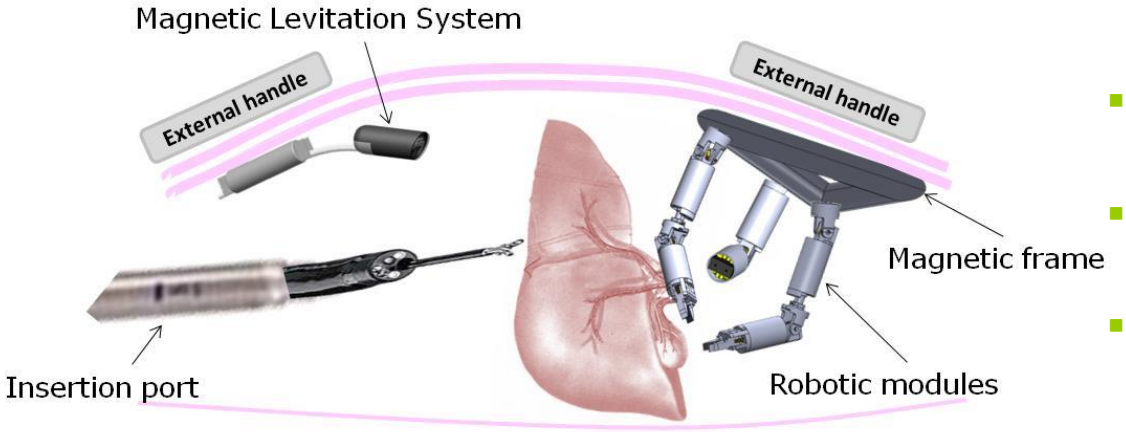
Laparoscopic surgery

Laparoscopic scar after 15 days

Umbilical incision **3 weeks after single-port nephrectomy** (kidney removal) leaves little to no scarring

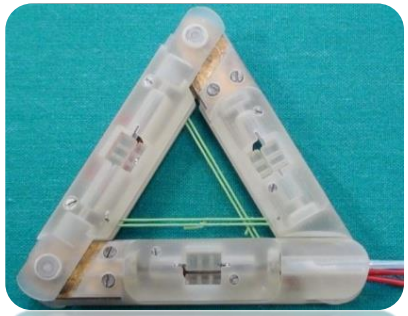
ARAKNES Research Platform: an Overview

ARAKNES Research Platform

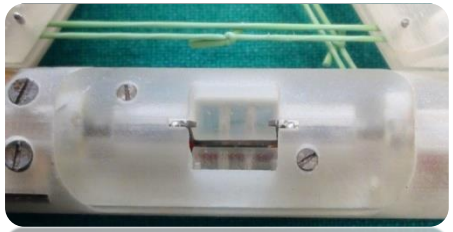


- ***Anchoring frame*** (3 DoFs, length 186 diameter 14)
- ***Docking/Undocking mechanism***
- Modular robotic units
  - **4+EE Dofs Manipulator** (length 80 diameter 12)
  - **2 DoFs Retractor** (length 48 diameter 12)
  - **2 DoFs Stereoscopic Camera** (length 60 diameter 12)
- Magnetic levitation camera ***MLC*** (4 DoFs)

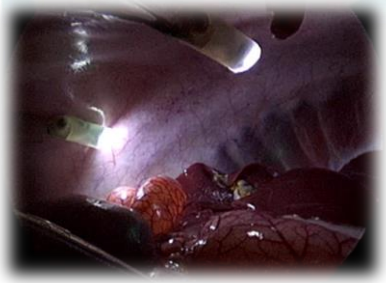
ANCHORING FRAME



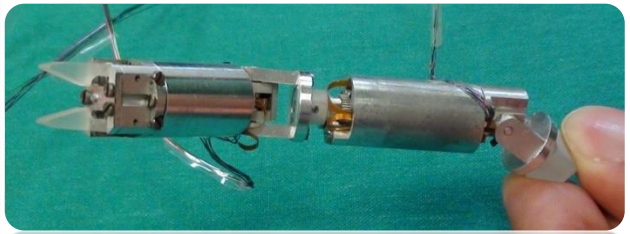
DOCKING/UN-DOCKING MECHANISM

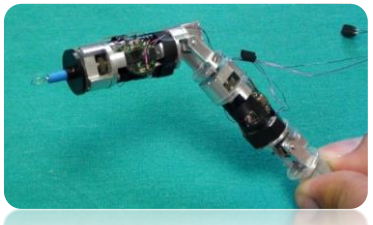


MLC

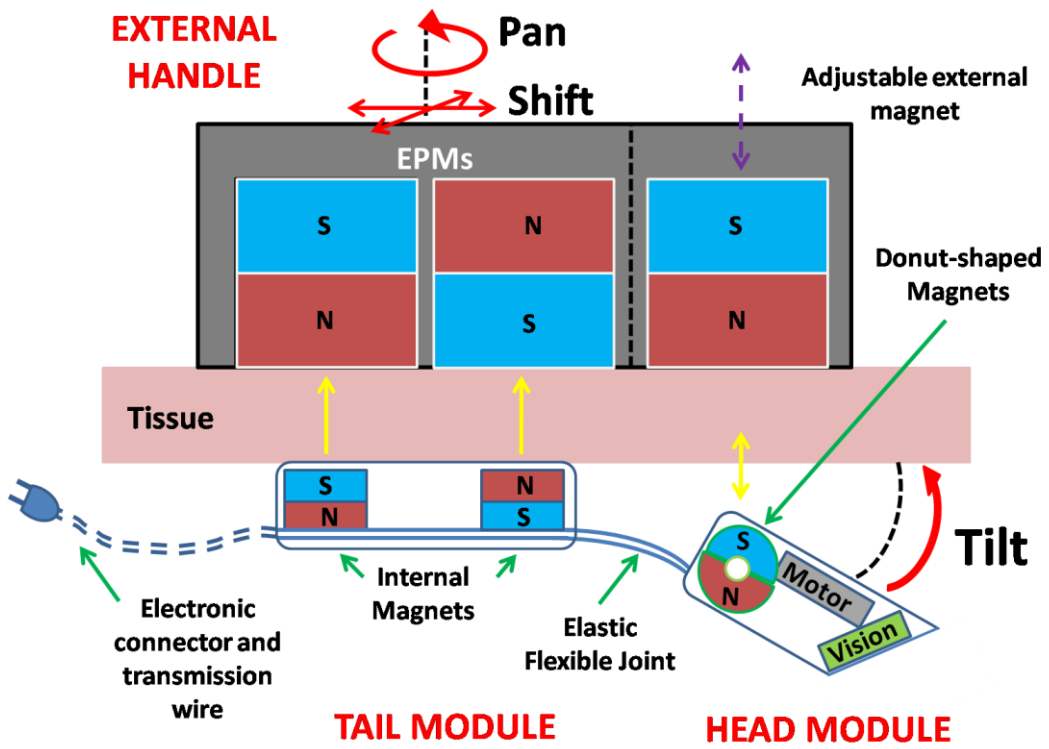


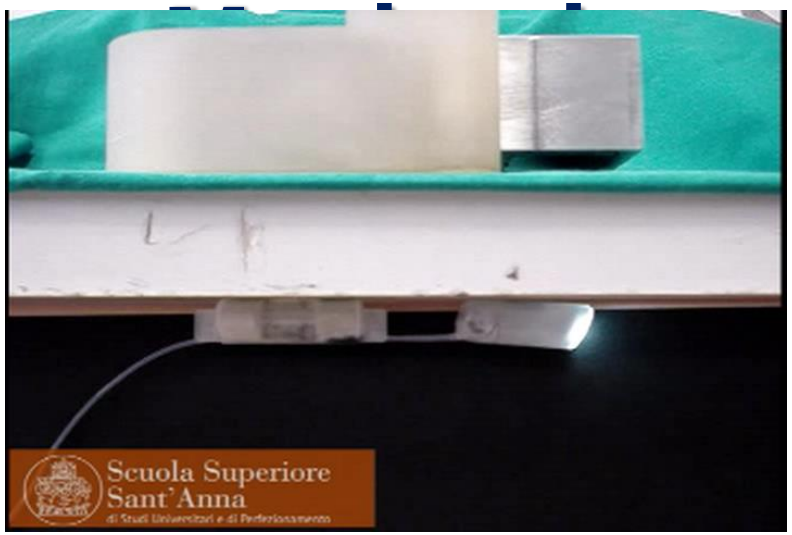
MODULAR ROBOTIC UNITS



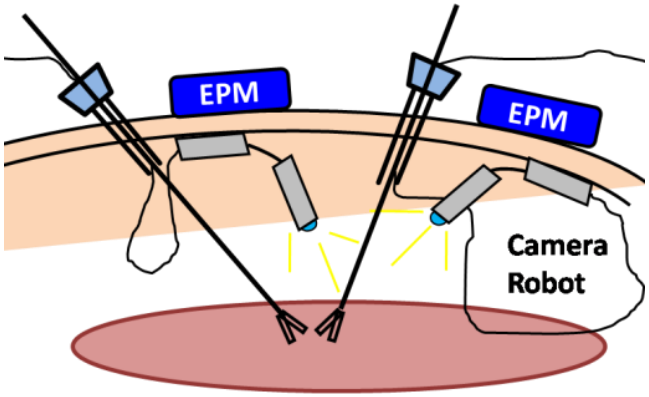


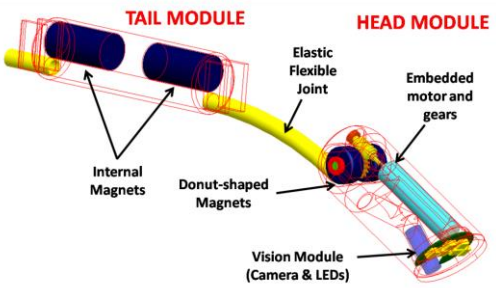
MIM: Magnetic Internal



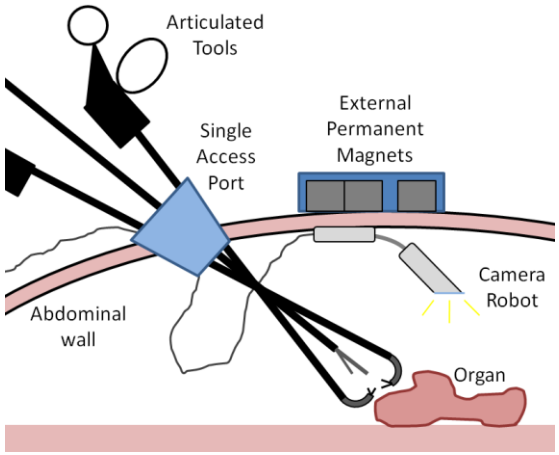


MLS camera enabling two port laparoscopy





Single Port Procedure

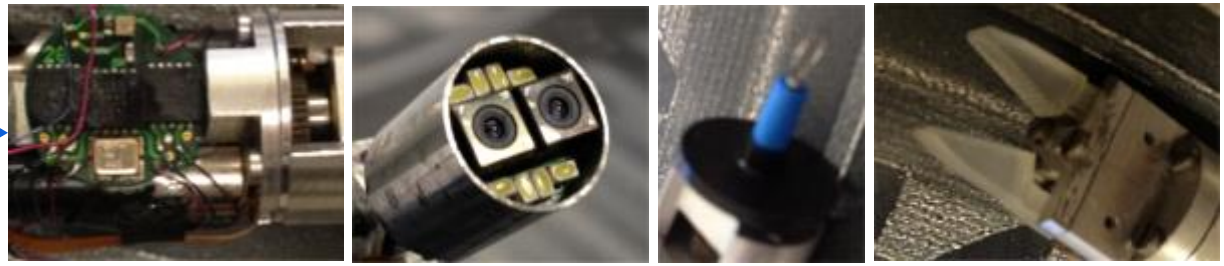


Miniature robotic units

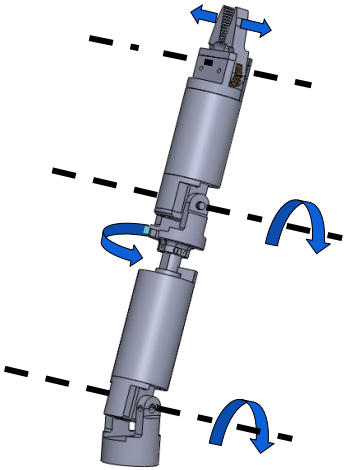
Main function: to perform basic surgical tasks (vision, manipulation, cutting)

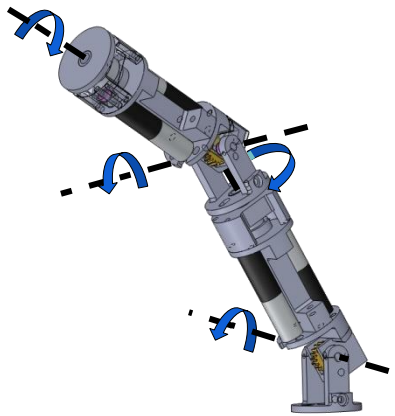
- **Each module can provide 51.3 mNm pitch torque and 10.15 rotation torque (that corresponds to 0.65 N a the tip of the manipulator)**

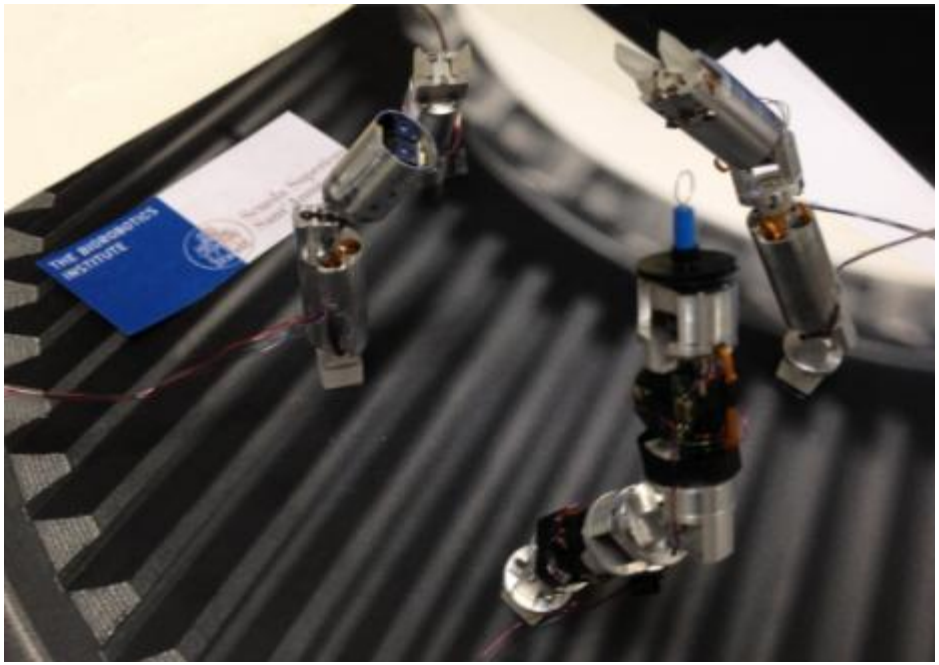
Camera robot (2 DoFs)



