

of refractive index of BMF is within  $\pm 0.0008$  for practical refractive index matching to the model. This is 2 - 3 times bigger than 0.000291. Therefore, if temperature dependence of mixture is almost the same as its components, permissible temperature deviation of the mixture is roughly estimated to be at  $\pm 2\text{--}3$  °C with respect to permissible deviation of refractive index.

Meanwhile, temperature dependence of dynamic viscosity of Gly. aq [17] and NaI aq. [23] was previously modeled with the following Arrhenius relation (8):

$$\ln(\mu) = c + \frac{d}{T} \quad (8)$$

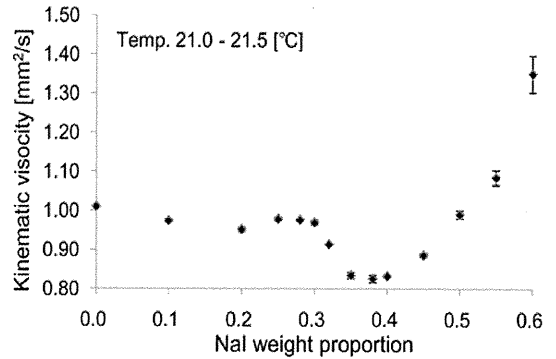
where  $c$  and  $d$  were constant. Viscosity change of Gly. aq. and NaI aq. were calculated as about 6.6 % and 2 %, respectively, with 1°C increment in range of room temperature, according to the above equation. The viscosity of BMF should not change because varying viscosity directly affects the varying flow parameters such as  $Re$  and  $W\phi$ . Therefore, the temperature should be controlled for a constant flow condition, especially with respect to viscosity.

#### 4.3. Wavelength dependency

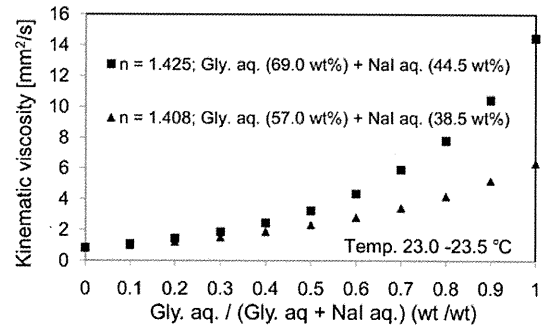
Budwig summarized the wavelength dependence of refractive index of typical solid and liquid materials [5]. Table 1 illustrates that the effects of dispersion (the variation of refractive index with wavelength) are different for each material. The dispersions between 486 nm and 589 nm are about 0.006, 0.0042 and 0.0062 for acrylic, water, and olive oil, respectively. A solution of Gly. aq. and NaI aq. has dispersions like such materials. The material of a biomodel can also have dispersion. In general, these dispersions depend on each material. Therefore, the refractive index matching should be performed based on the wavelength of PIV measurement in order to ensure high accuracy of the measurement. Since our measurements of the refractive index were performed with fluorescent light, including a wide range of wavelength, in the present work, the dispersions should be checked to carry out PIV measurements.

**Table 1** Typical dispersion characteristics of solid and liquid [5]

Wavelength [nm]	Refractive index at light wavelength		
	486	589	656
Acrylic Plastic	1.497	1.491	1.489
Fused silica	1.4632	1.4585	1.4564
Water	1.3372	1.3330	1.3312
Olive oil	1.4825	1.4763	1.4738



**Fig. 10** Kinematic viscosity of NaI aq. calculated with measured values as a function of NaI weight proportion



**Fig. 11** Kinematic viscosities of mixtures (Gly. aq. + NaI aq.) as a function of Gly. aq. weight proportion at constant refractive index;  $n$  to each proportion

## 5. Conclusion

The method of mixing two solutions using Gly. aq and NaI aq. enables the systematic preparation of BMF with respect to refractive index and kinematic viscosity. The refractive index is matched to various materials of biomodels with wide range of kinematic viscosity. The values of kinematic viscosities can cover the value of blood (around  $3.8 \text{ mm}^2/\text{s}$ ). The equations derived in the results can be used to adjust BMF with targeted refractive indices and targeted kinematic viscosities simultaneously. Even if refractive index needs to be adjusted and the kinematic viscosity needs to be changed for various research objectives, this mixing method is adaptable. Though temperature and wavelength dependences were not examined in this research, the changing parameters should be considered.

