carbon dioxide. This is of definite importance in those cases where CO_2 may influence growth, as for instance in lactic acid bacteria. If desired, effects of CO_2 on growth can be established by comparing parallel runs in culture vessels with and without an additional side bulb containing KOH, respectively.

Résumé. La fiole de culture décrite permet le mesurage par voie turbidimétrique de la croissance microbienne en culture anaérobie et agitée. Du gaz, produit par la culture, peut s'échapper par une valve. Par l'application additionnelle d'un bulbe latéral contenant de la potasse, la comparaison est possible entre des cultures parallèles, croissant soit en présence soit en absence de CO_2.

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Measurement of Blood Flow by Heated Thermocouple with Feedback Controlled Current

The principle of the heated thermocouple method[1] for regional blood flow measurement is that the degree of heat transmission from the hot junction varies with blood flow.

Slow response due to the heat capacity of blood and difficulty of calibration are disadvantages of this method. But this has been widely used for measurement of blood flow in various tissues, such as skin, muscle[2], liver[3], kidney[4] and bone marrow[5], partly because (1) its electrode is simple and flexible, (2) it can be buried in any tissue with little damage, and (3) it can afford continuous recording as well as separate recording from closely located spots.

However, as reported, the current required to raise the temperature of a thermocouple is kept constant irrespective of local tissue temperature so that the effect of local heat accumulation on vasomotor action[6] and nerve conduction velocity[7] cannot be neglected. Consequently, the error of measurement caused by such environmental changes cannot be avoided.

In the present study, a very low DC current is supplied to the heater in order to minimize such tissue reactions. Feedback control system is employed for automatic regulation of temperature difference between the hot and cold junctions to keep constant by adjusting heating current depending upon the change of flow rate. The characteristics of the constant current (CC) heating-method and the self-adjusting current (SC) heating-method have been compared with regard to their manner of response in application to animals and the linearity in response to the flow rate change in model experiment.

The structure of the electrode and the block diagram of the feedback control system are shown in Figure 1. The measuring element consists of a constantan wire (0.1 mm in diameter, 10 mm in length) to which 3 copper leads (0.1 mm in diameter) are connected at its middle (b in Figure 1) and both ends (a and c in Figure 1). The heater is a constantan wire (0.8 mm in length) coiled around the middle part of measuring element, and is insulated only electrically. Dimension of electrode should be appropriately chosen depending upon the flow rate. DC heating current is initially (during no flow) supplied to the heater so as to keep temperature difference of 0.35 °C. During the measurement, this temperature-difference is maintained constant by the feedback control system as mentioned above.

As the main purpose of this feedback control system is to measure the change of the flow rate, heating current is fed back proportionally to the change of a temperature-difference and an increase of this current is recorded. Loop gain of the system should be raised as much as possible within the stable range to reduce the temperature offset. The decrease of temperature-difference between the hot and cold junctions is also checked under the CC heating-method applied to this electrode.

Figure 2 shows a comparison of the CC and the SC heating-methods applied to the renal cortex of a dog. In the SC heating-method the rapid decrease of heating current occurs to compensate the total increase of temperature-difference caused by a temporary occlusion of renal artery. Prompter response and less influence of temperature-change to the tissue are observed in the SC heating-method than in the CC heating-method.

In the model system, the SC heating-method gives higher linearity and applicability over wider range of flow than the CC heating-method (Figure 3B). In the CC heating-method, as the flow rate increases, the decrement of temperature-difference decreases and gives a value nearly

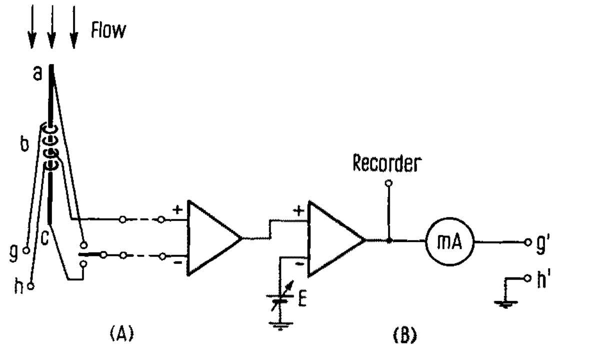

Fig. 1. (A) Structure of the electrode and (B) block diagram of the feedback control system. E, the reference voltage to set the temperature difference; a and c, both ends; b, central portion of constantan wire of measuring element; g and g', h and h' are connected respectively during the measurement.

