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Computherm. A New Device for Measurement of Coronary Blood Flow using the Continuous Thermodilution Technique

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ABSTRACT

A new device for an automatic determination of coronary sinus blood flow using the thermodilution technique is presented. The measuring equipment consists of four main parts; a thermal dilution-catheter with two signal amplifiers of analogue type, an analogue/digital converter controlled by a microcomputer system, a pump for the control of the rate of injection flow and a control panel and display. The device has been tested in a model test with flow levels between 75 and 200 ml/min. The error between a number of measurements with all parameters unchanged except minor variations in temperatures was less than 5 per cent.

INTRODUCTION

In 1971 Ganz et al (1) presented the continuous thermodilution technique for measurement of coronary sinus blood flow in ml/min. This method differs from that used for measurement of cardiac output (2). The injection of indicator is made against the blood stream and it is injected at a constant speed until the temperature of mixture of blood and indicator has reached a steady state.

The continuous thermodilution technique has recently been evaluated in experimental and clinical studies (3, 4). The difficulty to measure the exact blood flow was documented, but alterations of the flow could be reliably determined. The inability to measure the exact flow was mainly due to three factors; difficulties to obtain a total and uniform mixing between blood and indicator, heat leakage within the catheter as well as to ambient structures and the Wheatstone-bridge was found not reliable. It might thus, be considered important to develop a device which automatically corrects for some of these errors and also simultaneously gives the value of the blood flow in ml/min on a display.

The continuous thermodilution technique

The thermodilution is a variant of the indicator dilution principle. The injection of indicator is made at a constant speed against the blood stream until the temperature of the mixture of blood and indicator has reached a steady state. A specially designed catheter (Wilton Webster Laboratories, P O Box 237, Altadena, California, 91001, USA) is used. The catheter has two thermistors; one measures the indicator temperature and the other measures the temperature of the blood - indicator mixture. Isotonic saline or isotonic glucose are used as indicators. In order to calculate the blood flow it is necessary to know the rate of injection of the indicator and the specific heat and the density of the blood and indicator. As no heat is gained or lost by the system, the heat taken up by the indicator equals the heat lost by the blood.

$$F_B = F_I \times \frac{S_I \times C_I}{S_B \times C_B} \times \left(\frac{T_B - T_I}{T_B - T_M} - 1 \right)$$

F_B and F_I = flow of blood and indicator respectively in ml/min.

S_B and S_I = density in g/cm^3.

C_B and C_I = specific heat in $cal/g \cdot {}^0C$.

T_B and T_I = temperatures in ${}^0C$ of blood and indicator respectively.

TM = temperature of mixed blood and indicator during indicator infusion.

$\frac{S_I \times C_I}{S_B \times C_B}$ is constant if the same indicator is used, 1.08 for isotonic glucose and 1.19 for isotonic saline mixed with blood.

Construction and description

The measuring equipment is built of four main parts (Fig. 1).

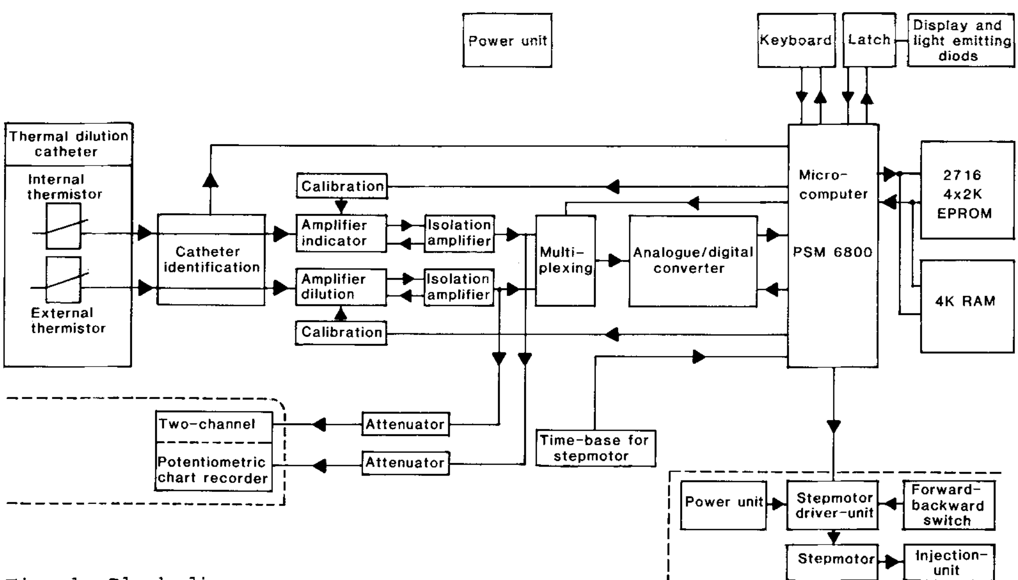

Fig. 1. Block diagram

a) A thermal dilution-catheter with two signal amplifiers of analogue type.

b) An analogue/digital converter controlled by a microcomputer system (MCS).

c) A pump for the control of the rate of injection flow.

d) A control panel and display.

All parts are incorporated in an instrument case, except the injection pump which is a separate unit (Fig. 2).

