MEMS Laser blood flow sensor

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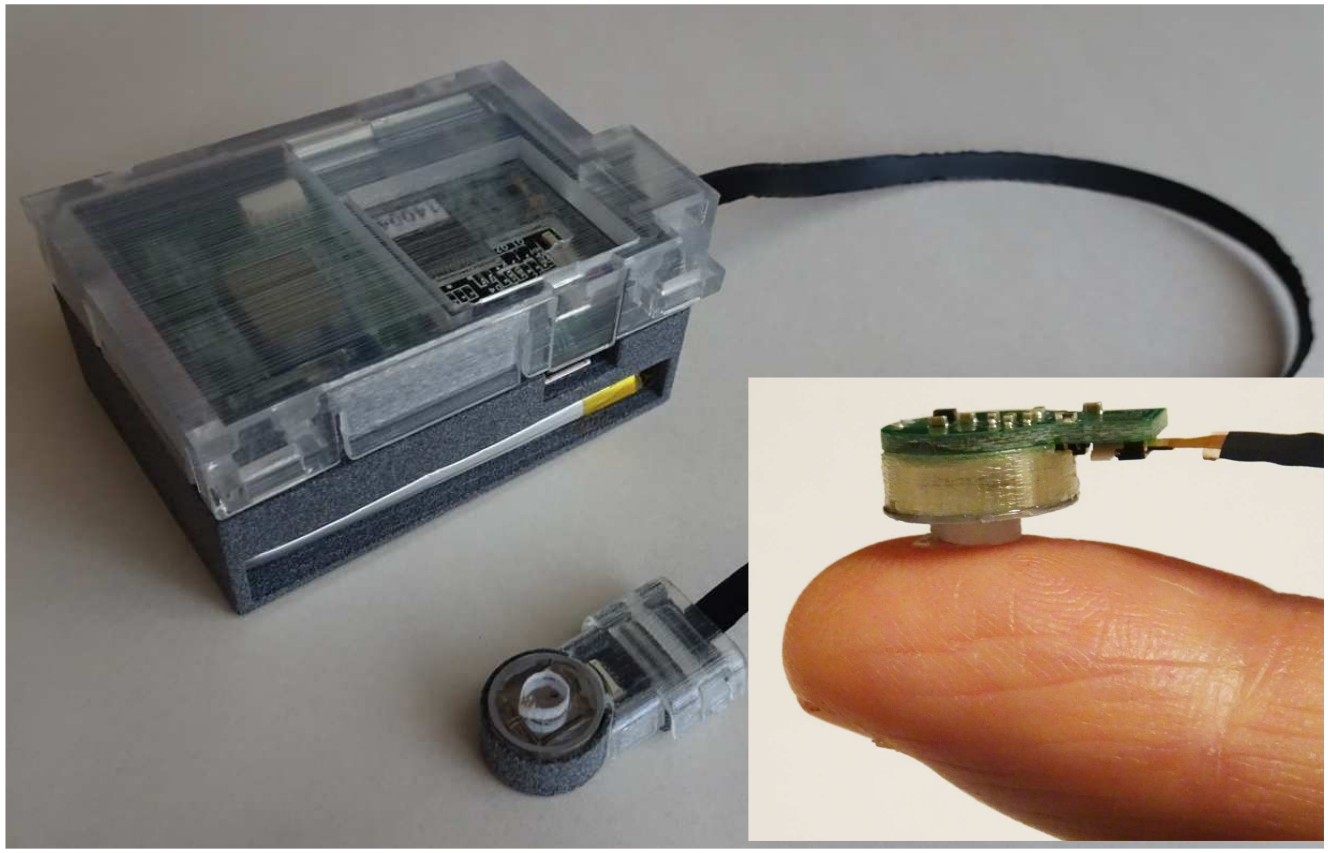

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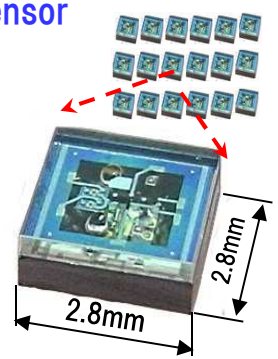
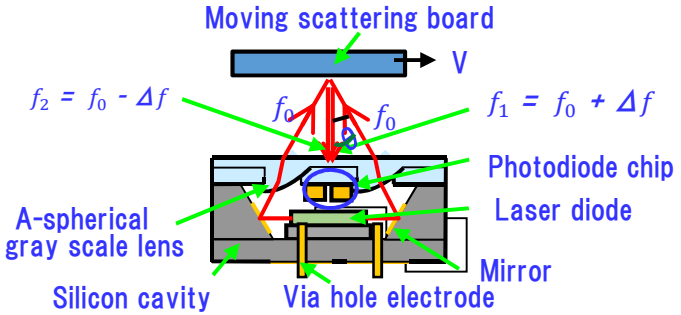
Two Types of MEMS Laser Doppler Sensors

μ-Laser Doppler sensor

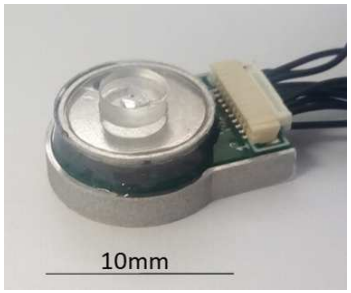


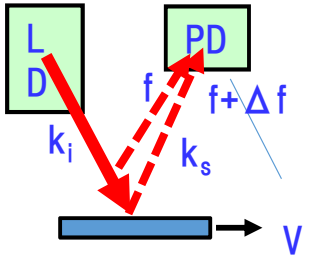


$F_{beat\ signal} = 2\Delta f = 2V \sin(\theta)/\lambda$

Beat signal created

Laser Laser blood flow sensor with a built-in pressure sensor





$\int \omega P(\omega) d\omega$

Probability application to speckle behavior

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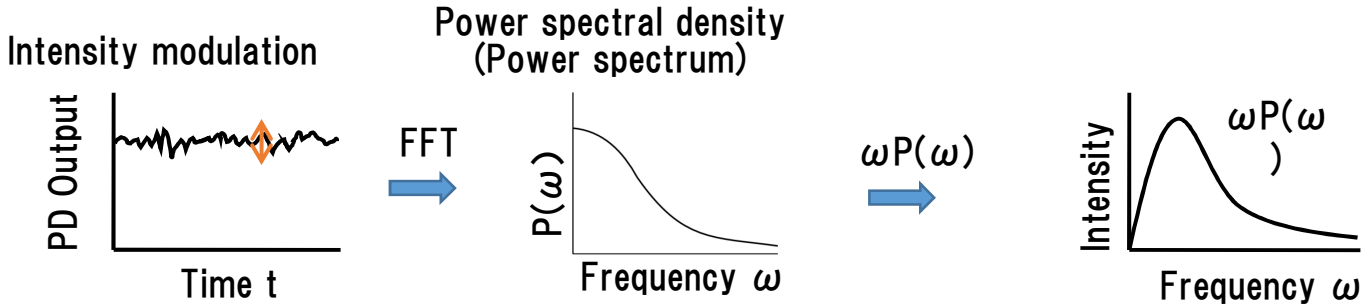
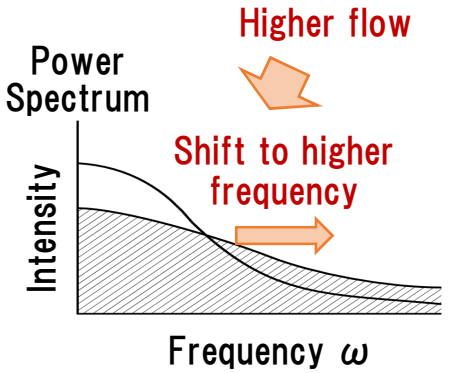
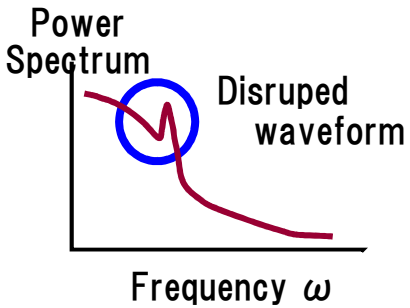
Measurement principle





Remove the components of the spectrum associated with body motion



The first moment
in moment generating function
is proportional to flow velocity

$\int \omega P(\omega) d\omega \propto$ Blood flow

Moment generating function

Kth moment about the mean, μ

$$\int_{-\infty}^{\infty} (x - \mu)^{k} \, f(x) \, dx$$

where f(x) is a density function.

$$\mu = \int_{-\infty}^{\infty} x \, f(x) \, dx$$

Density function f(x): power spectral density

μ is an average flow.