Electronics for motors control and wireless communication



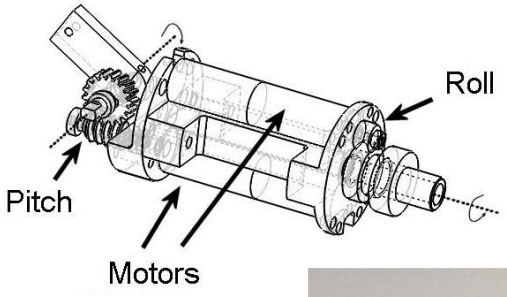


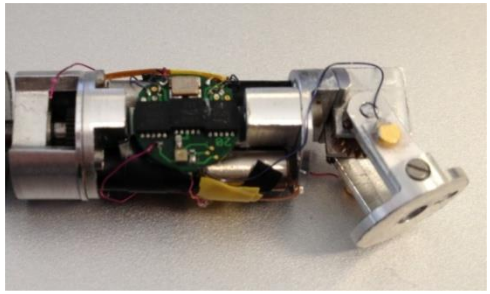


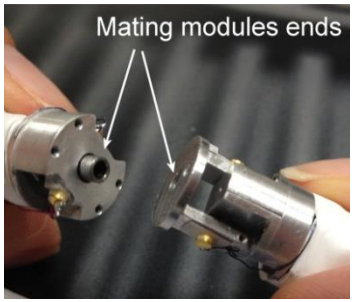
Manipulator and Electro-cutter robots

Each module has independent electronics, actuators, mechanisms, controller and dedicated powering from the anchoring frame

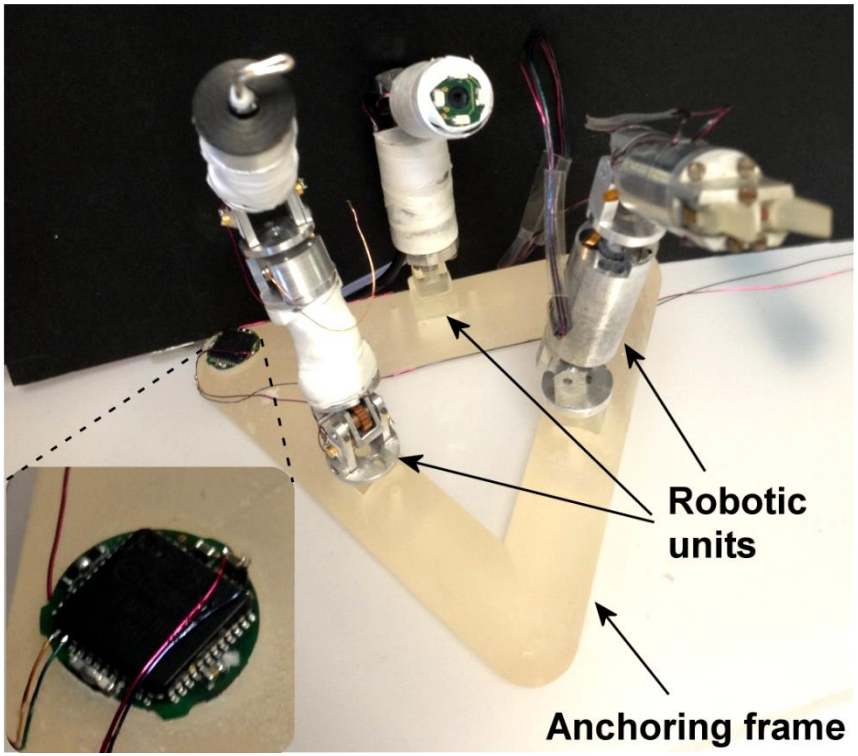
- 12 mm diameter, 30 mm length
- 2 DOF – 2 Brushless motors 4 mm diameter (Namiki, Japan)
- Roll motion – spur gears
- Pitch motion – worm and helical gear
- Measured pitch torque:51.3 mNm, speed 90 deg/s
- Measured rotation torque:10.15 mNm, speed 190 deg/s

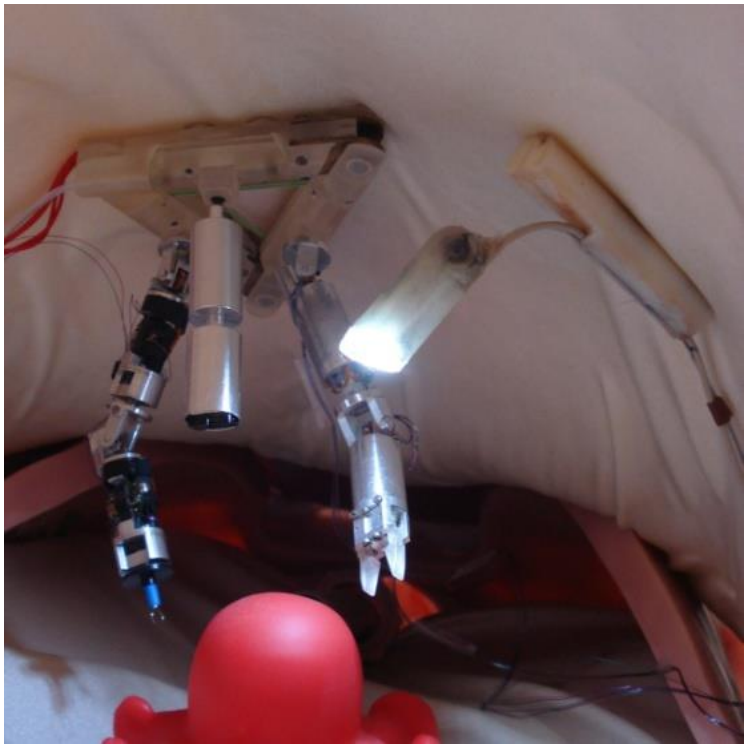


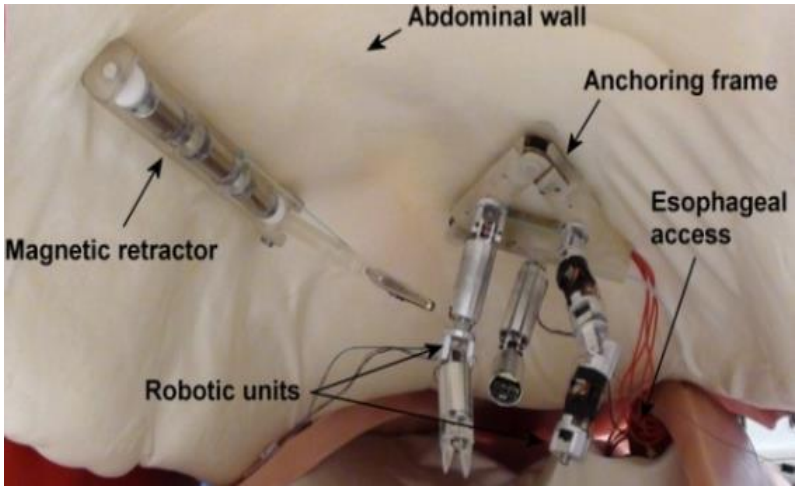




Experiments

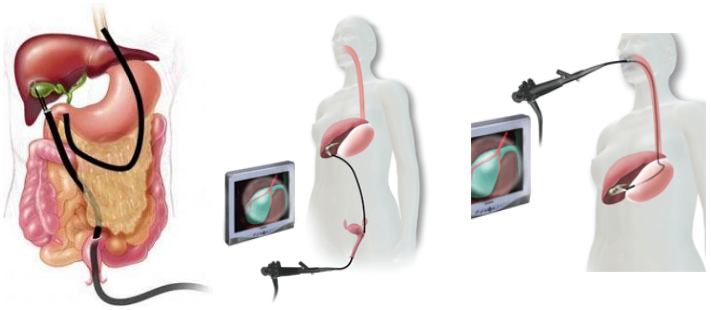






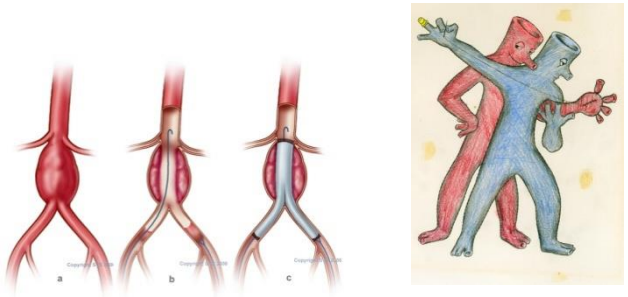
The Quest for Miniaturization

ABDOMINAL SURGERY



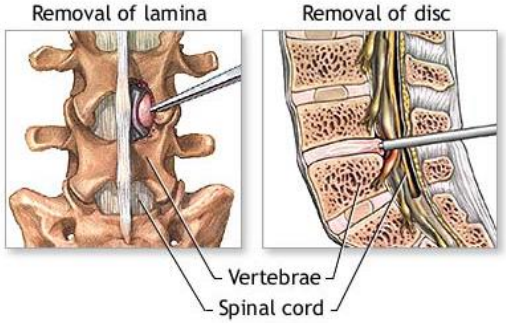
NOTES (Natural Orifice Transluminal Surgery) SURGERY
Reaching the target (esophagus diameter about 14 mm)
Bringing actions to the target

VASCULAR SURGERY



Challenges in vascular therapy:
Reaching the target (Vascular system diameter: **8 to 5 mm**)
Bringing therapeutic actions to the target

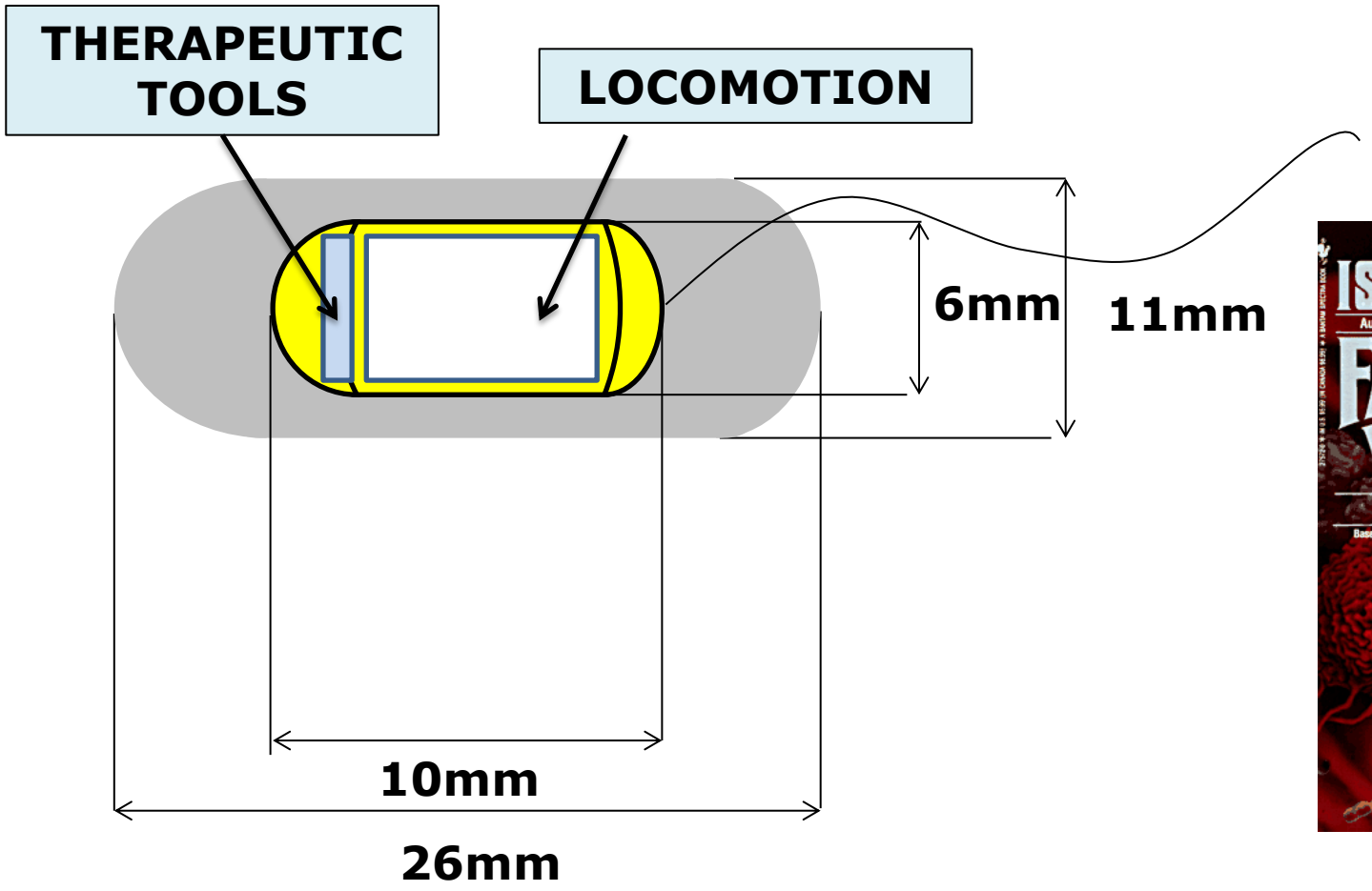
NEURO ENDOSCOPY

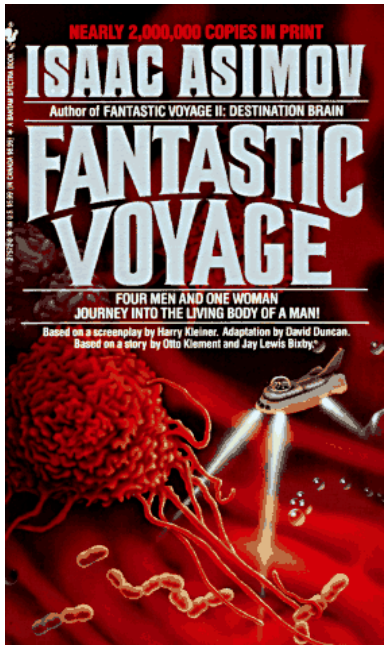


Challenges in neuro endoscopy:
Reaching the target (spinal cord diameter: **4 to 1.5 mm**)
Bringing actions to the target