## ACKNOWLEDGMENT

This work was supported by Tohoku University Global COE program.

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(添付2) 研究発表に関する資料

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## 03-07 「計測Ⅴ」

5月12日(土) 15:30~16:20 第4会場

座長：戸高 浩司 (九州大学)  
阿部 裕輔 (東京大学)

- 03-07-1** 心不全患者支援のための無意識生体計測に基づく遠隔医療ネットワークシステムの開発  
中村 心也 (金沢大学 理工研究域)  
Development of a network system for telemedicine in patient with heart failure using non-conscious physiological monitoring  
SHINYA NAKAMURA (College of Science and Engineering, Kanazawa University, Kanazawa, Japan)
- 03-07-2** 身体各部における脈波伝播時間の左右差に関する検討  
伊藤 賢 (静岡大学 大学院工学研究科)  
Bilateral difference of pulsetransit time at three different locations  
KEN ITOH (Graduate School of Engineering, Shizuoka University, Hamamatsu, Japan)
- 03-07-3** 遠心ポンプ内における血液状態の特性評価  
松本 健 (東京電機大学 先端科学技術研究科 先端技術創成専攻)  
Characterization of blood state in centrifugal pump  
TAKESHI MATSUMOTO (Graduate School of Advanced Science and Technology Advanced Multidisciplinary Engineering, Tokyo Denki University, Saitama, Japan)
- 03-07-4** 洗髪による洗浄効果の検討  
武田 真季 (大阪大学大学院 医学系研究科)  
Examination of cleansing effect by shampoo  
MAKI TAKEDA (Graduate School of Medicine, Osaka University, Osaka, Japan)
- 03-07-5** 細径光ファイバ圧力センサを用いた灌流圧測定機能を有する臓器灌流カテーテル  
引地 広介 (東北大学大学院医工学研究科)  
Organ perfusion catheters with perfusion pressure measurement function using fiber optic pressure sensor  
KOUSUKE HIKICHI (Graduate School of Biomedical Engineering, Tohoku University, Miyagi, Japan)

## 03-08 「光Ⅰ」

5月12日(土) 8:50~10:10 第5会場

座長：斉藤 俊 (山口大学)  
大川 晋平 (防衛医科大学校)

- 03-08-1** 脊髄損傷の低出力レーザー治療：偏光特性の影響  
安藤 貴洋 (慶應義塾大学大学院 理工学研究科)  
Low-level laser therapy for spinal cord injury: effects of polarization  
TAKAHIRO ANDO (School of Integrated Design Engineering, Keio University, Yokohama, Japan)
- 03-08-2** 光脳機能計測における表層近傍の血液量変化の選択的な計測法の提案  
福田 恵子 (東京都立産業技術高等専門学校 ものづくり工学科)  
Selective measurement of near-surface blood volume change in functional near-infrared spectroscopy  
KEIKO FUKUDA (Tokyo Metropolitan College of Industrial Technology, Tokyo, Japan)
- 03-08-3** ラット脳のリアルタイム光音響イメージング：低酸素に対する血行動態変化の観測  
川内 聡子 (防衛医科大学校 防衛医学研究センター 情報システム研究部門)  
Real-time photoacoustic imaging of rat brain: hemodynamics response to hypoxia  
SATOKO KAWAUCHI (Division of Biomedical Information Sciences, National Defense Medical College Research Institute, Saitama, Japan)
- 03-08-4** 血中レーザー光照射時の光学窓-血液界面における血液光学特性変化  
高橋 芽意 (慶應義塾大学大学院 基礎理工学専攻)  
Optical property changes of blood on the optical window-blood boundary during the laser irradiation in blood  
MEI TAKAHASHI (School of Fundamental Science and Technology, Graduate School of Science and Technology, Keio University, Yokohama, Japan)
- 03-08-5** 心筋細胞に対する細胞外での光増感反応：施行条件と細胞壊死  
小川恵美悠 (慶應義塾大学 大学院 理工学研究科 基礎理工学専攻)  
Photosensitization reaction outside myocardial cells: photosensitization reaction parameters effect on the cells necrosis  
EMIYU OGAWA (School of Fundamental Science and Technology, Graduate School of Science and Technology, Keio University, Yokohama, Japan)