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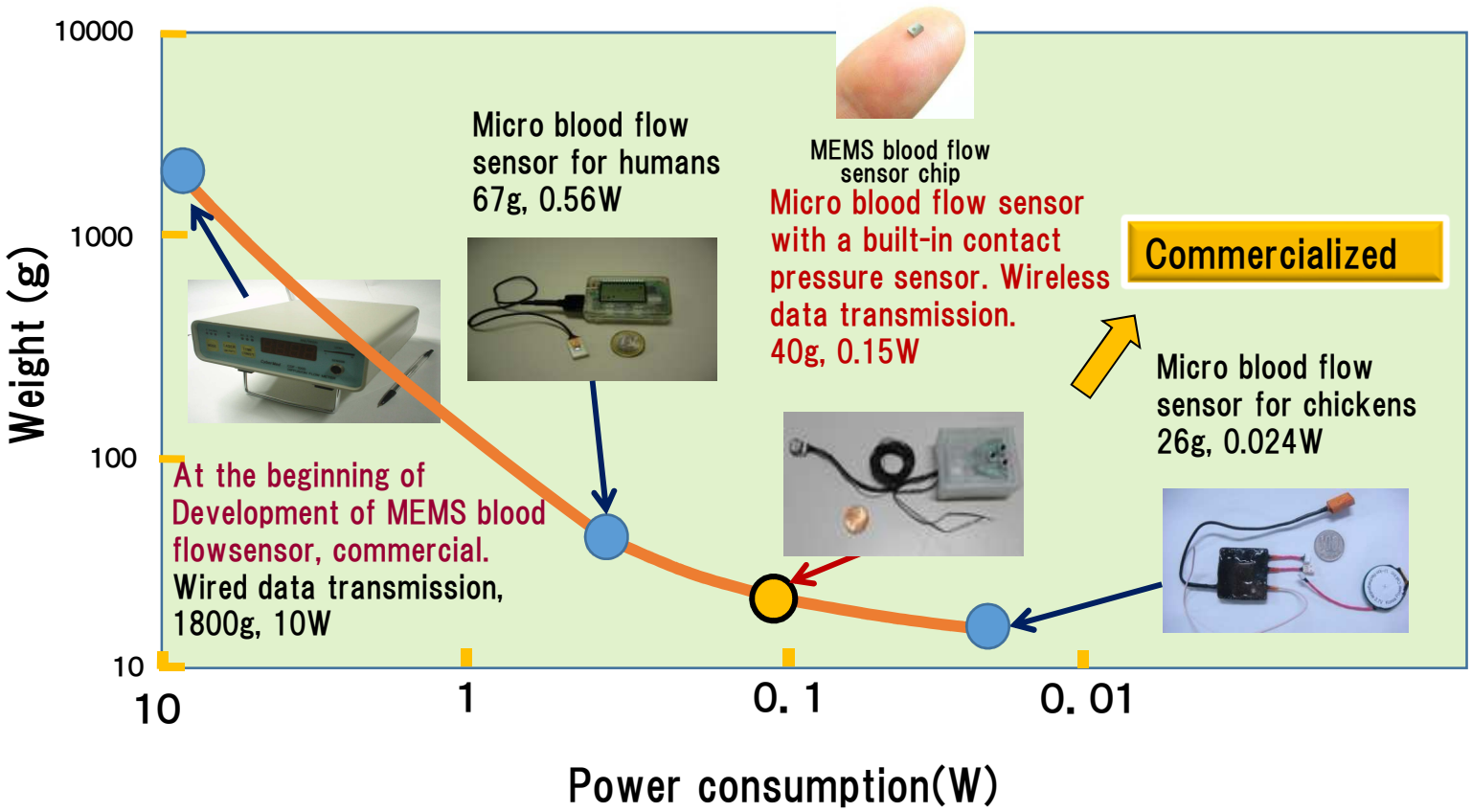
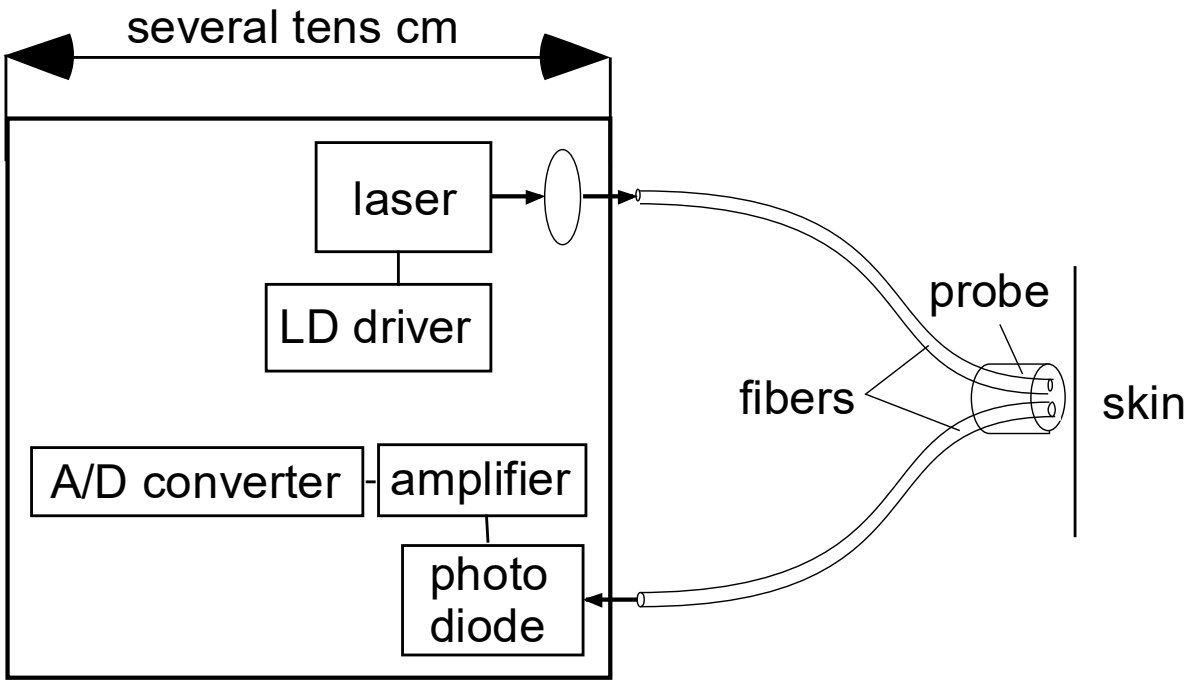
The transition of the developed blood flow sensors



At the beginning of Development of MEMS blood flow sensor(2001), commercial wired data transmission

Bulky instrument using fibers



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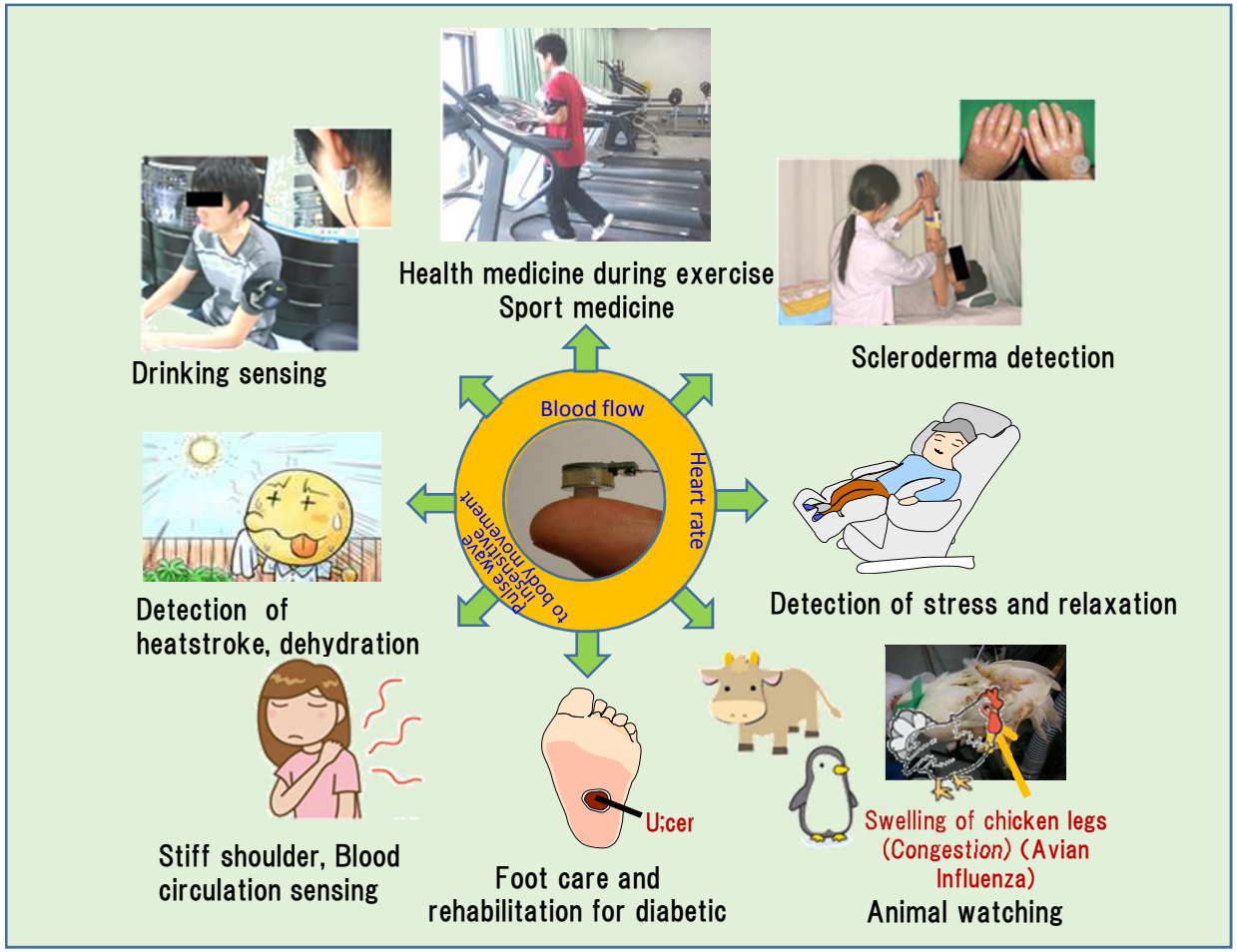
Health medicine during exercise
Sport medicine
Drinking sensing
Scleroderma detection
Blood flow
Heart rate
pulse wave
respiration
to body movement
Detection of
heatstroke, dehydration
Detection of stress and relaxation
Stiff shoulder, Blood
circulation sensing
U;cer
Foot care and
rehabilitation for diabetic
Swelling of chicken legs
(Congestion) (Avian
Influenza)
Animal watching

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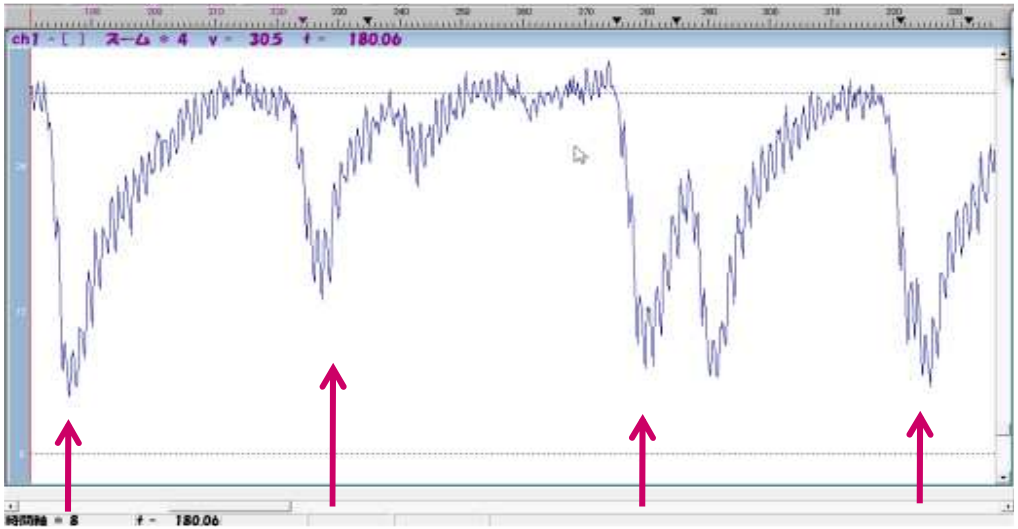
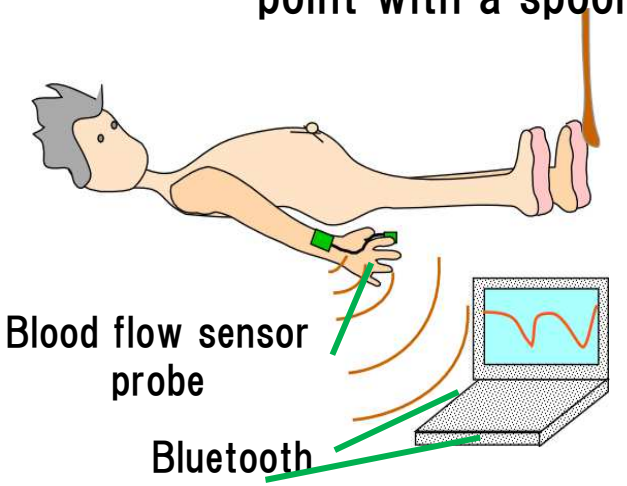
Effect of autonomic nervous system on blood flow