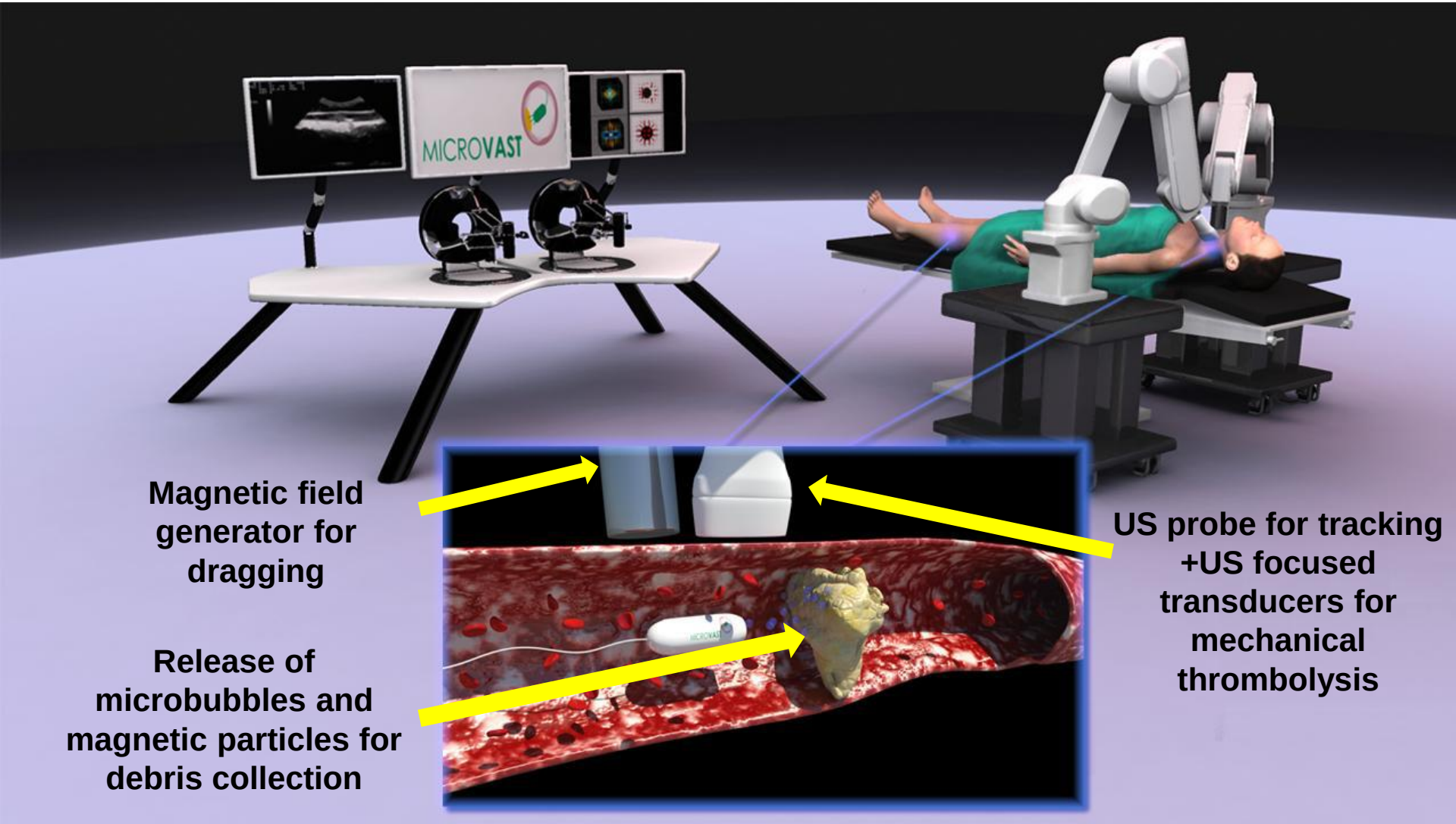
Case study #6. The GRAND CHALLENGE: from the gastrointestinal tract to the vascular system

Vascular system
Ø = 8 to 6 mm



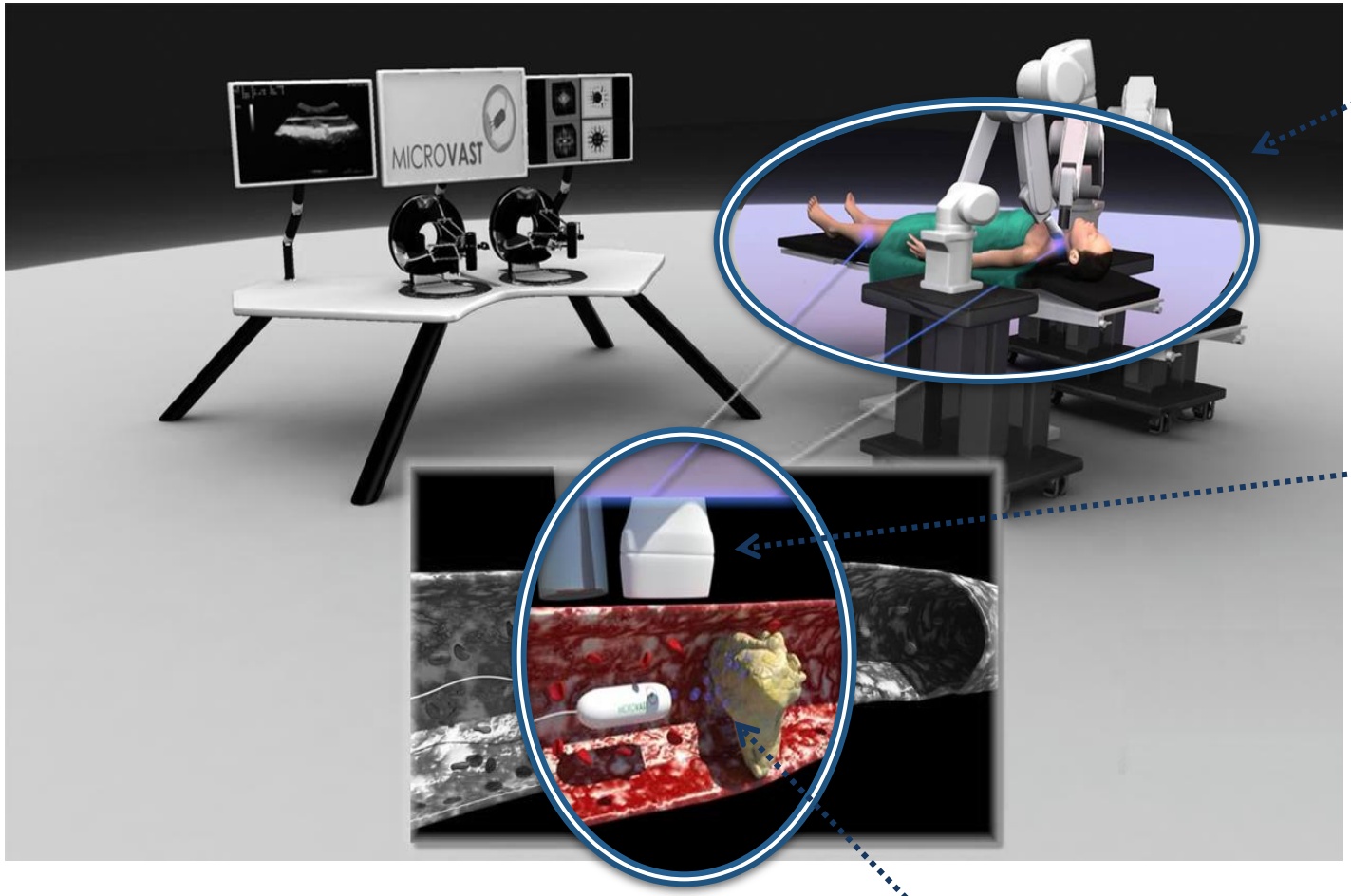


A computer-assisted robotic platform for soft-wired therapy of vascular obstructions



The MicroVast Platform

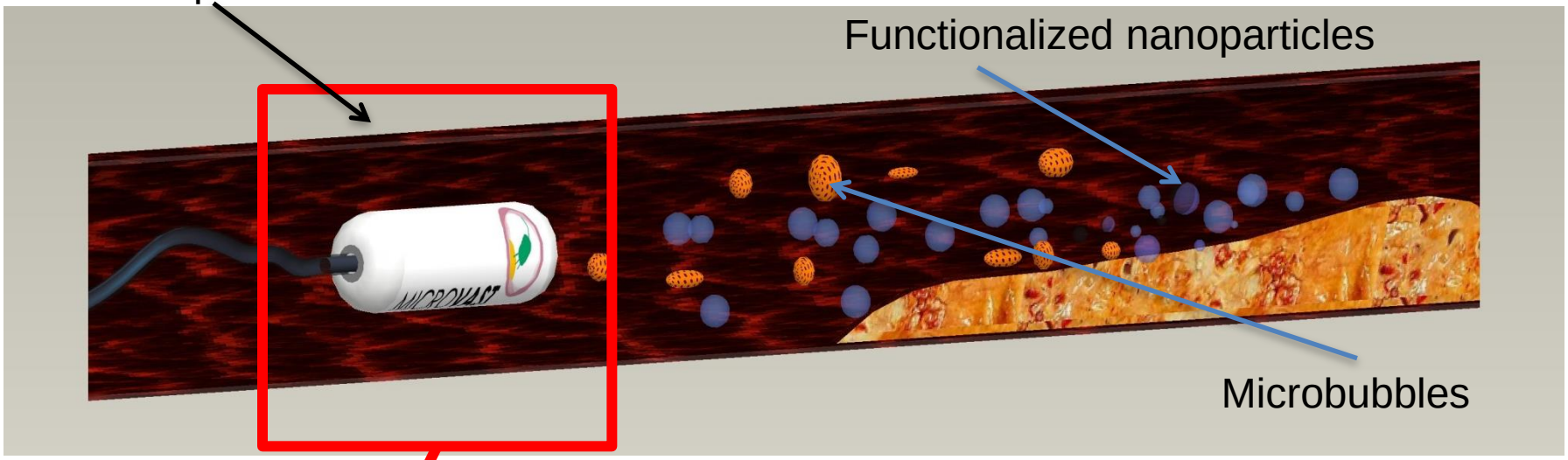
Navigation module: **External robots** holding a permanent magnet and a diagnostic US probe.

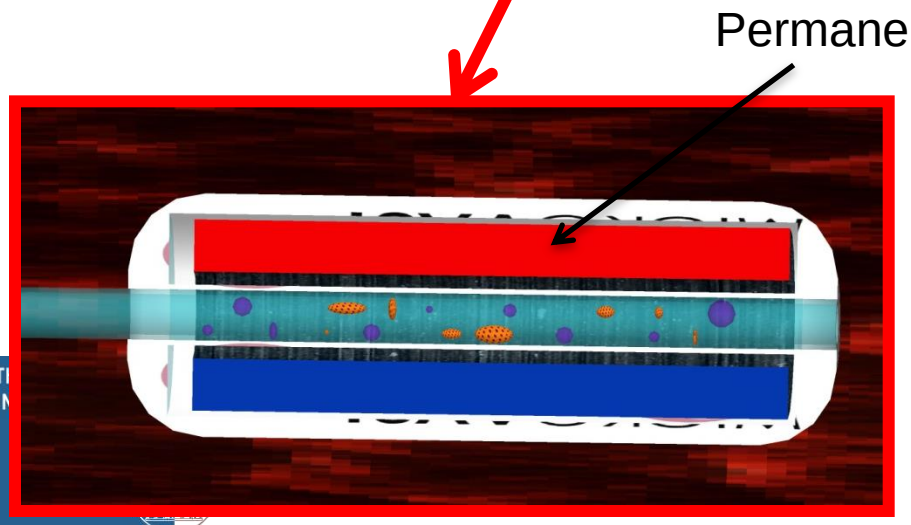


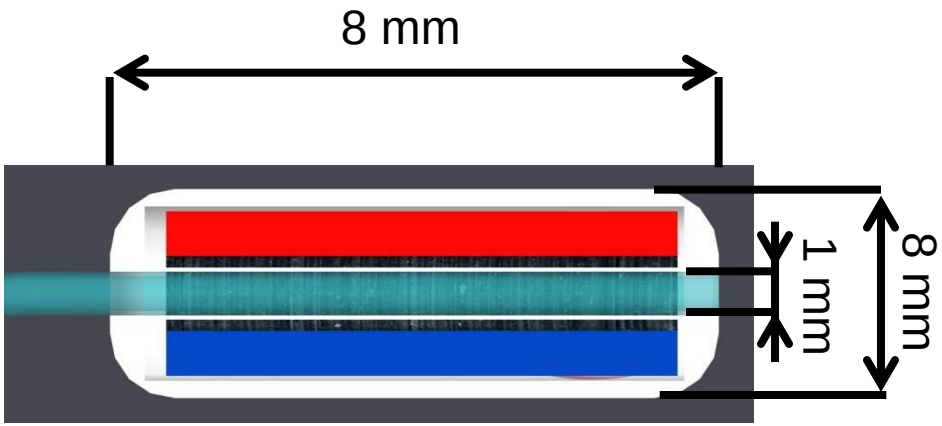
Therapeutic module: Focused US thrombolysis enhanced by microbubbles released by means of a magnetic internal mechanism