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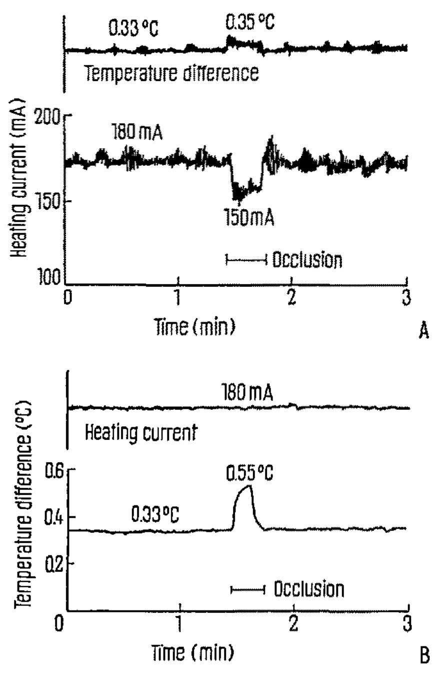

Fig. 2. In vivo experiment applied to renal cortex of a dog. The electrode is inserted into left renal cortex and the change in the blood flow is observed when left renal artery is occluded temporarily. (A) Under the condition of constant current heating of 180 mA, the change in the flow rate is represented as the increase of temperature difference by 0.22°C with constant current heating method. (B) In case of self-adjusting current heating-method, the change in the flow rate is represented by a prompt drop in heating current from 180 to 150 mA, giving less temperature change (0.02°C) to the tissue examined.

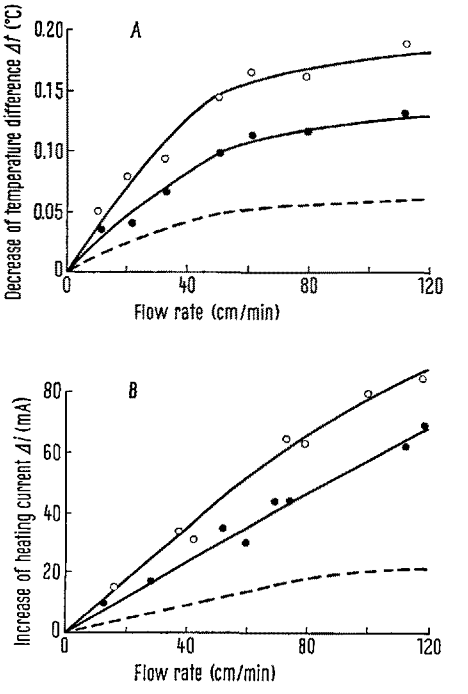

Fig. 3. (A) Relationship between decrease of temperature difference and flow rate in constant current heating-method and (B) relationship between increase of heating current and flow rate in self-adjusting current heating-method in model experiment. The electrode is designed in a needle form and placed along the central axis of the cylindrical glass tube (25 mm in a diameter) through which warmed water is perfused. The experiment should be performed with the whole system confined in the constant temperature of 37 °C. —o—: b–c measurement, —•—: a–b measurement, - - - - -: a–c measurement. a, b and c are explained in Figure 1.

proportional to the square root of the flow rate (Figure 3A).

The temperature-difference T varies generally in accordance with the flow rate V and the heating current I. Although GRÄNGSJÖ et al.[8] established the hyperbolic relationship between them, under the conditions above (in the steady state) their mutual relationship can be shown by an experimental formula as follows:

$$T = C\, I^2\, (1 - \sqrt{V/V_m}),$$

where C is a constant, V_m is the flow rate when a temperature rise becomes negligibly small. As the flow rate increases to V from zero, decrease of a temperature difference Δt in the CC heating-method can be given:

$$\Delta t \propto \sqrt{V/V_m},$$

and current increase Δi in the SC heating-method can be given:

$$\Delta i \propto \sqrt{V/V_m} + 3\, V/4\, V_m \cdot (V \ll V_m)\,.$$

Similar tendency can also be found in view of hyperbolic or exponential relationship. These facts seem to explain the experimental results in Figure 3.

Measurements with the hot junction upstream (b–c measurement) give higher values than those with the hot junction downstream (a–b measurement), in either method, presumably because the heat of the hot junction is conveyed by the flow to the cold junction to raise the temperature of the latter.

The brocken lines in Figure 3 represent the results of a–c measurement, i.e. the difference between a–b and b–c measurements. It shows linearity in a certain range. It should be noted that the polarity indicates the direction of the flow.

Polarity of the heating current should be fixed in view of Peltier effect.

AC current heating is in progress.

Zusammenfassung. Eine neue Messmethode für Durchblutungsmessungen besteht darin, dass selbstgeregelter Strom mit Hilfe des Rückkopplungsregelungssystems für die Heizung gebraucht wird. Mit dieser Methode wird der Temperaturunterschied zwischen den geheizten und den gekühlten Kontaktplatten ganz gering und konstant gehalten, so dass der Effekt der lokalen Wärmeakkumulation, der bei Heizung mit konstantem Strom entsteht, am geprüften Gewebe wegfällt. Diese Methode hat eine höhere Linearität und bessere Anwendungsfähigkeit über weitere Durchblutungsgebiete, und sie spricht auch schneller an als die frühere Methode der Heizung mit konstantem Strom.

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