Application to oriental medicine



Pressure points on the sole were lightly touched

Lightly touch the pressure point with a spoon



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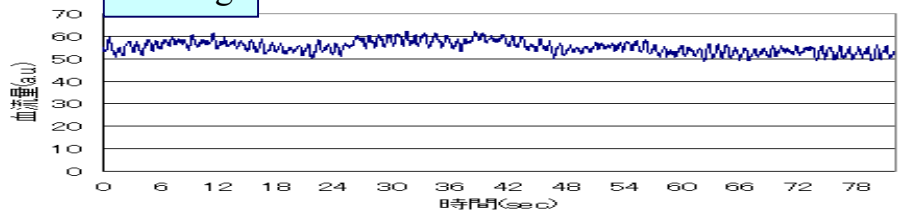
Body movement, etc. experiment (n=37)

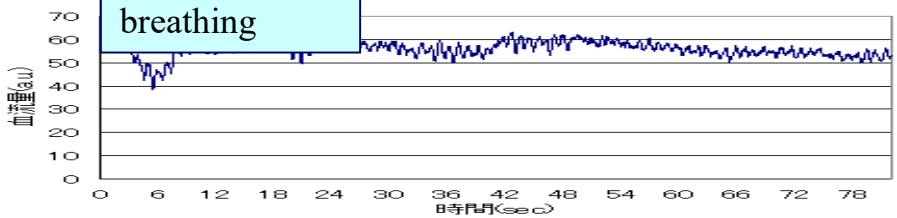
Blood flow waveform

Sensor probe attached to finger

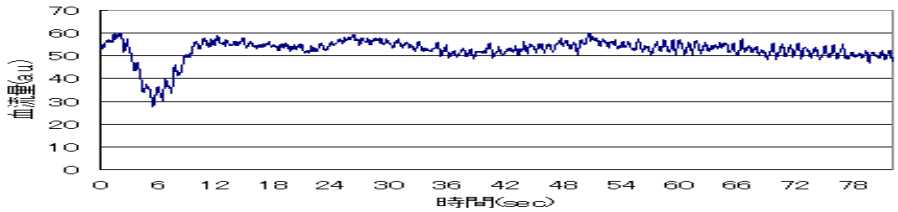
Resting



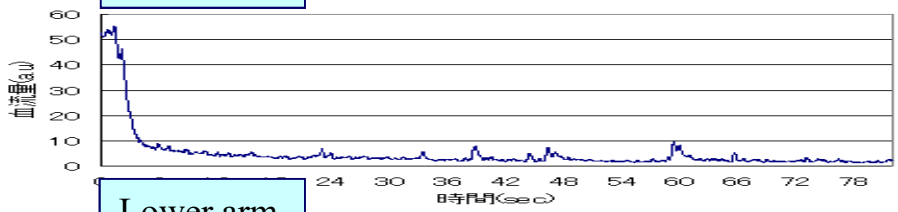
Deep breathing



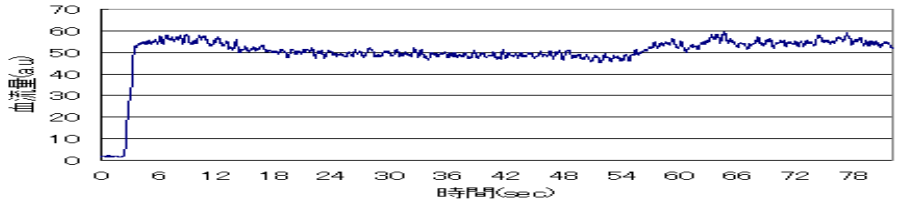
Breath-holding



Upper arm



Lower arm



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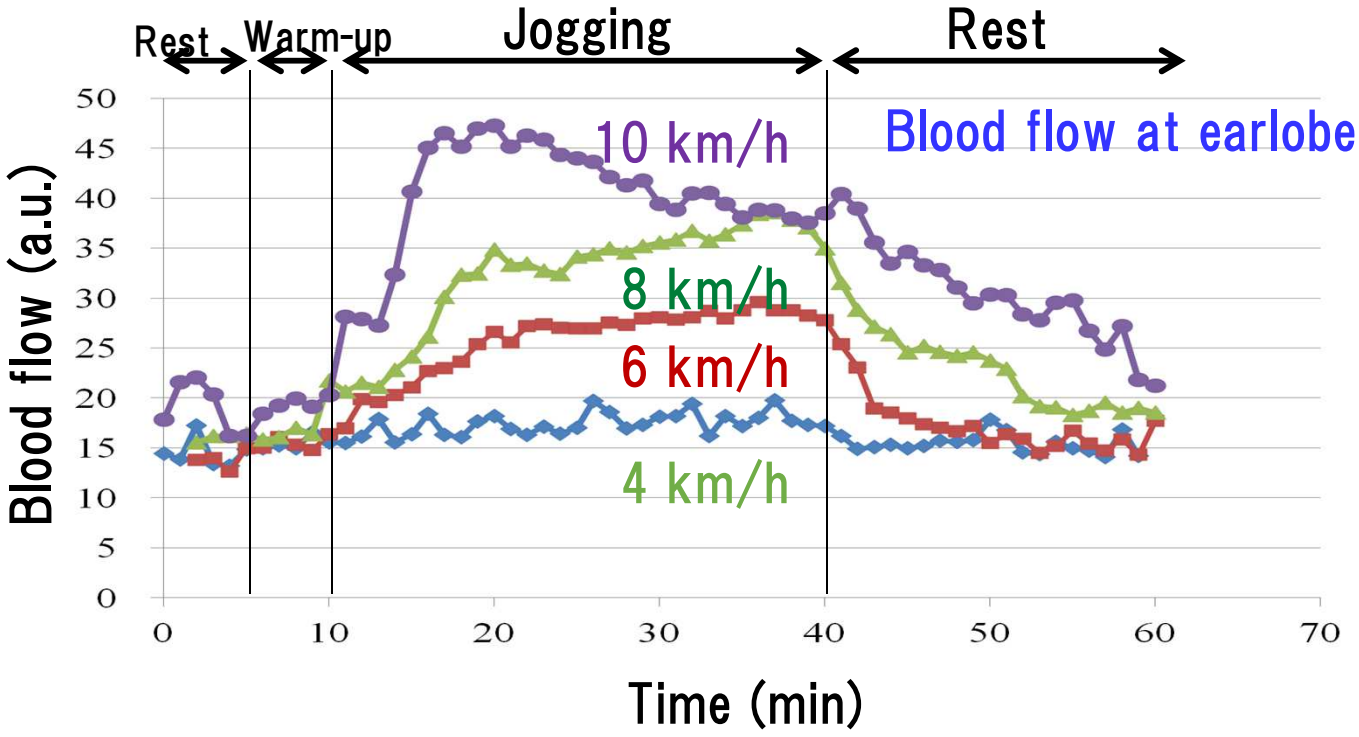
Jogging

Differences of blood flow among each running speed



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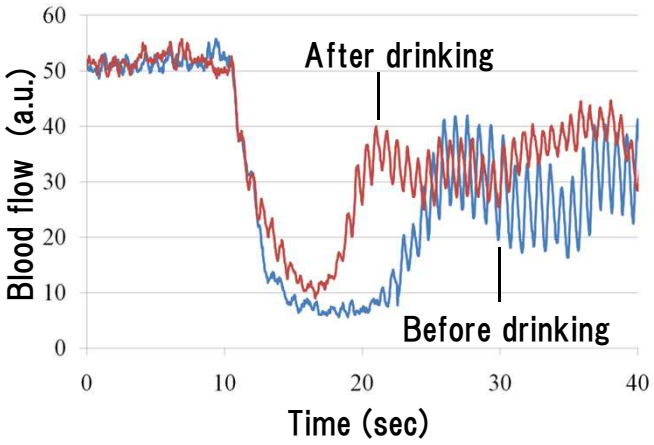
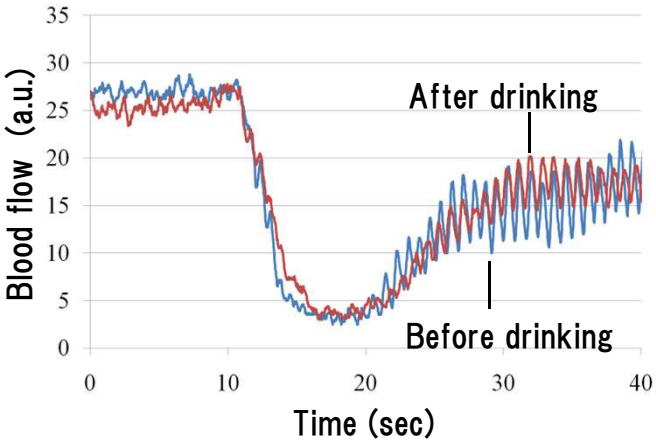
Drinking

Blood flow of fingertip during arm-raising before and 10 minutes after drinking

Decrease of pulse wave height after drinking for each subjects.



