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ARCTIC AEROMEDICAL Laboratory

TEMPERATURE CHANGES OF PULMONARY BLOOD DURING EXPOSURE TO COLD

PROJECT NUMBER 22-1301-0002
RESEARCH REPORT

LADD AIR FORCE BASE

A L A S K A

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Contract Number 18(600)–413

PROJECT NUMBER 22–1301–0002

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Alaskan Air Command

ARCTIC AERO MEDICAL LABORATORY

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March 1953

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It has been known since the days of Claude Bernard that although the central regions of the bodies of warm-blooded animals are maintained at a relatively fixed temperature, the peripheral regions undergo comparatively wide fluctuations. The variation of temperature in the different regions of the body has been a subject of interest in recent years, following the classical paper of Bazett and McGlone (1), who in 1929 investigated central-peripheral gradients. A few years after Bazett's original observations, Nedzel (2) measured liver and aortic temperatures during the application of cold and heat to the skin, and in 1942 Federov and Shur (3) introduced the angiostomy technique for placing thermocouples in deep visceral blood vessels. Bazett with coworkers (4, 5) again investigated tissue gradients in 1948 and demonstrated the cooling power of the venal comites on arterial blood. Eichna, Berger, and Rader (6), using thermocouples in catheters for the vascular system, measured temperatures of the right heart chambers and systemic arteries of men, while Horvath, Foltz, Rubin, and Hutt (7) measured similar temperatures in dogs.

The temperature changes of pulmonary blood as it passes through the lungs is of special interest for the studies of homeothermy because in the lungs the blood comes into close relation with air. The lungs can be considered as deep visceral organs close to other visceral organs where tissue temperatures are high. A cooling of blood passing through the lungs is to be expected, but the magnitude of the cooling effect would depend on the effectiveness of the airways in warming inspired air. In order to measure the temperature changes of blood as it passes through the lungs, temperature measurements have been made of the blood in the pulmonary artery and left atrium. These temperature measurements have been made with thermistors which are capable of measuring temperature to within ± 0.01° C. The thermistors are placed within angiostomy cannulas enabling temperature measurements of pulmonary blood to be made on dogs without opening of the chest, and especially important, without general anesthesia, which, as is well known, disturbs seriously the central-peripheral gradients of temperature.

METHODS

Angiostomy cannulas for the pulmonary vessels were used by London and Chloponina (8) with improvements and modifications contributed by Hamilton, Woodbury, and Vogt (9) and Katz and Steinitz (10). These cannulas consist of tubes with open ends, one end abutting against a blood vessel and the other end brought to the skin where it is temporarily plugged. Angiostomy tubes serve as guides for hypodermic needles which can be directed from the outside of the skin to a deep vessel. Silver cannulas fitted with stainless steel stilettes were surgically placed over the left pulmonary artery and the left auricular appendage of 15 kilogram dogs. The distal ends of these cannulas, the heart being the area of reference, were placed in the subcutaneous fascia of the left chest wall. Experiments were conducted six to ten days following cannula placement. The distal ends of the cannulas were exposed surgically following the administration of local procaine anesthesia. The stilettes were then removed from the cannulas, and specially designed 20-gauge hypodermic needles which contained thermistor assemblies were inserted into the left pulmonary artery and the left atrium through the angiostomy cannulas over these organs. In addition, a rubber catheter which also contained a thermistor assembly was inserted 10 cm. within the rectum of the experimental animal. The thermistor assemblies used had been previously calibrated with respect to temperature by means of a variable-temperature water bath and a resistance measuring assembly consisting of three Wheatstone bridges each having been adjusted with a Rubicon galvanometer. The apparatus was so adjusted that a one degree Centigrade temperature change caused a full-scale (10 cm.) deflection on the galvanometer; in addition, the resistance arms of the Wheatstone bridges were adjusted so that even degrees of temperature would fall on the "zero" and the "ten" on the scale of the galvanometer. With this arrangement it was possible to read the temperatures of the pulmonary artery, the left atrium and the rectum simultaneously and continuously with an accuracy of $\pm$ 0.01° C.

The experiments were conducted in a room in which the temperature was 20° C. and in a walk-in refrigerator which was maintained at a temperature of -18° C. Recordings were made for a two- to five-minute period at 30-second intervals in a room with a temperature of 20° C. after which the animal with the thermistor-containing needles and catheter in place was carried into the walk-in refrigerator. Temperature recordings were continued at 30-second intervals for a period of 15 to 40 minutes.

