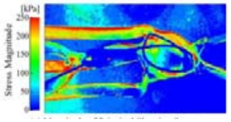
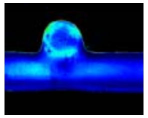

The EVE project

Challenging the Frontier of the Surgical Simulation since 1989





Basic 6
Micro-Nano Control for Medical Applications

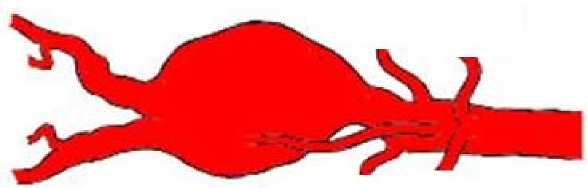
Prof. T. Fukuda

Dept. of Micro/Nano Systems Engineering

Nagoya University

1. Background

- Principal Vascular Diseases



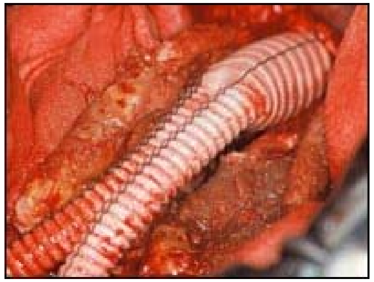
Aneurysms in Major Vasculature
(Inner Diameter >6mm)

Stenosis

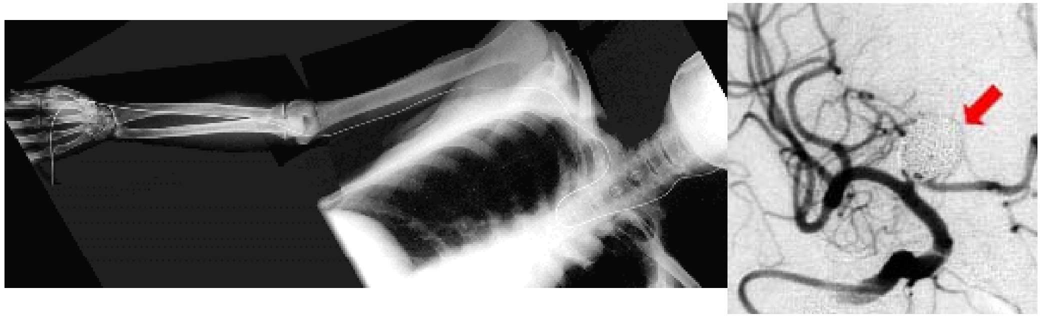
Aneurysms in Minor Vasculature
(Inner Diameter >6mm)

- Treatments

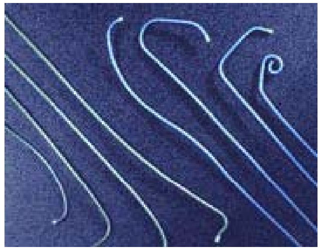
Grafts Implants



（TERUMO）
Polyethylene, ePTFE

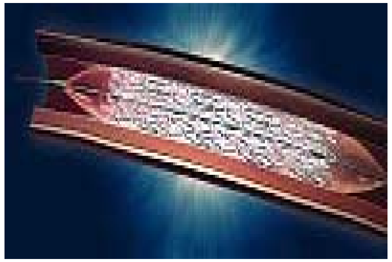


Endovascular Intervention



Catheters

Platinum
Coil



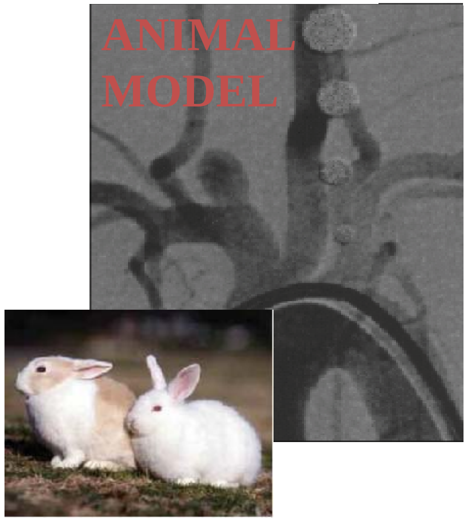
Ballon
Catheter

1. Background

- Need in the Medical Field

1. Medical Training Methods

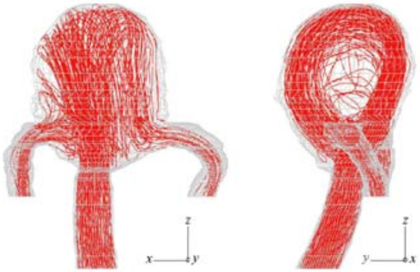
Simple Model



Experiments
in Animal

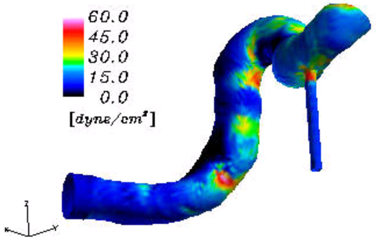
2. Quantitative Evaluation Methods

Flow Simulation



Uchiyama Lab.
Nagoya Univ.

Stress Simulation



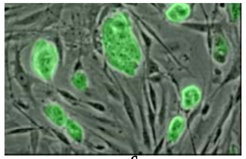
Oshima Lab.Tokyo Univ.

3. Implants for Minor Vasculature

Grafts Implants Produces :

- Early Occlusion
- Intimal Hypertrophy

Embryonic stem cell



www.nsf.gov

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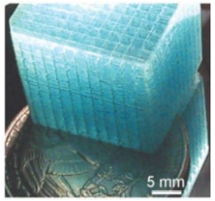
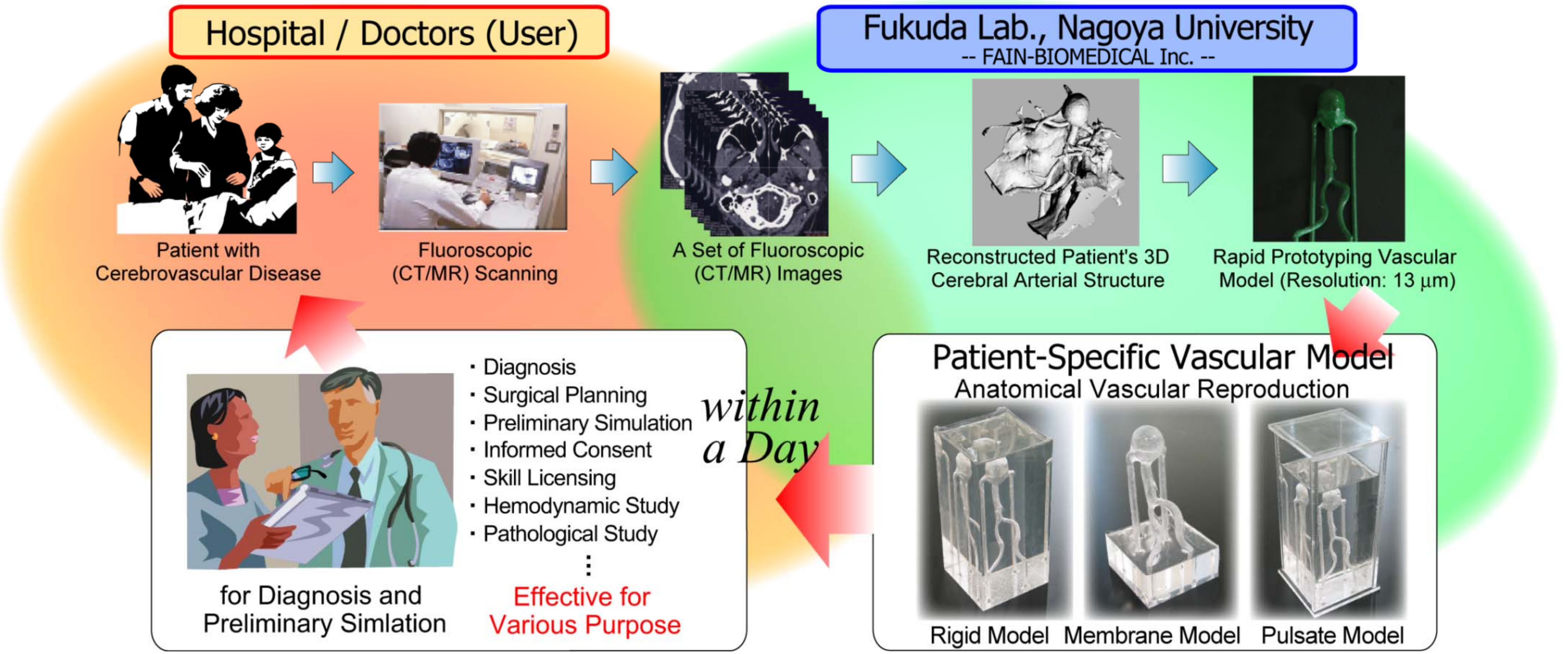


Therriault *et al.*
Adv. Mater. 2005

Implant combining Cell Culture in Scaffold and Grafts

Surgical Simulator for Endovascular Intervention

Patient Specific Vascular Modeling



Hospital / Doctors (User)

Fukuda Lab., Nagoya University
-- FAIN-BIOMEDICAL Inc. --

Patient with
Cerebrovascular Disease

Fluoroscopic
(CT/MR) Scanning

A Set of Fluoroscopic
(CT/MR) Images

Reconstructed Patient's 3D
Cerebral Arterial Structure

Rapid Prototyping Vascular
Model (Resolution: 13 μm)

Patient-Specific Vascular Model
Anatomical Vascular Reproduction

Rigid Model Membrane Model Pulsate Model

within a Day

- Diagnosis
- Surgical Planning
- Preliminary Simulation
- Informed Consent
- Skill Licensing
- Hemodynamic Study
- Pathological Study

⋮

for Diagnosis and
Preliminary Simlation

Effective for
Various Purpose

Specification:

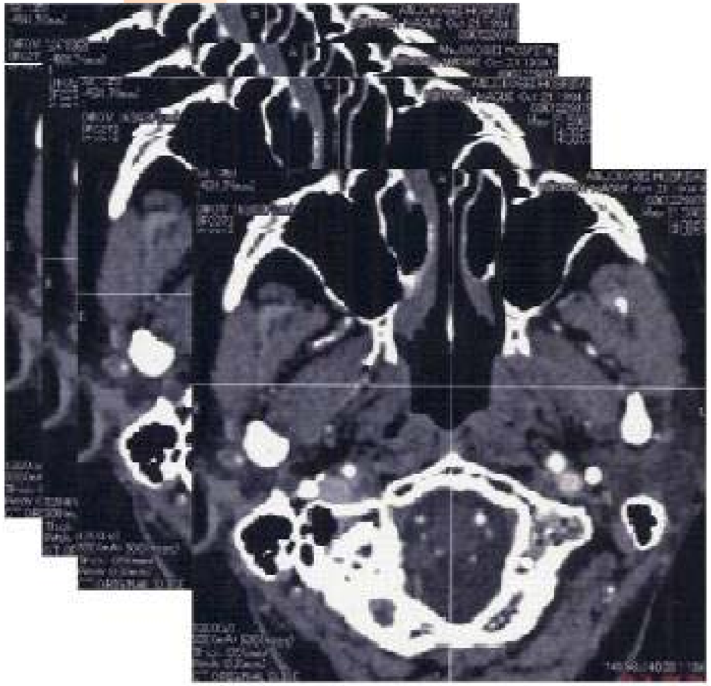
- Information: CT or MRI.
- Modeling Resolution: 13 mm
- Fabrication Time: < 24 hours

[S. Ikeda, JRM 2005]

Surgical Simulator for Endovascular Intervention

Patient-Tailored Biological
Model of Cerebral Artery

PATIENT-TAILORED
MODELING



Patient's Information
(CT / MRI Information)

[S. Ikeda, JRM 2005]

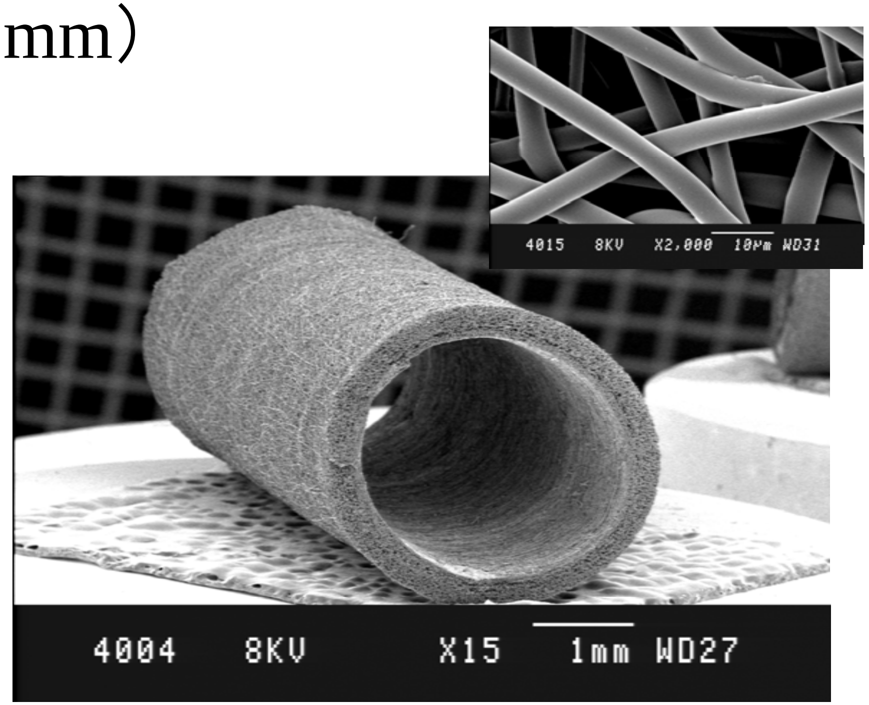
Implantation solution for small diameter

Three required conditions for artificial graft with small diameter (less than 6.0 mm）

①：Biodegradability, biocompatibility

②：Porous structure

③：Mechanical properties close to native blood vessel's properties.



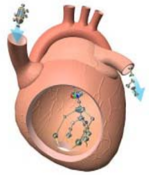
Scaffold made of biocompatible material （Matsuda et al., 2007）

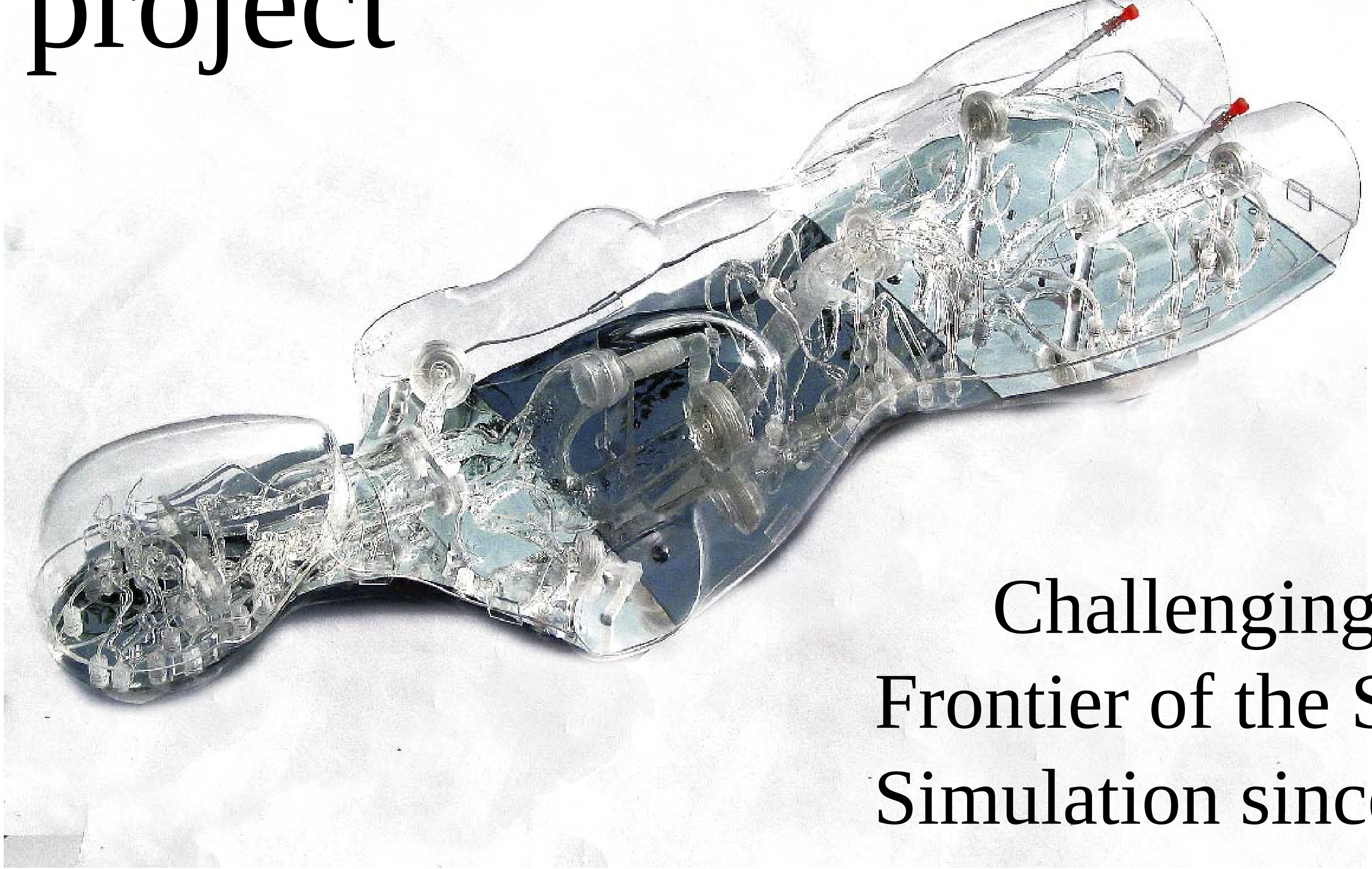
Problems of previous studies

- ■Only for tubular shape.
- ■No scaffold imitating the configuration of native blood vessel.

The EVE project

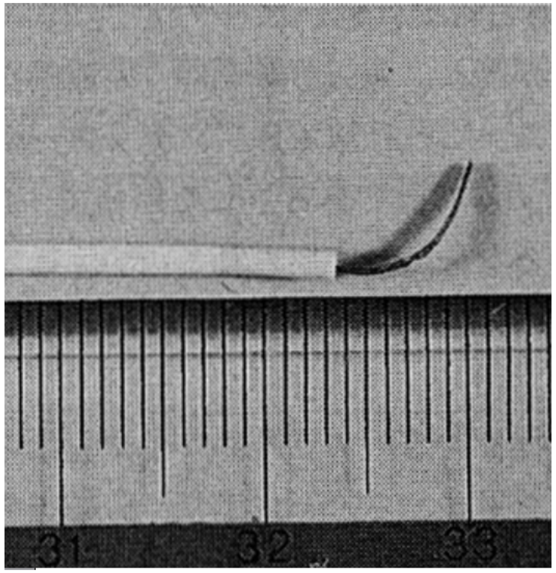
Nagoya University
Micro-Nano Systems Department
Fukuda Laboratory



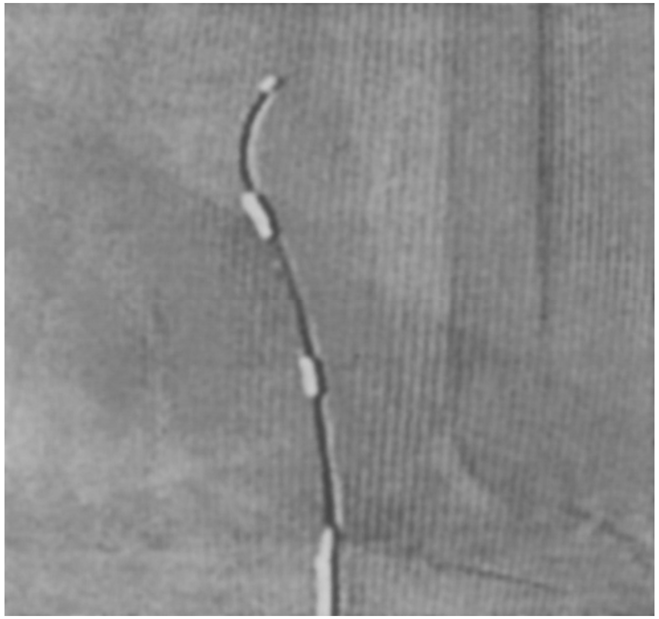


Challenging the
Frontier of the Surgical
Simulation since 1989

Active Catheters (1989-1996)



- Adds maneuverability to the catheter
- Endovascular techniques are new in minimally invasive surgery

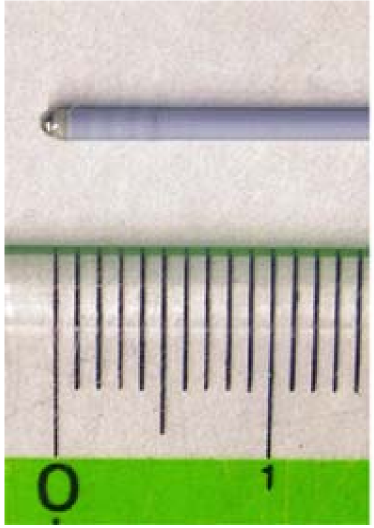


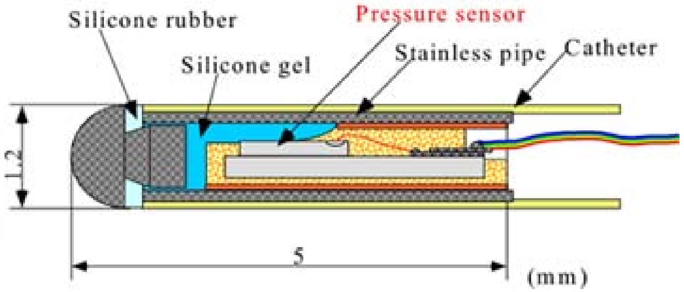
- Need to be compatible wit Xrays
- Requires micro systems as catheters has about 1 mm of lumen

[S.Guo, J. of Robotics Soc. of Japan. 1996]

1. Background

Force Sensor on catheter tip (1998)





- Prevents the damage of vessel wall

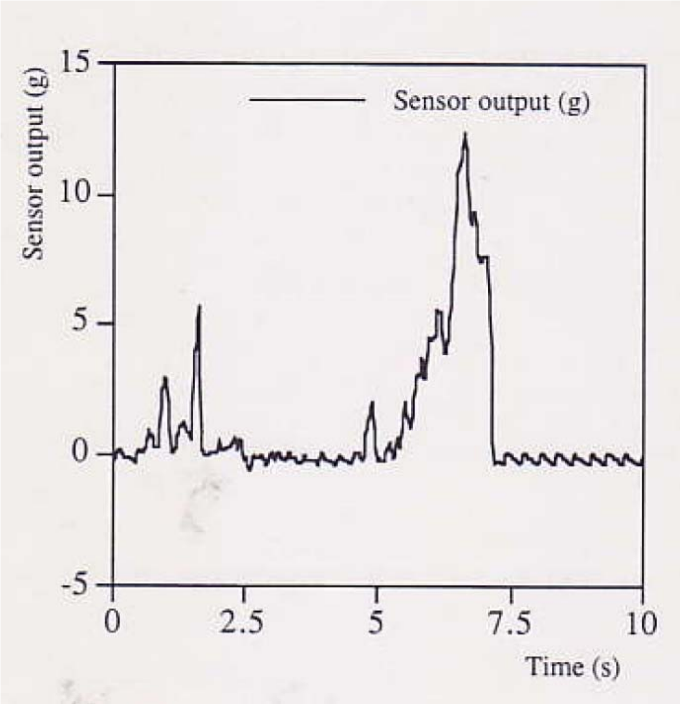
- A pressure sensor detects the force applied to the catheter tip

