Basic Res. Cardiol. 77, 93–99 (1982)

Department of Cardiothoracic Surgery, Hadassah University Hospital, Jerusalem
Department of Medical Engineering, Hadassah University Hospital, Jerusalem
Medical Physics Group, Racah Institute of Physics, The Hebrew University of Jerusalem and Department of Diagnostic Radiology. Hadassah University Hospital, Jerusalem

Correlation of blood temperature fluctuations with blood pressure waves

A. Appelbaum, Y. Mahler, and *M. Nitzan*

(Received May 18, 1981)

Summary

Constant blood temperature in the pulmonary artery is assumed when the thermal dilution method is used for cardiac output determination. In some cases, however, slow temperature fluctuations (2–6 cycles per min.) occur in arterial and venous blood and interfere in the measurement. Those thermal fluctuations were investigated in the pulmonary artery and venae cavae of dogs. The temperature variations were found to be correlated with blood pressure waves: an increase of blood pressure was accompanied by an increase in the blood temperature in the pulmonary artery and a decrease in the blood temperature in the venae cavae. Therefore, measurement of the temperature of the pulmonary artery relative to that of the venae cavae does not rule out those fluctuations, and will not improve the thermal dilution method.

Key words: blood pressure, blood pressure waves, blood temperature, blood temperature fluctuations, temperature regulation, thermocouple

Introduction

The thermal dilution method for cardiac output determination relies, among other conditions, upon a constant blood temperature basis at the location of the measurement. Many studies (1, 2, 4–6, 10, 13), however, showed variations in blood temperature which are related to respiration and pulse waves. The influence of these variations on the thermal dilution results is practically eliminated by taking the average temperature as the baseline fo the thermal dilution curve. In certain cases, however, Wessel (13) found that in addition to these variations there exist also much slower temperature fluctuations in venous and arterial blood of 2–6 cycles per minute. These variations are much greater than those related to the respiratory and pulse wave, and they appear simultaneously with blood pressure waves. Because of their high amplitude and long period, these changes cannot be averaged so easily as the faster ones. They are, however, not a common phenomenon (in Wessel's experiment they were found

in only 5 dogs out of 58) and hence even if we assume them to occur also in humans with similar probability, the thermal dilution method may still work well with the majority of patients. For some patients, however, these variations may cause a faulty assessment of the cardiac output. Also for such cases the applicability of the thermal dilution method could still be secured, would these variations occur equally and simultaneously in the pulmonary artery and the vena cava. For the determination of the cardiac output it would then suffice to measure the *relative* temperature between the two vessels. In order to investigate this possibility we studied the temperature variations in the pulmonary artery and the vena cava as well as the differences between the temperatures in both vessels. The results showed the fluctuations in the two vessels to be neither constant, nor equal and not in phase.

Methods

The experiments were performed on 5 mongrel dogs, males and females, of various weights. The animals were anesthetized with pentobarbital (30 mg/kg) and heparin was administered to avoid clots forming on the detectors which were inserted into their vessels. For the measurement of the blood pressure a catheter was inserted into the femoral artery. The catheter was connected to a transducer (Statham model P23Db) and a recorder (HP system 7700 with model 350-3000 Carrier preamplifier). In some of the experiments the amplifier gain was increased and zero suppression was used to demonstrate small changes in diastolic arterial pressure. The temperature was measured by copper-constantan thermocouple, placed in a different catheter which was inserted into the relevant vessels. In most of the cases the thermocouple catheter was inserted into the vessels after opening of the chest. The reference junction of the thermocouple was dipped into a water bath of constant temperature. We measured the relative temperatures between the various vessels as well as the absolute temperatures in each vessel. In one case, the measurement was done without opening the chest and the catheter in the vena cava was inserted through the femoral vein. This catheter held two thermocouple junctions: one in the inferior vena cava (IVC) and the other in the superior vena cava (SVC). In this case the blood temperature in the pulmonary artery (PA) was measured by a thermistor, which was inserted into the pulmonary artery by a Swan-Ganz catheter.