Light drinker



Heavy drinker

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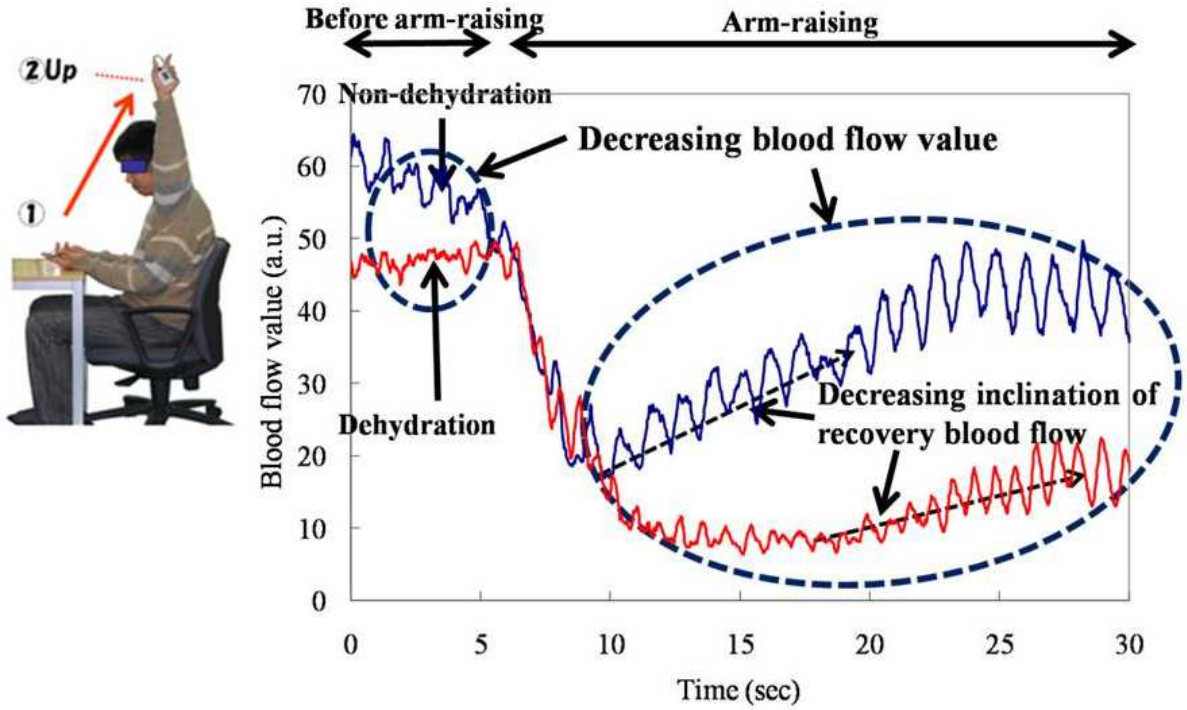
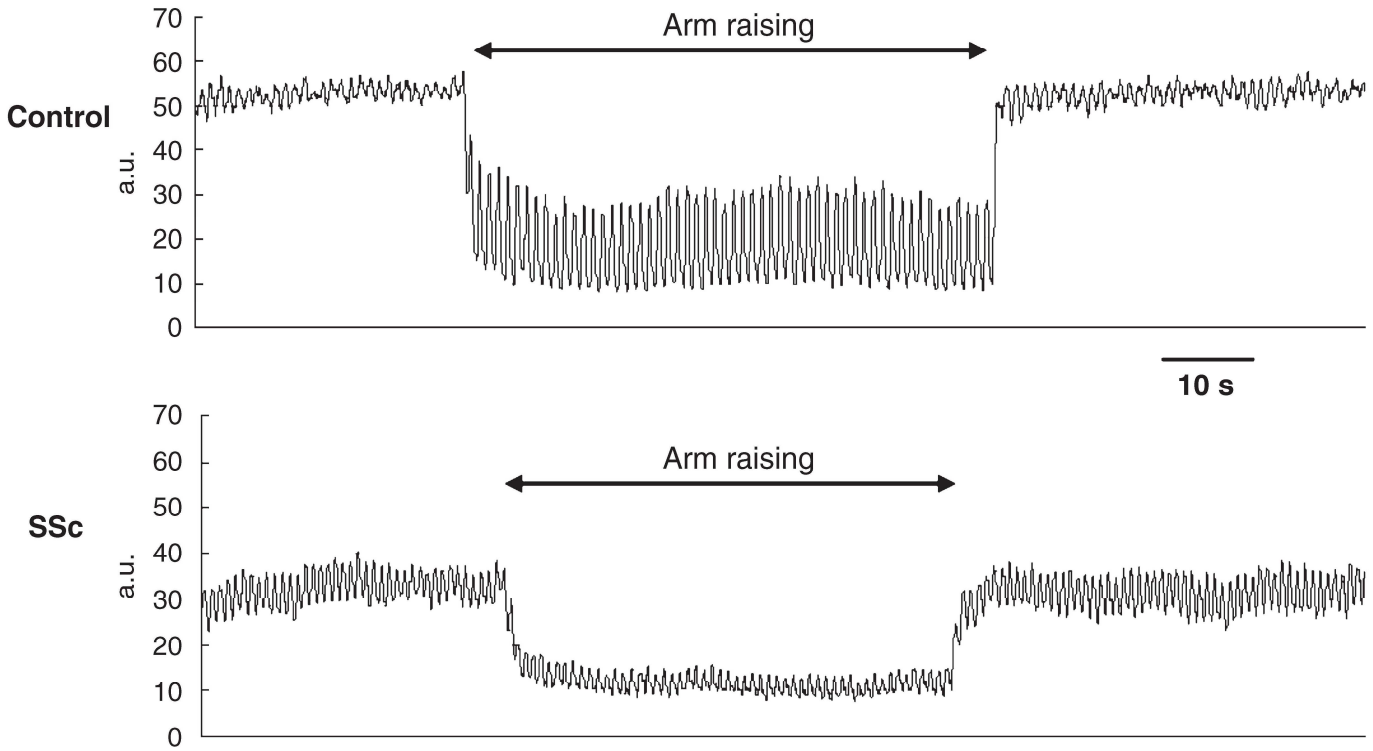
Arm raising test of dehydration

For the subject who was dehydrated by sweating until body weight decreased 2% less than the non-dehydrated state



Assessment for patients with systemic sclerosis



SSc: Patients with systemic Sclerosis

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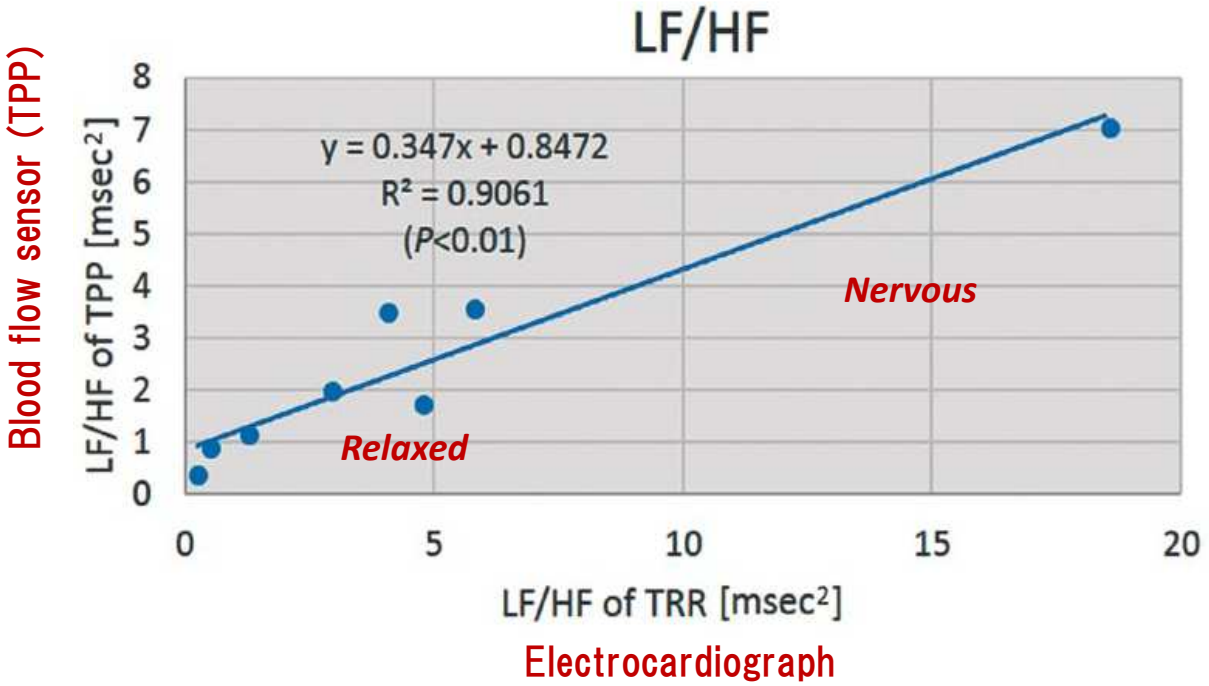
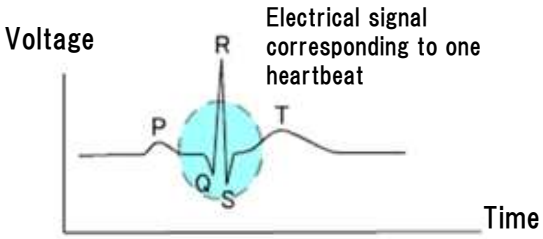
Correlation between blood flow signal (TPP) and electrocardiogram (ECG)

Low frequency region of RR Interval

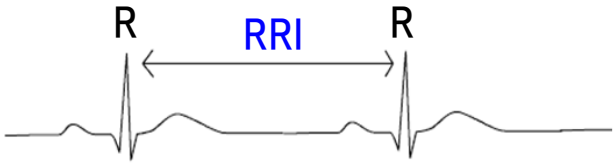
LF: 0.04-0.15 Hz, High frequency region of RR distance HF: 0.15-0.40 Hz



Electrocardiograph



Heart beat and electrocardiogram



RRI: RR Interval

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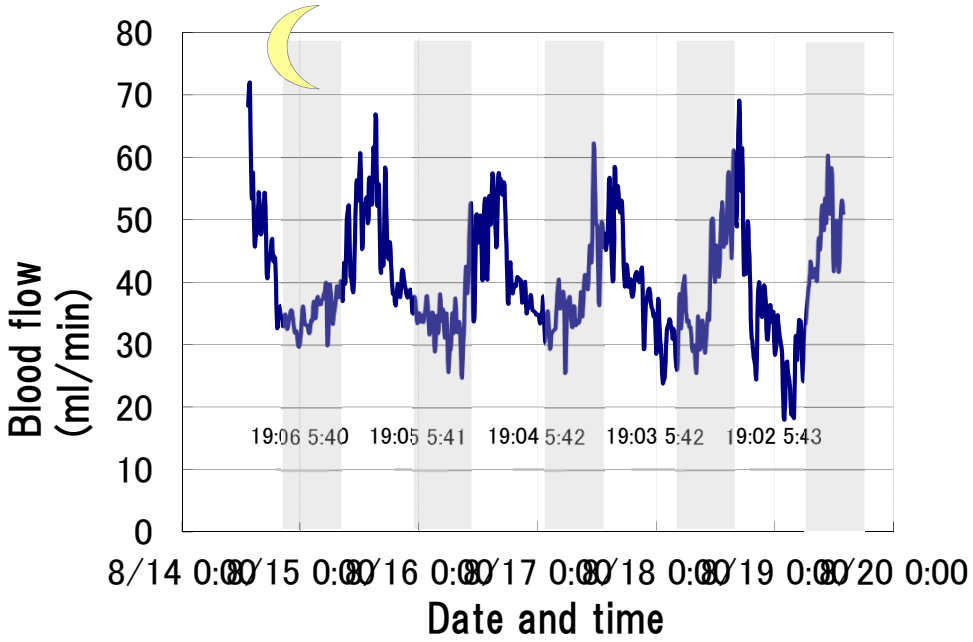
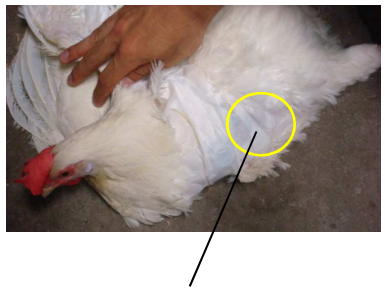
Daily variation of blood flow for healthy chicken during 5 days

Decreased blood flow at night





Blood flow sensor probe for chicken

There are several ways to eliminate the effects of movement such as body movement, such as removing the part of the spectrum ※corresponding to that movement, but the easiest and hassle-free method is to trace the minimum value. This makes it possible to eliminate the influence of movement. This is because the movement does not lower the measured value, but always raises it. This method has been used to measure diurnal fluctuations in blood flow for the purpose of detecting pathological conditions such as avian influenza in chickens.