In-Vivo Experiment

- Pressure done by the catheter to an aneurism of canine was measured

- Blood pressure fluctuation was measured

[M. Tanimoto, Trans. of the JSME 1997]

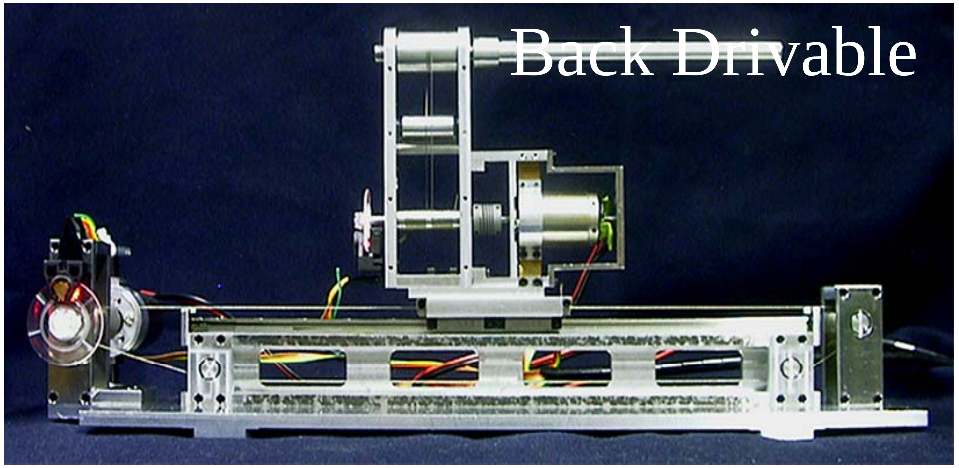


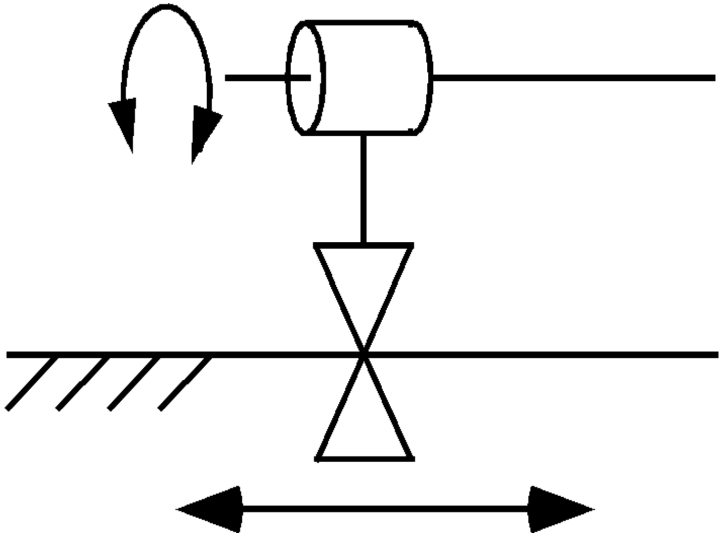
Force Sensor In Vivo Experiment Results

1. Background

Telesurgery (1996)

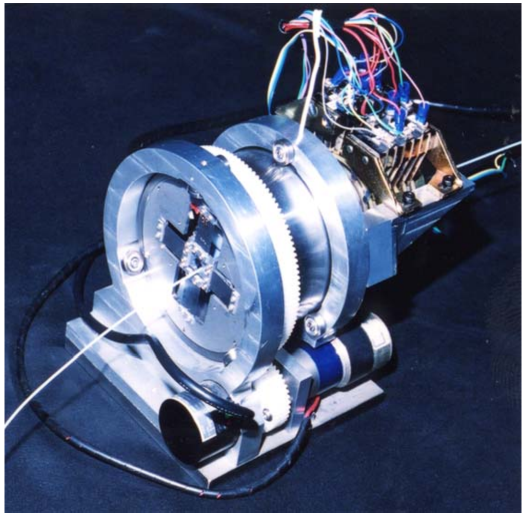
Master Arm

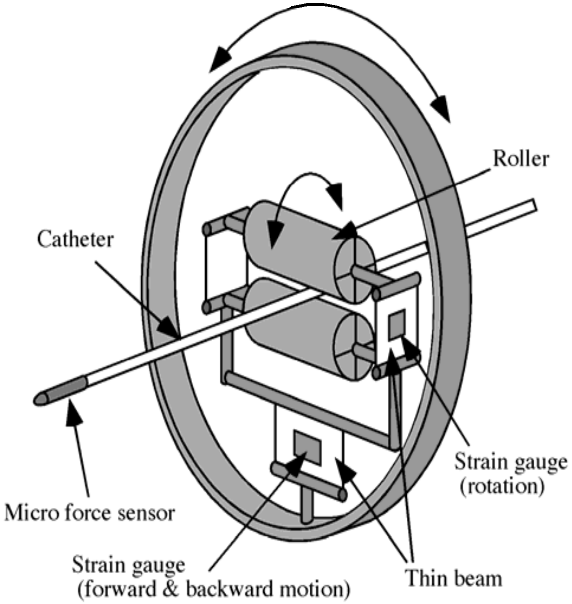




[F. Arai, IEEJ Trans. on Elec. 1997]

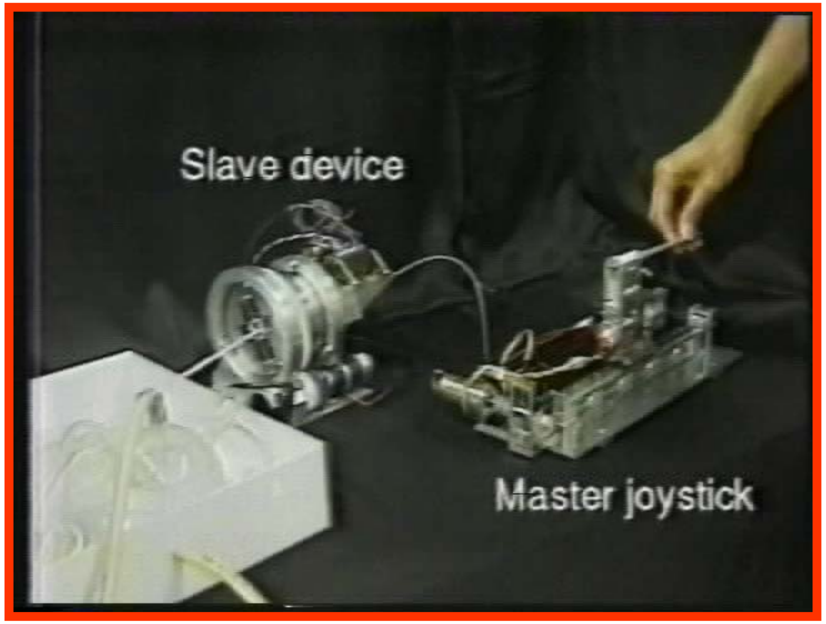
Slave Device





1. Background

Telesurgery (1997)



- First catheter manipulation mechanism using gum rollers

- Master device as human interface for catheter manipulation

Telesurgery System

- Reduces the X-rays irradiation to physicians

- Manipulated from outside of the surgical room

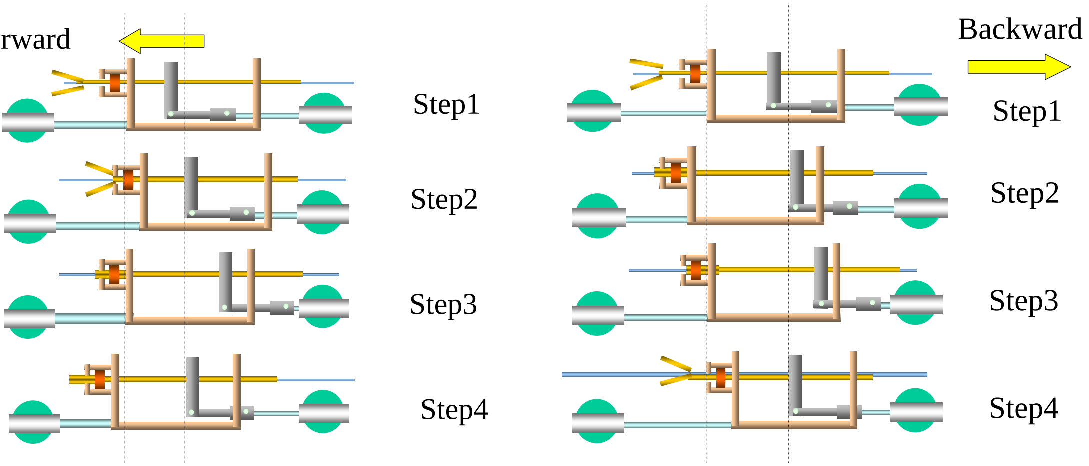
[F. Arai, IEEJ Trans. on Elec. 1997]

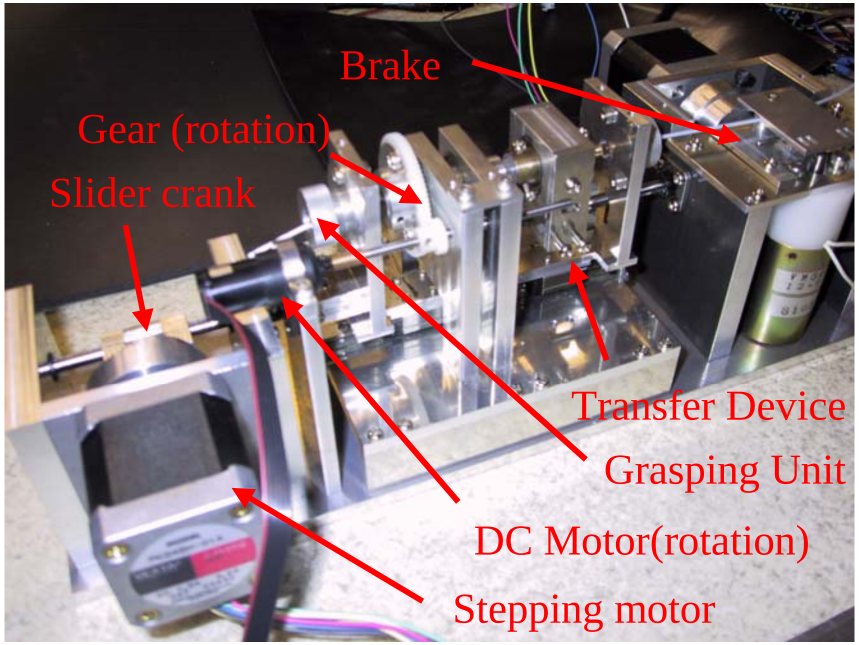
Experimentation inside surgical room

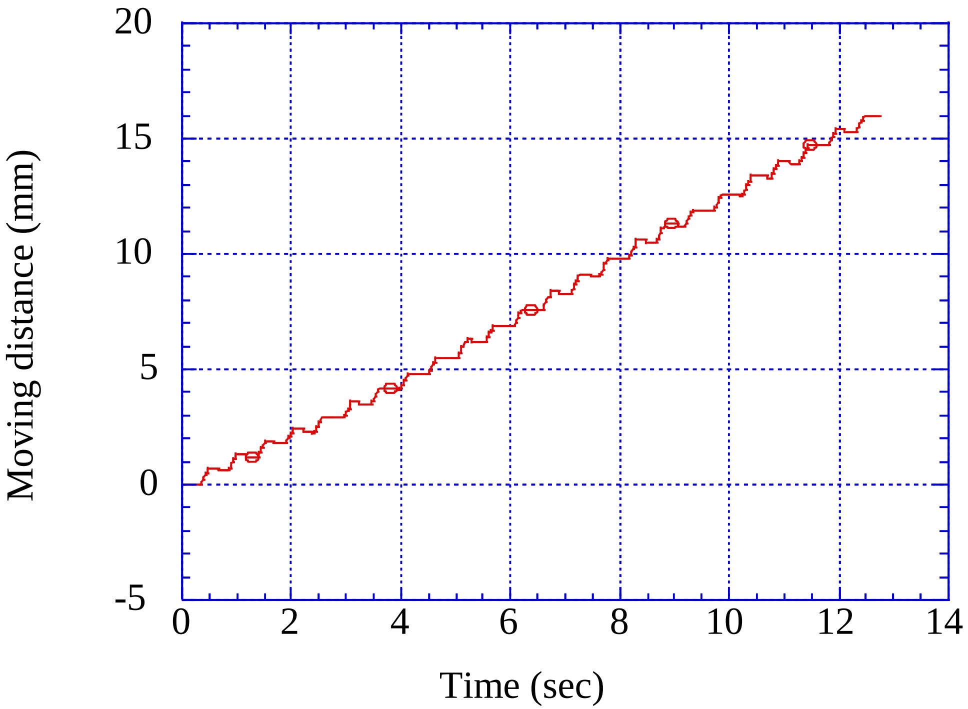
Linear Stepping Mechanism 1 (2003)

- First catheter grasping mechanism imitating a mechanical pencil

- Allows discrete motion of catheter



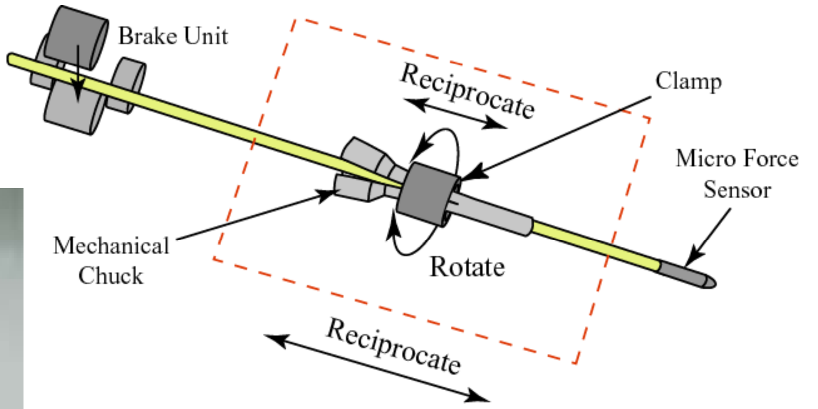




F. Arai et al., ICRA 2002

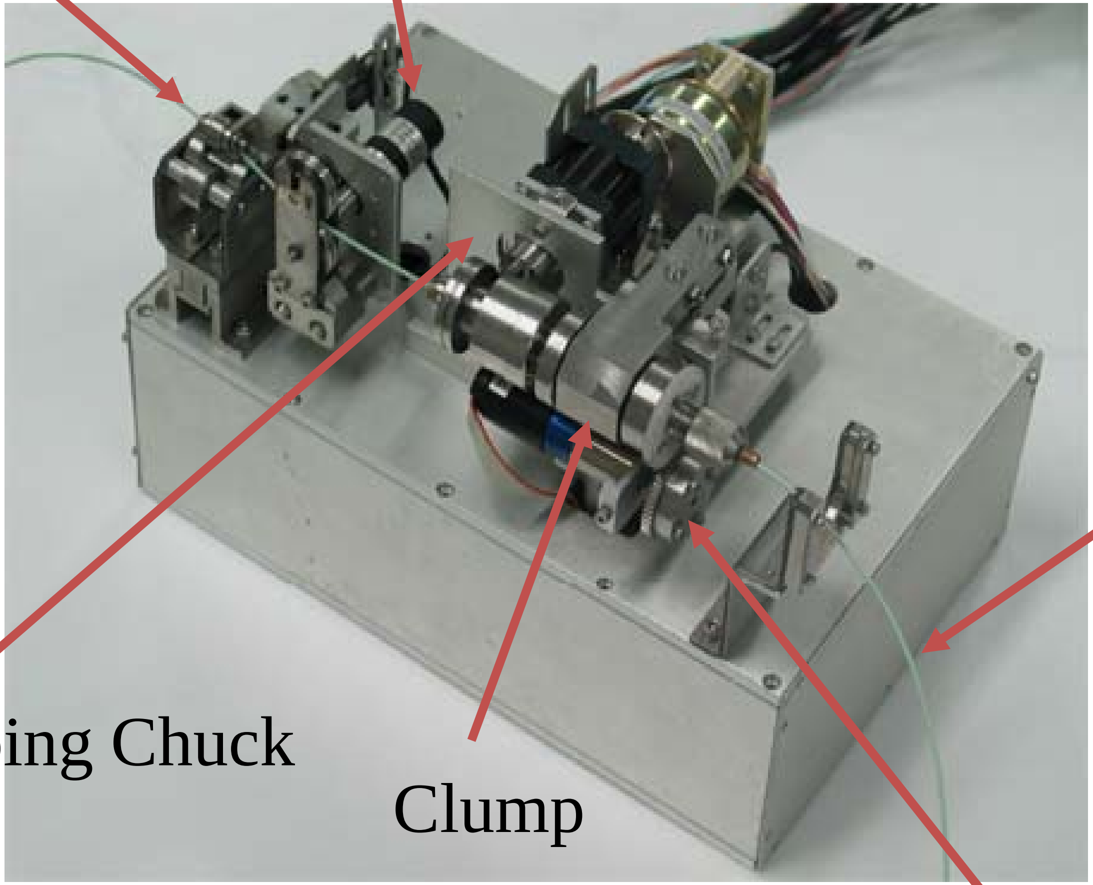
Linear Stepping Mechanism 2 (2003)

Fundamental Structure



Brake

Measuring Unit



Catheter

Grasping Chuck

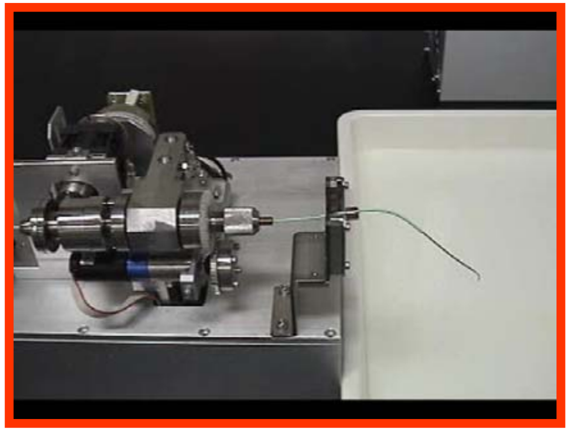
Clump

DC Motor for Rotation

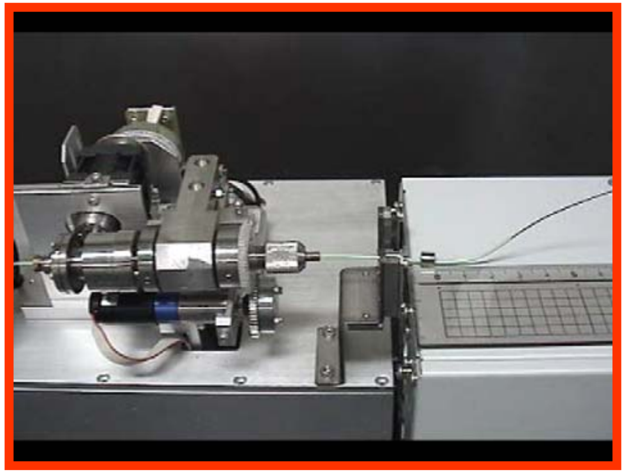
F. Arai et al., ICRA 2002

Linear Stepping Mechanism 2 (2003)

- Variable speed of insertion and extraction of catheter (Feeding force 2N)
- Variable rotation speed
- High resolution of discrete linear motion of catheter (up to 0.1 mm/cicle)
- Easy to clean



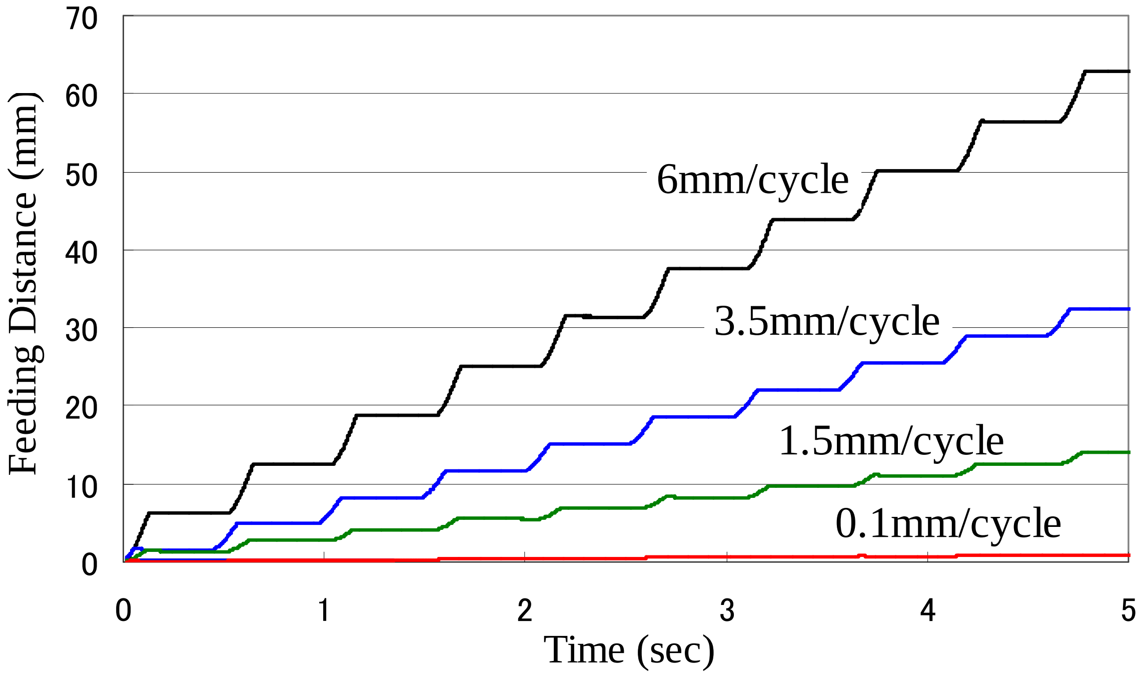
Rotation



Forward

at Variable Speed

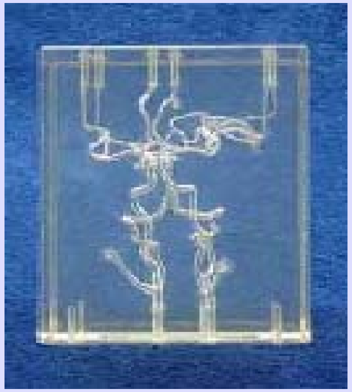
F. Arai et al., ICRA 2002



Forward feeding characteristics on several reciprocating distance of grasping unit

Surgical Simulator for Endovascular Intervention

Development of Simulator & Construction of Patent


Dissection Model


RP Model

Incompetent
As a Simulator

[S. Ikeda, JRM 2005]

