patients with other neurosurgical diseases. This finding does not necessarily imply that our original theory is correct. Thus the high frequency and the high degree of positivity in the SAH-spasm group could be a result and not the cause of the vasospasm. At present we suggest, however, that a positive test in a patient with SAH indicates that this patient runs the risk of developing vasospasm. It is, of course, too early to speculate about the therapeutic implications of the observation. The possibility, however, of preventing or treating vasospasm with immunosuppressive methods is an alternative that naturally presents itself.

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A Laser-Doppler-Velocimeter using an optical fiber and its application to local velocity measurement in the coronary artery

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Summary. A Laser-Doppler-Velocimeter with an optical fiber has been developed to measure arterial blood velocity accurately in a small sample volume. After fundamental experiments to evaluate the accuracy of the present method, blood flow velocity was measured in canine coronary arteries.

A Laser-Doppler-Velocimeter (LDV) may be an excellent tool for measuring the blood flow velocity accurately in a small sample volume. The practical application of the LDV to medical and biological fields, however, has been restricted to the measurement of the flow velocity in a vessel with a thin wall and/or a small diameter[2-7], because of the relatively low transparency of blood and the vessel wall for the laser light. In order to apply the LDV to the observation of arterial blood flow velocity, we have developed a LDV using an optical fiber as a light guide into the artery. We particularly intended to apply our method to an analysis of the local velocity in a relatively small artery, which has not been possible so far by other methods. After fundamental experiments to evaluate the accuracy of the present method, local blood flow velocities were measured in coronary arteries of mongrel dogs.

Methods. The basic optical system of our LDV is shown in figure 1. The He-Ne laser beam (632.8 nm, 10 mW) is divided by a beam splitter (BS). Half the initial light passed by the BS is focused onto the entrance of a graded-index multimode fiber (100 μm diameter) and transmitted through the fiber into a blood stream. A part of the light back-scattered by flowing erythrocytes is collected by the same fiber and is transmitted back to its entrance. The other half of the initial light divided at the BS is used as reference beam. A frequency shifter (40 MHz) is interposed on the path of the reference beam to differentiate the forward flow from the reverse. The optical heterodyning is made by mixing the Doppler shift signal from the moving erythrocytes with the reference beam. The photocurrent from the photodetector (APD) is fed into a spectrum analyser to detect the Doppler frequency. The dimensions of the measuring head (plastic holder) are 7 mm in length and 3–5 mm in outside diameter (see fig. 3).

Results and discussion. To evaluate the accuracy of the present measurement, known blood flow velocities in a circular groove on a rotating turntable were measured at various revolution speeds. The fiber was inserted into the blood stream at an angle of 55°. In general, the power spectrum of the Doppler shift frequencies was almost flat from 40 MHz (corresponding to zero velocity) to lower frequencies (higher frequencies for the reverse flow) and then fell to the shot noise level (see the spectrum pattern in the left side frame of fig. 2). The reason for the broadening is that the blood flow is disturbed locally at the fiber tip and the back-scattered light includes the flow information

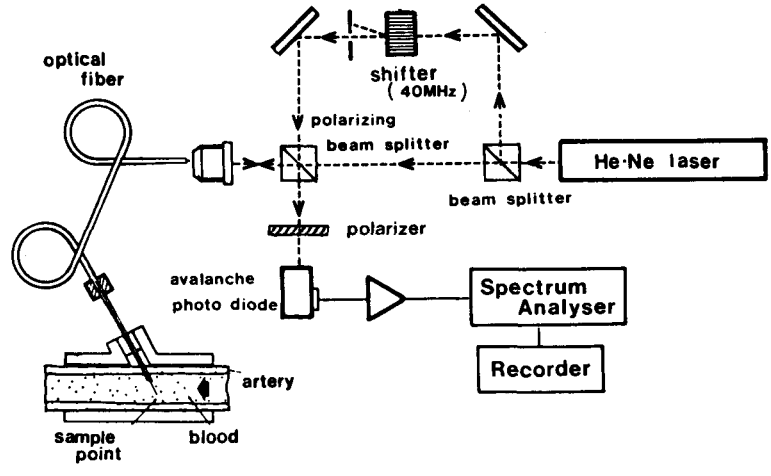

Figure 1. Experimental setup of a Laser-Doppler blood Velocimeter.