※The measurement principle of this blood flow sensor is based on the spectral distribution of reflected scattered light from body parts.

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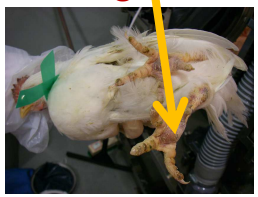
Application to animals

Detection of change in daily variation due to Avian flu

Swelling of feet (congestion



Blood flow measurement during swimming for

Blood flow measurement to improve conception rate (stress and estrus detection)

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Examples of possible cases where blood flow is key

Internal medicine	Examination of peripheral circulatory blood flow, peripheral circulatory disturbance of diabetic patients, autonomic nervous disorder, fingertip blood flow measurement thanks to Raynaud's disease, nerve function test, gastric mucosal blood flow measurement during endoscopy, fire extinguisher blood flow in animal experiments
Anesthesiology	Quantification of effect at pain clinic, early detection of intraoperative shock
Intensive care department	Emergency department Blood flow measurement during burns, peripheral circulation monitor
Gastrointestinal surgery	Gastrointestinal organ blood flow measurement (clinical and experimental), blood flow confirmation during organ transplantation
Neurosurgery	Brain tissue blood flow measurement (clinical and experimental)
Respiratory department	Blood flow measurement of bronchial mucosa
Vascular Surgery	Measurement for the diagnosis of Burger's disease (obstructive thromboangiitis), etc. (measurement of systolic blood pressure of the finger using a combination of cuff and mercury column), skin blood flow measurement for obstructive arterial disease, ASO (obstructive atherosclerosis)) Measurement for diagnosis
Plastic Surgery Dermatology	Flap blood flow measurement, blood flow monitoring in skin transplantation, quantification of allergic PCA reaction, measurement of skin (face) blood flow status
Orthopedic surgery	Spinal cord, nerve blood flow measurement, adhesive finger blood flow measurement
Urology	Testis blood flow measurement, blood flow erectile dysfunction (VED) diagnosis, human blood flow measurement during kidney transplantation
Pediatrics	Peripheral blood flow monitor at NICU, measurement of neonatal cerebral blood flow in animal experiments

Obstetrics and gynecology	Uterine cancer blood flow measurement, breast cancer blood flow measurement
Otolaryngology	Cochlea, nasal mucosa, flap blood flow measurement
Radiology Department	Tissue blood flow measurement during radiation therapy
Hypertension treatment department	Measurement of tissue blood flow during hypertension treatment
Oriental Medicine	Quantification of effects during acupuncture and moxibustion treatment
Dental and oral surgery	Gingival, pulp blood flow measurement, oral mucosal blood flow measurement
Pharmacology	Determination of drug effects (vasodilation, contraction, etc.)
Physiology	Autonomic nervous function and peripheral blood flow measurement, influence of stress on autonomic nervous system
Hygien	e Measurement of fingertip blood flow in white wax disease, Raynaud's disease, etc.
Forensic medicine	Examination of tissue blood flow during forensic suffocation
Department of Physical Education	Exercise rearranging research (measurement of blood flow during exercise, measurement of blood flow change before and after exercise)
Department of Home	Economics Clothing and Skin Blood Flow
Pharmaceutical companies	Evaluate the effects of drugs (vasodilators, blood flow constrictors, blood flow increasing substances, etc.)
Maintenance of daily health	Measurement of blood circulation and blood dryness, relaxation and sleep (drowsiness)
Others	Research on environmental physiology (comfort) and measurement of bedsores at R & D companies (automobiles, electricity, textiles, cosmetics, construction industry, etc.)

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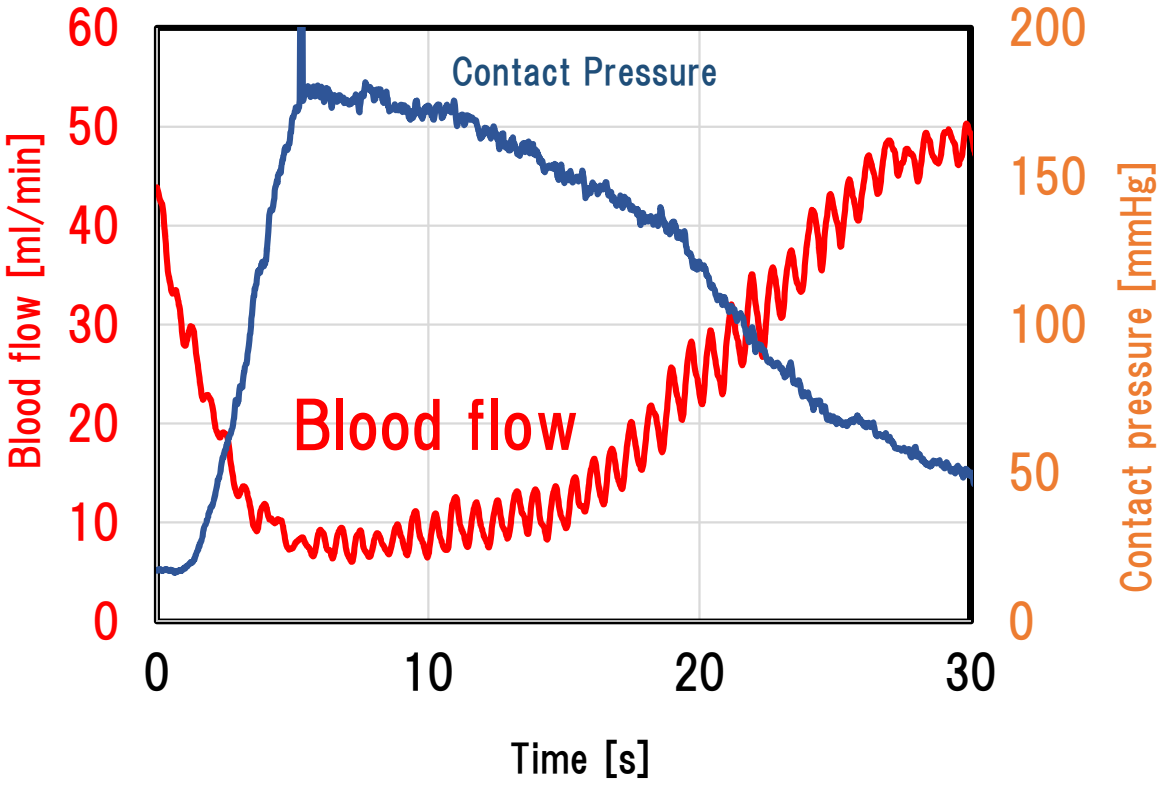
Blood flow greatly affected by contact pressure



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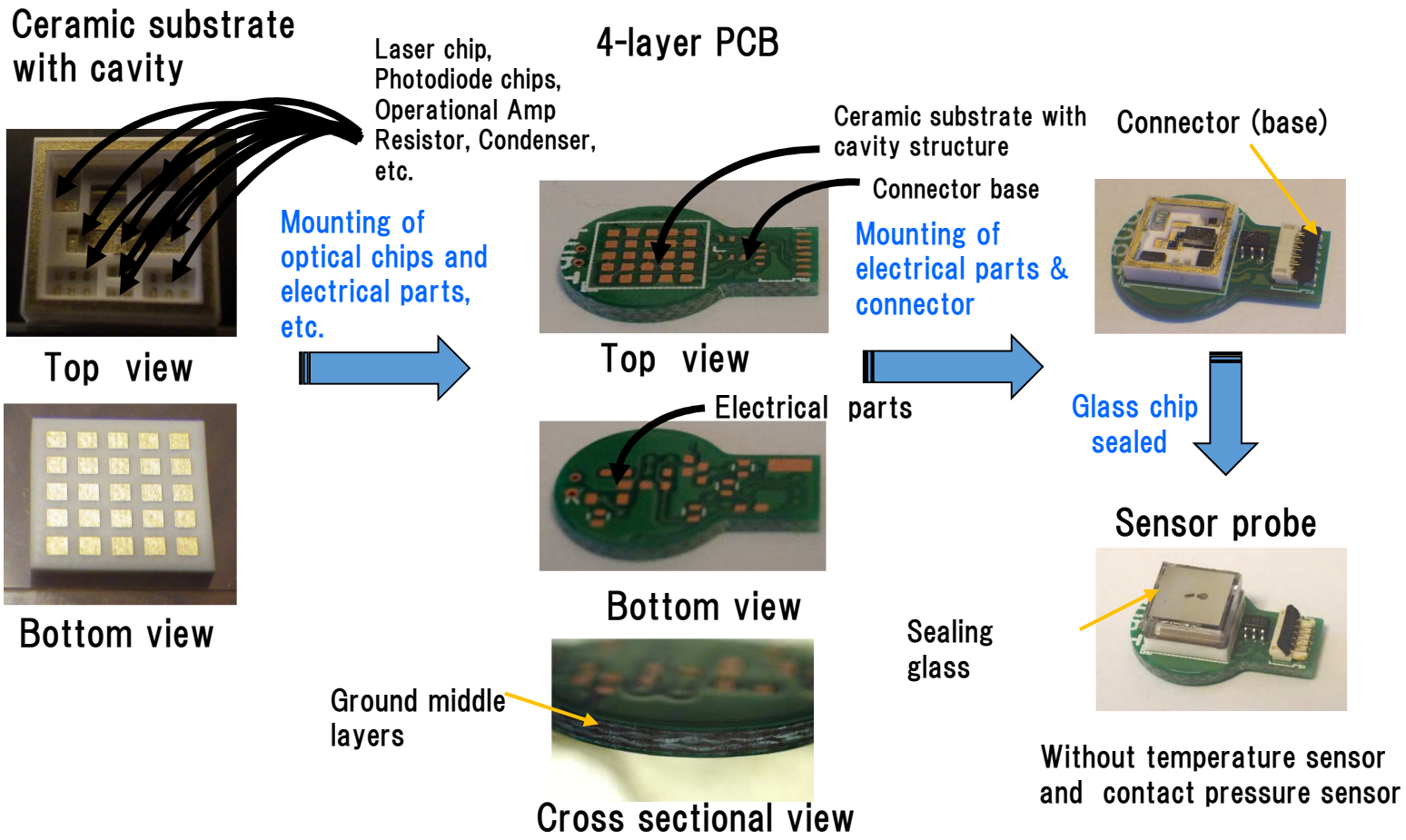
Main jisso process of sensor probe