1st Stage
Solid Model

2nd Stage
Membranous Model

3rd Stage
Composite Model

4th Stage
Whole Body Model

2002 → 2003 → 2004 → 2005

Fukuda Lab.
Set to the Work
in 2001

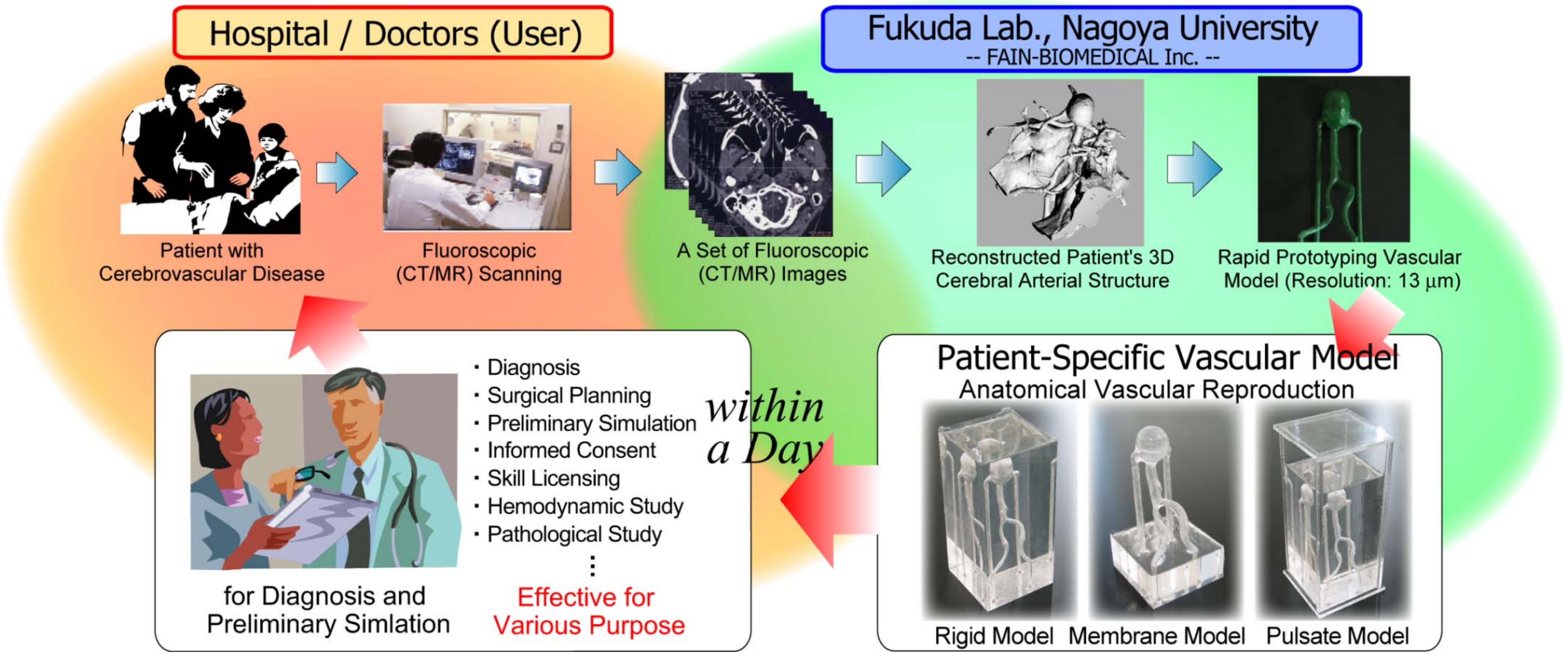
Pulsation
Reproduction

Stress
Visualization

Comprehensive
Simulator (EVE)

Surgical Simulator for Endovascular Intervention

Patient Specific Vascular Modeling



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[S. Ikeda, JRM 2005]

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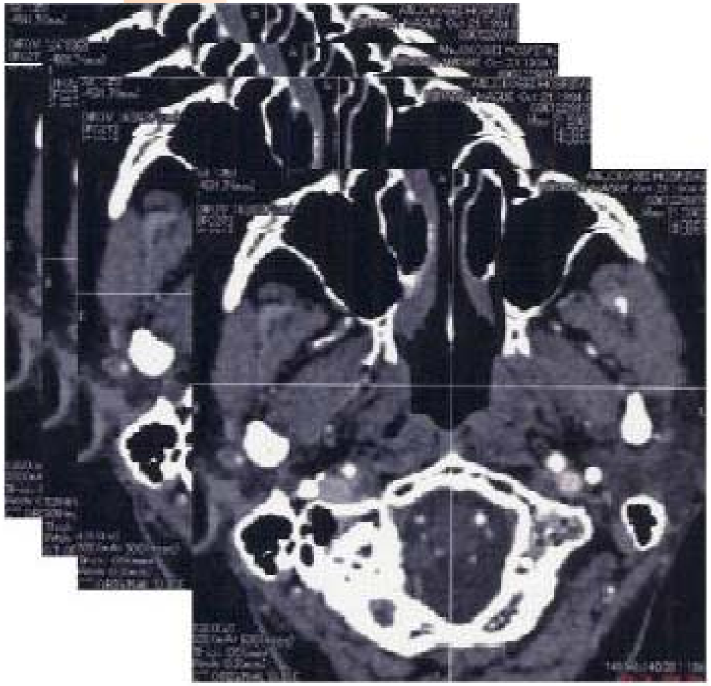
PATIENT-TAILORED
MODELING

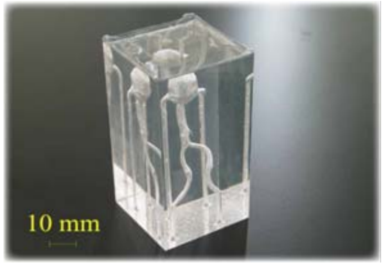


Patient's Information
(CT / MRI Information)

[S. Ikeda, JRM 2005]

Surgical Simulator for Endovascular Intervention

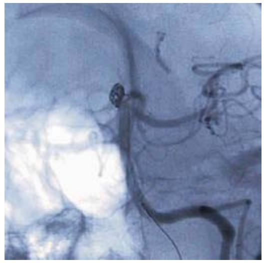
Solid Vessel Model



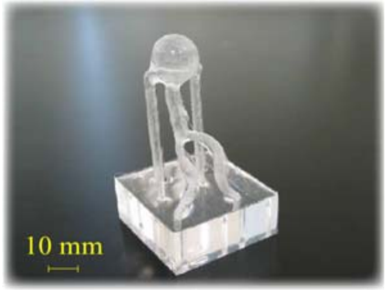
Reproduces the Vessel Lumen with 13 mm Resolution

Patient-Specific Cerebral Arterial Model

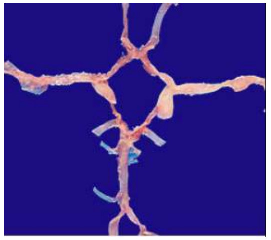
Fluoroscopic Information



Membranous Vessel Model

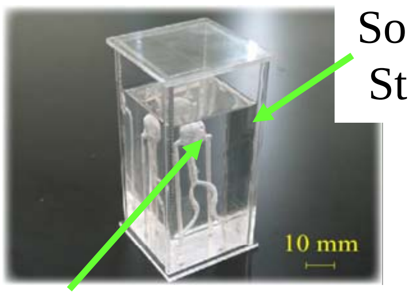


Patient-Specific Vascular Model with Membranous Structure



Membranous Structure Of Cerebral Artery

Soft Vessel Model



Reproduces the Circumferential Soft Brain Structure

Patient-Specific Vascular Model with Circumferential Brain Structure

Brain Structure around Cerebral Artery

[S. Ikeda, JRM 2005]

Surgical Simulator for Endovascular Intervention

Reproduction of Physical Characteristics

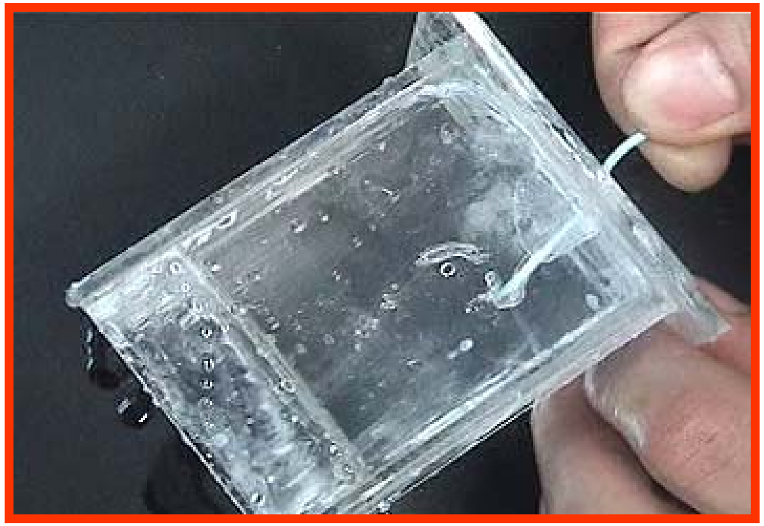
Elastic Property Reproduction

	Young's Modulus [MPa]	Poisson's ratio
Arterial Model	1.9	0.46
Arterial Tissue	1～3 (Carotid Artery)	0.45

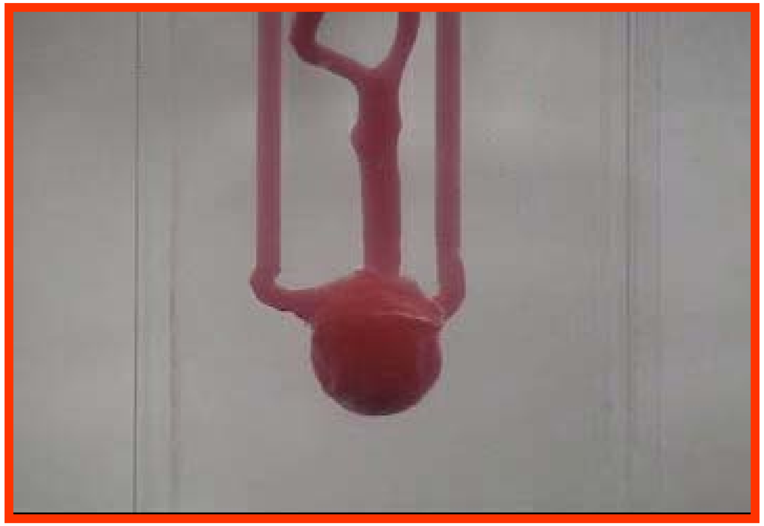
Frictional Property Reproduction

	Friction Coefficient	Lubricating Condition
Arterial Model	0.041	Surfactant
Arterial Tissue	0.039	Blood Serum

Simulation Results



Reproduction of
Viscoelastic Vascular Deformation



Reproduction of
Aneurismal Pulsation

[S. Ikeda, JRM 2005]

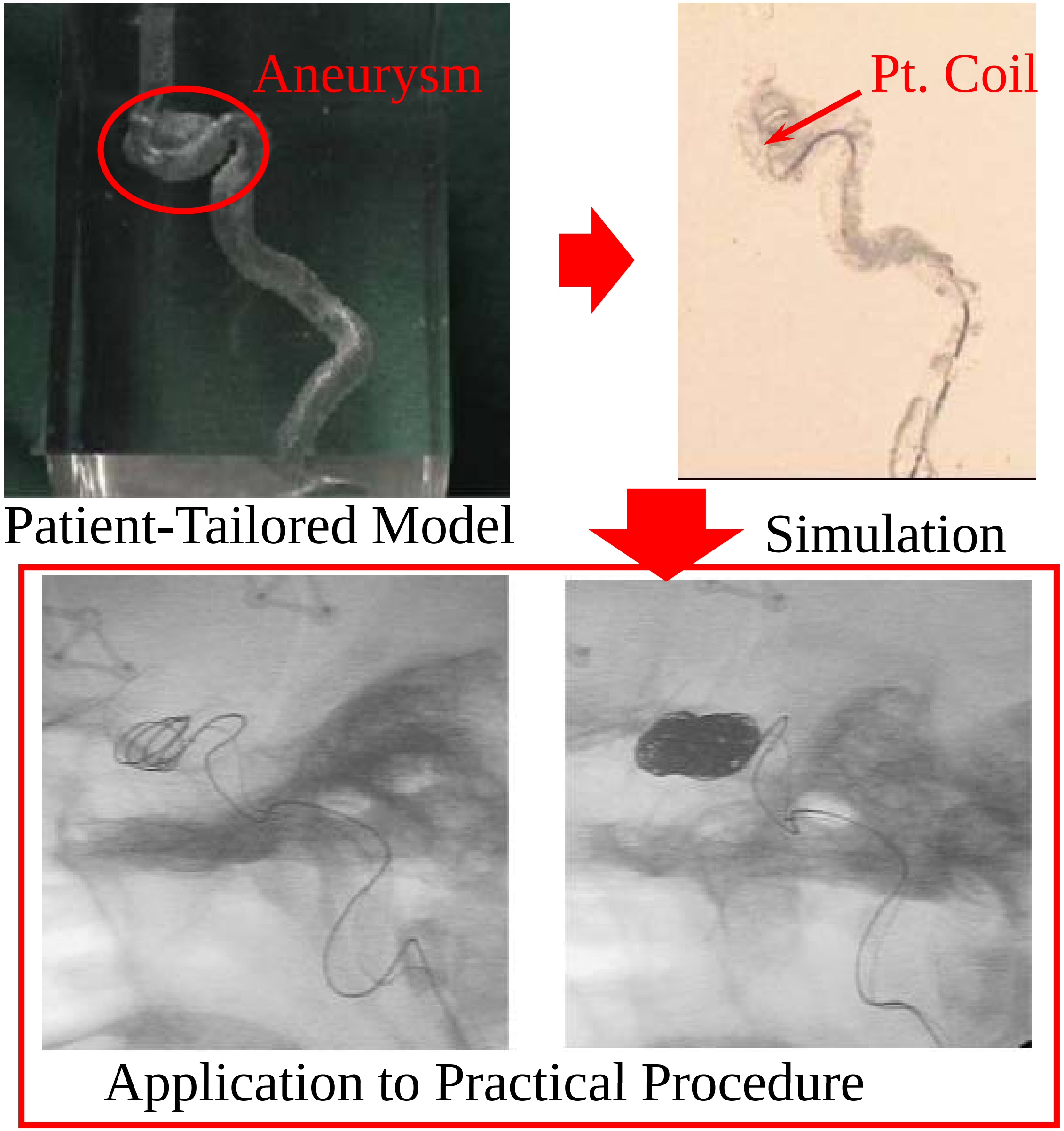
Surgical Simulator for Endovascular Intervention

Clinical Application

Preclinical Testing with Presented Cerebral Arterial Model

(Makoto Negoro, Dept. of Neurological Surgery, fujita Health University)

[S. Ikeda, JRM 2005]



Patient-Tailored Model

Simulation

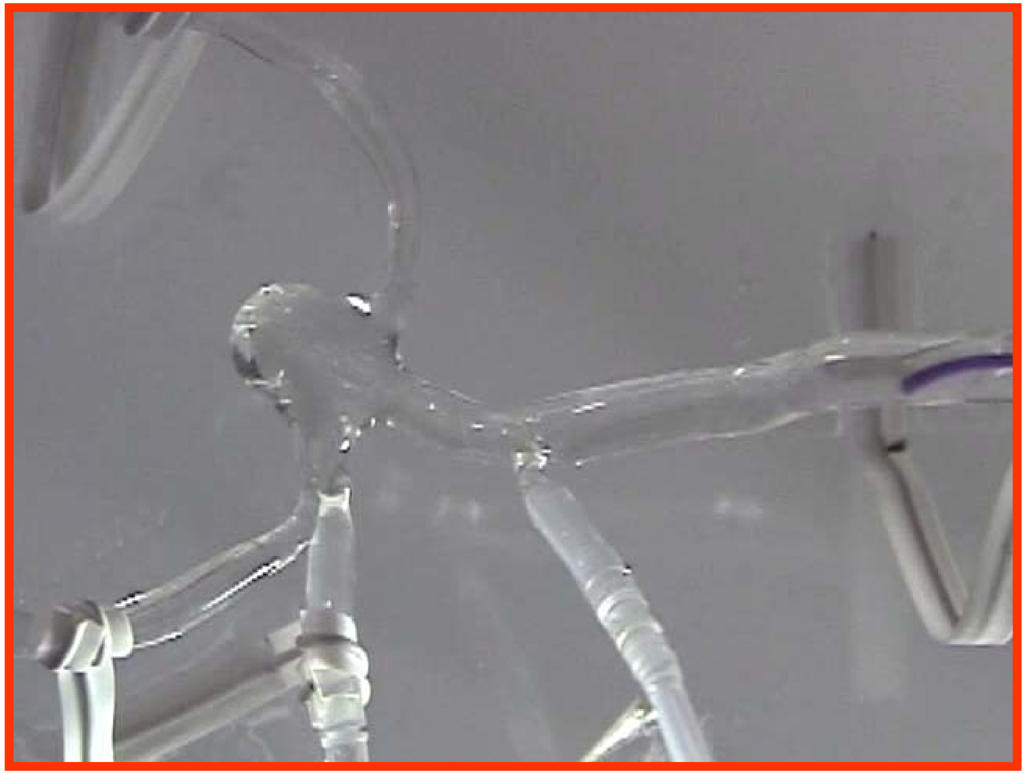
Application to Practical Procedure

Surgical Simulator for Endovascular Intervention

Procedures that can be simulated:

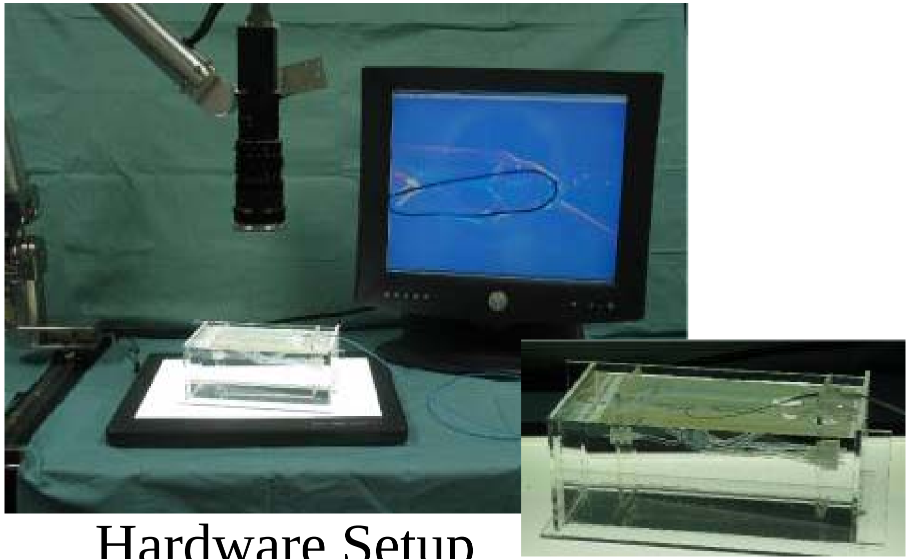
- Catheter and Guide Wire Insertion
- Aortic Stents Grafts
- Carotid Artery Stenting (CAS)
- Cerebral Artery Embolism with coil or balloon
- Percutaneous Transluminal Angioplasty (PTA) with a balloon or stents.
- Percutaneous Transluminal Coronary Angioplasty (PTCA)
- Transcatheter Hepatic Artery Embolization (THAE)
- Percutaneous Transluminal Recanalization (PTR)

Cerebral Artery Embolism Treatment Simulation

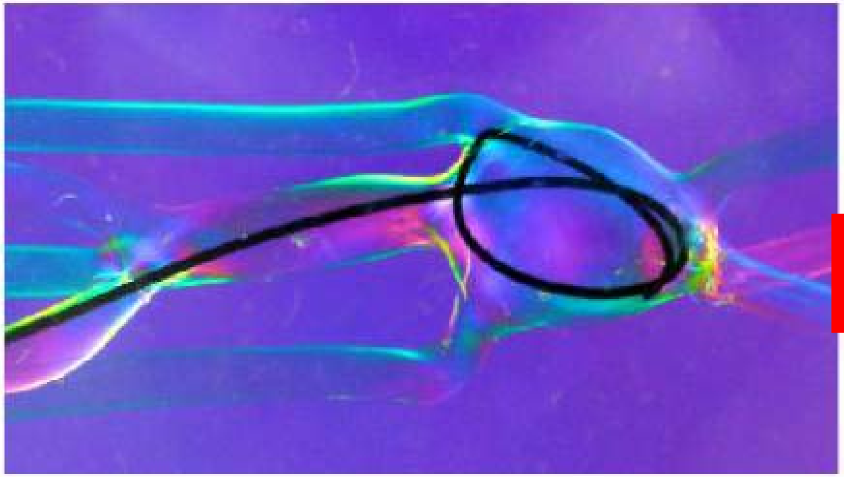


Surgical Simulator for Endovascular Intervention

Realtime Stress Visualization

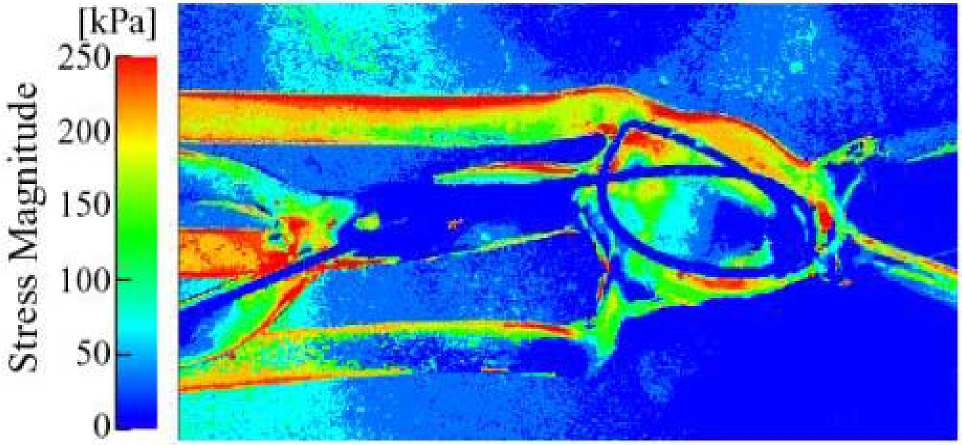


Hardware Setup



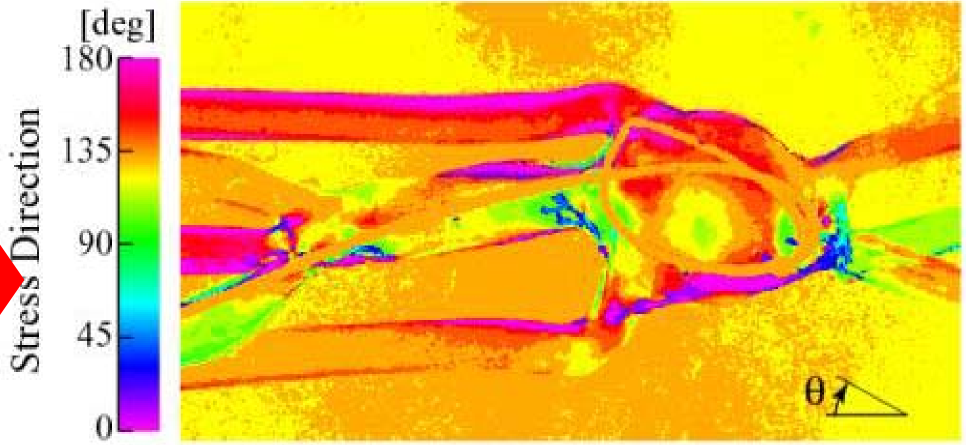
Observed Image

[S. Ikeda, in Proc. of MICCAI 2005]



(a) Magnitude of Principal Shearing Stress

(a) Analyzed Magnitude



(b) Direction of Principal Shearing Stress

(b) Analyzed Direction

Surgical Simulator for Endovascular Intervention

Quantitative Stress Analysis

Formulation:

$$\textit{Ratio of Transmitted Light} =$$

$$\begin{aligned}
&4\,c_1^2c_2^2\sin^2(Re_{\mathrm{ex}}/2)\cos^2(Re/2)\\
&+\{c_1^4+c_2^4+2\,c_1^2c_2^2\cos(Re_{\mathrm{ex}}/2)\}\sin^2(Re/2)\\
&+c_1c_2\sin Re\{(c_1^2-c_2^2)\sin 2\theta\\
&-c_1^2\sin(2\theta-Re_{\mathrm{ex}}/2)\\
&+c_2^2\sin(2\theta+Re_{\mathrm{ex}}/2)\}
\end{aligned}$$