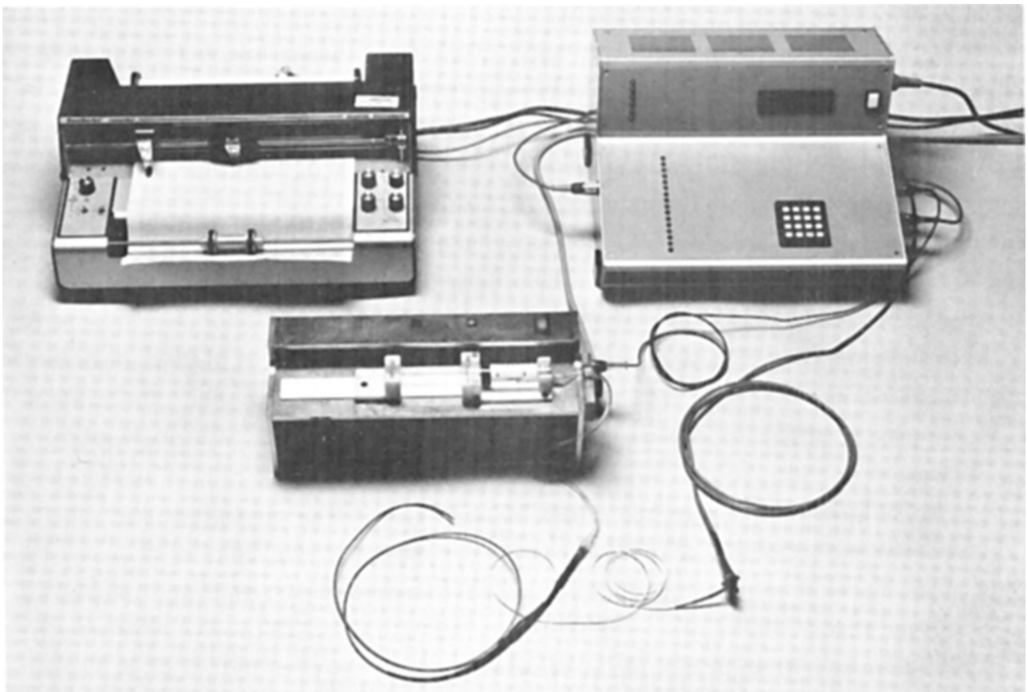

Fig. 2. The computherm device is presented to the right in the figure. To it a chart-recorder, an injection pump and a thermodilution catheter are connected.

The thermal dilution catheter used is a Wilton-Webster model CHA-F5. The catheter has an external and an internal thermistor. These have a resistance of 6000 ohm ($\pm$ 25%) at 25^{o} C. Each thermistor has its own resistance-temperature graph and must therefore be calibrated individually. The calibration can be performed with a temperature regulated water bath and a precision thermometer. The measured values are read in hexadecimal code on the display and can then be stored in the form of tables in an EPROM-memory of the microcomputer system. The used thermodilution catheters have their own identification through a special programmed contact. This in turn is sensored by the CPU which verifies that the correct table (from the EPROM) is used for each individual catheter.

The thermistors in the catheter are fed with a current that must not exceed 10 uA. The drop in voltage over the thermistors is amplified so that the maximal signal out with each respective scale have maximum/minimum levels that do not exceed ±5 V. Both amplifying channels are fed by the current supply and they transmit the output signal via an isolation amplifier. Calibration and reference signals are applied through MCS controlled relays. These relays have a very high isolation between the coil and the group of contacts. The thermal dilution catheter and the measuring amplifier fulfill the given regulations on current limitation and galvanic isolation for the type of measurement in question.

From the outputs of the isolated amplifiers the signals are fed jointly into a two-channel potential metric chart-recorder which gives a visual guide over the measuring process and to a multiplexer. The output of the multiplexer is fed to an analogue/digital converter (A/D) with a sampling rate of 200 samples per second and channel. The switching and receiving of the multiplexer of each respective measured voltage is controlled synchronously by the MCS. From the A/D converter the signal is fed in digital form directly to the MCS for further processing.

With help of the MCS and a suitably adapted program the following advantages can be obtained:

a) Automatic measuring and correction of zero level output from the amplifier.
b) Automatic adjustment in the speed of injection to an optimum value.
c) Controlled steering of injection flow and time durability.
d) Automatical formation of mean-values of measured data for a pre-set measuring time.
e) An automatic discrimination of artefacts.
f) Correction for possible measuring errors caused by unwanted heat transportation through the wall of the thermal dilution catheter.
g) An automatic processing of measuring data and other variables plus a direct presentation of the flow level in ml/min.
h) An automatic steering of the measuring process including a presentation of the flow values.
i) After completion of a measuring cycle it is possible that via the display read and control a number of variables from the measuring cycle.
j) Seven different thermodilution catheters with individual calibration constants can be used. In addition it is easy to replace any of these catheters.
k) From the keyboard it is possible to decide the rate of injection flow and the duration of the measuring period.

The pump used for the injection of indicator fluid is a step-motor driven syringe driver. The syringe is of disposable type and has a volume of maximum 25 ml. It can be driven both forwards and backwards. The syringe-driver is of the threaded type and has automatic stops in both end positions. The forward speed of the syringe is controlled by the MCS in combination with a time base generator and it is possible to vary the time base within wide limits.

In testing the measuring equipment in a model test, a water bath with a stirring moment was used. A precision gear driven pump was adjustable to give flow levels between 75 and 200 ml/min. There was also an arrangement for pulsing of the flow levels. The error between a number of measurements with all parameters unchanged except minor variations in temperatures was less than 5 per cent.

All the program information is kept stored in an erasable memory (EPROM 2716) and can therefore be complemented or modified. The MCS used is a single board computer (PSM 6800) manufactured by PEP Electronic System, GMBH.

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