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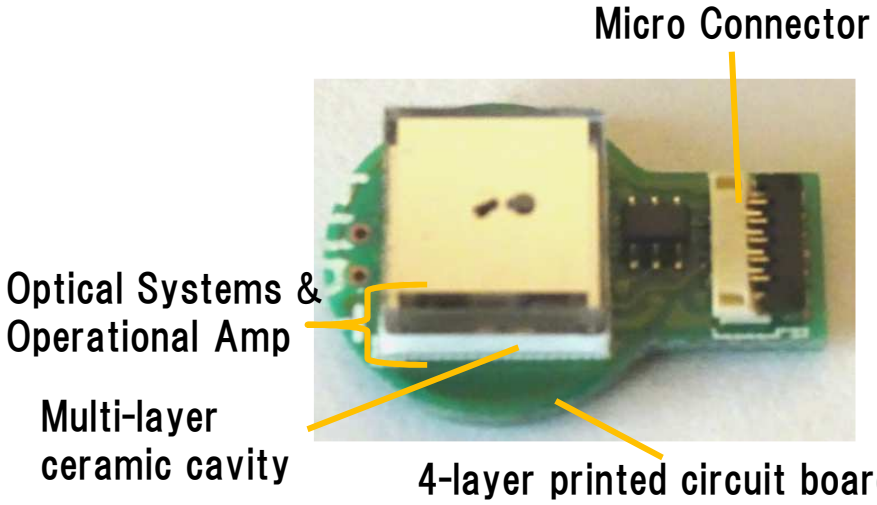
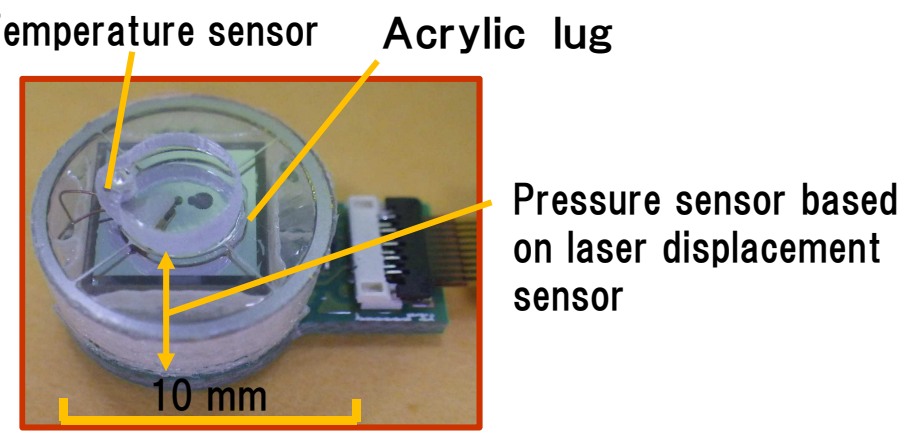
Contact pressure sensor mounted on the probe



(a) Before mounting contact pressure sensor



(b) after mouting contact pressure sensorn

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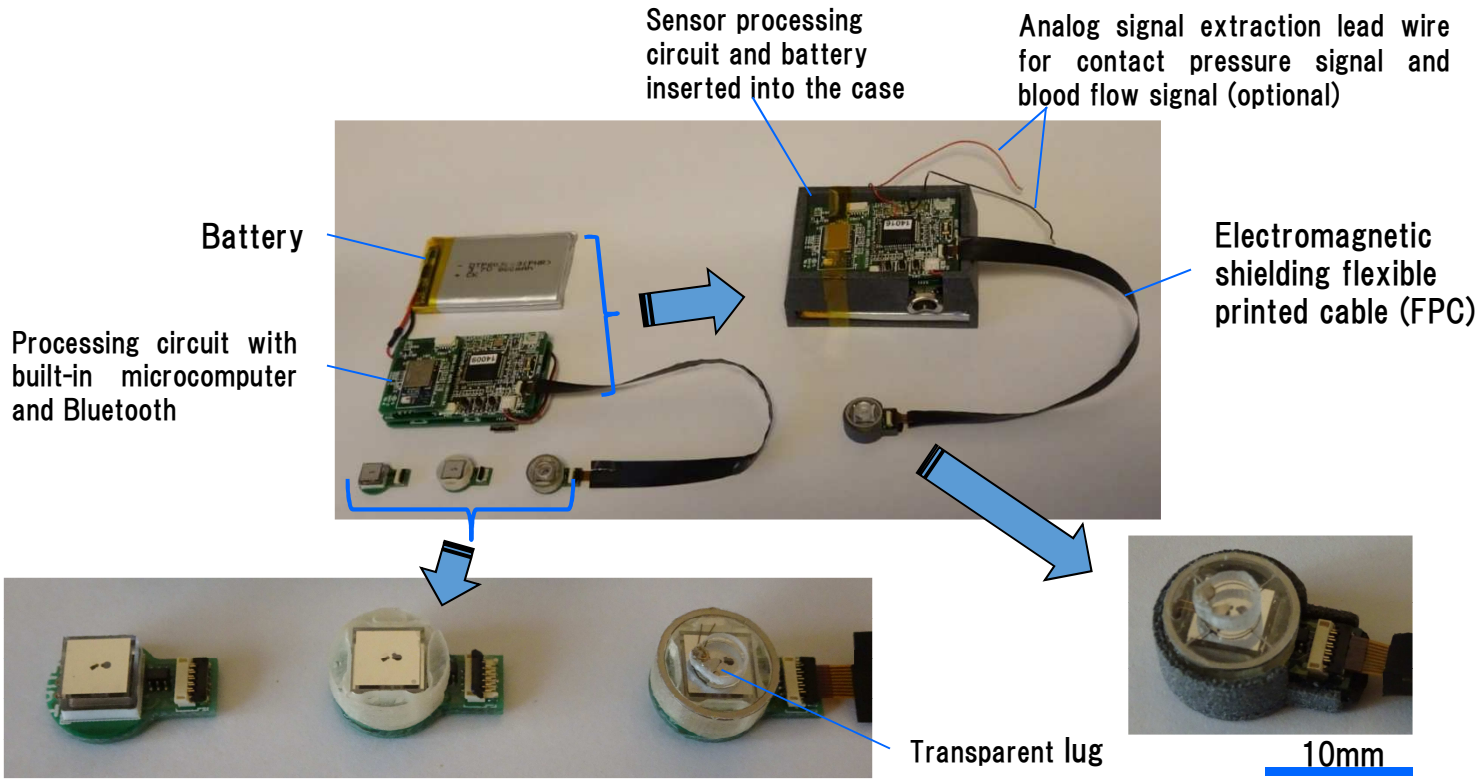
MEMS Laser Doppler Sensors



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Simultaneous measurement (1)

Blood Flow Signal

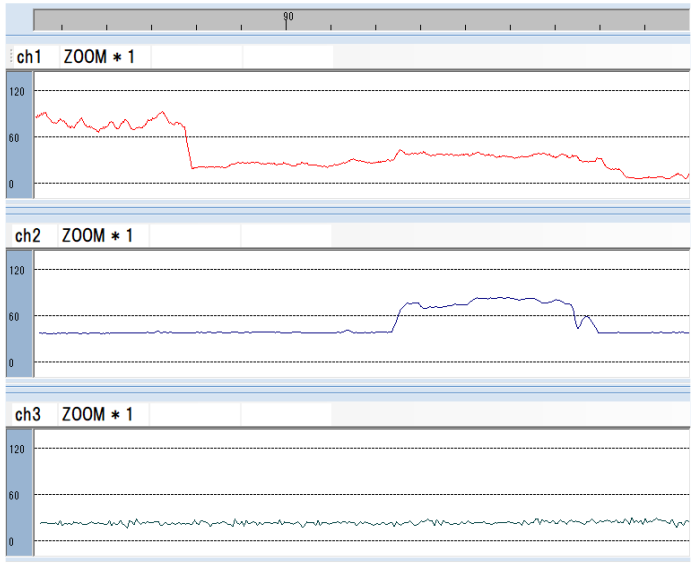
Contact Pressure

Skin Temperature

Simultaneous measurement 1

Time

Simultaneous measurement 2



Time

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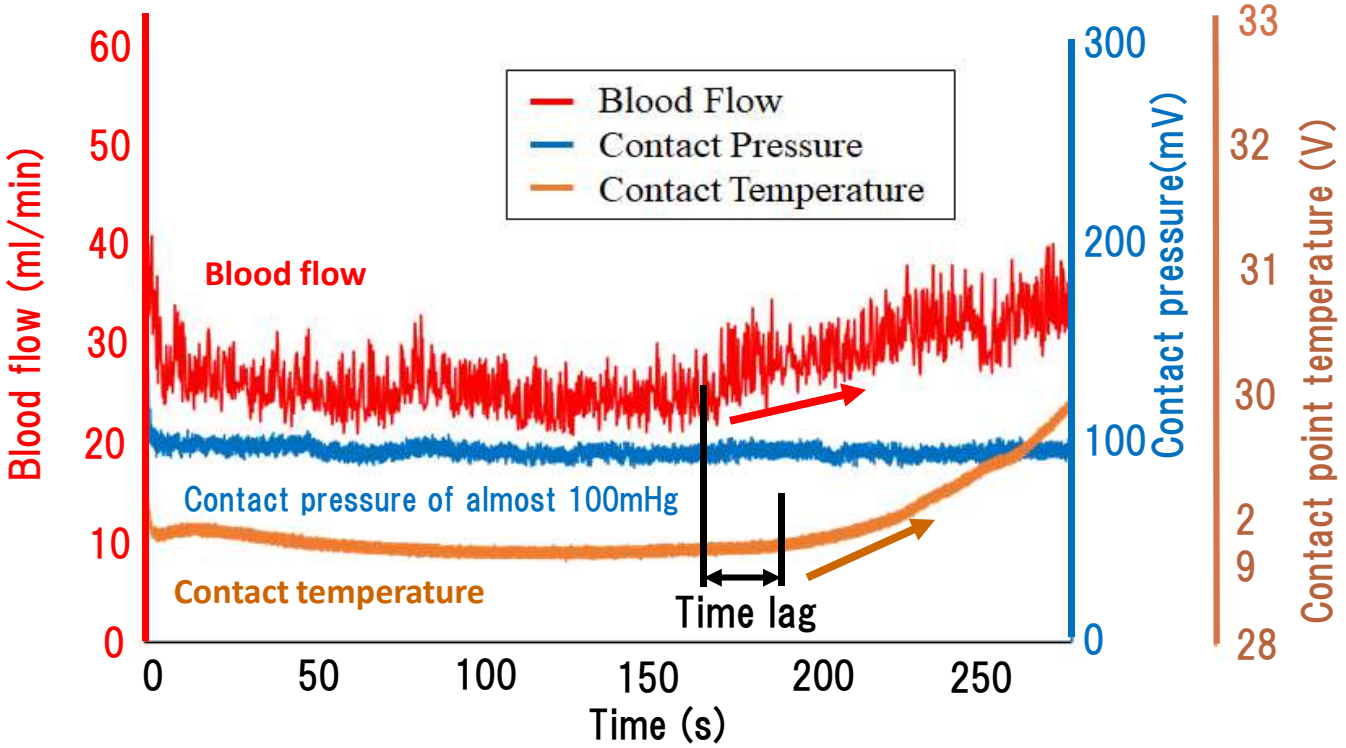
Simultaneous Measurement (2)