Re : Retardation of object

Re_{ex} : Retardation of 1λ plate

θ : Direction of Re

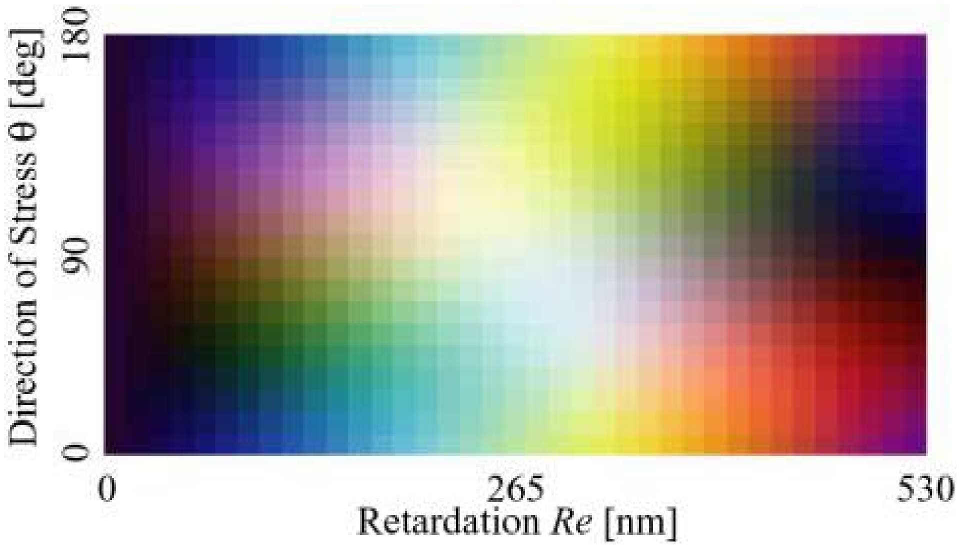
φ : Direction of Re_{ex}

$c_1 = \sin\varphi,\quad c_2 = \cos\varphi$

Calculate for R, G, B respectively

Color-Retardation Correlation

[S. Ikeda, in Proc. of MICCAI 2005]



Color-Retardation Correlation

$$Re = \alpha\,\boxed{(\sigma_1 - \sigma_2)}\,D$$

Principal Shearing Stress

Re : Retardation of object

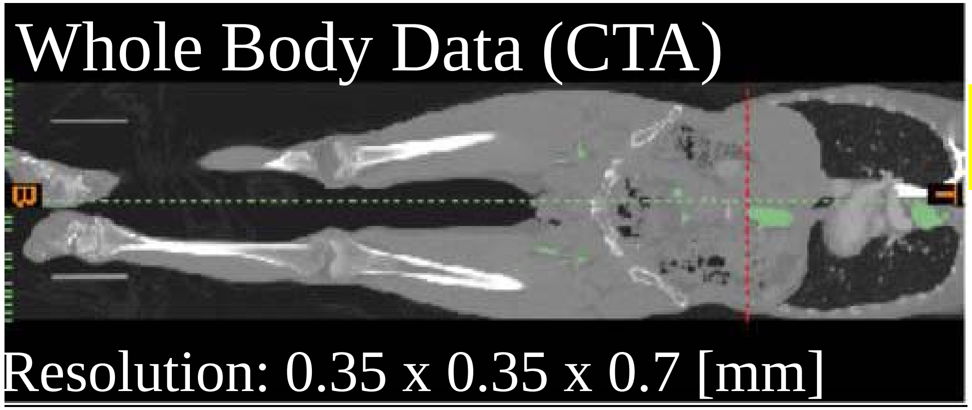
α : Photoelastic Coefficient

σ : Principal Stress

D : Thickness of object

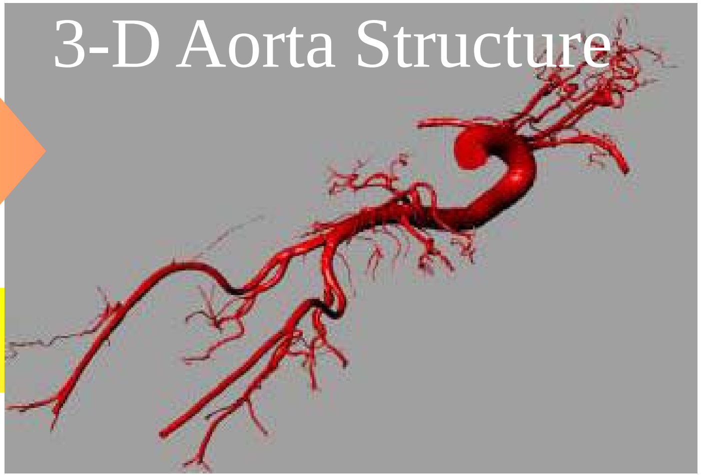
Surgical Simulator for Endovascular Intervention

Whole Body Modeling



Whole Body Data (CTA)

Resolution: 0.35 x 0.35 x 0.7 [mm]

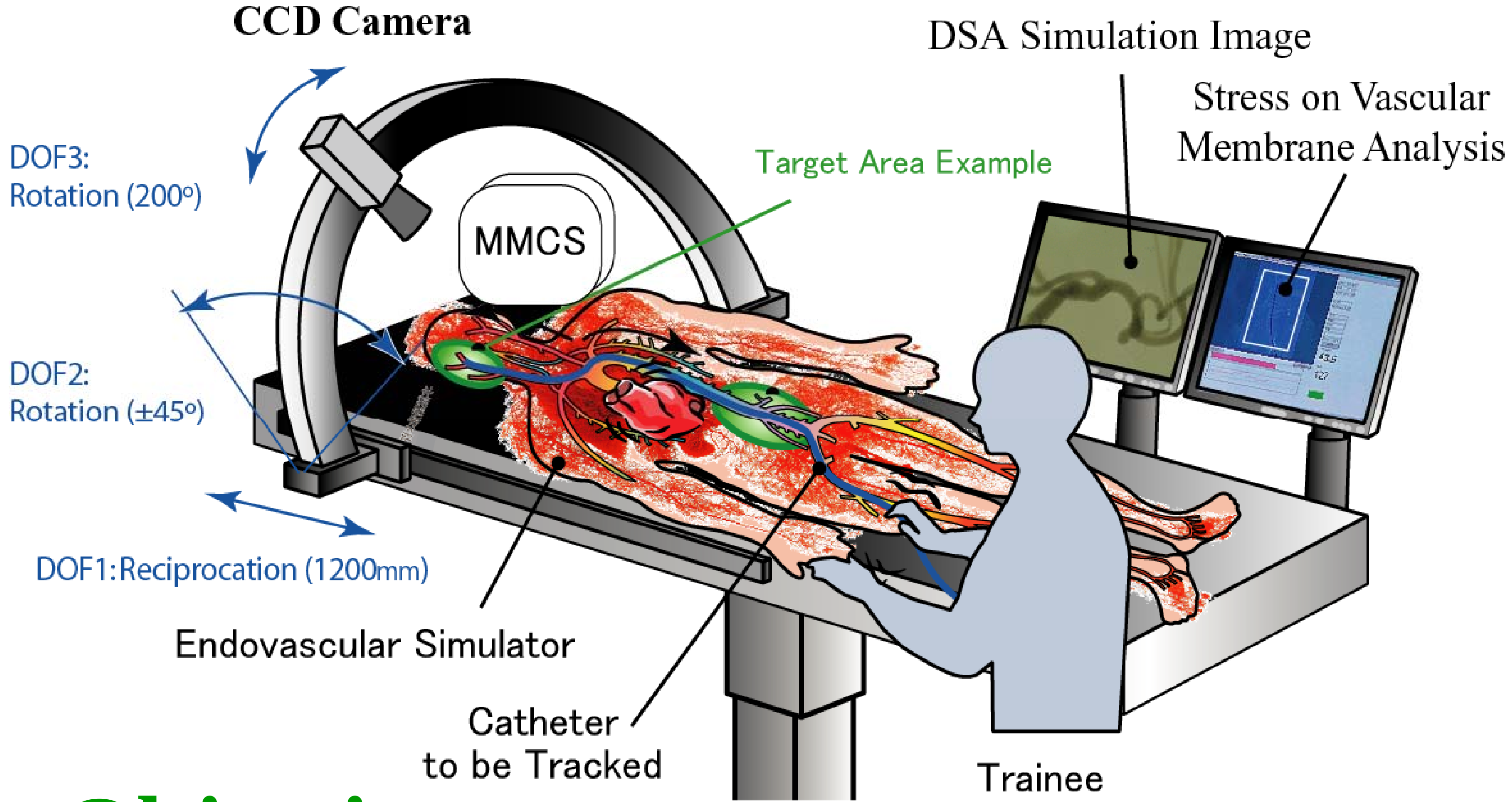


3-D Aorta Structure

Evaluation System for Endovascular Surgery

Robot Manipulation using a Magnetic Tracker

As One Application



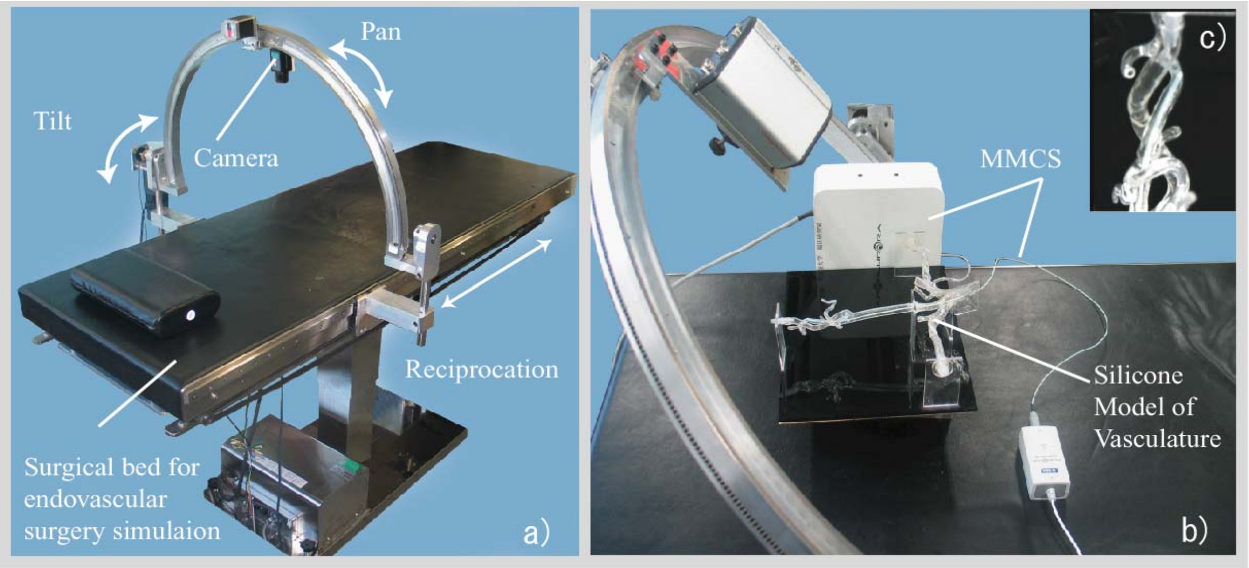
Objectives:

- Follow the catheter with the camera
- Manipulate the camera motion using a MMCS

Robot Manipulation using a Magnetic Tracker

Robotic Camera

Experimental Setup

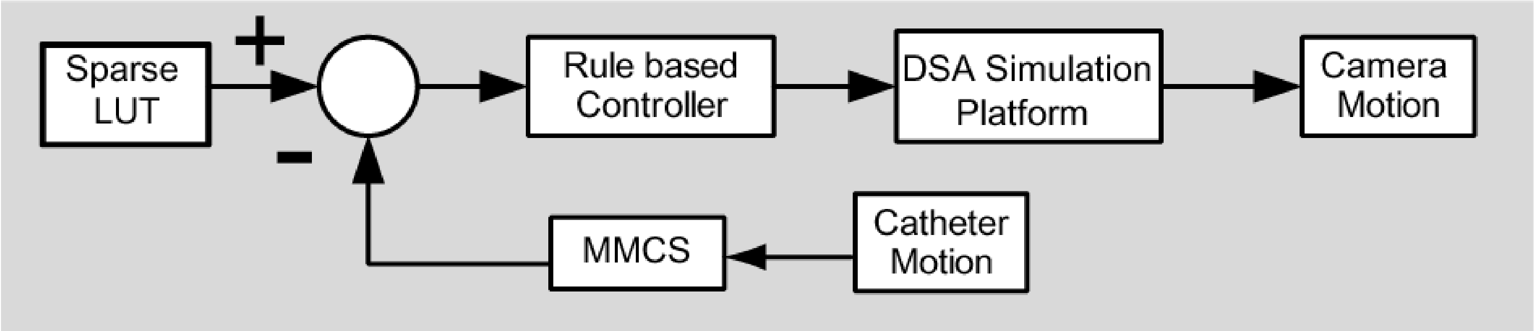


Vector of the Sparse LUT

$$\overrightarrow{P_n} = (p_{xn}, p_{yn}, p_{zn}, C_{0n}, C_{1n}, C_{2n})$$

Controller Equation

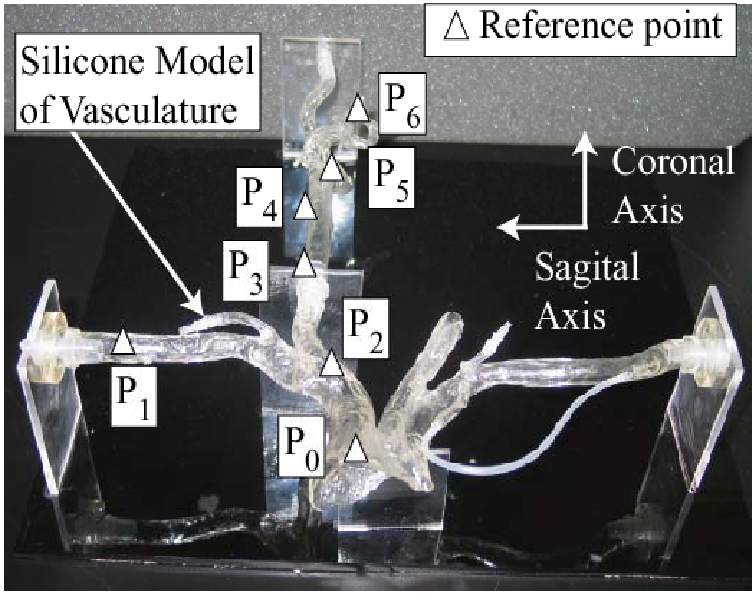
$$\sqrt{(p_{xn}-X^{t}_{mag})^2+(p_{yn}-Y^{t}_{mag})^2+(p_{zn}-Z^{t}_{mag})^2} \le d_n$$



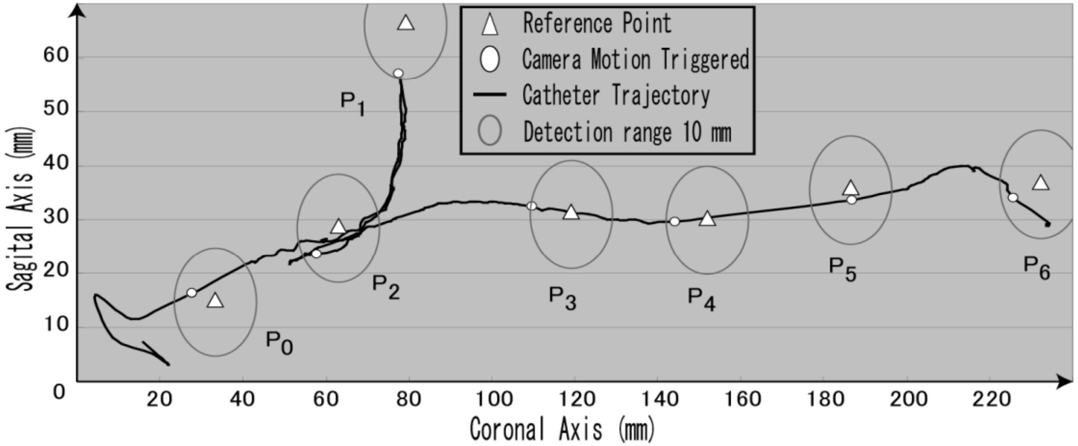
[C.Tercero, JRM 2007]

Robot Manipulation using a Magnetic Tracker

Reference points inside silicone model of vasculature



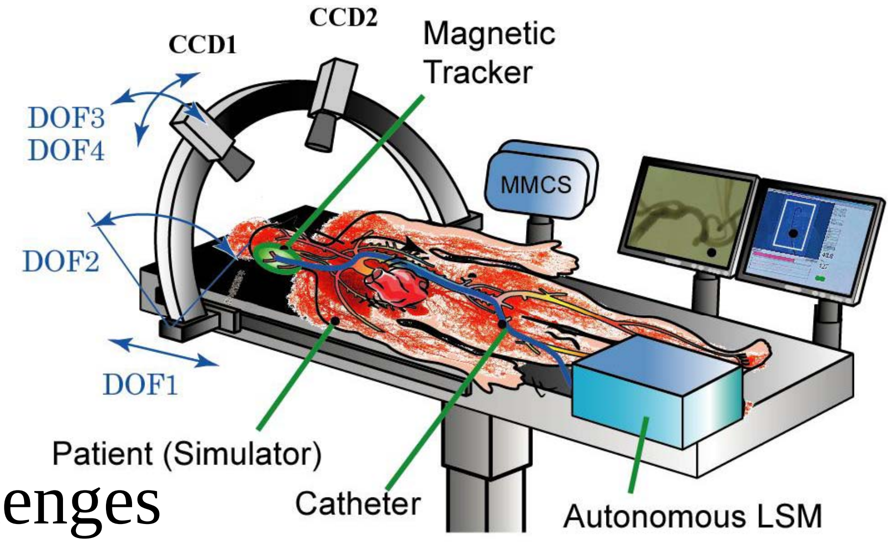
Motion Capture Data (Maximum error 10mm)



[C.Tercero, JRM 2007]

Robot Manipulation with Magnetic Tracker

Robot Teaching using a Magnetic Tracker



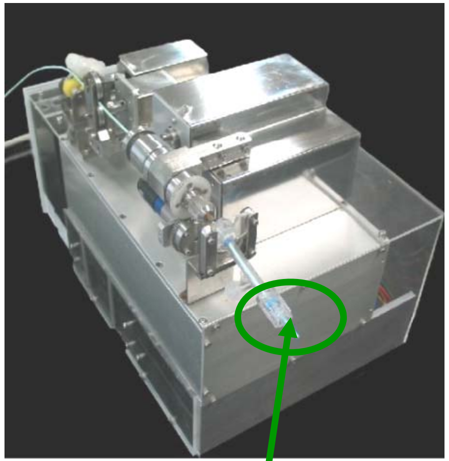
Objective

Contribute for Development of an Autonomous Catheter Insertion System for Endovascular Surgery

Challenges

- Develop an Aseptic and Efficient Catheter Insertion Mechanism
- Motion Capture of Catheter Tip
- Catheter Insertion Path Planning and Reconstruction
- Avoid Puncture of vascular membrane
- Reduce the use of the Fluoroscope
- Create catheter prototypes

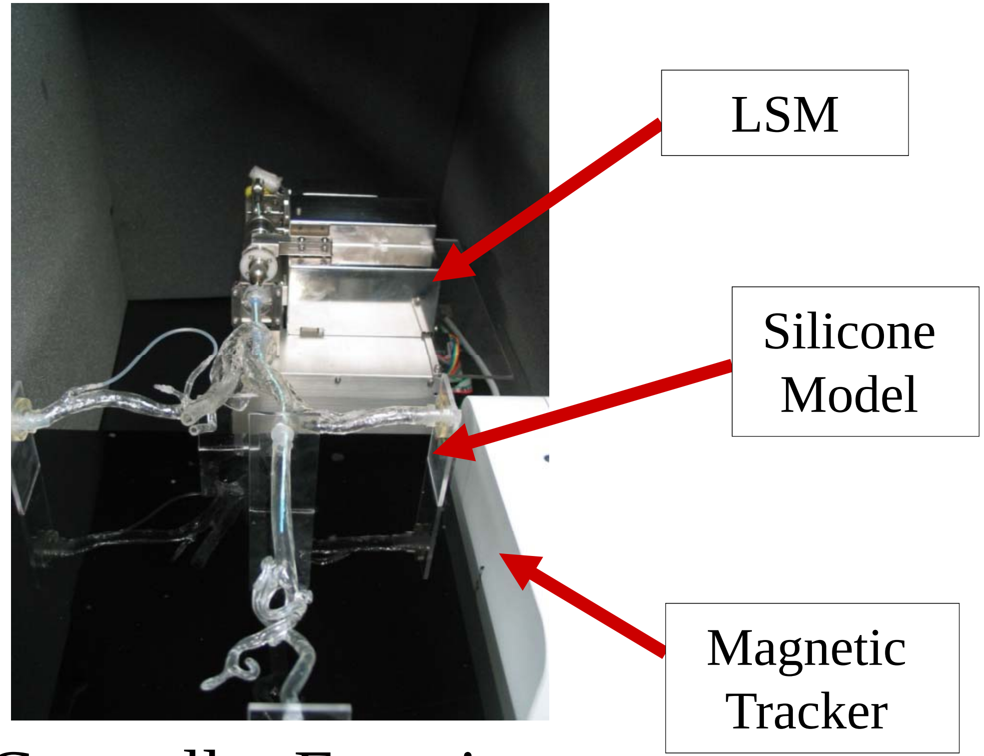
LSM3



Magnetic Tracker (MMCS)

Robot Teaching using a Magnetic Tracker

- Collect coordinates of reference points with the magnetic tracker
- Associate each collected coordinate to a desired command to be sent to LSM at each point.
- Put the tracker inside LSM at the entrance of the model
- Reproduce path automatically

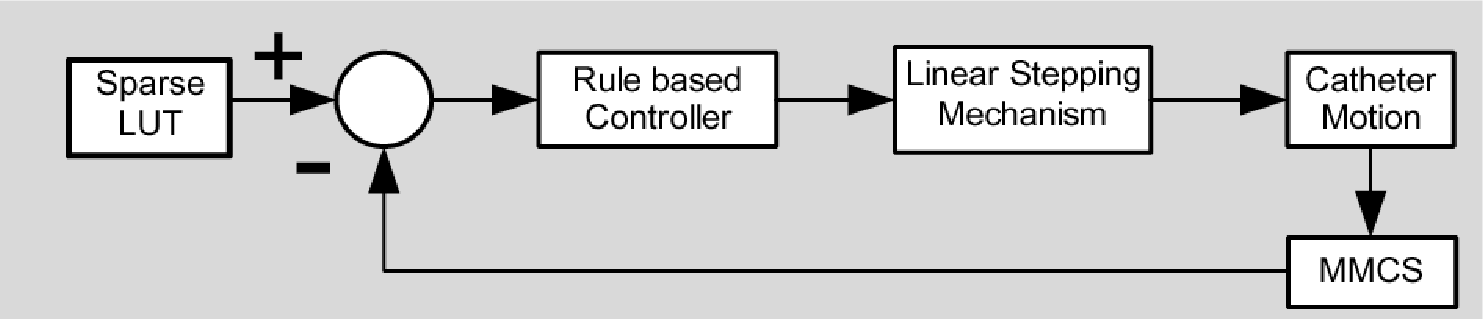


Vector of the Sparse LUT

$$\overrightarrow{P_n} = (p_{xn}, p_{yn}, p_{zn}, C_{0n}, C_{1n}, C_{2n}, C_{3n})$$

