Bionic Humanoid: Eye Model for Surgical Training of Inner Limiting Membrane Peeling Task

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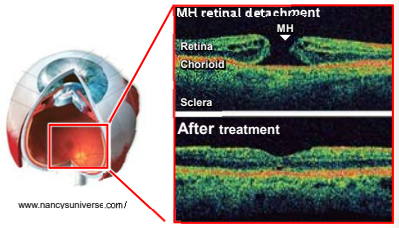
眼科手術シミュレータ: 3 μm 眼底膜の剥離性再現

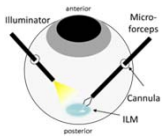
Introduction

Macular hole (MH) treatment



OBJECT

- **Fundus of the model has artificial ILM**, retina, sclera, which are mimicked bionic properties, respectively.
- An assembled artificial eye model can place on **a novel concept of an ophthalmological simulator**.



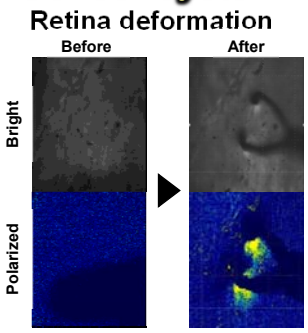
Conceptual image of eye model for ILM peeling task

Operation model

ILM peeling | Micro-cannulation

Sensor system

Retina deformation

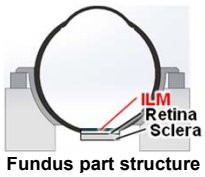


Photoelastisity

Concept

Concept of our artificial eye model:

- **To make three ports with a trocar** for inserting illuminator, micro-foreceps and infusion needle,
- **To peel artificial ILM in exactly the same way as actual surgical behavior in water condition**,
- To construct three layer of fundus part of the eye model such as artificial ILM, retina and sclera,
- **To mimic mechanical properties of artificial ILM, retina and sclera.**



Fundus part structure

Mechanical characteristics

Tissue	Thickness [μm]	Elastic modulus [kPa]
ILM	3	100
Retina	280	20
Sclera	1000	2000

K. Chen *et al.*, View issue TOC, 102, 2014; A. Halfter., *et al.*, Vitreous, 2014

Design for artificial ILM

Physical model for hydrogel sheet as ILM

Let us consider classical rubber elastic theory for designing a mechanical property of hydrogel sheet as artificial ILM.

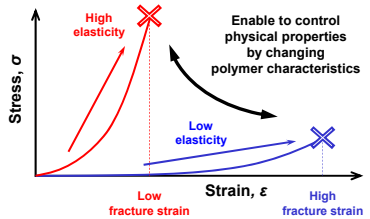
Stress-strain relationship:

$$\sigma = E\left((\varepsilon+1) - \frac{1}{(\varepsilon+1)^2}\right)$$

Here we use a poly(vinyl alcohol) (PVA) which is simple hydrophilic polymer, and can easily calculate a Young's modulus of a chemically cross-linked PVA hydrogel below:

Young's modulus:

$$E = \left.\frac{d\sigma}{d\varepsilon}\right|_{\varepsilon=0} = \frac{3\rho_m RT}{M_m M_{CL}}\rho_{CL}\left(\frac{1}{D_P} + \frac{M_m}{M_{CL}}\frac{\rho_{CL}}{\rho_m}\right)$$



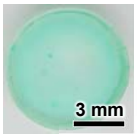
Chang on stress-strain curve

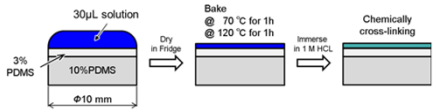
ρ	: Concentration
M	: Molecular weight
D_P	: Degree of polymerization
m, CL	: Monomer of PVA, Cross-linker

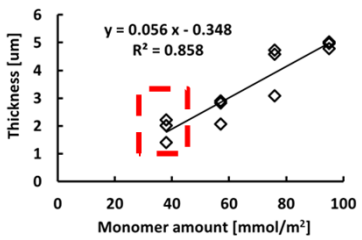
Fabrication process of artificial ILM in fundus part

Materials conditions

- Main polymer: poly(vinyl alcohol)(PVA)
  - polymerization degree: 300, 1000, 1700, 2400
  - Saponification degree: 88%
  - Monomer concentration: 100 mM
- Cross-linker: 500mM Glutaraldehyde
- Protein: 1 mM gelatin (MW: 2000)
- Dye: 40 μM Brilliant Blue

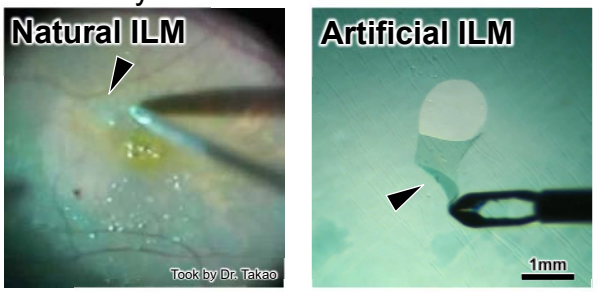






Evaluation of fabricated ILM

Sensory evaluation of fabricated ILMs



Arrowhead: peeled natural/artificial ILM; Each peeling: under water

Sensory evaluation of fabricated ILMs

		Polymerization degree (Molecular weight) 300 (13200)	1000 (44000)	1700 (74800)	2400 (105600)
Thickness [μm]	1.9 ± 0.3	×○	○○	△○	△○
	2.6 ± 0.4	—	△△	—	—
	4.1 ± 0.7	—	××	—	—
	4.9 ± 0.1	—	××	—	—

Grade for armature training: ○: suitable; △: slightly suitable; ×: not suitable.

Success to control a suitable artificial ILM!

Conclusion

We developed a novel concept of an ophthalmological surgery simulator for training ILM peeling task under wet condition. We succeed a real artificial eye model which could be mounted on the simulator and had an artificial ILM consist of PVA hydrogel film. We can control characteristics such as thickness and sensory evaluation by adjusting monomer amount and polymer specifications onto artificial retina.

Reference:
S Omata *et al.*, *Robomech 2017*, Fukushima, May 12, 2017.

Abstract: A well-mimicked human model is useful to improve surgeon's skill of complicated surgeries and to evaluate new medical devices. The human model with artificial organ modules is expected not only to mimic anatomical characteristics and mechanical properties of a human, but also to be integrated with sensors for quantitative evaluation of skills, we called the human model, "Bionic-Humanoid". Here, we focused on an eye surgery and proposed an eye model which is eye part of Bionic-Humanoid. For training the ILM peeling task using micro forceps in retinal surgery, fundus part of the eye model has an artificial retina and inner limiting membrane (ILM) which is superficial layer of the retina. We then succeeded to establish an artificial bionic eye with fundus part having artificial ILM which can be peeled by micro forceps, and it was assembled in an artificial skull of the Bionic Humanoid.

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This work was funded by ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).