Blood flow and contact temperature for numb finger



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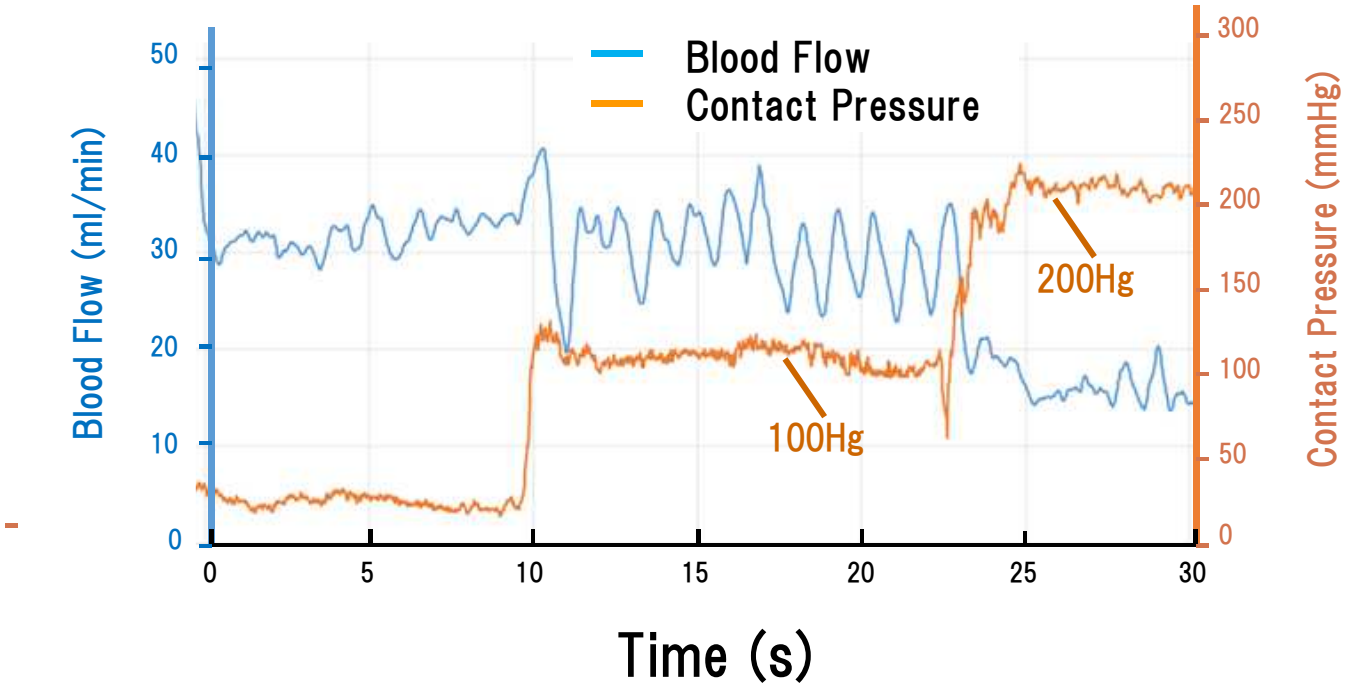
Simultaneous measurement (3)

Blood flow and contact pressure



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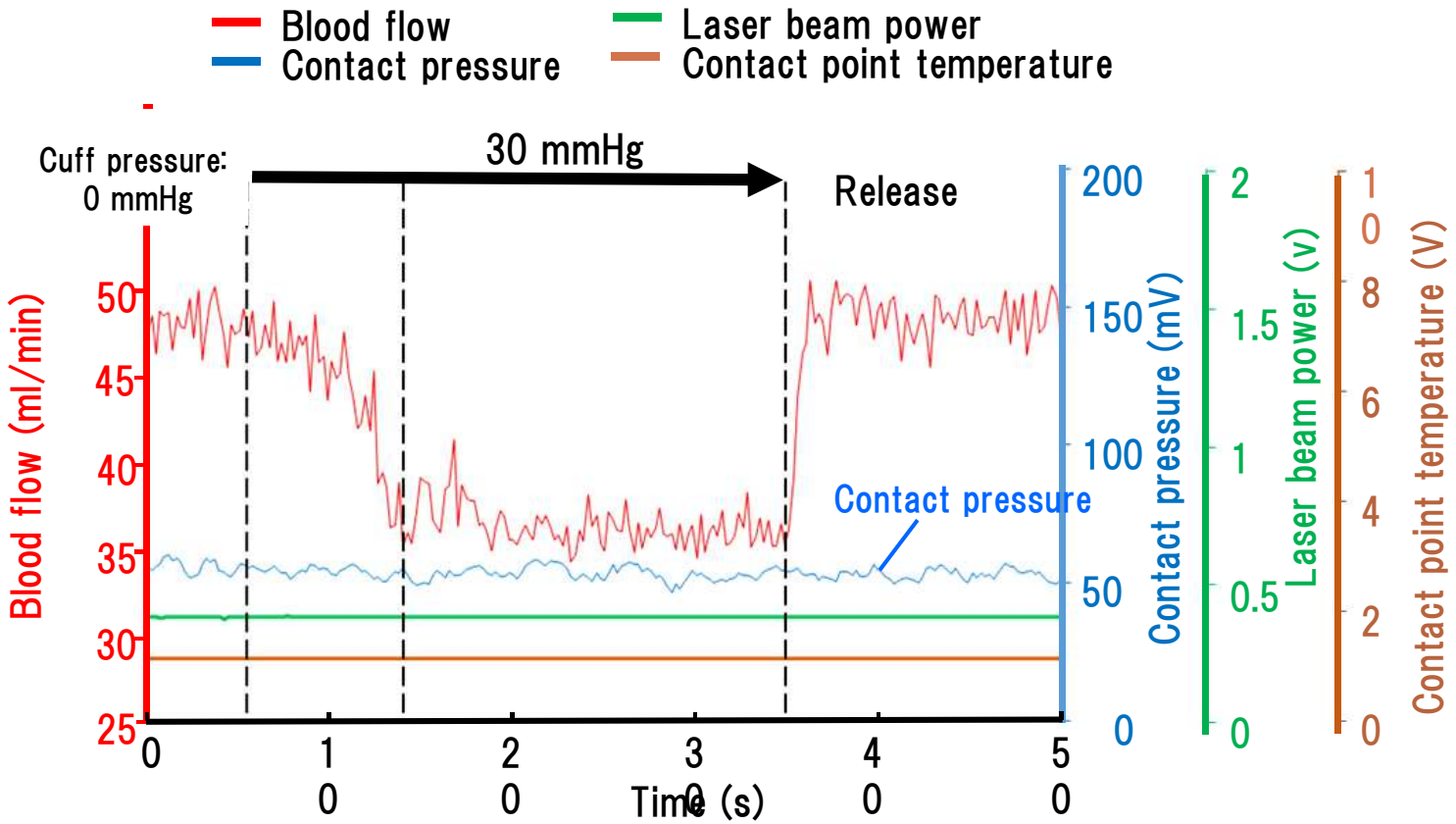
Simultaneous Measurement (4)



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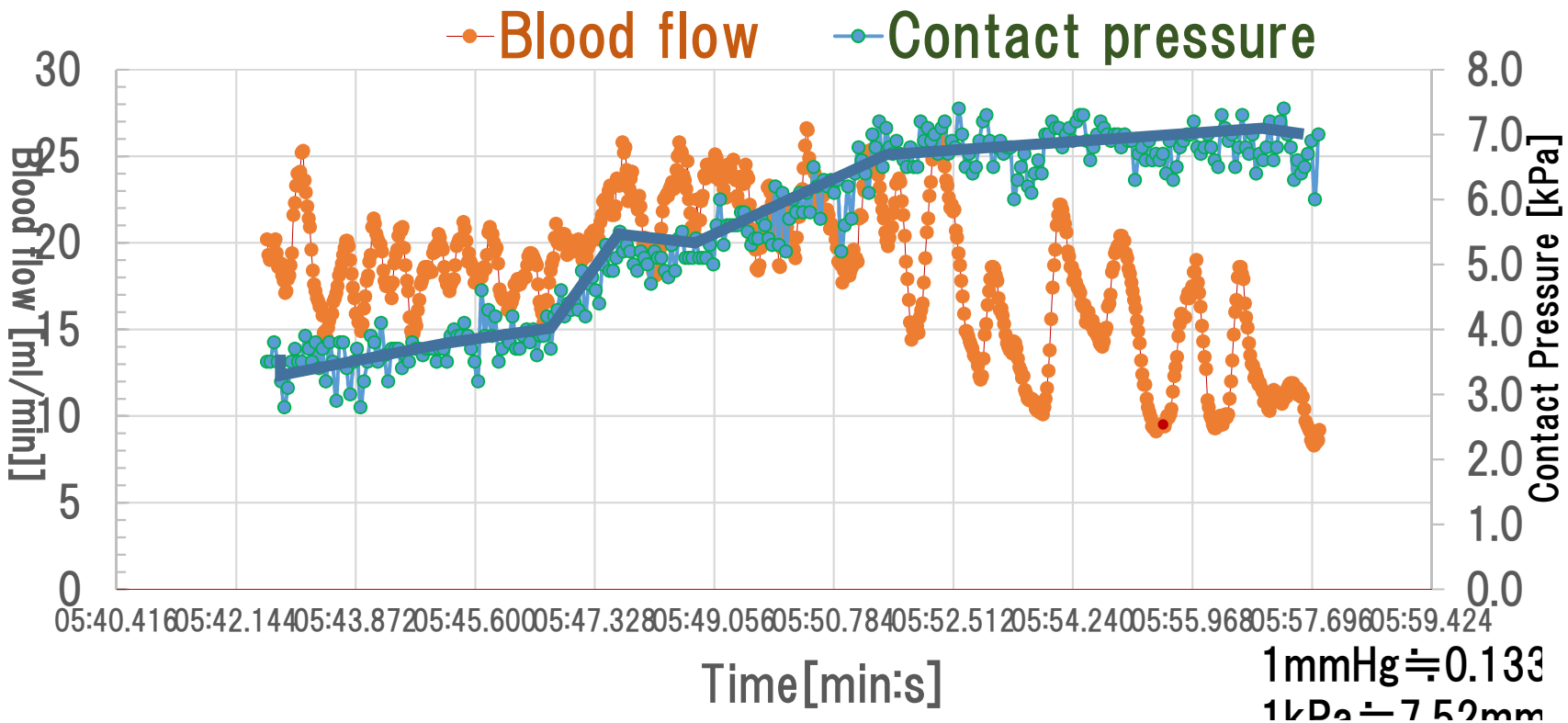
Blood flow vs Contact pressure in a minute contact pressure range