Controller Equation

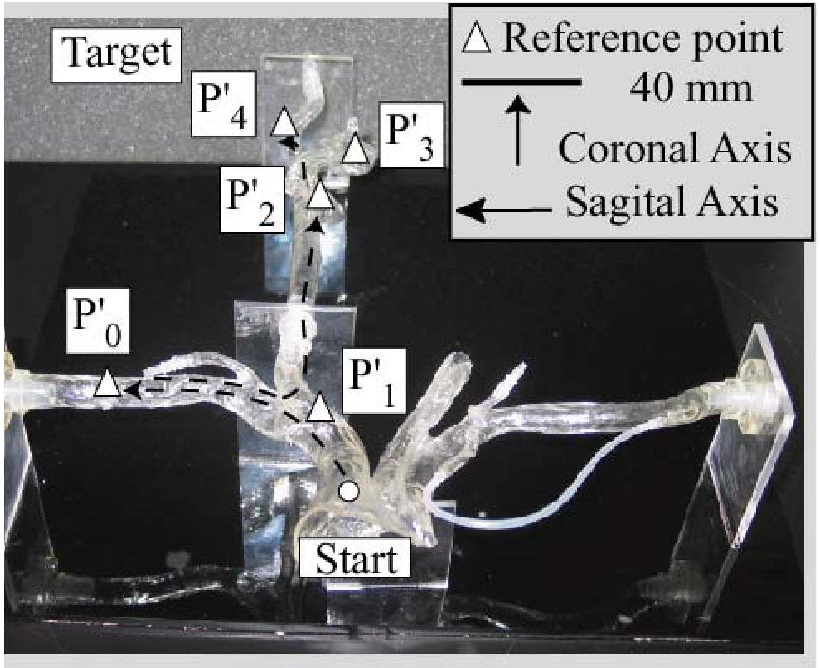
$$\sqrt{(p_{xn} - X^t_{mag})^2 + (p_{yn} - Y^t_{mag})^2 + (p_{zn} - Z^t_{mag})^2} \le d_n$$



[C.Tercero, JRM 2007]

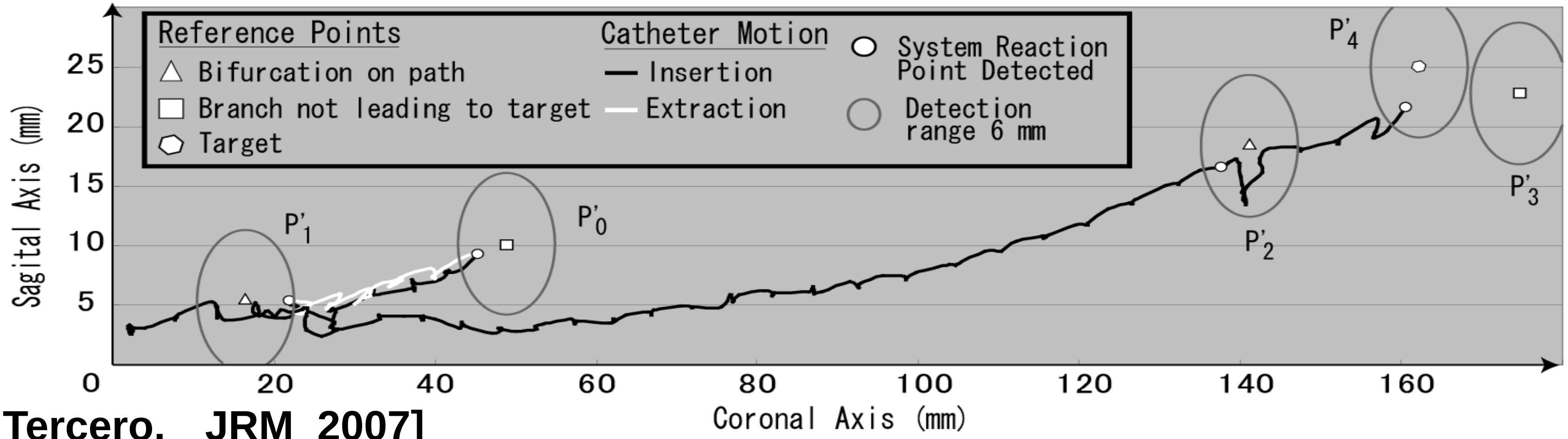
Robot Teaching using a Magnetic Tracker

Path given to the robot



Path Reconstruction

Motion Capture of Catheter Trajectory Maximum (Error 6 mm)



[C.Tercero, JRM 2007]

Numerical Evaluation of Catheter Performance

Objective:

- Create an in-vitro numerical evaluation method for catheter performance
- Compare numerically MMCS probes to a Medical Use Catheter

Requirements:

- Evaluation field similar to human vasculature
- For each evaluation homogeneous manipulation of the catheters is needed
- A method to register the catheter performance

[C.Tercero, IJMRCAS 2007]

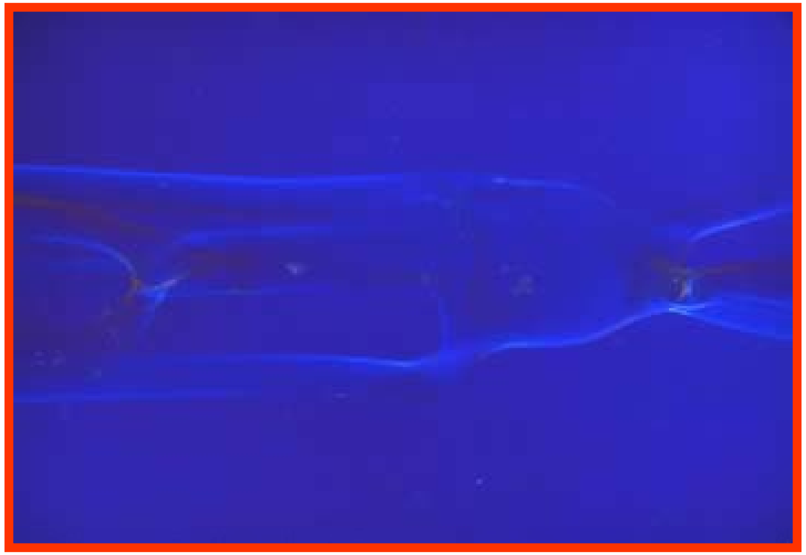


Photo-elastic Effect

Linear Stepping Mechanism 3

Numerical Evaluation of Catheter Performance

Method to deduce performance

Reproduce predefined trajectory of the catheter with LSM inside model of vasculature

↓

Capture in video birefringence produced during trajectory reconstruction

↓

Video segmentation at 10 frames per second

↓

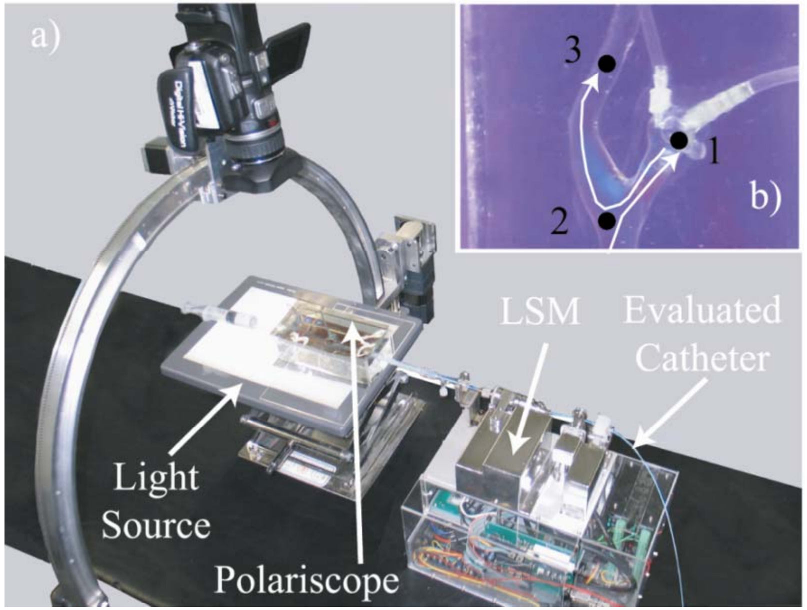
Calculate the correlation between each consecutive frame separately for all frames

↓

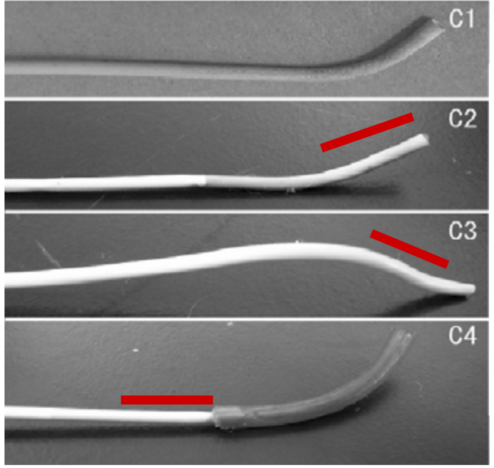
Calculate the average and minimum correlation

[C.Tercero, IJMRCAS 2007]

Experimental Setup and Trajectory



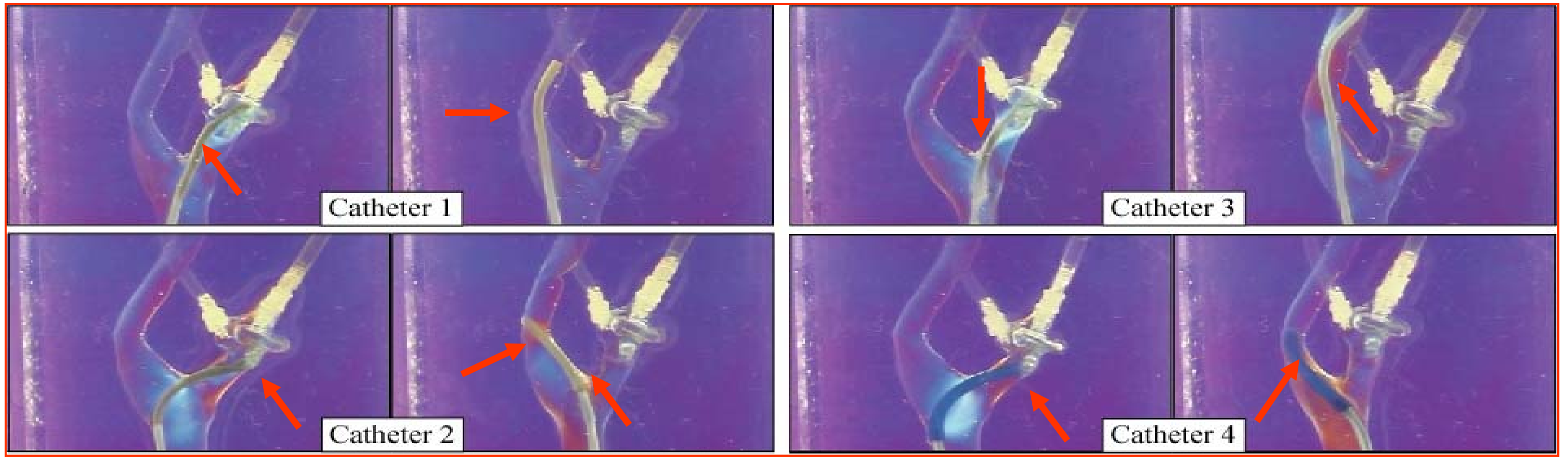
Evaluated Catheters



— Micro Coil Location

Numerical Evaluation of Catheter Performance

Local Maxima of Birefringence Captured with all the prototypes



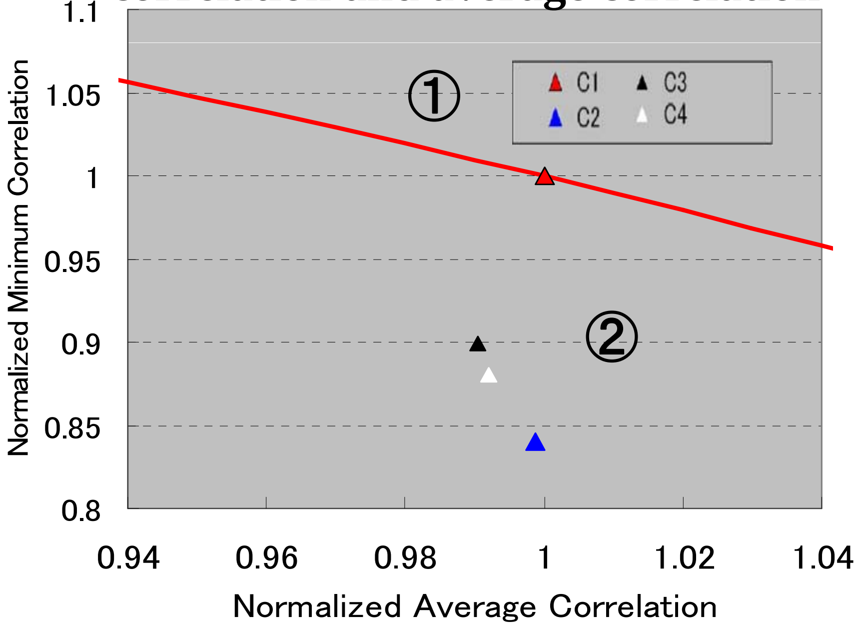
- When birefringence appears the correlation coefficient between consecutive video frames is reduced
- Minimum correlation and average correlation is then calculated and normalized

① Performance Above Medical use Catheter

② Performance below Medical use Catheter

C1 Medical use catheter

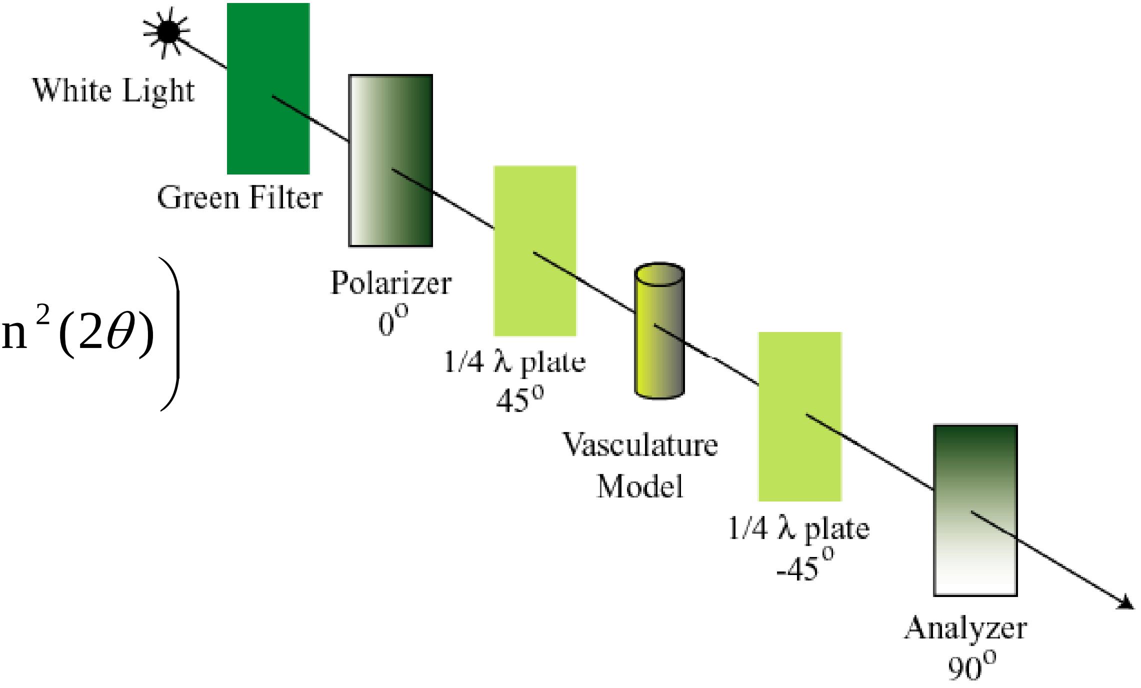
Relation between normalized minimum correlation and average correlation



[C.Tercero, IJMRCAS 2007]

1. Photoelastic Stress Analysis Theory

Green Light Intensity relates with Stress by:

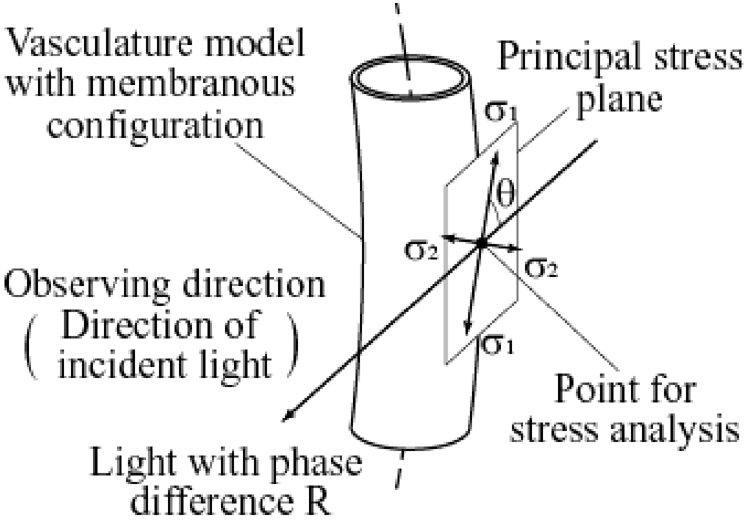


$$I_{GN} = \sin^2 \frac{\pi \mathrm{Re}}{\lambda_G}\left(\cos^2(2\theta)\sin^2\left(\frac{\lambda_{ex}\pi}{2\lambda_G}\right) + \sin^2(2\theta)\right)$$

Stress Visualization

$$\sigma_1 - \sigma_2 = \frac{\mathrm{Re}}{CD}$$

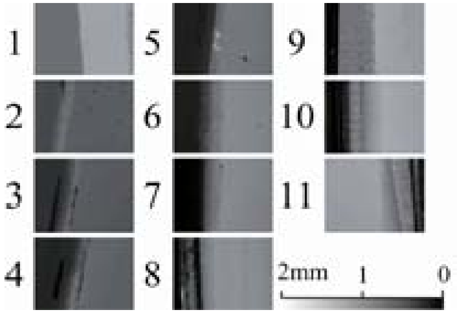
- I_{GN} = Normalized Green Light Intensity
- Re= Retardation of Green Light
- D= Model Thickness
- C= Photoelastic Coefficient
- σ_1,σ_2 = Principal Stress Components

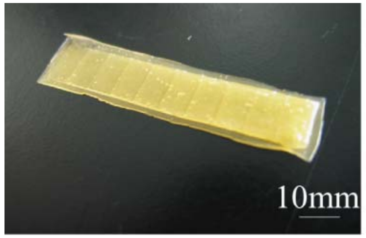


[C.Tercero, IEEE/ASME Trans. on Mech 2010]

3. Membrane Thickness Measurement

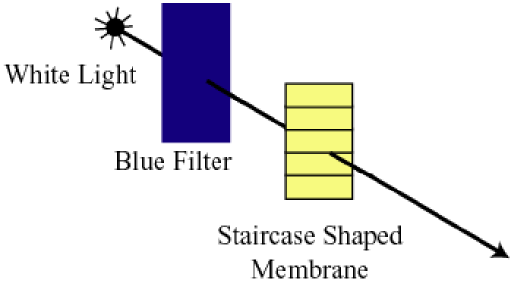
Blue Light Transmittance Coefficient Measurement



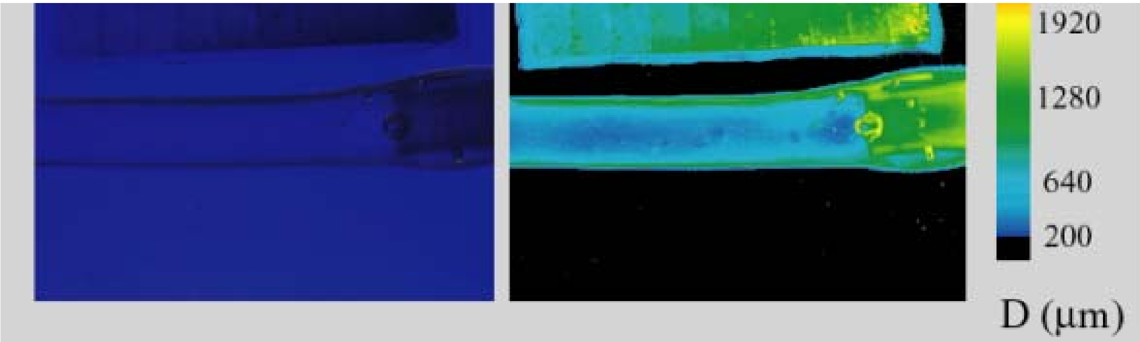


Variable Thickness Membrane

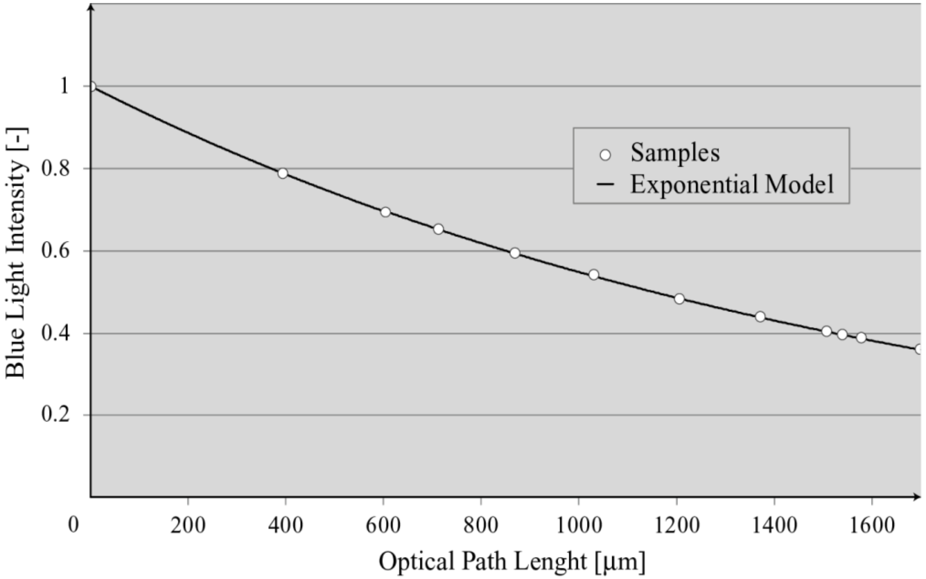
Laser Microscope Measurements



Optical Path Length (D) Measurement



Relation Between Blue Light Intensity and Laser Microscope Measurements



$$D = -T_c \ln(I_B / I_{BMax})$$

$$T_c = 1666.66$$

$$R^2 = 0.99$$

- I_B = Blue Light Intensity
- I_{BMax} = Maximum I_B

[C.Tercero, IEEE/ASME Trans. on Mech 2010]