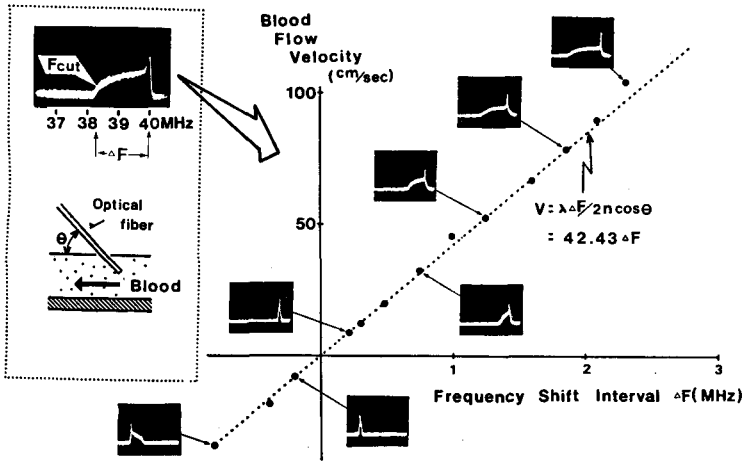

Figure 2. The relationship between the frequency shift ΔF and the known blood flow velocity V in a circular groove on a rotating turntable. The dotted line represents the theoretical relationship obtained by $V = \lambda \Delta f / 2n\cos\theta$, where Δf is the Doppler shift frequency, n the refractive index of blood, θ the angle of incident beam to the blood stream and λ the wave length of the laser beam. Note the good agreement between ΔF and the known V both for the forward and for the reverse flow velocity.

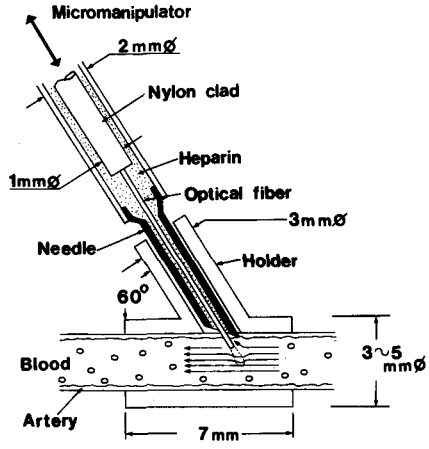

Figure 3. Schematic drawing of the fiber catheter and the plastic holder to control the fiber tip at an appropriate position in the vascular lumen. The fiber was inserted into the vessel at an angle of 60° with the aid of the holder, selected out of several holders with different diameters to fit the vessel snugly. Heparin can be injected to prevent blood coagulation around the fiber tip.

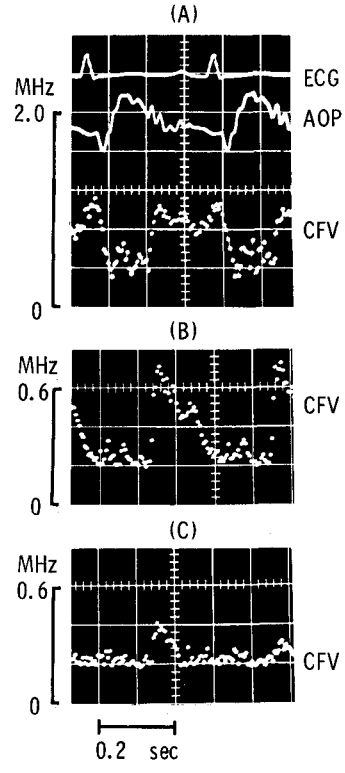

Figure 4. Blood flow velocity patterns in left circumflex coronary artery of a mongrel dog measured by the present method. (A) shows the velocity pattern at a sampling point near the central axis of the vessel, (B) at a little way off from the vessel wall, and (C) at a sampling point close to the vessel wall. A higher flow velocity was obtained during diastole at any sampling point. But the flow velocity pattern changes with the sampling points, especially at the vicinity of the vessel wall. Notice difference in calibrations. ECG, electrocardiogram; AOP, aortic pressure; CFV, coronary flow velocity.

from this region. The maximum Doppler frequency (designated by 'Fcut' in fig. 2) will give the actual flow velocity. The frequency interval ΔF from 40 MHz to Fcut were then plotted against the known blood flow velocities. As can be seen, ΔF shows an excellent linear relationship with the known blood flow velocity both for the forward and the reverse flow (fig. 2). The linearity was held for any angle of the fiber insertion to the blood stream from 45° to 70°. The ΔF also coincided well with the value of the frequency shift calculated from the known blood flow velocity by using the equation in the legend of figure 2. In practice, ΔF was read automatically every 5 msec and recorded as time sequential data.

The maximum detectable distance from the fiber tip for the back-scattered light amounted to approximately 0.25 mm in the blood. This gives the axial length of the sample volume of our system. The actual length, however, will be less than 0.25 mm, since the velocity components in the immediate vicinity of the fiber tip were eliminated by taking Fcut. The cross-sectional area of the sample volume is considered to be almost equivalent to that of the core of the fiber ($\pi \times 0.0025$ mm^2).