Since the temperature variations are of the order of 0.1 °C, which corresponds to voltage variations of only 4 μV between the junctions of a copper-constantan thermocouple, we used a specially built amplifier of amplification factor 10^4. The amplified signal was filtered by a low-pass filter, in order to cancel the 50-Hz noise. The response time of the whole temperature measurement system was about 1 sec. because of the heat capacity and thermal characteristics of the electrical insulation of the thermocouple, and the high frequency filtration. Therefore, only information about temperature variations which were slower than 1 sec. could be obtained.

Results

The temperature fluctuations were found to be a function of the duration of the experiment. Generally, at the beginning of the experiment the temperatures were almost constant and their variations did not exceed 0.02 °C. At that stage of the experiment the blood pressure (BP) was stable. As the experiment proceeded, 3 of the dogs had developed fluctuations in BP which were accompanied by blood temperature changes. Figure 1

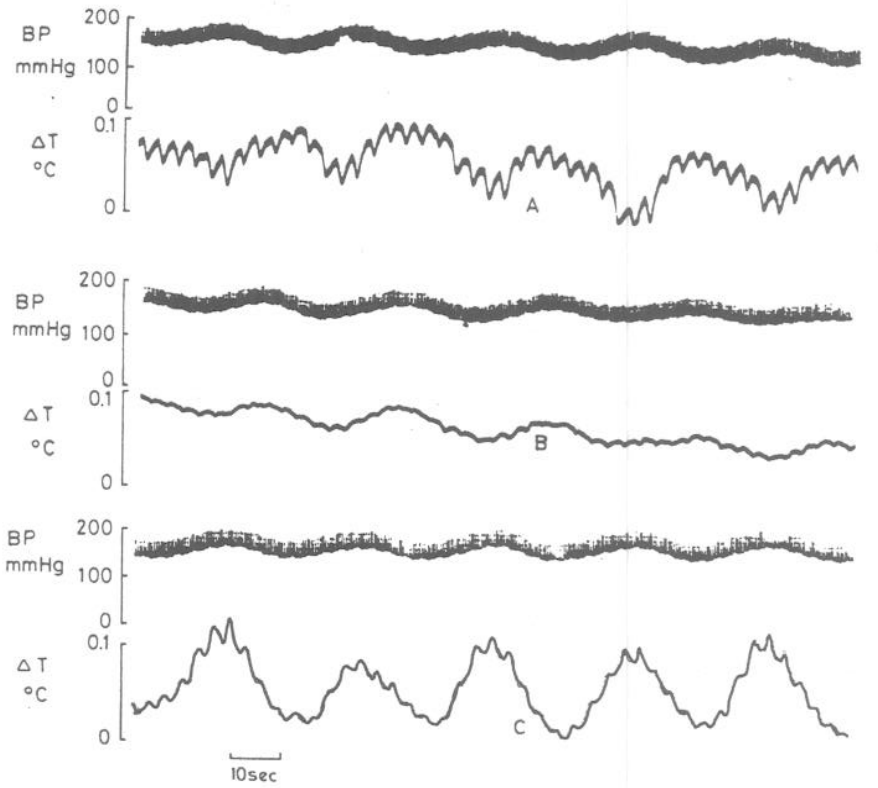

Fig. 1. Fluctuations of blood pressure and blood temperature for an open-chest dog. a) The blood temperature at the superior vena cava. b) The blood temperature at the pulmonary artery. c) The temperature difference between them.

shows such variations for one of the dogs with open chest. Figure 1 A shows the temperature in the SVC (relative to the external reference point) and the arterial BP as a function of time. Both the temperature and BP show fast fluctuations superimposed on slow fluctuations. The rate of the faster fluctuations coincides with the respiratory rate. The slow temperature changes have a magnitude of about 0.07 °C, and a period of about 30 seconds. The BP fluctuations have the same period and the appearance of Meyer waves (3, 13).