4. Photoelastic Coefficient Measurement

Stress Measurements in Thin Membrane

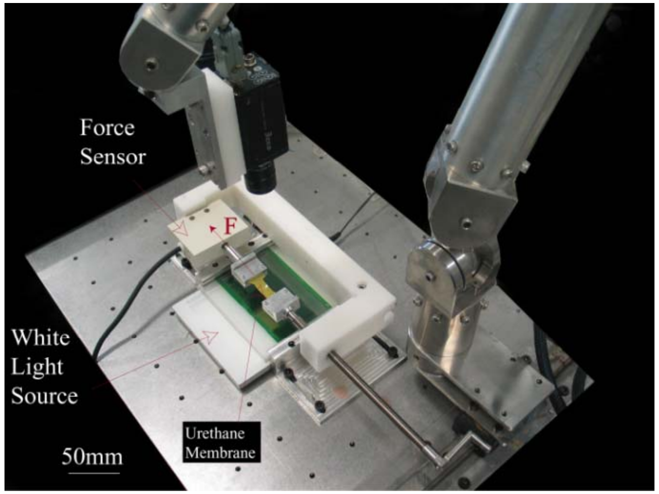
- Force Sensing

$$\sigma_1 - \sigma_2 = \frac{F}{LD} = \frac{\mathrm{Re}}{CD}$$

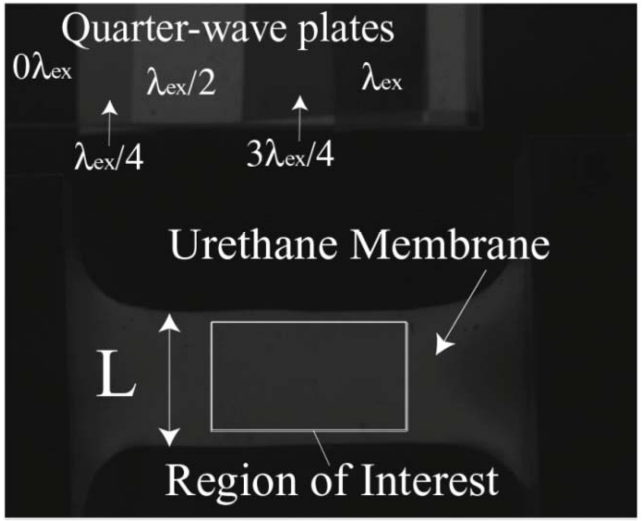
- Photoelastic Stress Analysis

$$\sigma_1 - \sigma_2 = \frac{\mathrm{Re}}{CD}$$

$$C = \frac{\mathrm{Re}\,L}{F} \Rightarrow \quad \overline{C} = 1.284 \times 10^{-9}\,Pa^{-1}$$



Measurement System to apply Variable Tension to the Membrane



Light Retardation through the Membrane

[C.Tercero, IEEE/ASME Trans. on Mech 2010]

5. Error Quantification

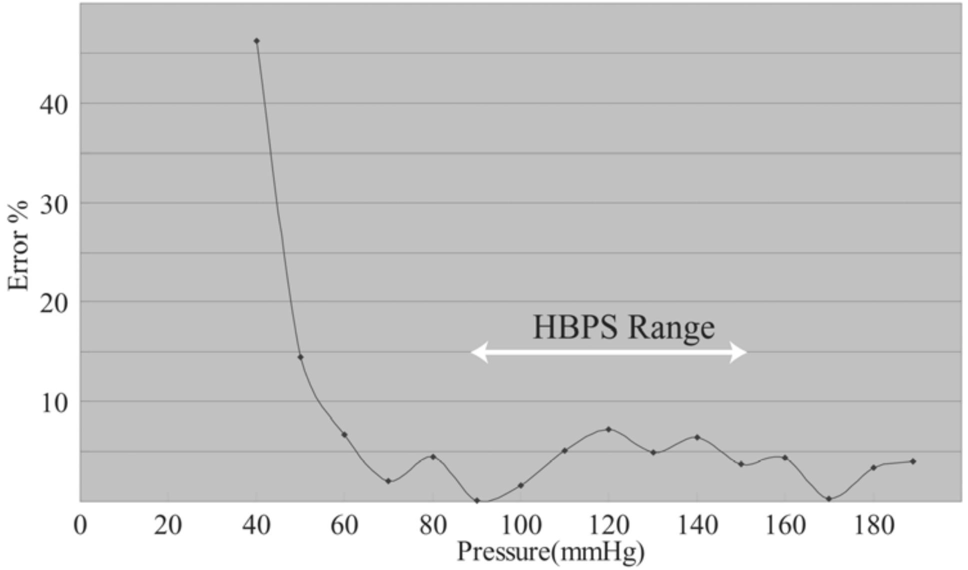
Stress Measurements in Pipe Model

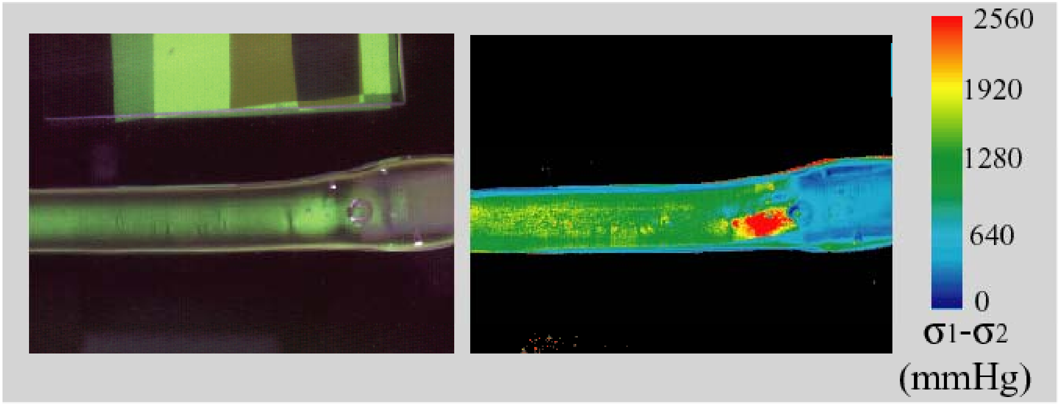
- Using pressure and radial deformation (Reference)

$$\sigma_1 - \sigma_2 = \frac{2rP}{D}\left(\frac{r-D}{2r-D/2}\right)$$

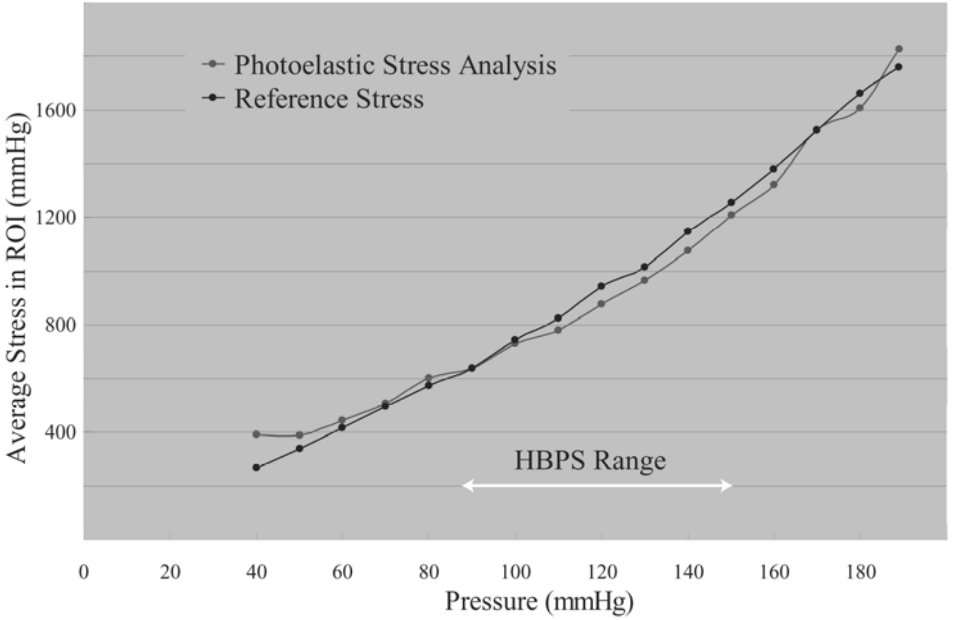
- Photoelastic Stress Analysis

$$\sigma_1 - \sigma_2 = \frac{\mathrm{Re}}{CD} \qquad I_{GN} = \sin^2\frac{\pi\,\mathrm{Re}}{\lambda_G}$$





Photoelastic Stress Analysis at 189mmHg

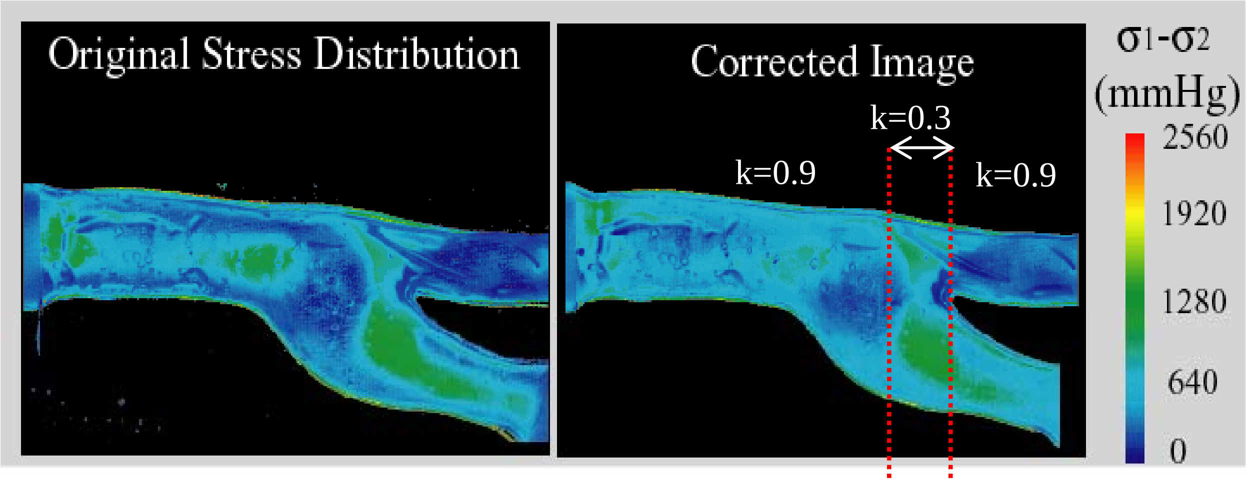


[C.Tercero, IEEE/ASME Trans. on Mech 2010]

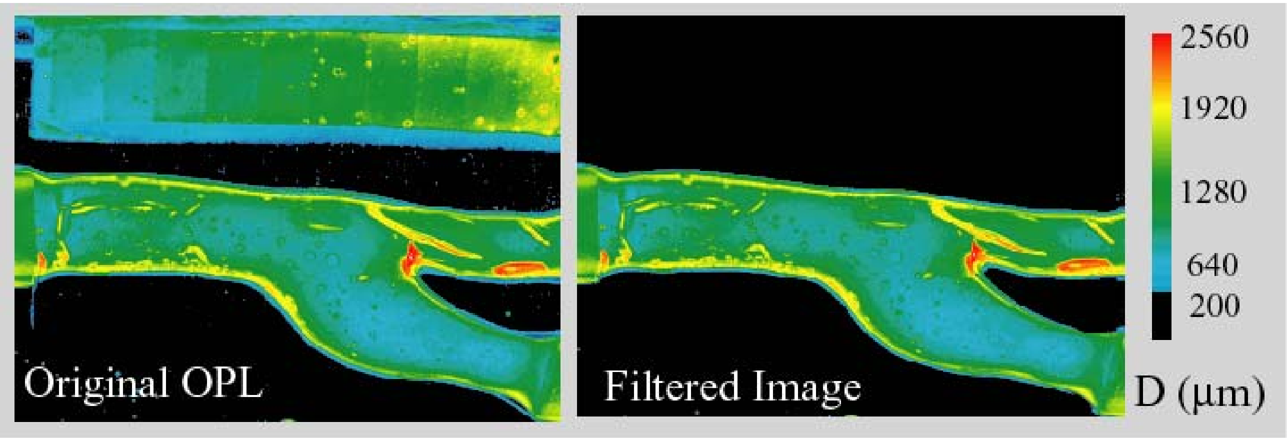
6. Application to the Carotid Artery Model

- **Stress Distribution Correction for each image column**

$$(\sigma_1-\sigma_2)'_{(x,y)} = (\sigma_1-\sigma_2)_{(x,y)} + k\cos\left(\frac{2\pi y}{40}\right)\left((\sigma_1-\sigma_2)_{AVG(x,ROI)} - (\sigma_1-\sigma_2)_{\min(x,ROI)}\right)$$



- **Noise Suppression Filtering**



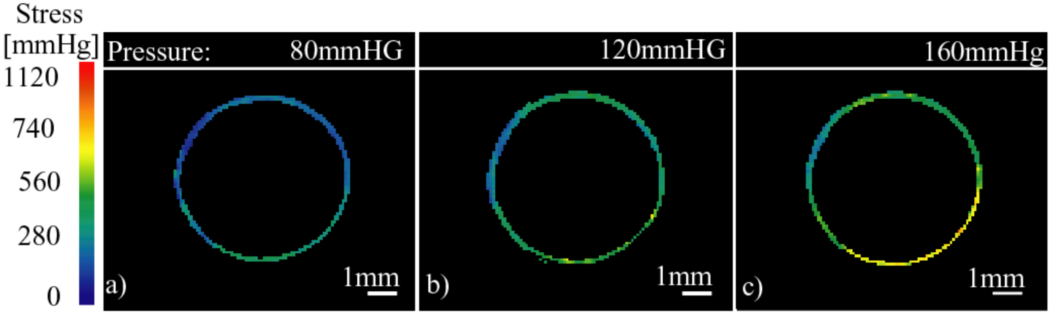
$$S = \Sigma_{n\_x\_5}^{x+5} P(n, y-5) + P(n, y+5)$$
$$+\Sigma_{n\_y\_5}^{y+5} P(x-5, n) + P(x+5, n)$$

If the S<1400 then P(x,y) must be zero

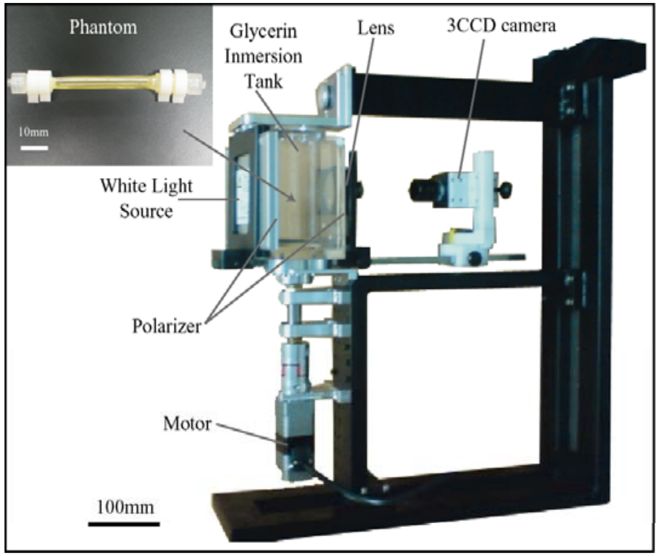
[C.Tercero, in Proc. of ISR 2010]

9. Three Dimensional Visualization of Photoelastic Stress Analysis

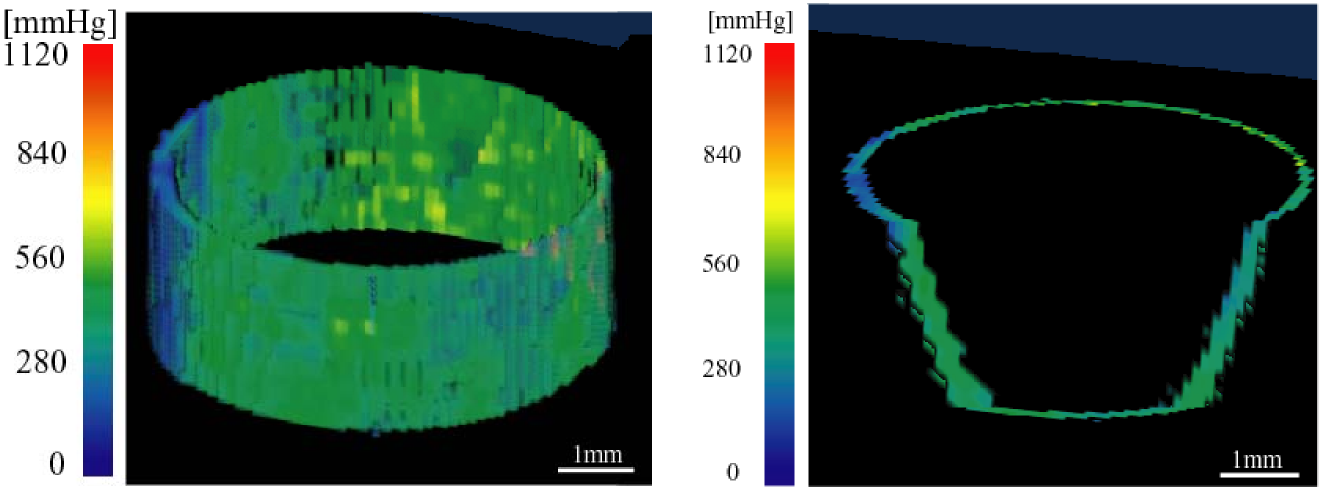
- Sinograms of Thickness and Retardation were registered using a rotary scan
- Slices of were reconstructed using ML-EM Method
- 3D Visualization of stress were calculated



Slices of Stress in pipe at different pressures



3D Scanner and Blood Vessel Model



3D Visualization of Photoelastic Stress Analysis of Pipe Segment

[M. Matsushima,   IROS2010]

Hybrid Pump

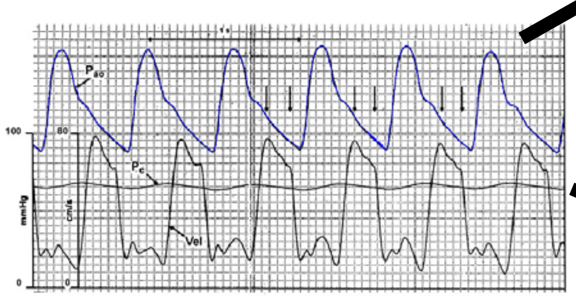
Objective:

Reproduce Human blood flow and pressure variation using a Hybrid Pump

Requirements:

- Low inertia to allow fast changes on the flow rate.
- Sustain a minimum pressure of 90 mmHg
- Do not introduce vibration on the vascular model

Applications



Human Blood Pressure in Coronary

de Bruyne, B. et al. Circulation 1996;94:1842-1849

PLCL Scaffold Evaluation

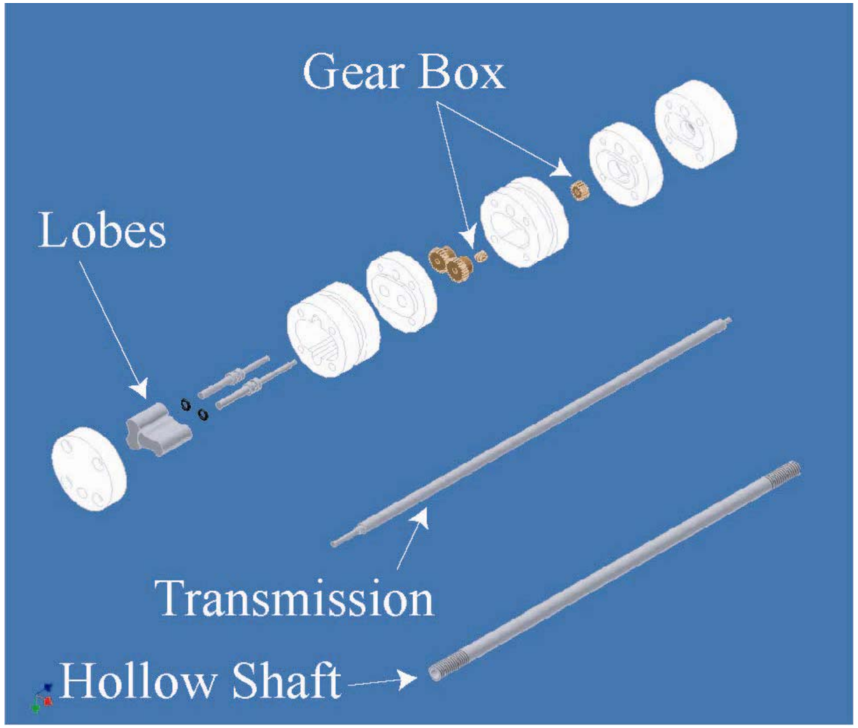
Stress Analysis with Photo Elastic Effect

Endovascular Surgery Simulation

Medical Robot Evaluation

Hybrid Pump

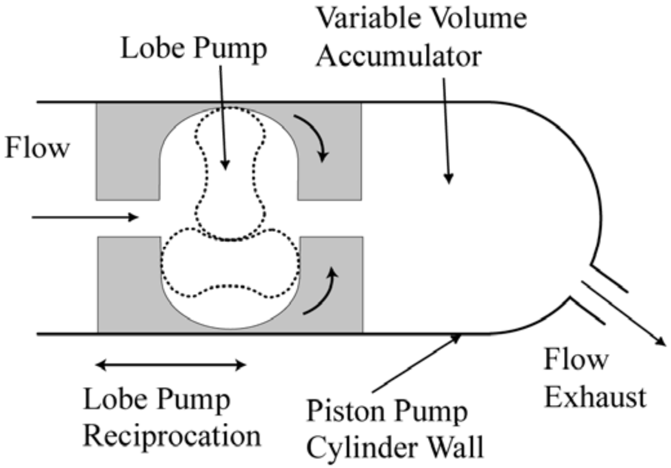
Piston Head Mechanism



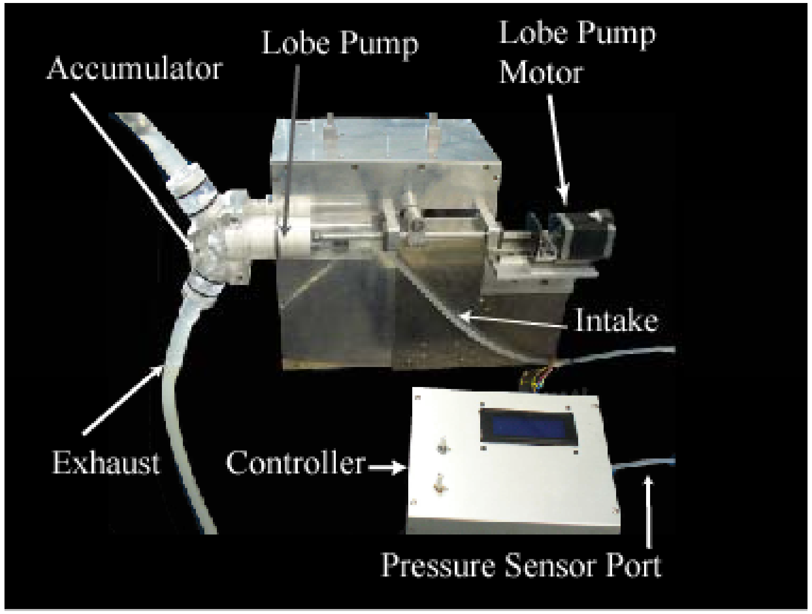
- ABS Plastic body and lobes
- Stainless Shafts and Transmission
- Stainless Bearings
- Gearbox

[C. Tercero, SYROCO 2009]