## 細径光ファイバ圧力センサを用いた 灌流圧測定機能を有する臓器灌流カテーテル

引地広介<sup>1</sup>, 松永忠雄<sup>2</sup>, 早津幸弘<sup>3</sup>, 佐藤充<sup>3</sup>, 深谷昌宏<sup>4</sup>, 飯沼貴章<sup>4</sup>,

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<sup>3</sup>東北大学大学院 医学系研究科

<sup>4</sup>富士システムズ株式会社

### Organ perfusion catheters with perfusion pressure measurement function using fiber optic pressure sensor

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Makoto Ohta<sup>1</sup>, Yoshikatsu Saiki<sup>3</sup>, Yoichi Haga<sup>1</sup>

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<sup>1</sup> Graduate School of Biomedical Engineering, Tohoku University

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<sup>4</sup> Fuji Systems Corporation

**Abstract:** This paper describes designs and characteristics of organ perfusion catheters with perfusion pressure measurement function using fiber optic pressure sensor. By measuring the tip pressure of organ perfusion catheters, it is expected that the correctness of perfusion can be observed. Conventionally, perfusion pressures were measured using externally transducers depends on water-filled lumen of catheters to transmit pressure from tip section. However, since the miniaturization of the lumen to transmit pressure was limited in this method, it was difficult to apply to small diameter catheters. In contrast, the ultra-miniature optical fiber pressure sensor which we developed has a small diameter, so that measurement function of the pressure can be attached to small catheters without sacrificing a diameter of main lumen. As a result of the animal experiment of organ perfusion, the characteristics of prototype 4.4 and 8 Fr organ perfusion catheters with perfusion pressure measurement function were clarified.

**Keywords:** Optical Fiber Pressure Sensor, Perfusion Pressure Biomedical Engineering

### 1. Introduction

大動脈の手術中は、各臓器が虚血することを予防するため、枝分かれした動脈に対して人工心肺からそれぞれ個別に血液を還流し臓器虚血を予防する必要がある。この際、カテーテル先端部の灌流圧力を測定することで、灌流が正しく行われていることを確認することができる。従来は、灌流用のメインルーメンとは別に設けた圧力測定用のルーメンを液体で満たすことで、カテーテル先端部の圧力を外部へ導き、外部におかれた圧力センサで圧力を測定する手法が一般的であった。しかし、細径のカテーテルでは、圧力伝達用のルーメンを設けると十分な灌流流量を確保することが難しくなるため、灌流圧力は注視されていないのが現状である。

本研究で用いる光ファイバ圧力センサは外径が細いため、メインルーメンの断面積を確保したまま圧力の測定機能を付加することができ、細径の灌流用カテーテルに搭載しても十分な灌流流量を確保することが可能である。また、従来の液体で満たした圧力測定用のルーメンを通して外部の圧力センサで圧力を測定する手法では、流路や圧力センサ内の気泡の影響や流路の変形により、圧力のダンピングが発生して正しい灌流圧力を測定することができなくな

る恐れがあった。これに対し、光ファイバ圧力センサではカテーテル先端におかれたセンサ部で直接、正確な灌流圧力を測定することが可能である。

本研究では光ファイバ圧力センサを搭載した 8 Fr および 4.4 Fr 臓器灌流カテーテルについて、その構造と特性を記す。

### 2. Fiber optic pressure sensor

図 1 に光ファイバ圧力センサの構造を示す<sup>[1]</sup>。外形 125  $\mu\text{m}$ 、コア径 50  $\mu\text{m}$  のグレーデッドインデックスマルチモード光ファイバの先端には Cr 薄膜でハーフミラーが形成されている。センサチップは、圧力によってたわむダイアフラム部と、Al のミラー、ミラーを支えるメサ部、およびスペーサ部で構成される。このセンサチップが、光ファイバの先端に接合されている。センサチップに圧力が加わるとダイアフラムがたわみ、ハーフミラーとミラーとの距離が変化する。したがって、この距離の変化を、白色光を用いた干渉計を用いて光学的に検出することで圧力を測定することができる。