Debris collection module: Binding of magnetic particles to thrombus for collection and retrieval of debris

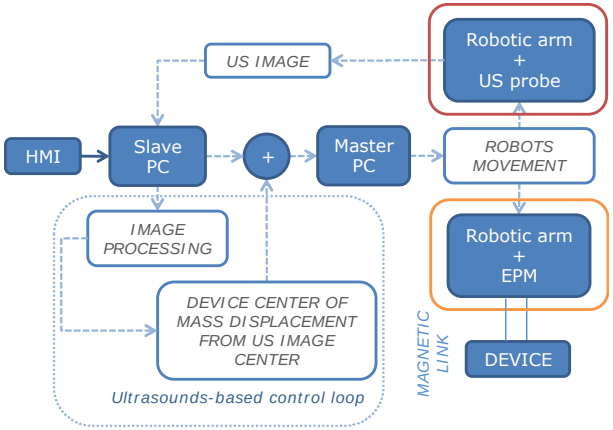
The MicroVast Robot Carrier



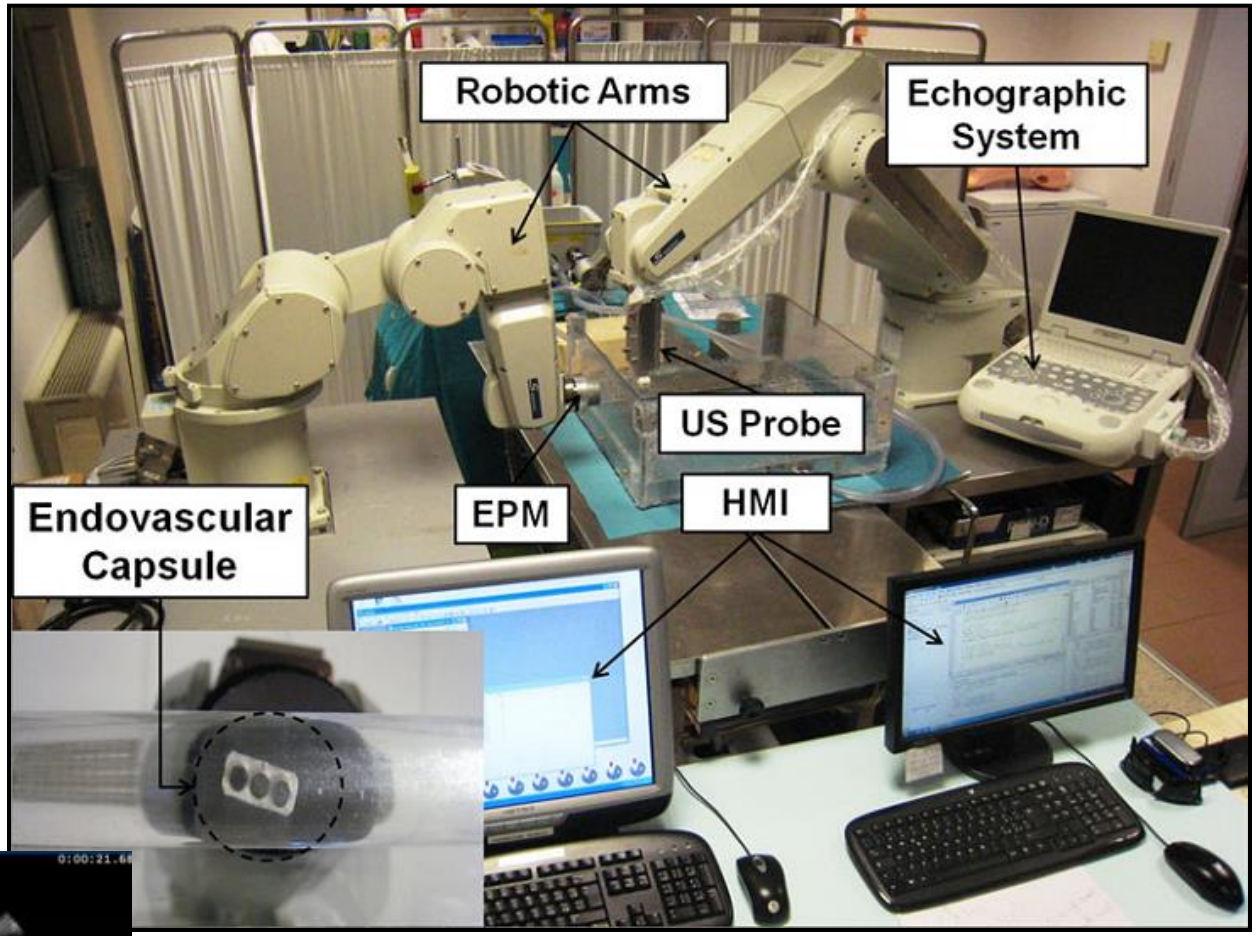


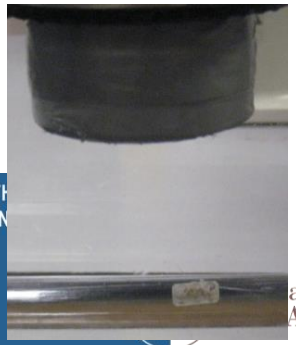


Navigation Module: System Overview



Navigation module:
External robot holding a permanent magnet and a diagnostic US probe



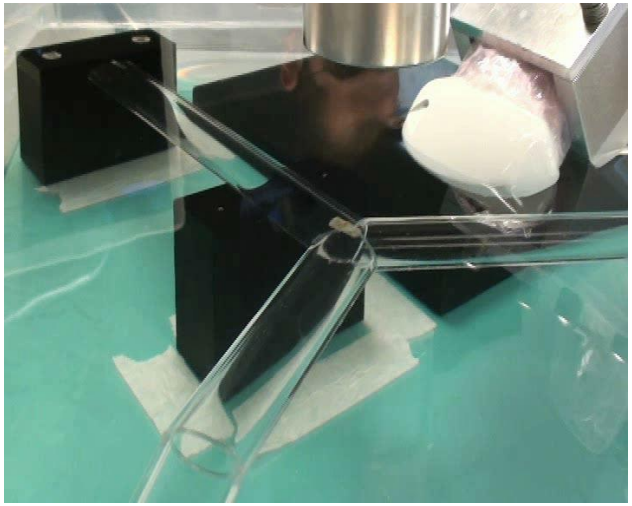


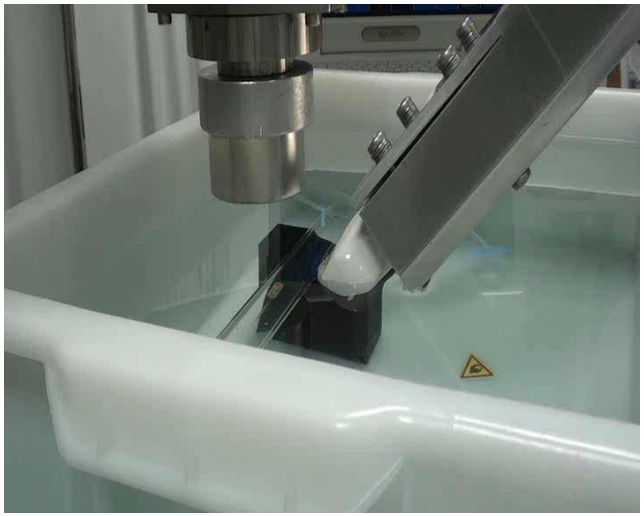
EPM: External Permanent Magnet - HMI: Human Machine Interface

Navigation Module: in-vitro test

In-vitro experimental test of the MicroVast platform on a cardiovascular ecographic compatible phantom with US-based tracking algorithm

In-vitro 3D tracking algorithm validation: 3D model based on the combination of the US-based tracking algorithm and the pre-operative path registration





Navigation Module: ex-vivo test

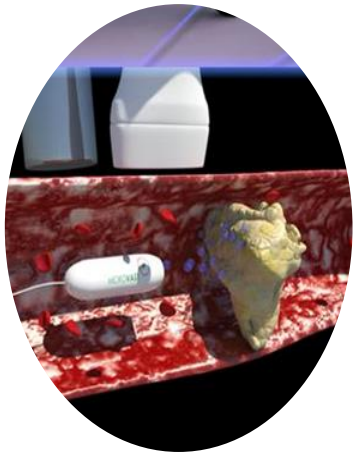
Ex-vivo MicroVast platform validation on an explanted aortic vessel– combination of US-based tracking algorithm and pre-operative path registration for autonomous locomotion.

The US-based algorithm control loop is processed with an average time of 13 ms. An average number of 12 features were extracted from each frame of the segmented endoluminal capsule

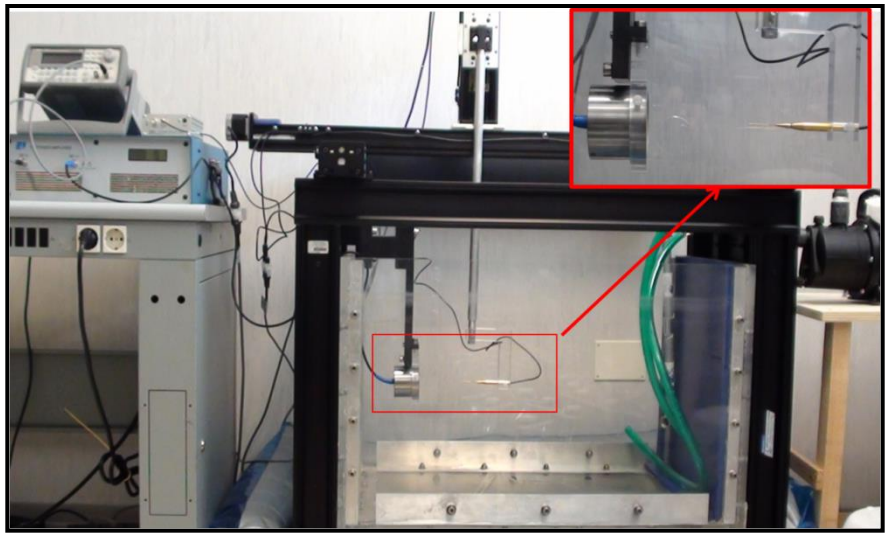
Therapy Module: Set-up

High Intensity Focused Ultrasound (HIFU) Thrombolysis (dissolution of a blood clot):

Therapeutic module: Focused US thrombolysis enhanced by microbubbles released by means of a magnetic internal mechanism



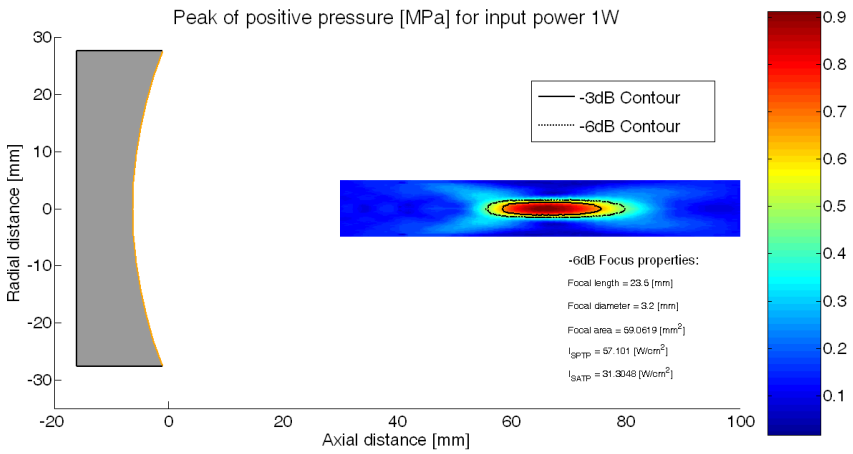
- US can transmit high levels of energy through the body and its effectiveness in attacking thrombi has been demonstrated in several works *
- However, clinical application is **still** limited mainly because of lack of information on involved phenomena, optimized parameters and safety for healthy tissues
- Cavitation is credited to play a major role in the dissolution process; addiction of micro-bubbles can augment treatment efficacy

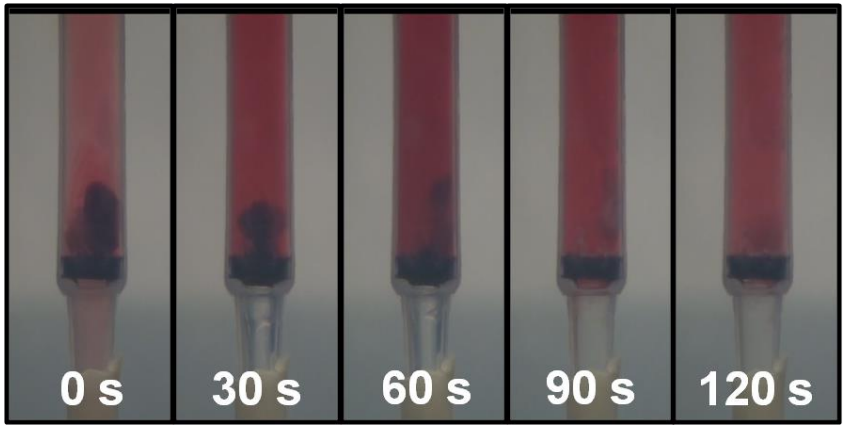


* R. Medel et al., "Sonothrombolysis: an emerging modality for the management of stroke" , Neurosurgery,65(5),2009.