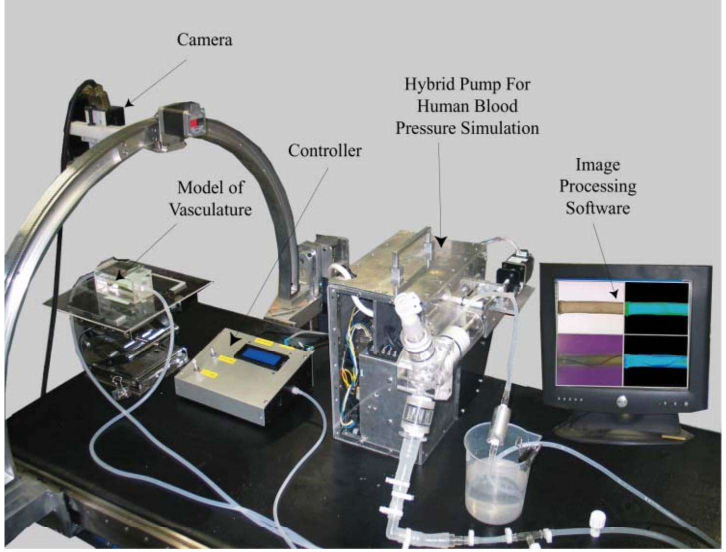
Hybrid pump concept



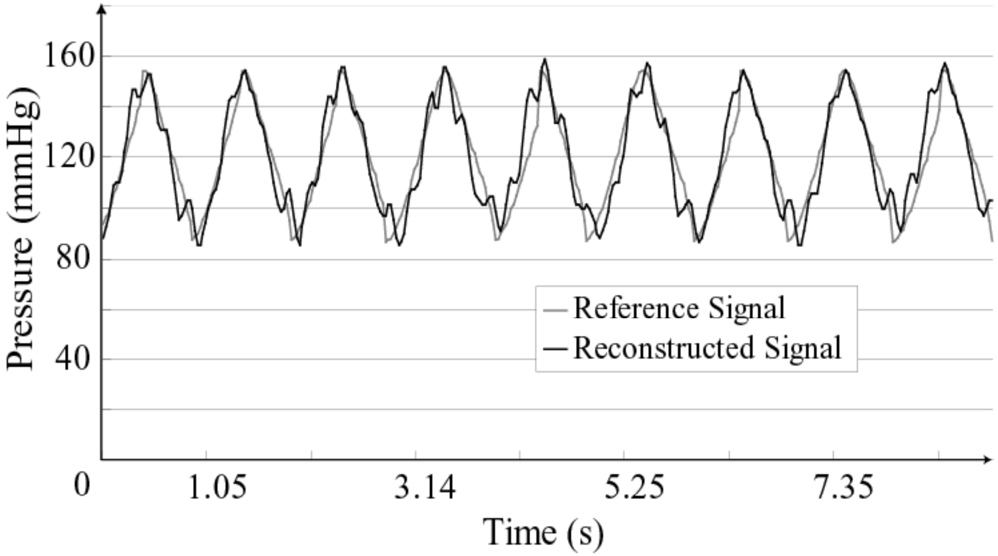
Coupling of Piston and Lobe Pump



Hybrid Pump and Photoelastic Stress Analysis



System Setup



Human Blood Pressure Simulation

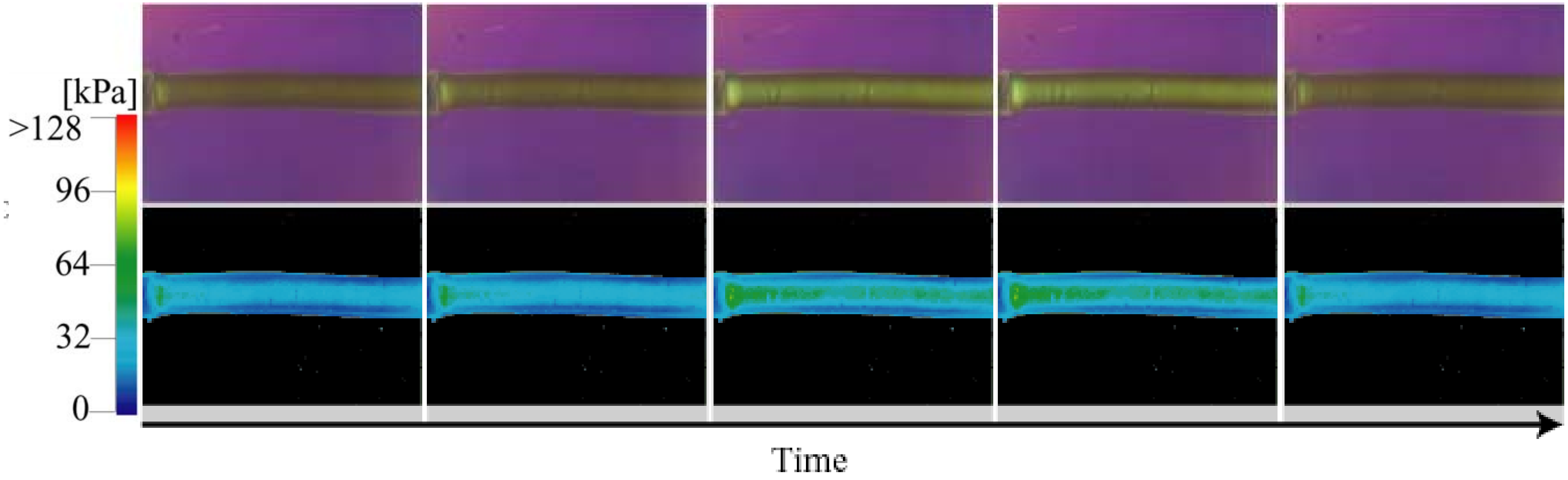
Human Pressure Simulation

Guide Wire and Human Pressure Simulation

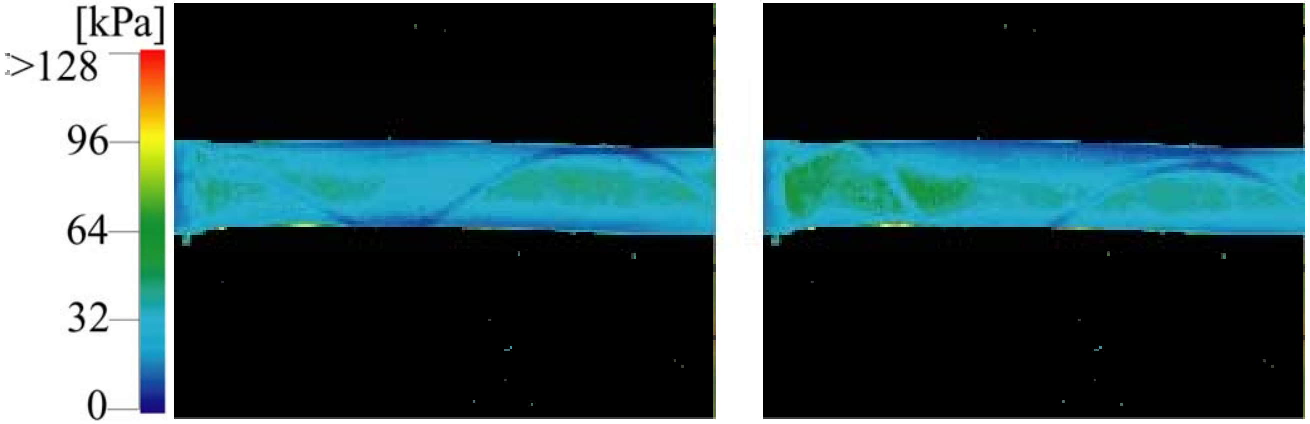
[C. Tercero, IJAT 2009]

Hybrid Pump and Photoelastic Stress Analysis

Human Pressure Simulation



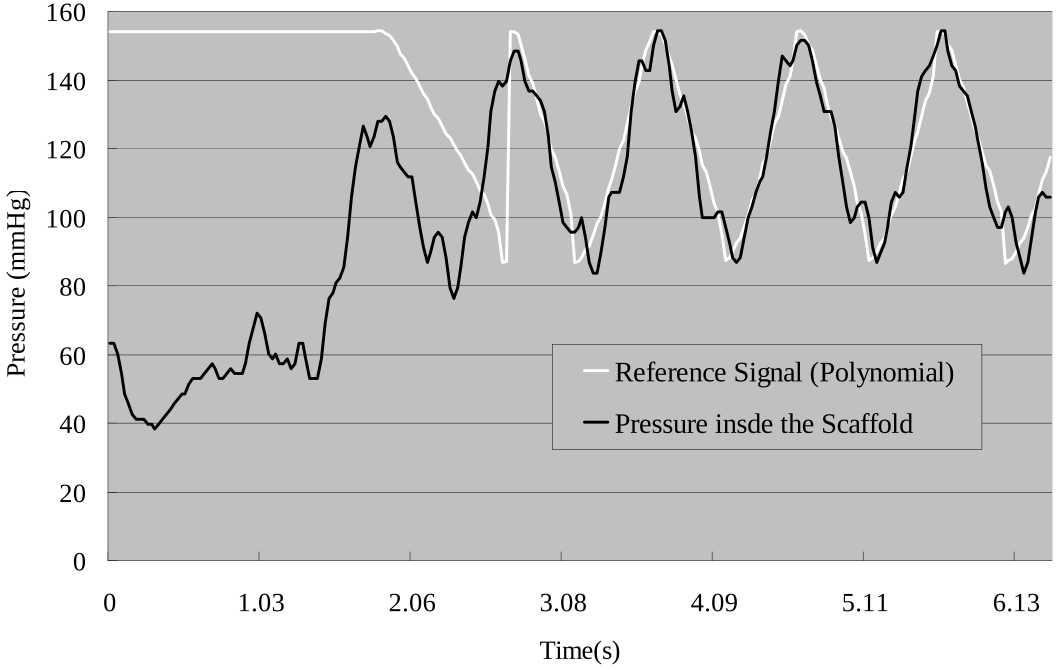
Catheter +Human Pressure Simulation



[C. Tercero, IJAT 2009]

Hybrid Pump For Scaffold Evaluation

Response to pressure waveform



Reference Signal Waveform	Polynomial command signal
Average Error (mmHg)	5.07
Maximum Pressure (mmHg)	154.35
Minimum Pressure (mmHg)	83.79
Maximum Error (mmHg)	15.55

[C. Tercero, SYROCO 2009]

PLCL Scaffold Evaluation

Diastolic

Systolic

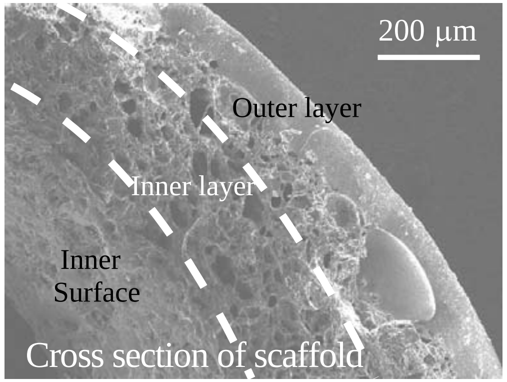
Systolic Diameter (mm)	6.11
Diastolic Diameter (mm)	5.94
Diameter at relaxation state (mm)	5.3

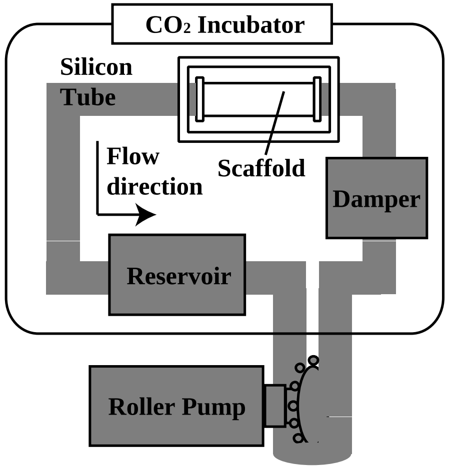
Artificial Blood Vessel

Final goal of this research

Implantation of tailor-made artificial blood vessel, fabricated in-vitro, in the place of diseased blood vessel.

Three steps to achievement the goal





Development of small diameter scaffold, which is

①Small diameter scaffold three dimensional and tailor-made

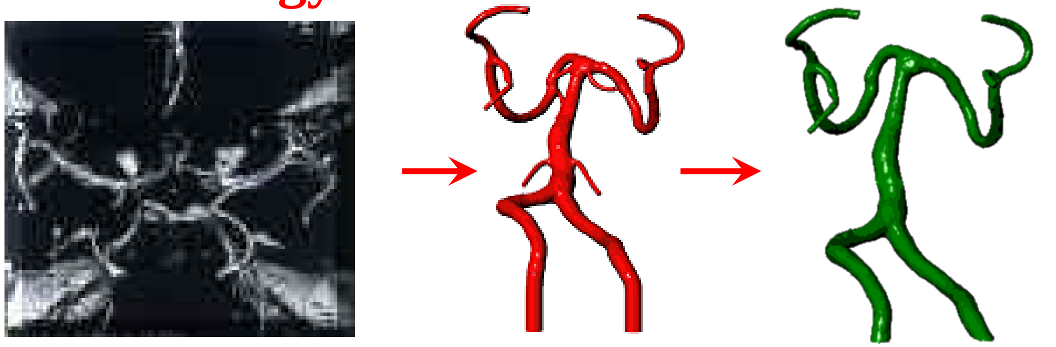
②Multi layer scaffold imitating human blood vessel

③Three dimensional cell culture to grow patient's cells on the scaffold

Artificial Blood Vessel

Fabrication method of scaffold

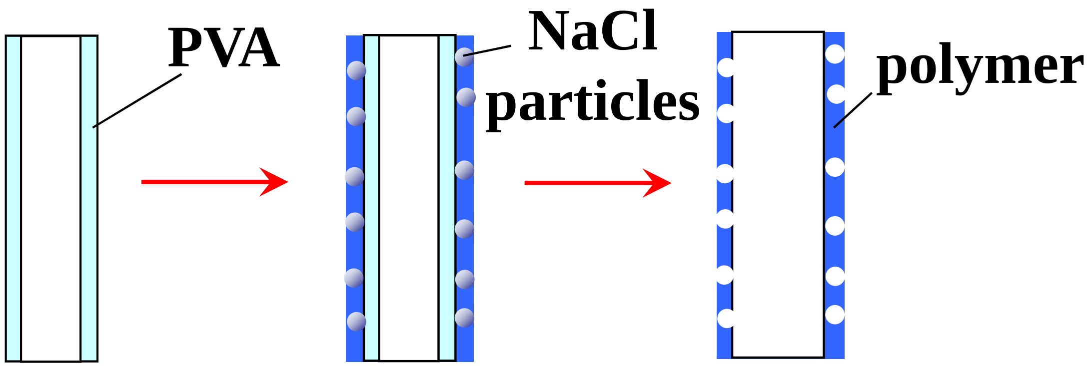
Macro technology



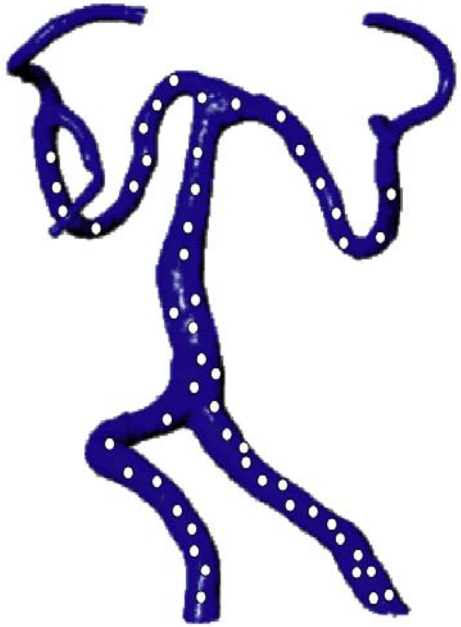
CT **CAD data** **Wax model**

Fabrication of 3D membrane using rapid prototyping.

Micro technology



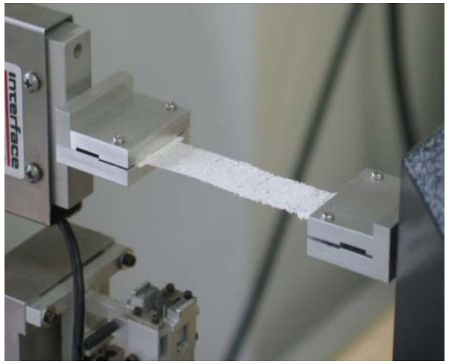
Fabrication of porous structure using salt-leaching method
（Widmer et al., 1997）



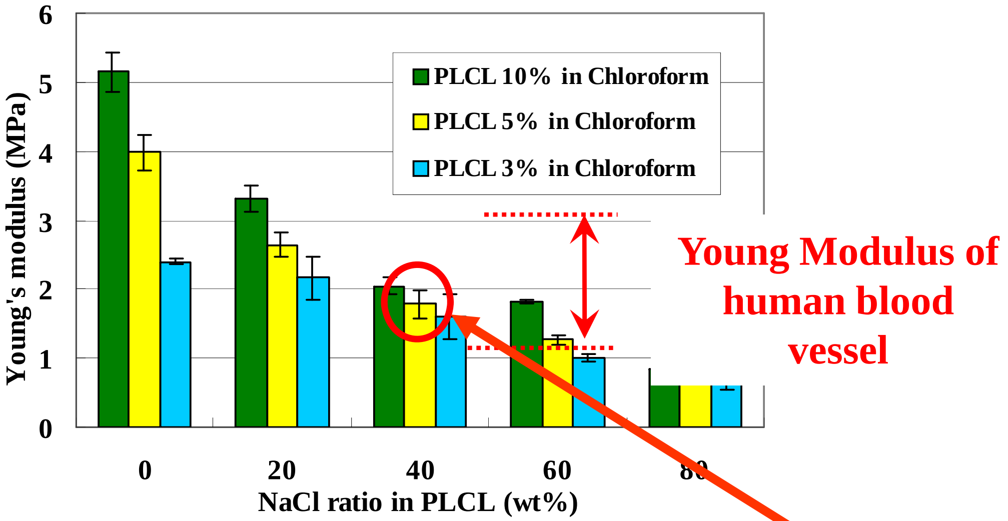
Development of tailor-made scaffold, which is biocompatible

Artificial Blood Vessel

Relation between porosity and Young Modulus



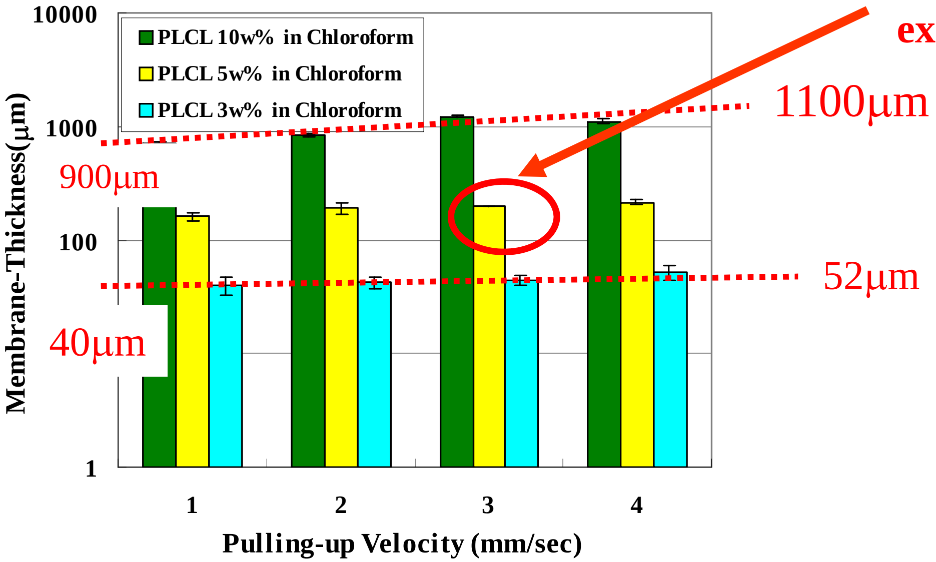
Young Modulus measurement



Selected Relations for experiments

Relation between Coating speed and membrane thickness

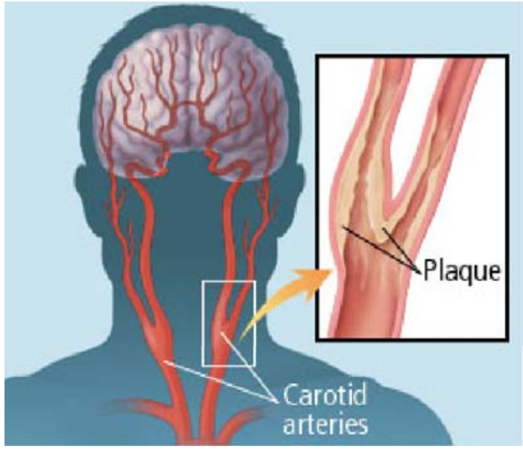
Deep coating procedure



Artificial Blood Vessel

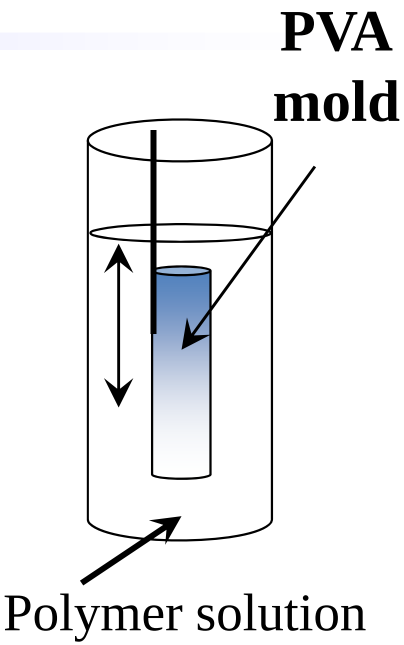
Fabrication method of the 3D carotid arterial scaffold

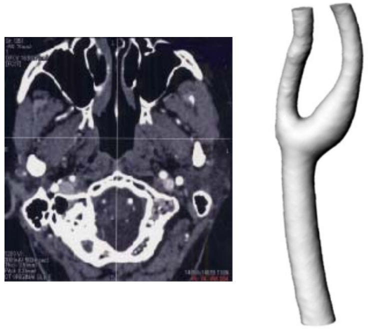
Target : carotid artery



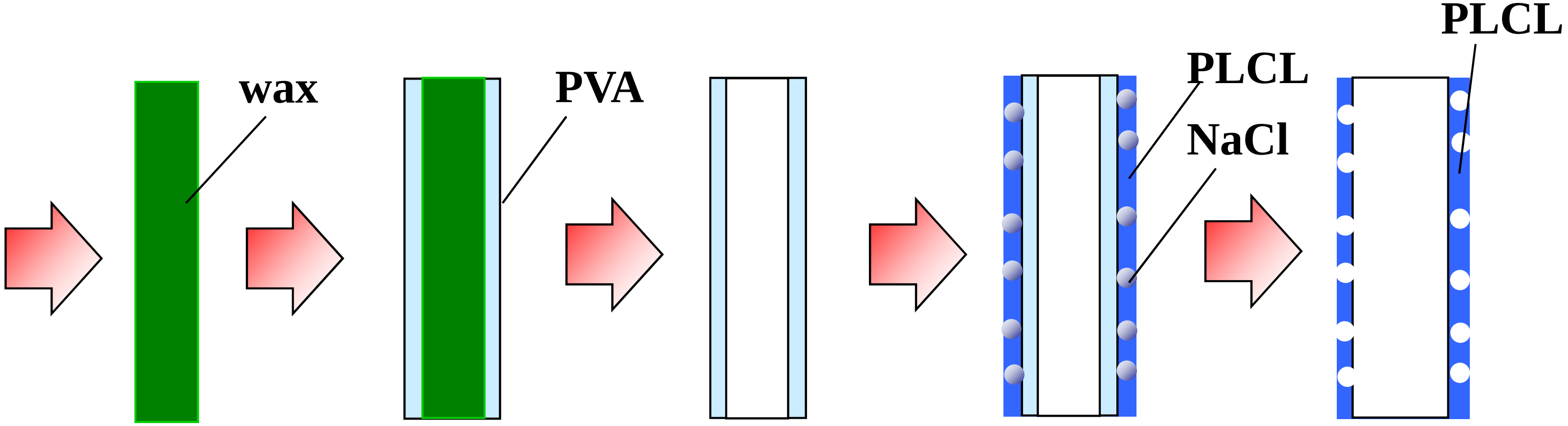
Condition of fabrication

Chloroform : PLCL	100 : 5 (wt%)
NaCl : PLCL	4 : 6 (wt%)
Diameter of NaCl	90 ~ 106 μm
Coating times	6 times
Pull-up velocity	3.0 mm/s





Extraction of carotid artery’s data from patient’s CT data.