A similar effect was observed in the IVC. In both venae cavae the variations in blood temperature were in "antiphase" with those of the BP, i.e., the increase in BP coincided with a decrease in blood temperature, namely that the temperature of the blood which is returned to the heart through the venae cavae is lowered when the systemic BP increases. Figure 1 B shows the BP and the blood temperature in the pulmonary artery as function of time. The magnitude of the temperature variations here is less than half of those in the vena cava. Like in the vena cava, the temperature and BP variations have the same period, but here they are "in

phase", i.e., an increase in BP occurs simultaneously with an increase in blood temperature. Comparison of the temperatures in the pulmonary artery (fig. 1 B) and venae cavae (fig. 1 A) shows that temperature waves in these two vessels are in antiphase. This can be further demonstrated by measurement of the temperature difference between PA and SVC (fig. 1 C). To ensure that the above results are not due to ambient temperature effects, caused by the opened-chest approach, a closed-chest experiment was performed. In this experiment, junctions of thermocouple were inserted by means of a catheter to IVC and SVC. The dog had BP waves and temperature variations at respiratory rate. In addition, there appeared fluctuations in BP and temperature which lasted about 3 seconds, at intervals of 10–20 seconds. Figures 2 A and 2 B show the blood temperature in the IVC and the temperature in the SVC respectively, together with the diastolic arterial BP as function of time. Both figures show temperature variations synchronous with BP waves, superimposed on uncorrelated variations. In the SVC the synchronized variations are smaller than the unsynchronized ones; they can, however, be clearly distinguished at the points at which there occurs a sudden rise in BP.

In this dog too, the variations in blood temperature in the venae cavae are in "antiphase" with the BP variations. The magnitude of the temperature changes in the venae cavae is 0.03–0.08 °C. The temperature at the PA

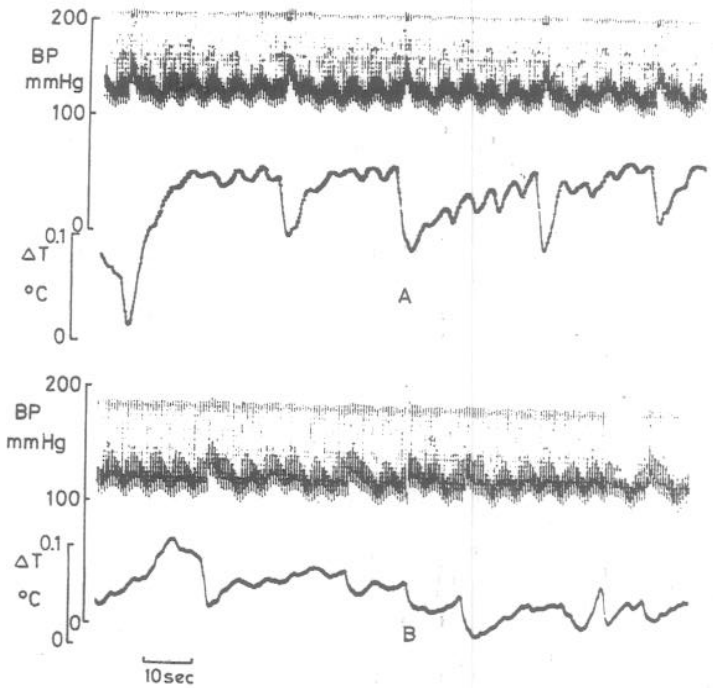

Fig. 2. Fluctuations of blood pressure and blood temperature for a closed-chest dog. a) The blood temperature at the inferior vena cava. b) The blood temperature at the superior vena cava.

was measured simultaneously, and its variations were less than 0.03 °C, and did not show any detectable correlation to BP changes.