Therapy module - High Intensity Focused Ultrasound Thrombolysis: Results

Clots can be dissolved at high power (65W) in approximately 2 minutes





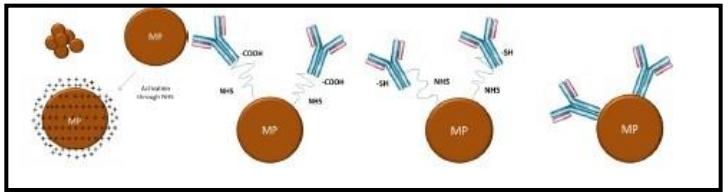
Velocity 4X

Freq. 1MHz - Power 65W - Pulse Length 450μs - Duty Cycle 1:10 - Flow rate 2ml/min

Debris collection: Set-up & Validation

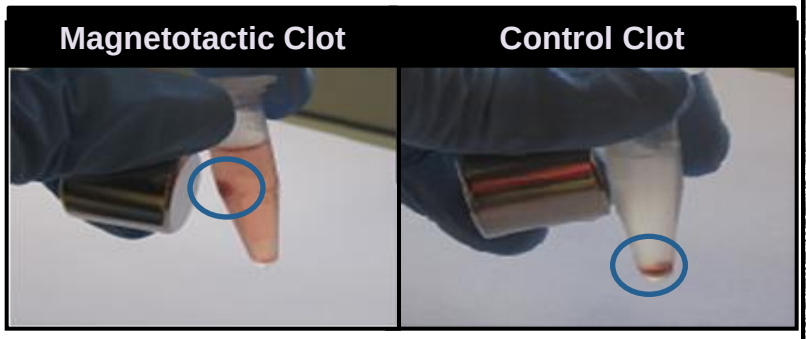
❑ Preparation technique

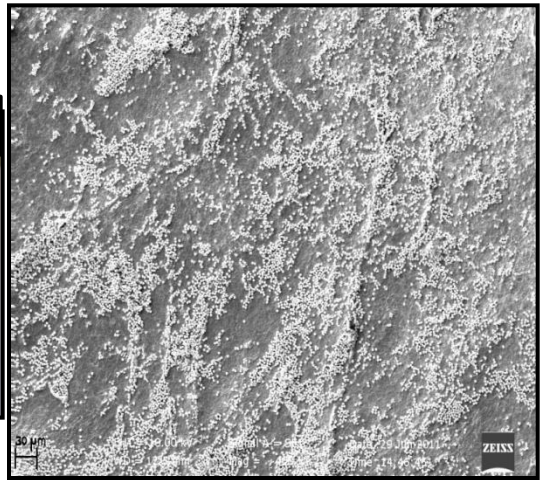
- ✓ Magnetic particles binding to antibody
- ✓ Electrostatic & clot antigen binding to magnetic particles (MPs)

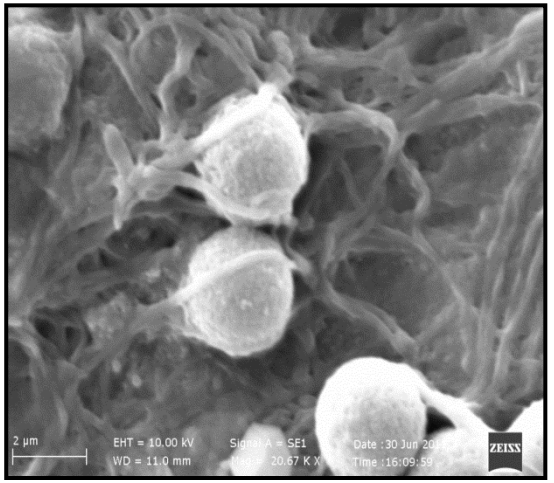


Debris collection module: Binding of magnetic particles to thrombus for collection and retrieval of debris.

❑ Qualitative assessment of obtained magnetotactic clot





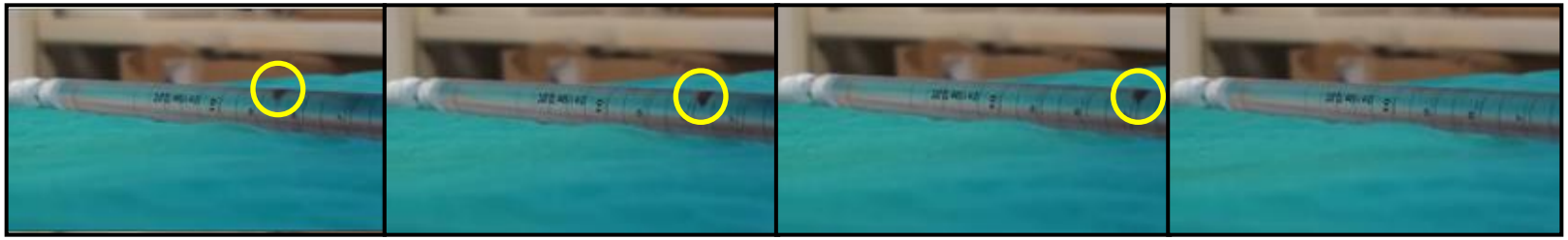


Debris Collection: Set-up & Results

❑ Magnetotactic clot dragging

❑ Magnetotactic Clot Dragged in a fluidic channel.

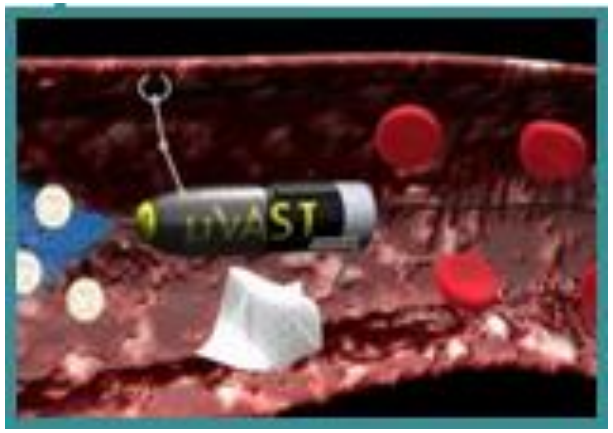
Results: Magnetotactic clot dragged inside a fluidic channel by means of External Permanent Magnet

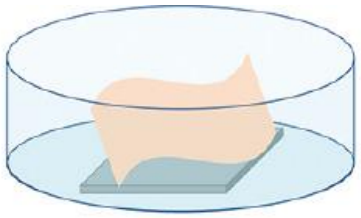


Khorami Llewellyn et.al "Magnetic Dragging of Vascular Obstructions by Means of Electrostatic and Antibody Binding", ICRA 2012

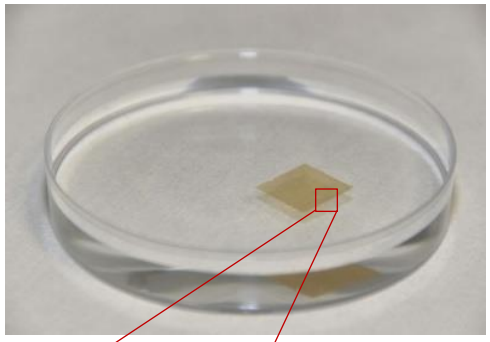
Polymer nanofilms for intravascular applications

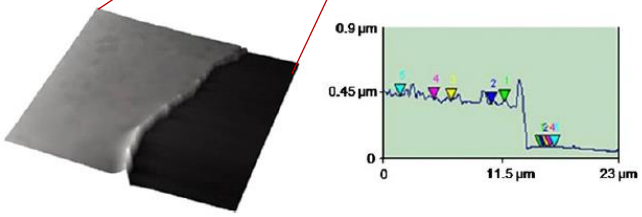
Challenge: development and positioning of functionalized nanostructured polymeric membranes to be used as devices for drug delivery and/or physical stimulation





Release in water

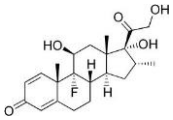




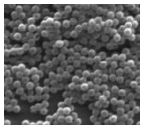
Thickness: from ~ 50 nm to ~ 500 nm

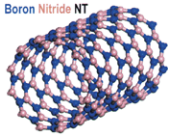
Inclusion of specific drugs or active nanoparticles in the different layers of the polymeric matrix

Anti-restenosis drugs (e.g. Dexamethasone)



Magnetic or piezoelectric nanoparticles





Ricotti *et al. Biomed Microdev.* 12: 809 (2010)

Ricotti *et al. Biomed Mat.* 6: 031001 (2011)

Pensabene *et al. Acta Biomater.* 7: 2883 (2011)

Mattoli *et al. Proc Comp Sci.* 7: 337 (2011)

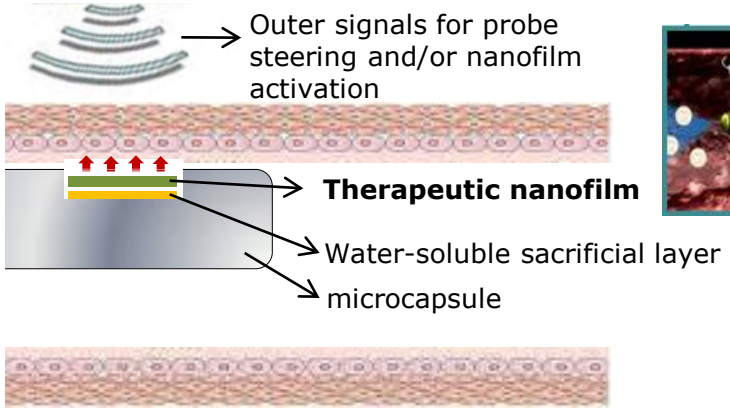
Polymer nanofilms for intravascular applications

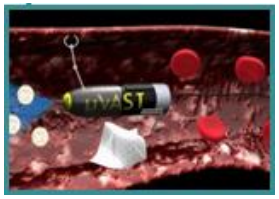
Biodegradable nanofilms able to stably adhere to the artery internal wall and to release there therapeutic agents in a temporized (or triggerable) way would accomplish both the functions of restenosis prevention and wall regeneration.

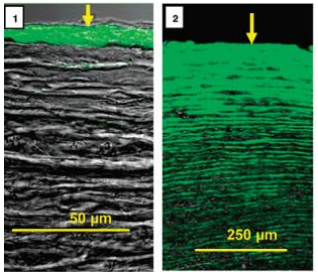
Critical issues:

- controlled and safe film positioning

- long-term film stability in dynamic flow conditions







Damaged wall cells: negatively charged

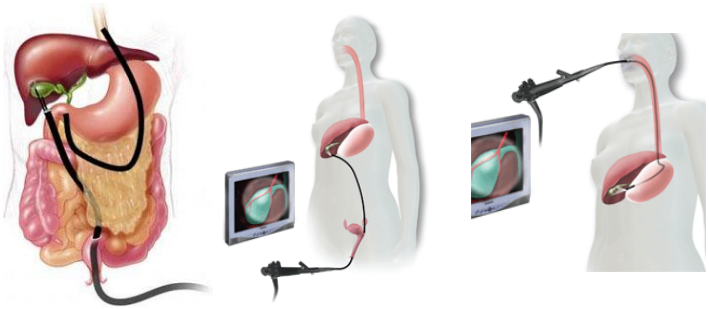
Multilayer nanofilms: positively charged

Electrostatic-mediated stability

Lower nanofilm thickness ➡ Higher mechanical stability

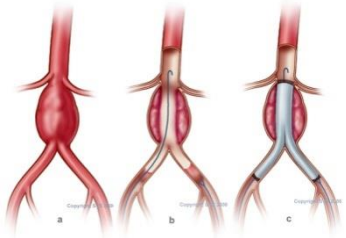
The Quest for Miniaturization

ABDOMINAL SURGERY



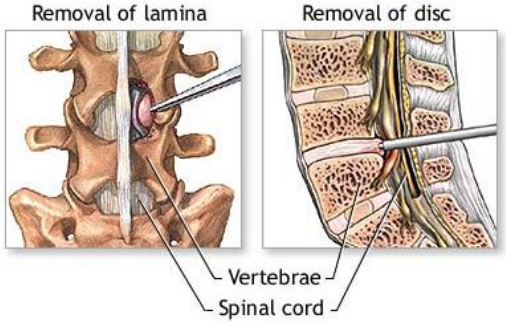
NOTES (Natural Orifice Transluminal Surgery) SURGERY
Reaching the target (esophagus diameter about 14 mm)
Bringing actions to the target

VASCULAR SURGERY



Challenges in vascular therapy:
Reaching the target (Vascular system diameter: **8 to 5 mm**)
Bringing therapeutic actions to the target

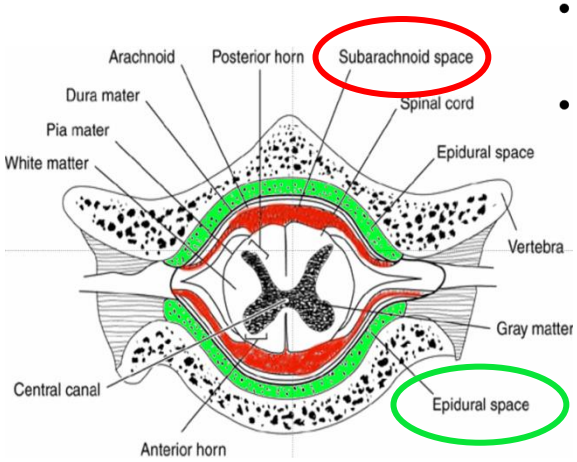
NEURO ENDOSCOPY



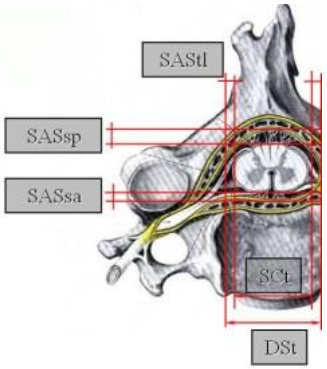
Challenges in neuro endoscopy:
Reaching the target (spinal cord diameter: **4 to 1.5 mm**)
Bringing actions to the target