Rapid Prototyping

Dip-coating PVA solution

Removing wax

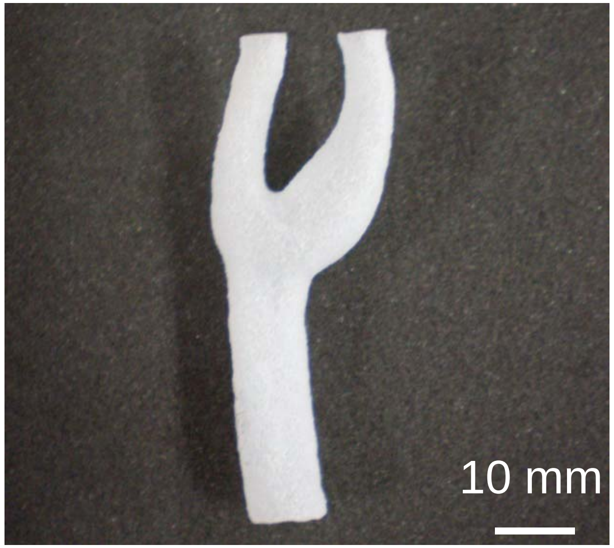
Dip-coating Polymer solution

Salt-leaching method

[T. Uchida, J. of Biotech 2008]

Artificial Blood Vessel

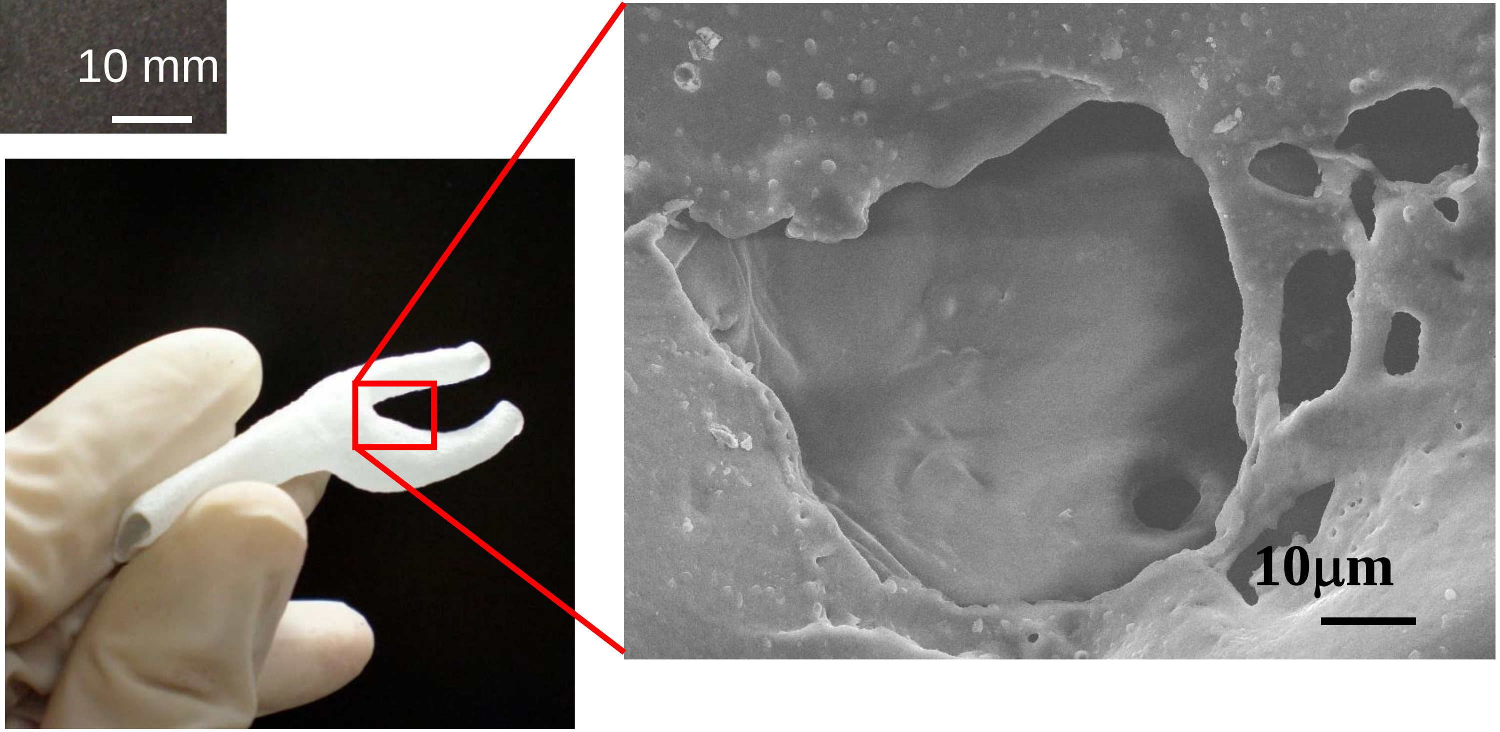
Developed porous scaffold



- Porous scaffold replicating the shape of a carotid artery
- Replicates human blood vessel elasticity (Young Modulus : 1.8 MPa)
- Porous structure, which was constructed by elusion of salt particles, was confirmed.

Observation by SEM

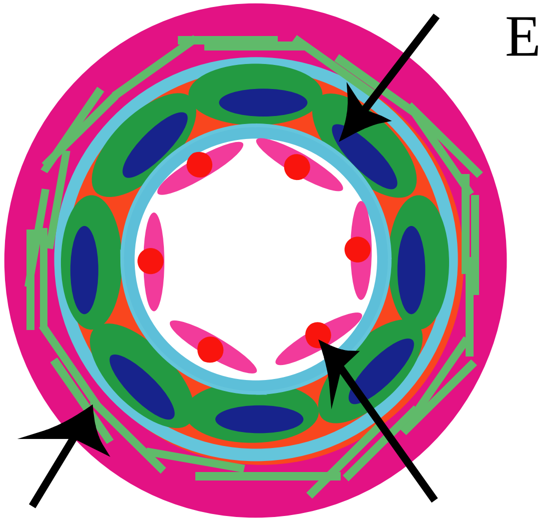
Inner diameter of:
Entrance 7.0 mm
Exit 4.0 mm



[T. Uchida, J. of Biotech 2008]

Artificial Blood Vessel

Schematic of native elastic blood vessel



Smooth muscle cell(SMCs)

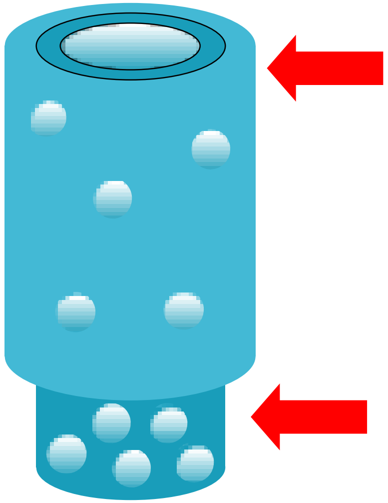
Elastic layer

Fibroblast

Secretion of protein

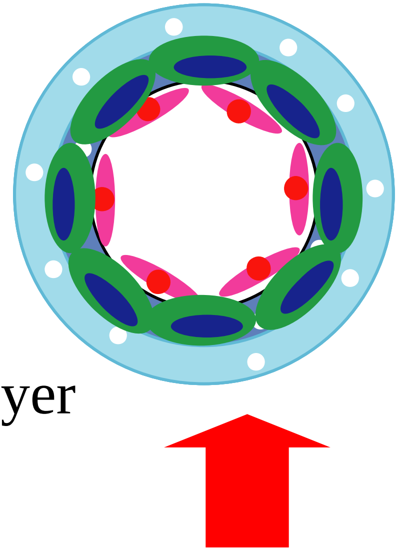
Endothelial cells(ECs)

Preventing clot



Elastic layer

Affinity layer for cell



SMCs in inner layer

ECs on inner layer

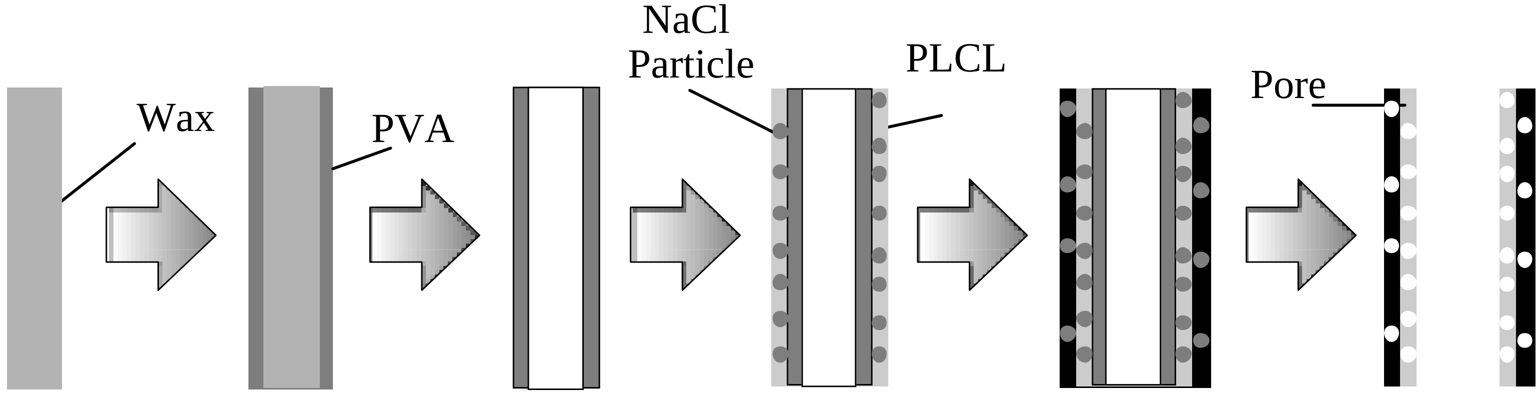
Benefits of bi-layered scaffold

- Elastic layer for withstanding blood pressure.
- High porosity layer as the base for ECs and SMCs.

[H. Oura, in Proc. of Robomec 2008]

Artificial Blood Vessel

Fabrication of bi-layered scaffold by Salt-leaching method



Rapid Prototyping

Dip-coating PVA solution

Removing wax

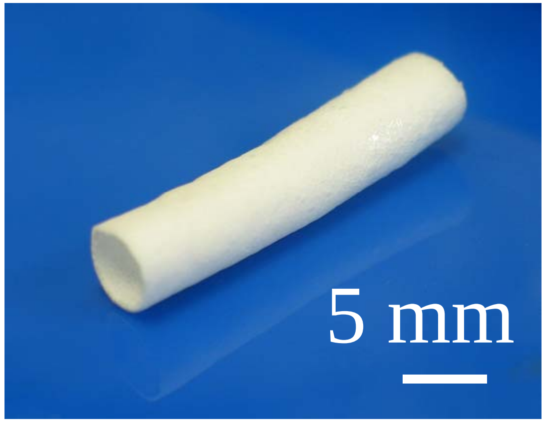
Dip-coating Polymer Solution①

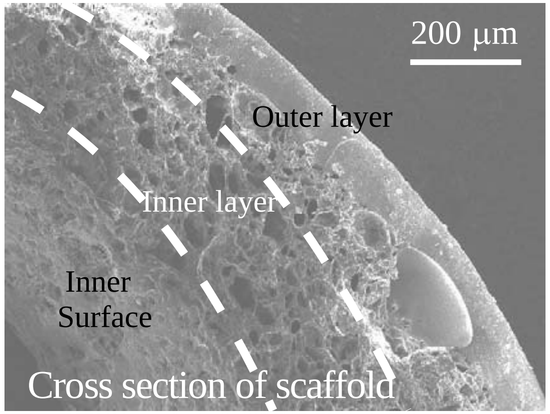
Dip-coating Polymer Solution②

Salt-leaching method

	solution①	②
NaCl:PLCL	8:2	0:10
Chloroform:PLCL	100:5	100:5
Coating times	6	6

Bi-layered scaffold



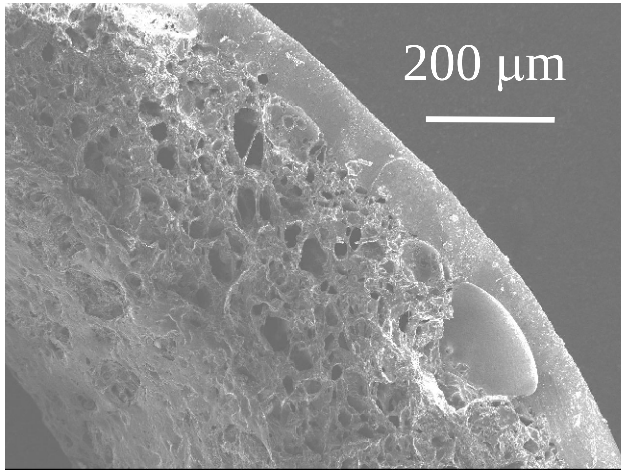


Cross section of scaffold

[H. Oura, in Proc. of Robomec 2008]

Artificial Blood Vessel

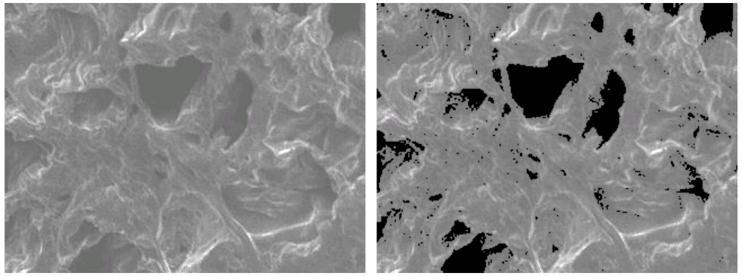
Evaluation of porosity by image processing



Experimental conditions

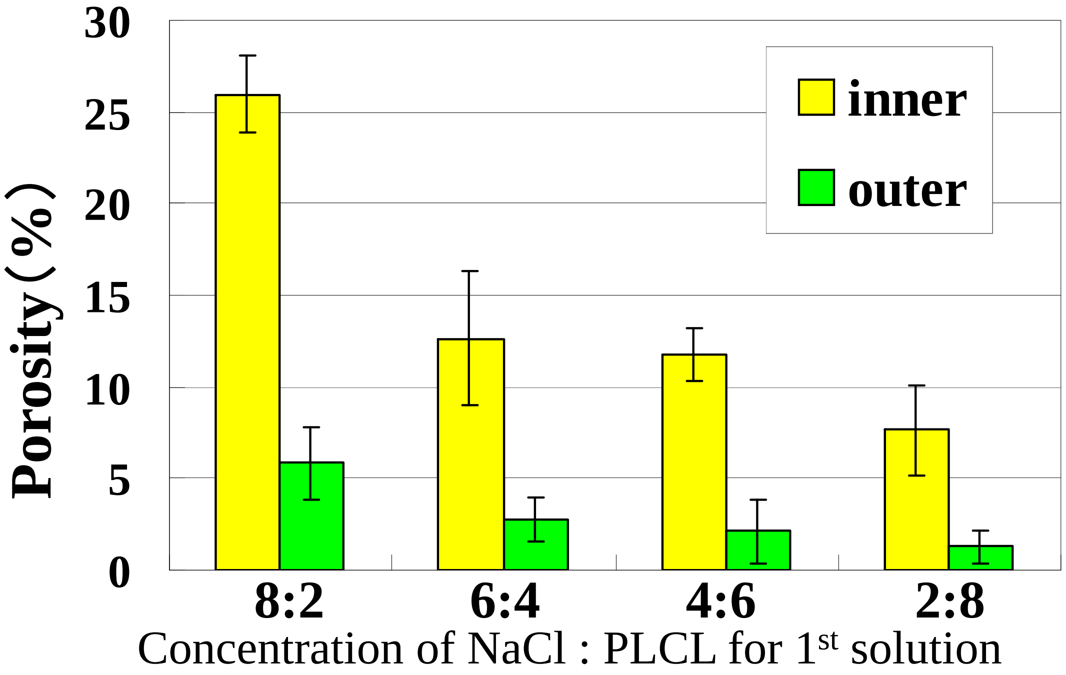
Chloroform:PLCL	**100 : 5 (wt%)**
NaCl : PLCL for inner layer	**8:2, 6:4, 4:6, 2:8(wt%)**
NaCl : PLCL for outer layer	**0 : 10 (wt%)**
Sample number	**N=10**

Image processing

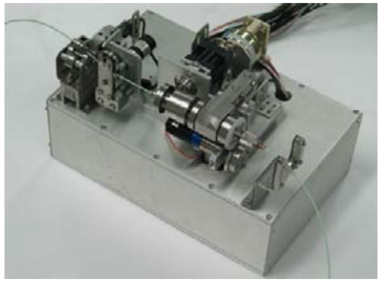


$$\textbf{Porosity(\%)} = \frac{\textbf{Porous area}}{\textbf{Cross section area}}$$

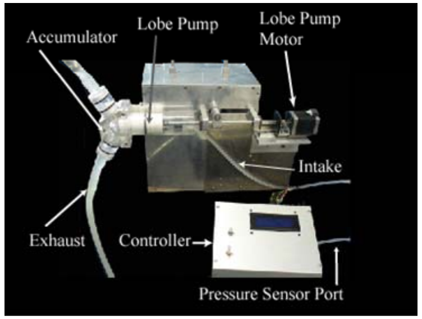
[H. Oura, in Proc. of Robomec 2008]



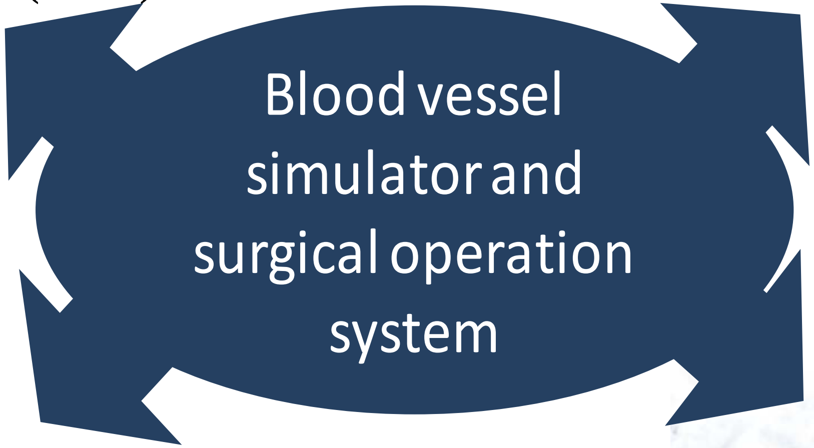
Blood Vessel Simulator and Surgical Operation System



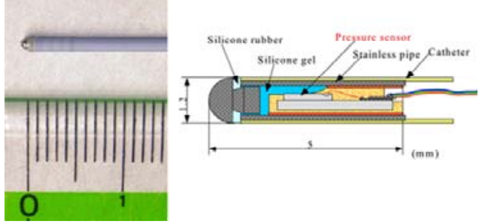
Linear Stepping Mechanism (LSM) for catheter control (2003)



Human Blood Pressure Simulation (2008)



Blood vessel simulator and surgical operation system

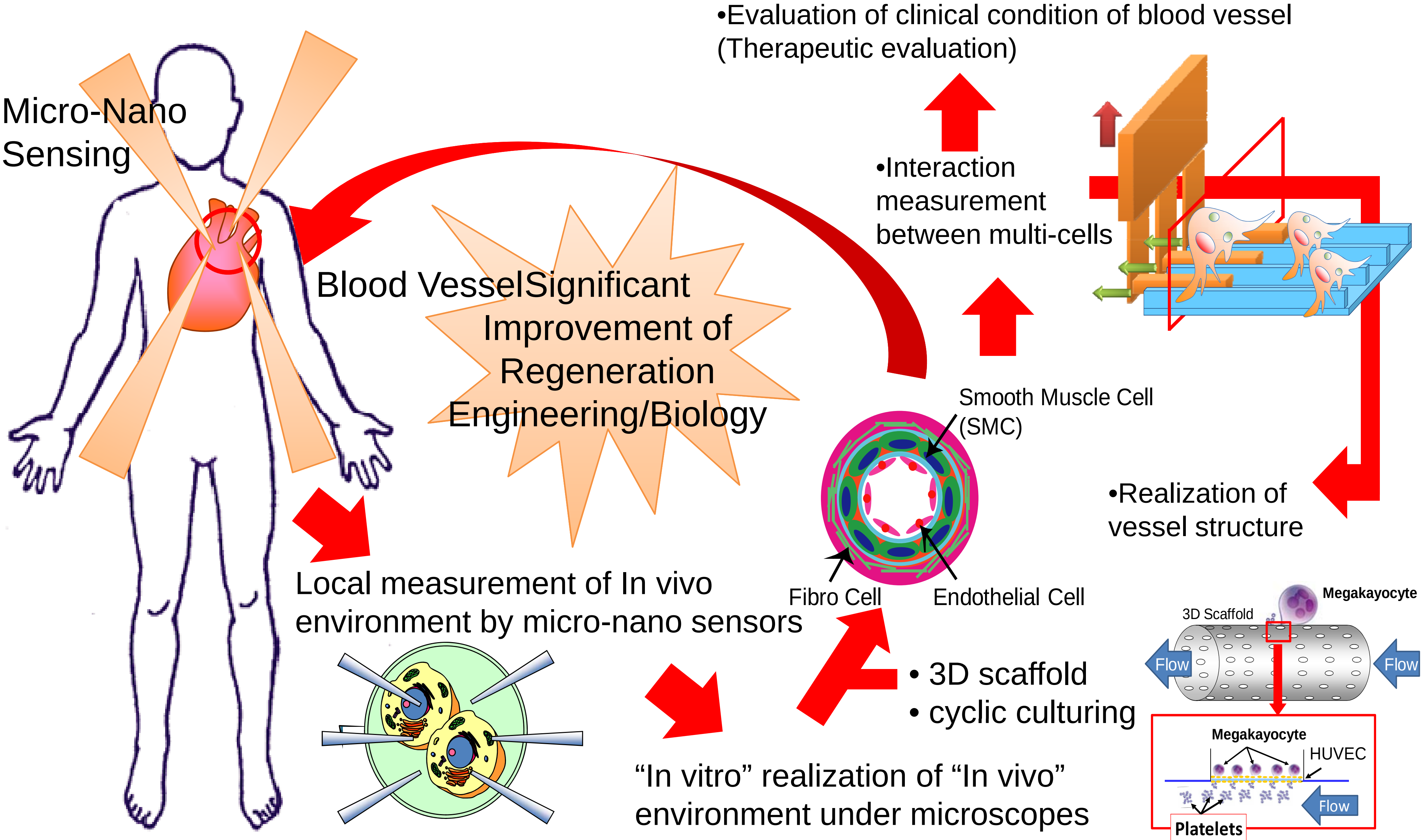


Catheter with Micro Force Sensor (1997)

Endovascular Evaluator and Photoelastic Effect of Arterial Models (2005-)

T. Fukuda et al., IEEE Industrial Electronics Magazine, Vol. 4,pp. 13-22, 2010.

“In vitro” Realization of “In vivo” Environment ~Blood vessel~



•Evaluation of clinical condition of blood vessel (Therapeutic evaluation)

•Interaction measurement between multi-cells

•Realization of vessel structure

Micro-Nano Sensing

Blood Vessel

Significant Improvement of Regeneration Engineering/Biology

Local measurement of In vivo environment by micro-nano sensors

- 3D scaffold
- cyclic culturing

“In vitro” realization of “In vivo” environment under microscopes

T. Fukuda et al., IEEE Industrial Electronics Magazine, Vol. 4,pp. 13-22, 2010.