### 3. Organ perfusion catheters

光ファイバ圧力センサを用いた灌流圧測定機能付

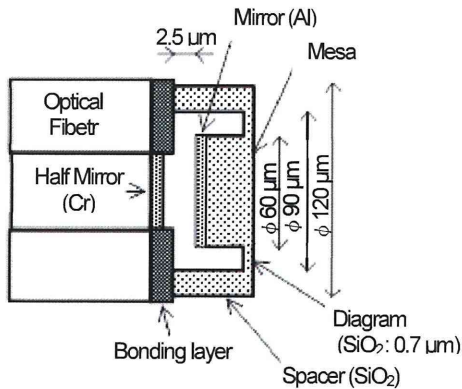
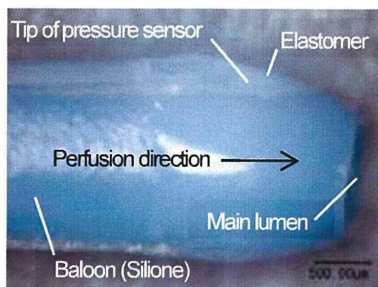
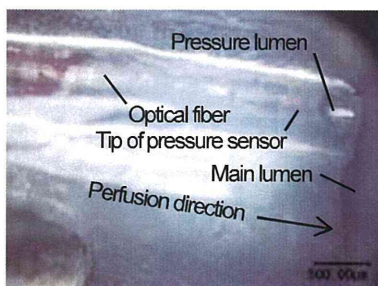


Fig.1. Structure of the fiber-optic pressure sensor



(a) 4.4 Fr catheter



(b) 8 Fr catheter

Fig.2 Tip structure of organ perfusion catheters

臓器灌流カテーテルとして、4.4 Frと8 Frのカテーテルに光ファイバ圧力センサを実装し、特性を測定した。試作したカテーテルの先端構造を図2に示す。

4.4 Frカテーテルでは、バルーンルーメン内に光ファイバ圧力センサを通してあるため、メインルーメンの流路断面積は減少しない。センサ部はエラストマーによってカテーテル側面に固定されているため、過負荷がかかってもセンサが脱離することなく、センサ部に血栓が付着することを防いでいる。

8 Frカテーテルでは、光ファイバ圧力センサのセンサ部をシリコンゴムで薄くコーティングし、センサの破損と血栓の付着を防いでいる。光ファイバ圧力センサを通すためのルーメンを別に設けているが、光ファイバ圧力センサは十分に細いため必要な灌流流量を確保することができる。

#### 4. Results of animal experiments

図3に示すように、ブタの動脈の一部を切断して

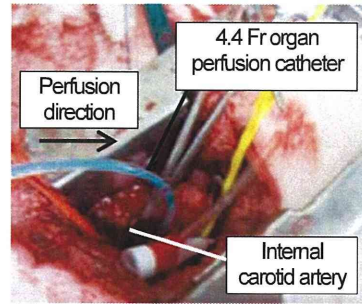
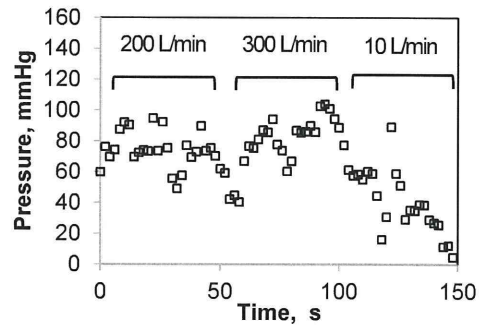
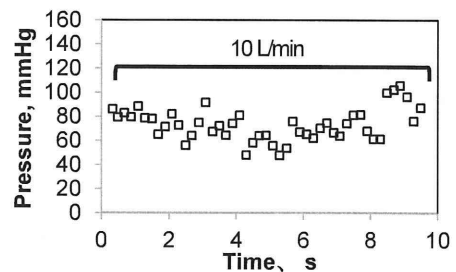


Fig.3 Overview of animal experiments



(a) 4.4 Fr catheter



(b) 8 Fr catheter

Fig.4 Measurement result of animal experiment

その一方を閉塞し、もう一方に対して灌流を行い、その時のカテーテル先端圧力を測定した。図4に測定結果の一例を示す。灌流にローラー式の輸液ポンプを用いたため、圧力の測定値に変動がみられる。しかし、灌流流量を変えることで圧力が変化していることがわかる。4.4 Fr, 8 Fr共に使用後も血栓の付着などは見られなかった。

#### 4. Conclusion

光ファイバ圧力センサを搭載した8 Frおよび4.4 Fr臓器灌流カテーテルを試作し、動物実験で灌流圧力を測定した。圧力の測定に光ファイバ圧力センサを使用することで、内腔の小さいカテーテルでも十分な灌流流量を得ることができ、圧力の測定により適切な灌流の制御ができると期待される。

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