Neuroendoscopy of the spinal cord

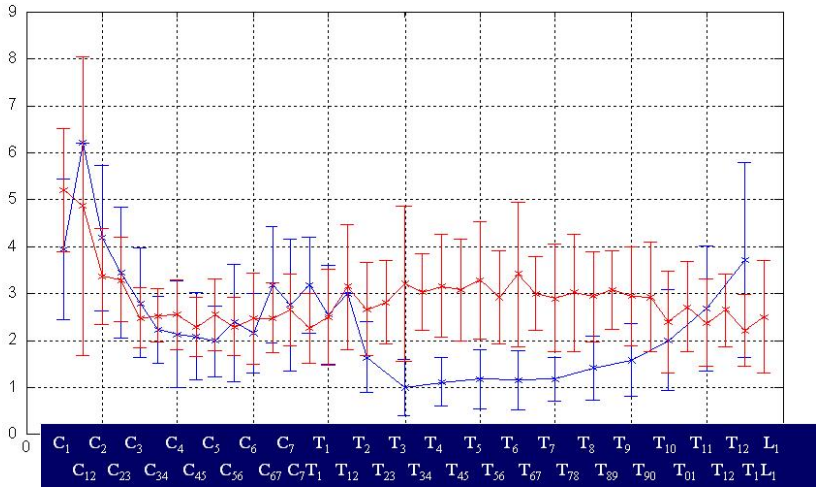
- **Diseases of CNS** can be particularly **devastating** because of limited intrinsic regenerative capacities and **currently** available **therapies** provide **limited functional recovery**;
- Owing to the low penetration rate, it is difficult using **systemic delivery** to achieve the suitable localized drug concentration

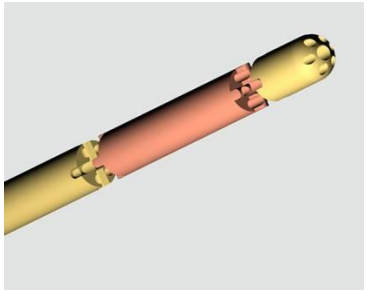


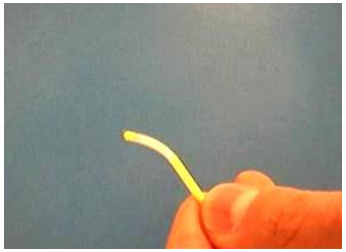
- The medium is suitable for navigation (Cerebro-Spinal Fluid, water-like liquid)
- The **workspace is extremely small (few millimeters)**



Size of the Sub Arachnoid Space, mm



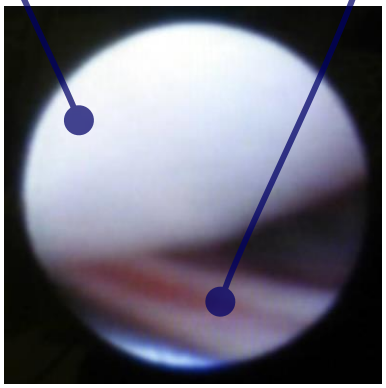


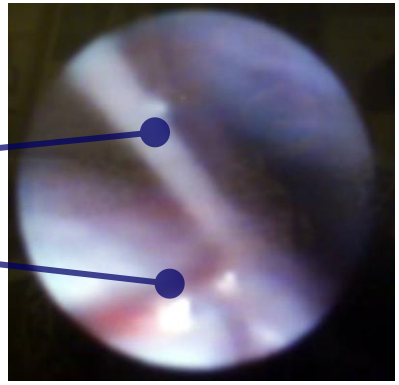


Neuroendoscopy by an active catheter: in-vivo validation

In vivo experimentation on Pig in Ozzano (Bologna)

Successful endoscopy (see images below) of the whole spinal cord, from lumbar access up to cervical tract, with **direct nerve stimulation through endoluminal electrode**





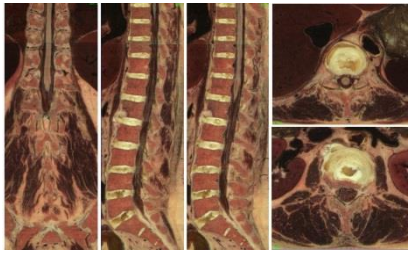
Magnetic micro/milli-robots inside the Central Nervous System (CNS)

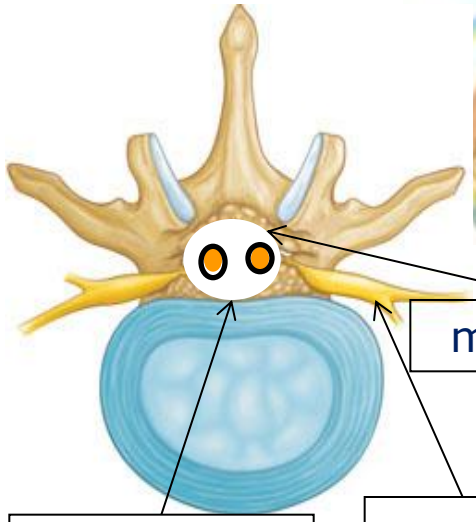
- **Medical diseases of CNS** can be particularly **devastating** because of limited intrinsic regenerative capacities and **currently** available **therapies** provide **limited functional recovery**;
- Owing to the low penetration rate, it is difficult using **systemic delivery** to achieve the suitable localized drug concentration;
- **Medical micro/milli robots** could enable minimally invasive access to reach these locations reducing the morbidity of current procedures while also enabling a broad range of new ones ;
- A feasible approach to the wireless propulsion and control of robots is through externally applied **magnetic fields**.

Permanent magnet

Magnetic Resonance

Electromagnets



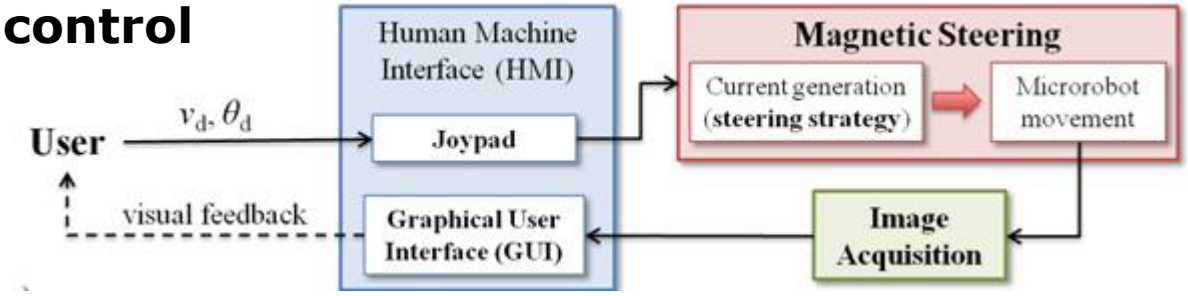


Control by electromagnets

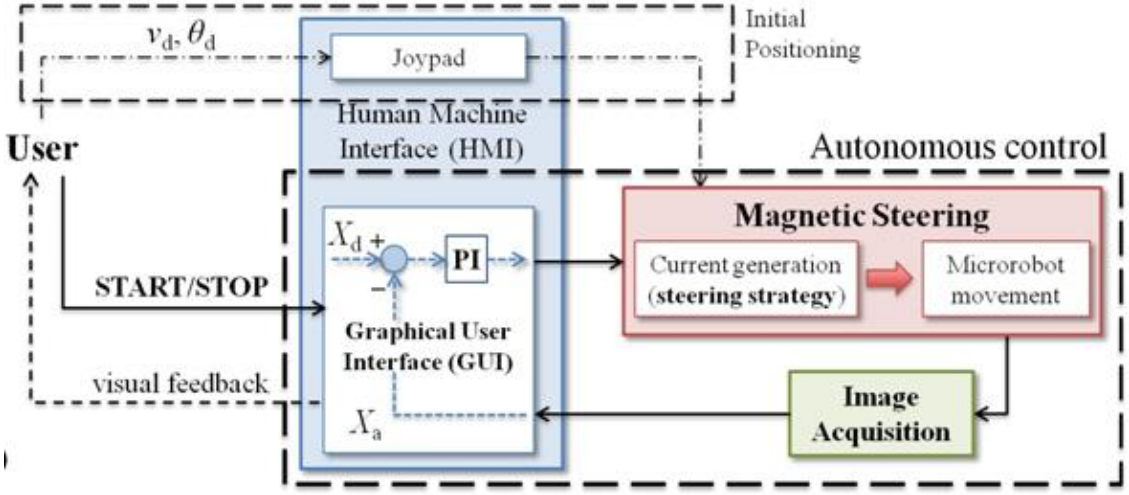
G. Lucarini et al, *Accurate and smooth navigation of magnetic microrobots under different control architectures,* IEEE Transactions on Automation Science and Engineering, under revision.

- Teleoperated and autonomous control were implemented and compared in terms of maneuverability of the microrobot along an eight-shaped path

Teleoperated control



Autonomous control



Next Grand Challenges for Robotics Surgery: transforming (more) dreams into reality

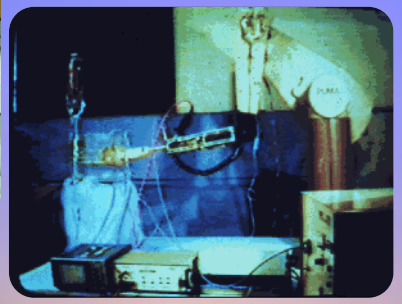
We had many … Now Some of Them are Reality!

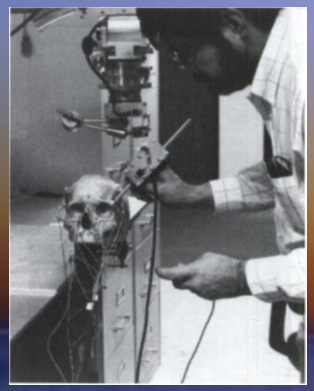
Dreams …

1985

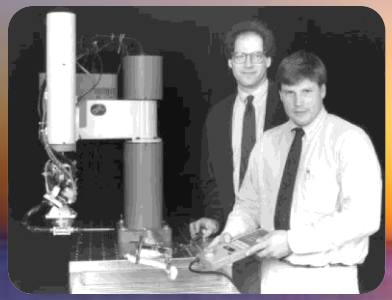
1988

1991



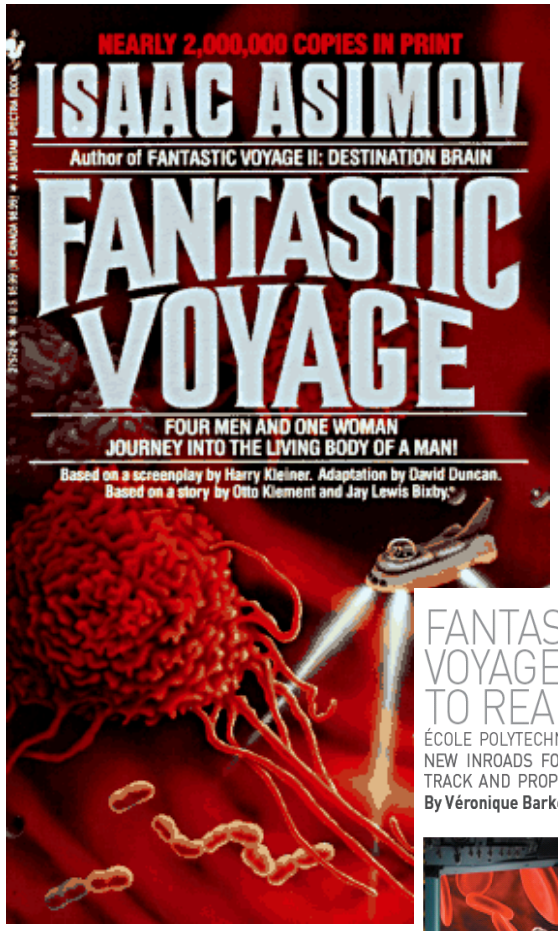


1992



Science Fiction Becoming Reality

SCIENCE fiction

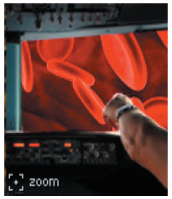


FANTASTIC VOYAGE—FROM FICTION TO REALITY

ÉCOLE POLYTECHNIQUE DE MONTRÉAL RESEARCHERS MAKE NEW INROADS FOR CANCER TREATMENT BY USING MRI TO TRACK AND PROPEL DEVICES THROUGH THE BLOODSTREAM.

By Véronique Barker

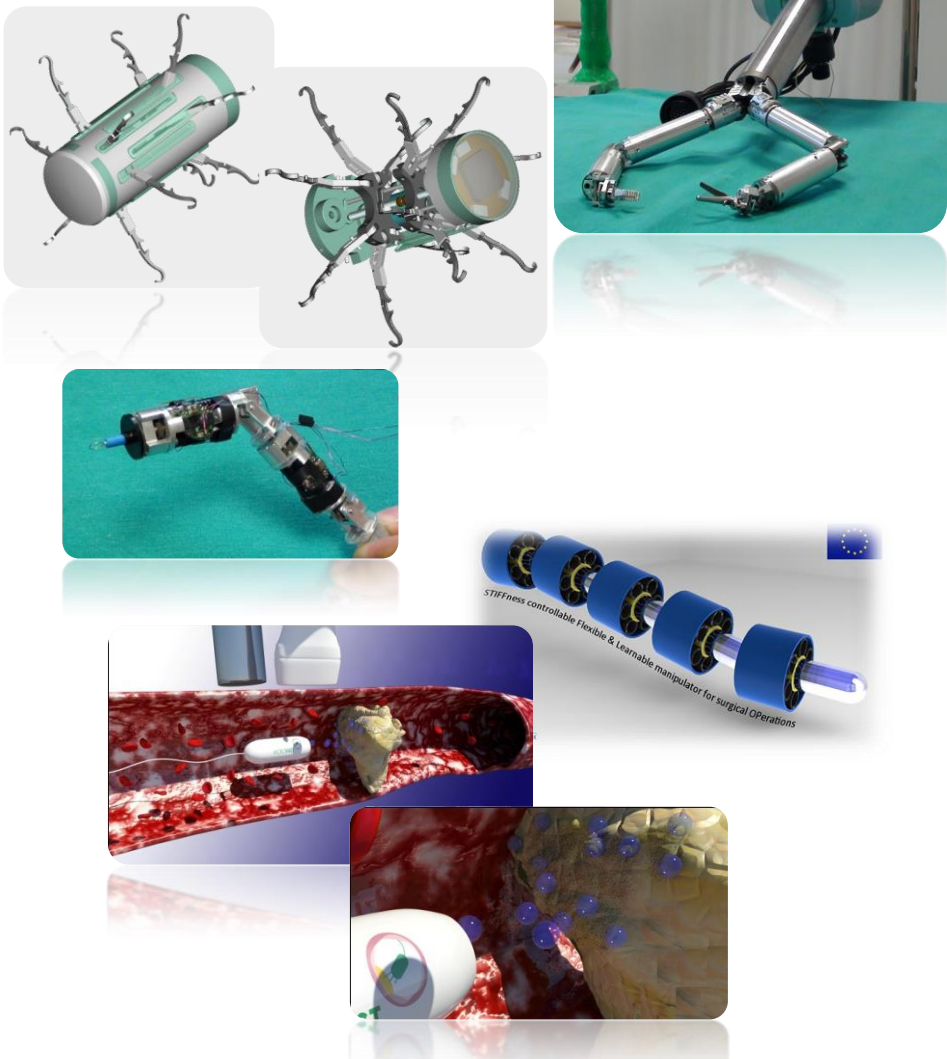
ISSUE #29 // JULY-AUGUST 2007



PROJECT

In the same vein as the 1960s classic movie, Fantastic Voyage, where a crew of scientists are miniaturized and injected into the bloodstream, Sylvain Martel [1], director of the NanoRobotics Laboratory at École Polytechnique de Montréal, has successfully made travel through a living animal's bloodstream possible. "This is really what we are doing, except that we