The measurements on the third dog were performed with its chest open. Like those of the second dog, the BP and the temperature fluctuations were pulsatile, but their time intervals were shorter: 8–12 seconds. The temperature change was 0.06–0.1 °C at SVC and IVC, and about $^1/_5$ of it at the PA. Here, too, the temperature changes at SVC and IVC were in the same direction, and both were in opposite direction to the fluctuations at the pulmonary artery. When blood temperature variations which are related to respiration and heart pulses are dealt with, one has to exclude the possibility of signal fluctuations due to mechanical movements of the detectors which occurs by the movement of the vessels by respiration and heart beats. The fluctuations investigated by us have no connection with any physiological mechanical movement, and thus it is not reasonable to relate them to some change of position of the detectors. In order to check it experimentally, we have put in SVC and IVC a catheter beyond a window, cut in the wall, and the other on the catheter wall. Because of the unsymmetry of the positions of the two junctions, thermal fluctuations resulting from possible mechanical movement of the detectors are expected to appear. No meaningful fluctuations occurred, confirming the hypothesis that the detected signals were a result of a change in blood temperature.

Discussion

3 types of fluctuations in BP were observed in this study: two wavelike fluctuations, one at the respiratory rate and the other of a frequency of 2 per minute, and the third type were non-periodical pulsatile variations which appeared at intervals of 10–20 seconds. The two first BP variations are termed Traube-Hering waves (3, 11) and Meyer waves (3, 13), respectively. Non periodical BP variations have been found in the capillaries of human nailfold (9) and bat wing (14).

The control of BP is achieved by selective vasoconstriction in the skin of internal organs. Since the various organs supply venous blood of different temperatures, thermal fluctuations in the venous blood should be expected to appear together with the BP variations. Some details of the effect, however, require further explanation. In our experiment, the increase of arterial pressure was accompanied by a decrease of the temperature in venae cavae. If the BP increase would be due to constriction of the arterioles in the external periphery, the venous return of blood from the skin would have diminished, and that would have caused an increase in the average temperature in the vena cava. Since we found that an increase in BP is accompanied by a decrease in temperature, we must assume, that, in our experiments, the increase of BP was caused by constriction of arterioles in internal organs, whose temperature is relatively high. Even the temperature decrease in the SVC can be explained by a decrease of the blood flow to the brain. In spite of the autoregulation of the blood supply to the brain, we can still expect variations in its blood supply, at least in anesthetized animals (7, 8, 12). Comparison of the temperature fluctuations in the pulmonary artery and the venae cavae reveals another interesting phenomenon. The blood temperature in the

pulmonary artery fluctuates less than in the vena cava in spite of the fact that most of the blood arriving at the pulmonary artery went through the vena cava. Moreover, the temperature variations in the vena cava and in the pulmonary artery are in antiphase, and this occurs even when the period of the variations is much longer (30 sec.) than the time (2–4 sec.) needed for the blood to pass from the thermocouple site at the vena cava to the thermistor site in the pulmonary artery. This phenomenon seems to be related to the fact that the blood arriving at the pulmonary artery includes blood from the coronary arteries. When blood of low temperature enters the heart from the vena cava, there is still a possibility that the temperature in the pulmonary artery will increase due to the blood supply from the coronary arteries which has a higher temperature at that instant.

The results presented in this study show that the assumption that the temperature of the blood in the large vessels is constant and can be used as a reference for thermal dilution cardiac output measurement is not always valid. A change of temperature of 0.1 °C, which lasts for 8 seconds, corresponds to an area of 0.8 °C seconds, which is about 10 % of typical areas under thermal dilution curves in dogs. When the injectate is at room temperature the error is doubled. Those variations cannot be overcome by compensating measurements of the temperature difference between the pulmonary artery and vena cava. Since these fluctuations cannot be averaged like those of higher rate, the thermal dilution method is somewhat inaccurate when applied to patients with Meyer waves in the blood pressure.