As an in vivo application of our method, the blood flow velocity was measured in the left circumflex coronary artery (1.8-2.8 mm outside diameter) of 5 anesthetized mongrel dogs. After the artery was exposed, a small plastic holder was placed around the vessel to fix the fiber tip at an appropriate position in the vascular lumen (fig. 3). The optical fiber was inserted into the vessel at 60° to its longitudinal axis through the holder with the aid of a small needle. The fiber tip was moved across stepwise from the

near to the far wall by a micromanipulator in order to measure a local velocity at each sampling point.

The blood flow velocity measured near the central axis in the coronary artery showed a diastolic dominant pattern which is a characteristic of the coronary arterial flow. A typical example is shown in figure 4A. Usually 2 peaks were observed on the flow velocity pattern during the early and the late diastolic phase. This flow velocity pattern showed a good agreement with the results of the theoretical calculation for the dog coronary artery by Atabek et al.[8]. Nerem et al.[9] measured the coronary flow velocity of a horse by a hot-film anemometer. They also observed the presence of these oscillatory velocity components in the early and the late diastolic phase. However, the systolic component of the horse coronary artery was much larger than that of the dog. As the fiber tip traversed towards the vessel wall, the flow velocity decreased especially during late diastole (fig. 4B) and also during early diastole at sampling points very close to the vessel wall (fig. 4C).

In conclusion, we have found that the LDV using an optical fiber permits the measurement of the pulsatile blood flow velocity in a small sample volume. This LDV has the following advantages: (a) The sample volume of our system is roughly 100 μm which is much smaller than that of conventional methods, e.g., the ultrasound-Doppler method. The temporal resolution is also high (approximately 5 msec). (b) The optical fiber is thin and flexible. Thus, it has excellent accessibility to objects and the perturbation of the flow by fiber insertion will be small comparing with other catheter-type blood flow velocimeters. (c) Our method is free from electrical induction noises.

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Feather position of the pigeon after intrahypothalamic injections of noradrenaline, 5-hydroxytryptamine and carbachol[1]

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Summary. A slowly increasing ptiloerection was seen after the intrahypothalamic injections of NA; 5-HT was followed by preening and subsequent rapid feather fluffing, and carbachol produced an immediate sleeking of feathers. The naturally occurring complementary relationship between shivering thermogenesis and ptilomotion diminished or disappeared after the drugs, but feather position seemed to remain well related to the arousal state of the pigeon.

Hypothermia follows the injections of both noradrenergic, cholinergic, and serotonergic agonists into the anterior part of the hypothalamus of the pigeon in a cold environment[2-5]. The main cause for hypothermia after administration of noradrenaline (NA), 5-hydroxytryptamine (5-HT), and carbachol (CCh) seems to be the abolishment of shivering thermogenesis, and enhanced heat loss due to increased vasodilatation in the legs. The position of the feathers and thus the insulative properties of the plumage could be adjusted by smooth pennamotor muscles (musculi pennati)[6], and according to the hypothesis of McFarland and Budgell[7] the changes in feather position are primarily under hypothalamic control. It was therefore of interest to study whether the intrahypothalamic injections of NA, 5-HT and CCh have any effects on the regulation of feather position in the pigeon.

Materials and methods. 8 adult pigeons *(Columba livia)* of either sex, weighing 260–360 g, were used. A guide cannula was implanted unilaterally into the anterior hypothalamus as described earlier[4,8]. The coordinates were 7.8–8.0 mm anterior to the intra-aural line, 1.2 mm lateral to the midline and 9.0–10.0 mm below the surface of the calvarium. Each bird received first an injection of NA in a volume of 1 μl, after that, CCh, and finally 5-HT, with at least 1 week between successive injections. NA (L-arterenol bitartrate, Sigma, 15 μg/μl) was dissolved in 0.85% NaCl, CCh (carbamylcholine chloride, Sigma, 1.5 μg/μl) and 5-HT (as creatinine sulfate, Sigma, 15 μg/μl) in distilled water. In controls the same volume of vehicle was injected. All experiments were carried out in the afternoon between 13.00 and 17.00 h. After an equilibration time of at least 30 min in a cage located in a cold room at +5 °C, the drugs were injected via polyethylene tubing, which was connected to a 10-μl syringe located outside the cold room.

During the experiments the pigeons were observed through a TV-monitor (Philips LDH 25 camera and Finnvideo VM 12 FI monitor). The magnitude of ptiloerection was estimated once per min by applying the method of McFarland and Baher[9] originally devised for the barbary dove. The contour feathers of 6 body regions were scored according to their postures in 3 classes: 0 = sleeked, 1 = normal, and 2 = raised, and the scores of different regions were summed together to give the feather index (FI) with a minimum of 0 (fully sleeked) and a maximum of 12 (fully raised). The arousal state of the pigeons was estimated by visual observations. Axillary and foot temperatures and shivering from the pectoral muscle were measured as described earlier[10].

Results and discussion. All 8 pigeons showed the hypothermic response to NA but only 7 of them to CCh and 5 to 5-