REALITY @ SSSA



Next Grand Challenges for Robotics Surgery

- Transforming (more) dreams into reality
- Dreaming new dreams

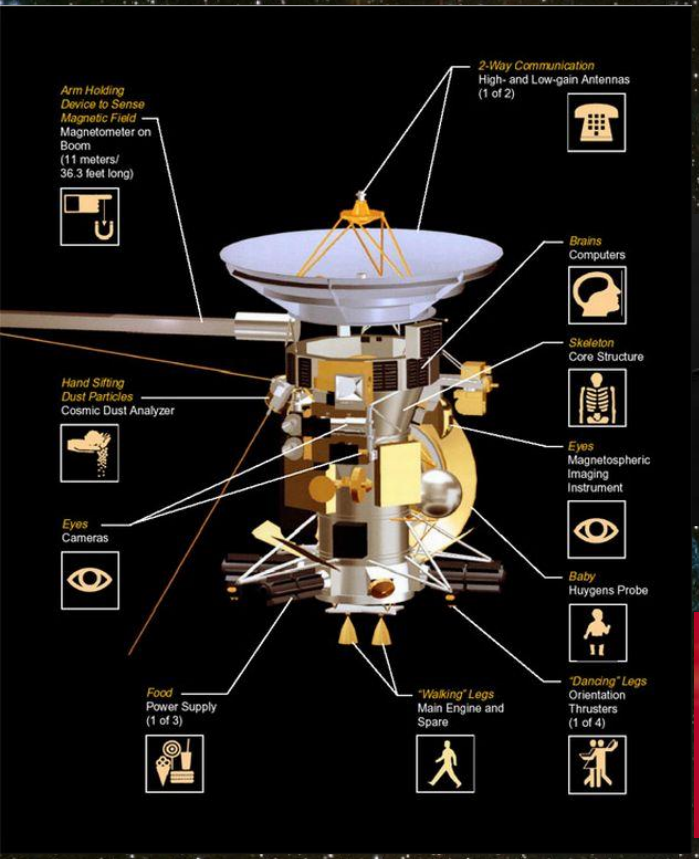
Next Grand Challenges for Robotics Surgery: *Dreaming New Dreams, Building Bridges and Breaking Barriers*

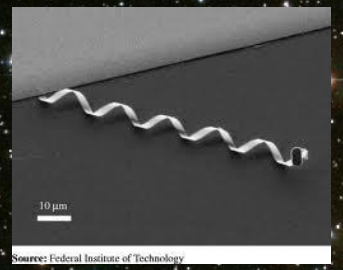
… from wired to wireless

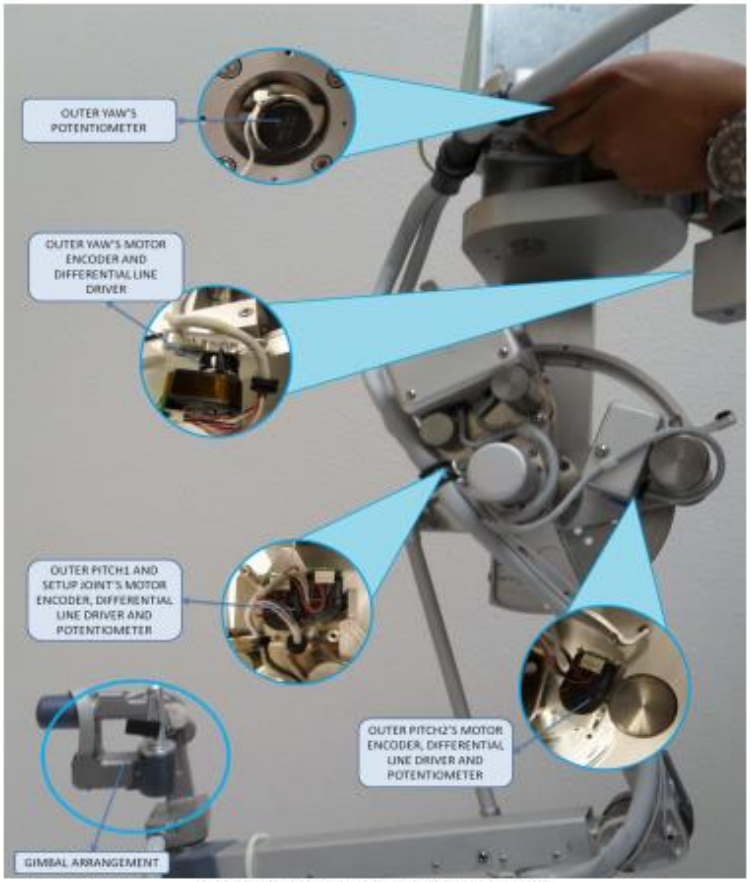
… from external (e.g. magnetic) powering to harnessing internal actuation and environmental energy

…

… up to the hyper-integration of micro-/meso-/nano-components





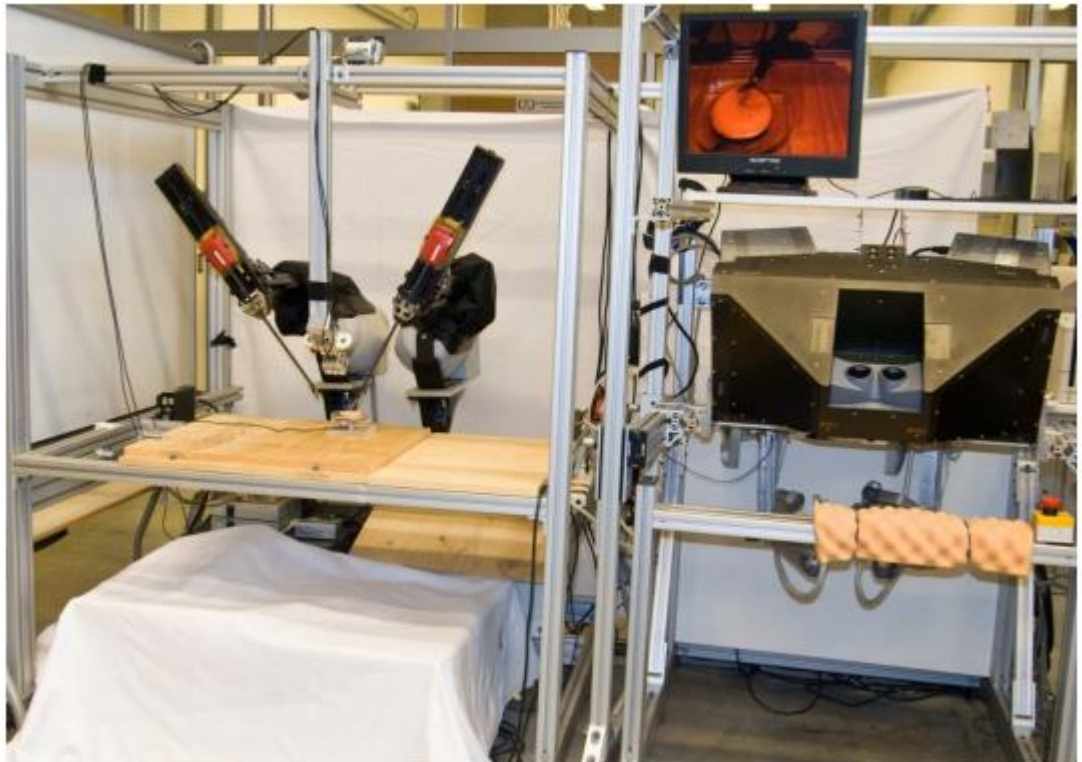


ENT PLACEMENT.

SURGICAL ROBOTICS & ALLIED TECHNOLOGIES LAB

Within October, a Da Vinci Research Kit with an open controller will be available at the Institute of BioRobotics (location to be defined 3mx1.5mx2m) .

We **look forward collaboration opportunities between different areas** and we propose the use of the kit for **educational activities.**



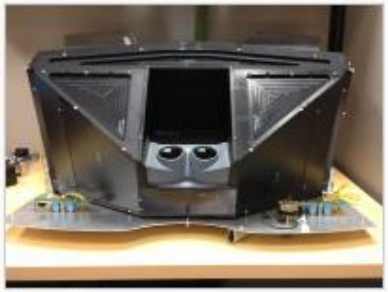
ERC | CISST

https://trac.lcsr.jhu.edu/cisst/wiki/sawIntuitiveResearchKitTutorial#a1Introduction

User group of Da Vinci Research Kit


MTM


PSM


Stereo Viewer


Foot Pedal Tray

The User Group

University/Group:	*PI*	*PI Email*	*PI URL*	*Group Wiki Page*
The Johns Hopkins University	Professor Russell Taylor	*rht-at-jhu.edu*	[1] [2] [3]	JHU Group Page
Worcester Polytechnic Institute	Professor Greg Fischer	*gfischer-at-WPI.EDU*	[4]	WPI Group Page
Stanford University	Professor Allison Okamura	*aokamura-at-stanford.edu*	[5]	Stanford Group Page
The University of British Columbia	Professor Tim Salcudean	*tims-at-ece.ubc.ca*	[6]	UBC Group Page
Vanderbilt University	Professor Nabil Simaan	*nabil.simaan-at-vanderbilt.edu*	[7]	Vanderbilt Group Page
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Carnegie Mellon University	Professor Howie Choset		[9]	CMU Group Page
Sick Kids Children's Hospital	Professor James Drake	*james.drake-at-sickkids.ca*	[10]	Sick Kids Group Page
SUNY, Buffalo	Professor Venkat Krovi	*vkrovi-at-buffalo.edu*	[11]	SUNY Group Page
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University of Western Ontario & CSTAR	Professor Rajni Patel	*rvpatel-at-uwo.ca*	[13]	CSTAR Group Page

El.En. S.p.A. a Global Leader in Medical Laser Technology

The strategy: integrating medical lasers with image-guided robotic manipulators

El.En. S.p.A. a Global Leader in Medical Laser Technology

EL. EN. Group
EL. EN.
DEKA
ASALASER
CUTLITE PENTA
OT-LAS
LASIT
VALFIVRE
LIGHT FOR ART

Codice etico
Job opportunities

Latest news

El.En. S.p.A.: Notice of change in the composition of the Statutory Board to better come into line with the law about less-represented gender

Notice of the publication and availability of the minutes of the Shareholders meeting occurred on 15th May 2013 and the relevant updated by-laws

El.En. S.p.A.: Share capital issued and fully paid-up

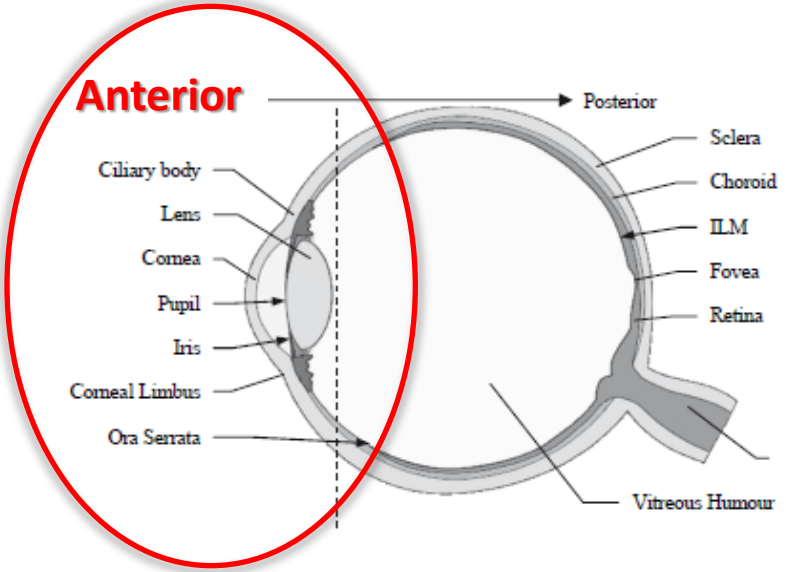
Complete archive on events

Three new restoration projects with El.En. lasers
Cappella Maggiore di Santa Croce in Florence,
Loggia della Mercanzia, in Siena and
Pietà da Palestrina in Galleria dell'Accademia, Florence

Minimally Invasive Laser Robotic assisted Diagnosis and Surgery

(MILoRDS, Regione Toscana)

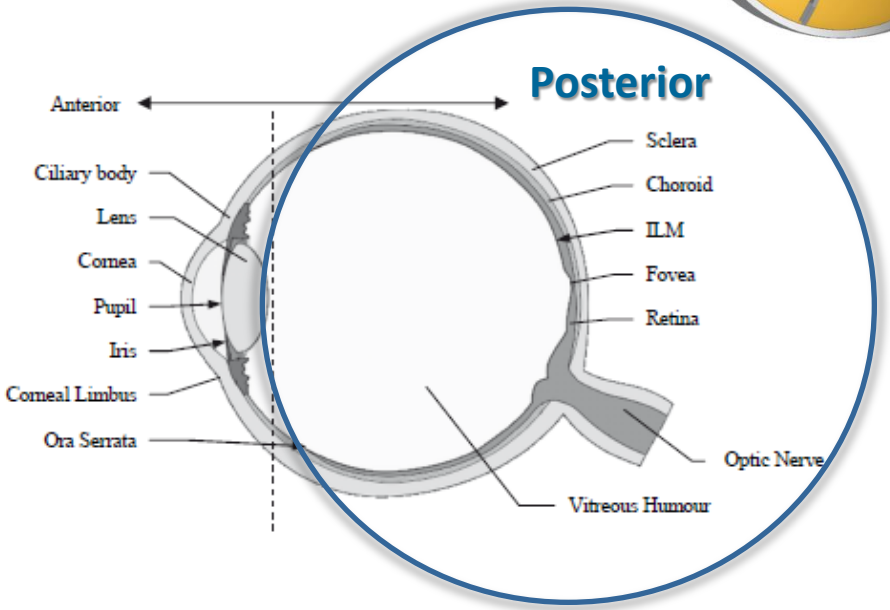
Objective 1



Laser assisted surgery of the **anterior eye**:

- Corneal transplants
- Glaucoma

Objective 2

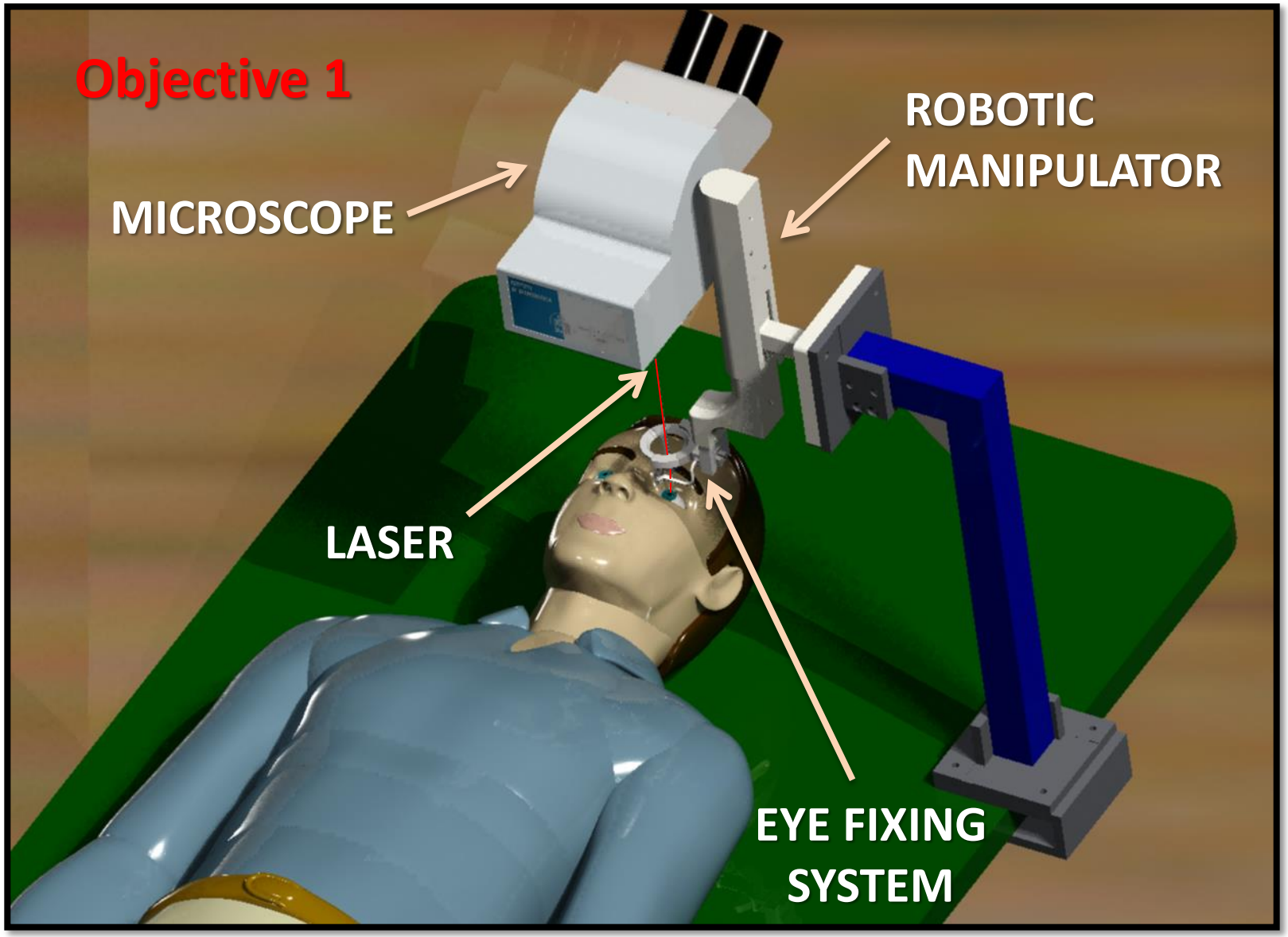


Laser assisted surgery of the **posterior eye**:

- Retinal diseases
- Vitreous humour

Minimally Invasive Laser Robotic assisted Diagnosis and Surgery

(MILoRDS, Regione Toscana)

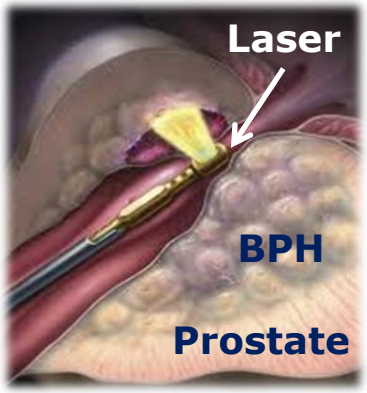


ISTITUTO DI BIOROBOTICA

Scuola Superiore Sant'Anna

Laser assisted robotic surgery in UROLOGY

MILORDS

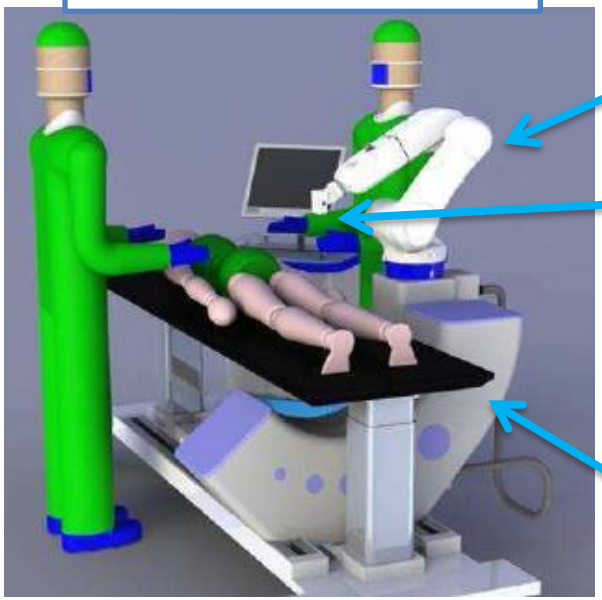


PROBLEM:

- To perform the **laser treatment of benign prostatic hypertrophy** (BPH), by reconstructing the channel of the prostatic urethra in a homogeneous way
- To increase the accuracy of the treatment
- To ensure the contact between the laser fiber and the tissue, thus avoiding thermal damage (carbonization) as much as possible

SOLUTION: a guidance system to provide the surgeon with a 3D visualization and sensor feedback

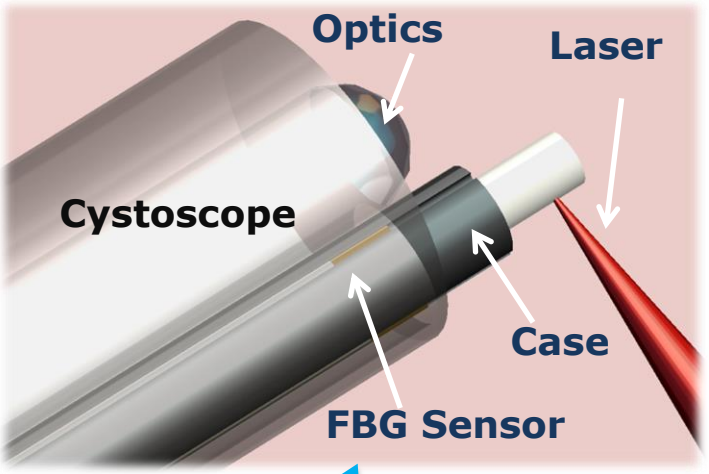
ROBOTIC PLATFORM



6 DOF ADEPT Robot

<u>Shared control:</u>
Cystoscope is mounted on the robot's end effector and moved by surgeon

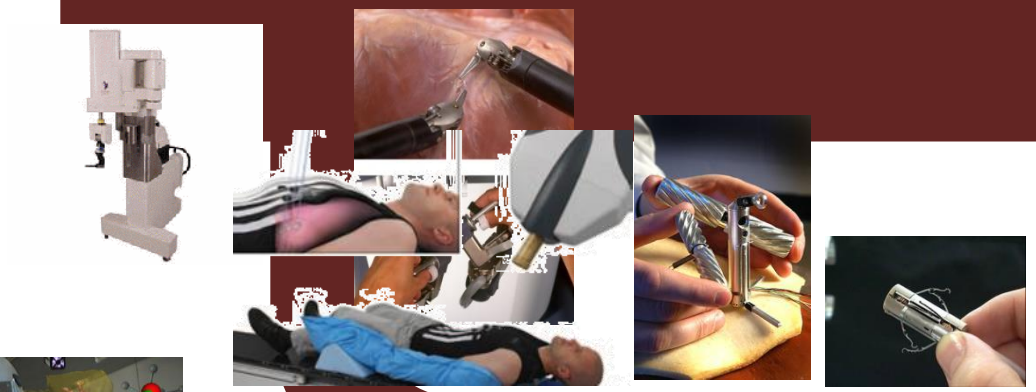
Imaging system (3D RX)



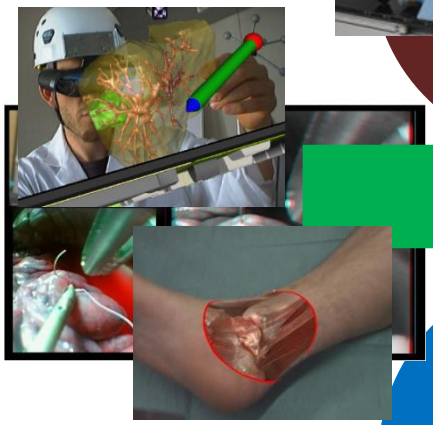
<u>Strain sensor</u> for detecting contact with tissue

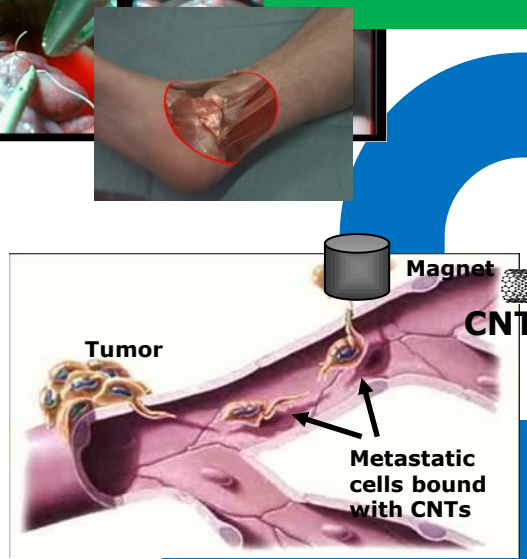
Regione Toscana

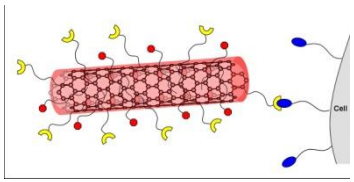
Robotics Technologies



Imaging







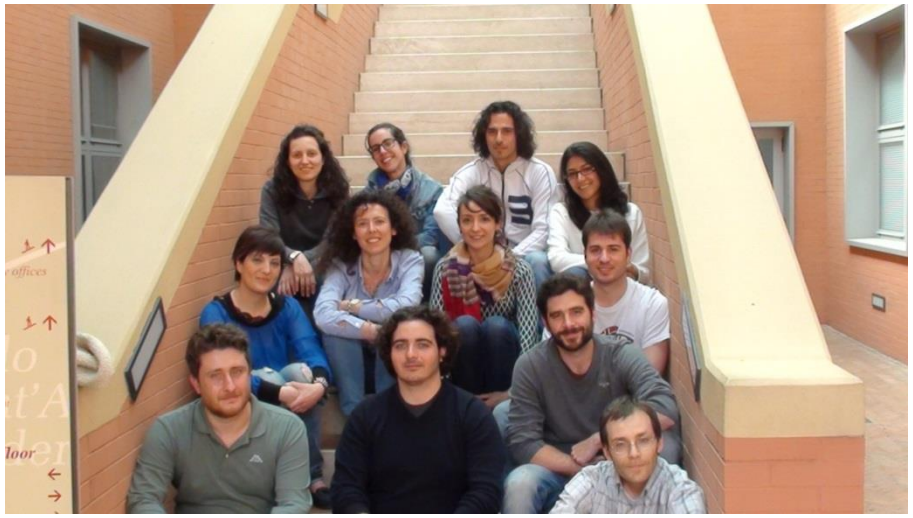
Better Healthcare?

Nanoengineering

Concluding Remarks

- Robotics technologies just begin to show their tremendous **potential** in Surgery
- The advantages of robotics (accuracy, repeatability, motion control, image-based planning, "intelligence", learning and cognition, etc.) has effective potential for **filling the gap between academic research and real clinical applications**
- An extraordinary opportunity to explore and implement new and even **visionary ideas** (just as happened **25 years ago, when the robots now in clinical use were conceived and preliminarily tested**)
- The grand challenges for robotics: the performance of **therapeutic** technologies should match the progress of current **diagnostic** technologies, and including as many functions/capabilities (mechanical, optical, chemical, powering, electronic …) into a miniaturized shell
- Extraordinary **opportunities** for imaginative surgeons and for **collaboration between surgeons, robotics researchers and industry**

Acknowledgments



SURGICAL ROBOTICS GROUP

Special thanks to many funding Agencies and to Surgical Robotics group