Zusammenfassung

Bei Bestimmung des Herzminutenvolumens nach der Kälteverdünnungsmethode wird eine konstante Bluttemperatur in der Pulmonalarterie unterstellt. Jedoch treten in einigen Fällen langsame Temperaturfluktuationen (2–6 Zykl. pro Minute) im arteriellen und venösen Blut auf, die mit der Messung interferieren. Diese Temperaturfluktuationen wurden in der Pulmonalarterie und V. cava des Hundes untersucht. Es zeigte sich, daß die Änderung der Temperatur mit den Blutdruckwellen korreliert sind: Ein Anstieg des Blutdrucks war von einem Anstieg der Bluttemperatur in der Pulmonalarterie und einem Rückgang der Temperatur in der V. cava begleitet. Die Meßprozedur läßt sich nicht dadurch verbessern, daß die Temperatur in der Pulmonalarterie auf die der Hohlvenen bezogen wird.

References

1. Afonso, S., J. F. Herrick, W. B. Youmans, G. G. Rowe, C. W. Crumpton: Temperature variations in the venous system of dogs. Amer. J. Physiol. **203**, 278–282 (1962).
2. Boyd, E.: Respiratory artefact in the thermal dilution technique for measuring cardiac output. In: Clinical Blood Flow Measurement, ed. J. Woodcock, Sector Publishing Ltd., pp. 181–184 (London 1976).
3. Data, S. P.: In: Principles of Human Physiology, ed. H. Dawson and M. Eggleton, J. & A. Churchill Ltd., p. 265 (London 1968).
4. Fischer, A. P., A. M. Benis, R. A. Jurado, E. Seely, P. Teirstein, R. S. Litwak: Analysis of errors in measurement of cardiac output by simultaneous dye and thermal dilution in cardiothoracic surgical patients. Cardiovasc. Res. **12**, 190–199 (1978).

5. Ganz, W., R. Donoso, H. S. Marcus, J. S. Forrester, H. J. Swan: A new technique for measurement of cardiac output by thermodilution in man. Amer. J. Cardiol. **27,** 392–396 (1971).
6. Khalil, H. H., T. A. Richardson, A. C. Guyton: Measurement of cardiac output by thermal dilution and direct Fick methods in man. J. Appl. Physiol. **21,** 1131–1135 (1966).
7. Kontos, H. A., E. P. Wei, R. M. Navari, J. E. Lavasseur, W. I. Rosenblum, J. L. Patterson Jr.: Response of cerebral arteries and arterioles to acute hypotension and hypertension. Amer. J. Physiol. **234,** H371–H383 (1978).
8. Mackenzie, E. T., S. Strandgaard, D. I. Graham, J. V. Johns, A. M. Harper, J. K. Farrar: Effects of acutely induced hypertension in cat on pial arteriolar caliper, local cerebral blood flow and the blood brain barrier. Circulat. Res. **39,** 33–41 (1976).
9. Mahler, F., M. H. Muheim, M. Intaglietta, A. Bollinger, M. Anliker: Blood pressure fluctuations in human nailfold capillaries. Amer. J. Physiol. **236,** H888–893 (1979).
10. Olsson, B., J. Pool, P. Vandermoten, E. Varnauskas, R. Wassen: Validity and reproducibility of determination of cardiac output by thermodilution in man. Cardiology **55,** 136–148 (1970).
11. Rothe, C. F., J. J. Friedman: Control of the cardiovascular system. In: Physiology, ed. E. E. Selkurt, Churchill, 1971, p. 373.
12. Vatner, S. F., D. Franklin, E. Braunwald: Effects of anesthesia and sleep on circulatory response to carotid sinus nerve stimulation. Amer. J. Physiol. **220,** 1249–1255 (1971).
13. Wessel, H. U., G. W. James, M. H. Paul: Effects of respiration and circulation on central blood temperature of the dog. Amer. J. Physiol. **211,** 1403–1412 (1966).
14. Wiederhielm, C. A., B. V. Weson: Microvascular lymphatic and tissue pressures in the unanesthetized mammal. Amer. J. Physiol. **225,** 992–996 (1973).

Authors' address:

M. Nitzan, Medical Physics Group, Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem (Israel)