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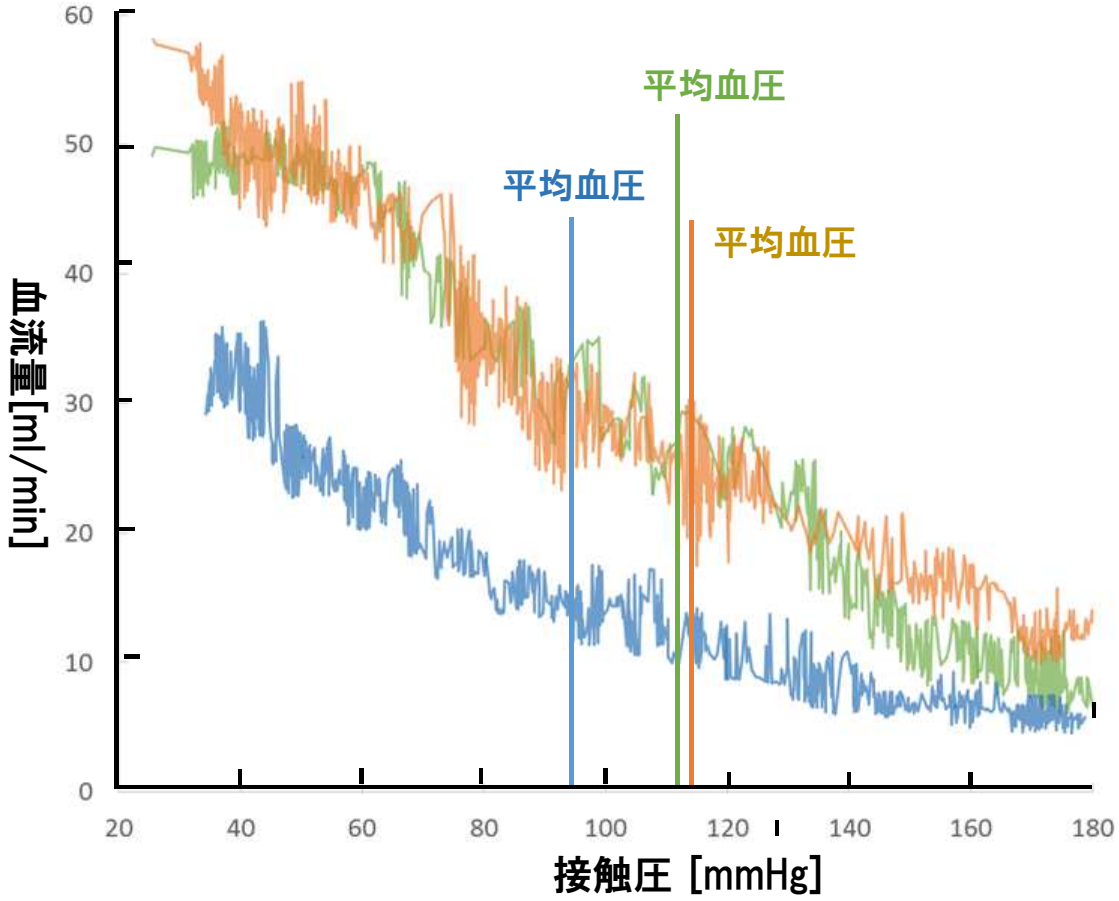
運動前，中，後の血流量の変化



運動前

最高血圧
132mmHg
最低血圧
75mmHg
平均血圧
94mmHg
脈圧 57mmHg

運動中

最高血圧
160mmHg
最低血圧
93mmHg
平均血圧
115mmHg
脈圧 67mmHg

運動後

最高血圧
150mmHg
最低血圧
95mmHg
平均血圧
113mmHg
脈圧 55mmHg

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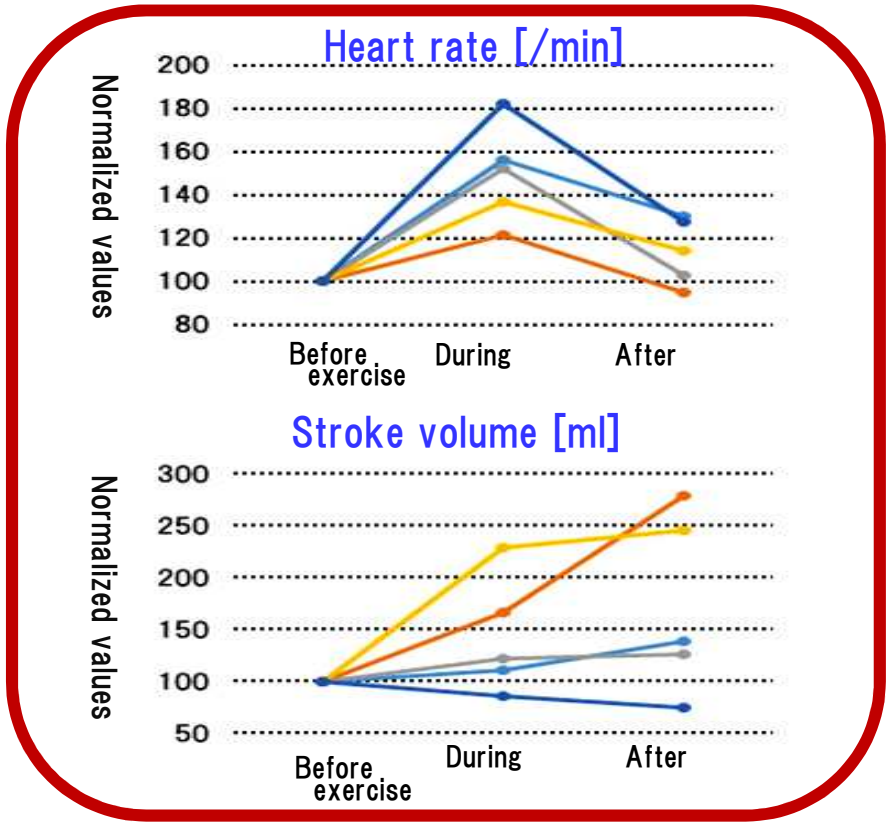
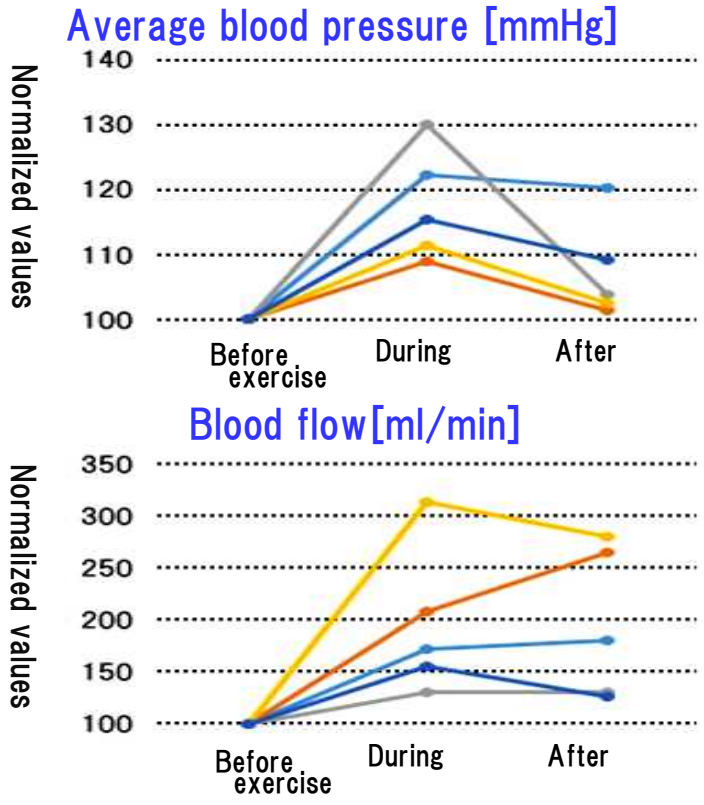
Blood flow per pulse (Stroke volume) changed by exercise





被験者1　2　3　4　5

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Articles for our micro laser blood flow sensor (including Japanese papers and patents)

1. Nobutomo Morita, Hirofumi Nogami, Eiji Higurashi 3,4 and Renshi Sawada, Grasping Force Control for a Robotic Hand by Slip Detection Using Developed Micro Laser Doppler Velocimeter, Sensors **2018**, 18, 326.
2. N. Morita, H. Nogami, E. Higurashi, T. Ito, and R. Sawada, Development of a Built-In Micro-Laser Doppler Velocimeter, Journal of Microelectromechanical Systems, vol. 25, No.2, pp. 380-387, 2016.
3. R. SAWADA, H. TANAKA, O. OHGUCHI, J. SHIMADA, F. SHIMOKAWA, Fabrication of Optical Microencoder, Int. J. Japan Soc. Prec. Eng., Vol. 28, No. 1, 1994, pp1-4.
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5. ポリイミドを用いた集積化マイクロセンサの設計・製作に関する研究、伊藤高廣学位論文、東京大学、2001年10月2日。(In Japanese)
6. C. Riva, B. Ross, and G. B. Benedek, Laser-Doppler measurements of blood flow in capillary tubes and retinal arteries, Invest. Opthalmol., vol. 11, pp. 936-944, 1972.
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8. D. Watkins and G. A. Holloway, Jr, An instrument to measure cutaneous blood flow using the Doppler shift of laser light, IEEE Trans. Biomed. Eng., vol. BME-25, no. 1, pp. 28-33, 1978.
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