RESULTS

A study of the data obtained in 12 experiments revealed the following:

a. When the animals were in an environment of 20° C., the blood temperature in the pulmonary artery was slightly higher than that in the left atrium in nine of the twelve experiments conducted. In 3 of 12 dogs the blood temperature in the left atrium was slightly higher than that in the pulmonary artery. With the animals in this environment, temperatures of the pulmonary artery blood were found to range from 38.82° C. to 40.04° C., the average being 39.37° C. The left atrial blood temperatures varied from 38.82° C. to 40.00° C.; the average was found to be 39.36° C.

b. The temperature difference between the pulmonary artery blood and that of the left atrium varied from 0.00° C. to 0.04° C. when the experimental animals were in an environment of 20° C. The average of this difference in all the experiments conducted was 0.01° C.

c. In an environment of 20° C. the average rectal temperature was found to be 0.21° C. above the temperature of the pulmonary artery blood and 0.22° C. above the temperature of the left atrial blood.

d. In ten out of twelve experiments there were significant and rather sudden increases in temperatures of the blood of the pulmonary artery, blood of the left atrium, and within the rectum when the animals were moved from the comparatively warm environment of 20° C. to the comparatively cold environment of -18° C. These increases in the pulmonary artery and in the left atrium varied from 0.01 to 0.53° C., while the rectal temperatures increased from 0.02 to 0.17° C. These findings were believed to be of considerable physiological significance because they demonstrated the existence of a rapidly acting compensatory mechanism which, when alerted, can rapidly increase the temperature of the viscera of an animal.

Figure 1 shows the relationship between the average temperatures in the pulmonary artery, left atrium, and rectum in the 12 experiments conducted when the animals were in a 20° C. environment and also when in a -18° C. environment; in the latter the values represent an average of the temperature taken over successive five-minute periods.

e. In an environment of -18° C. the blood temperature in the pulmonary artery was higher than that in the left atrium. This difference varied from 0.00 to 0.07° C. with the computed average of this difference amounting to 0.025° C. It was found that the temperature difference between blood in the pulmonary artery and left atrium was greatest immediately after the animal was introduced into the cold environment, and that this difference appeared to remain relatively constant for 10 minutes after which it decreased slightly.

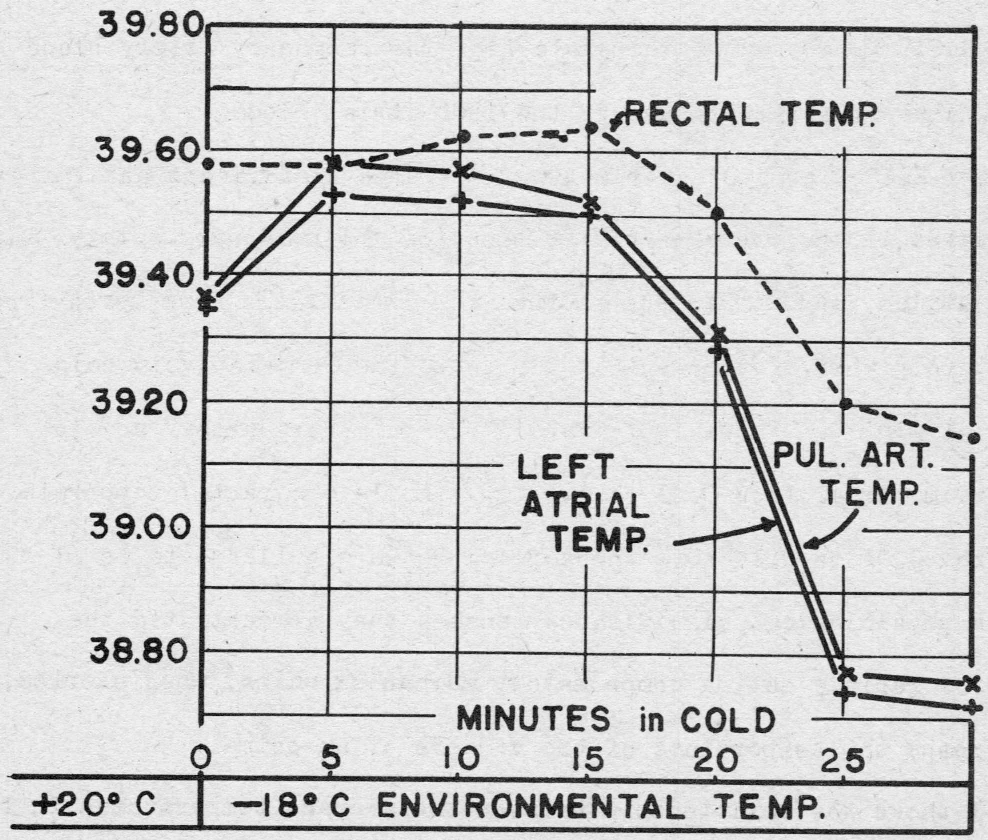

Figure 1. The relationship between the average temperatures in the pulmonary artery, left atrium, and rectum in 12 experiments conducted in 20° C. and -18° C. environments. Values represent averages taken over successive five-minute periods.

Figure 2 shows the relationship between the temperature difference of the pulmonary artery blood and left atrial blood (the amount in degrees Centigrade by which the pulmonary artery temperature exceeds the left atrial temperature) and the length of exposure to the cold environment of -18° C.

f. In an environment of -18° C., the rectal temperatures were somewhat above those of the blood in the pulmonary arteries in all of the experiments except for an occasional short period of time in three experiments. Immediately after the animals were introduced into the cold room, this temperature difference became greater in 10 out of 12 experiments. After this initial rise there was a tendency for the rectal temperatures to

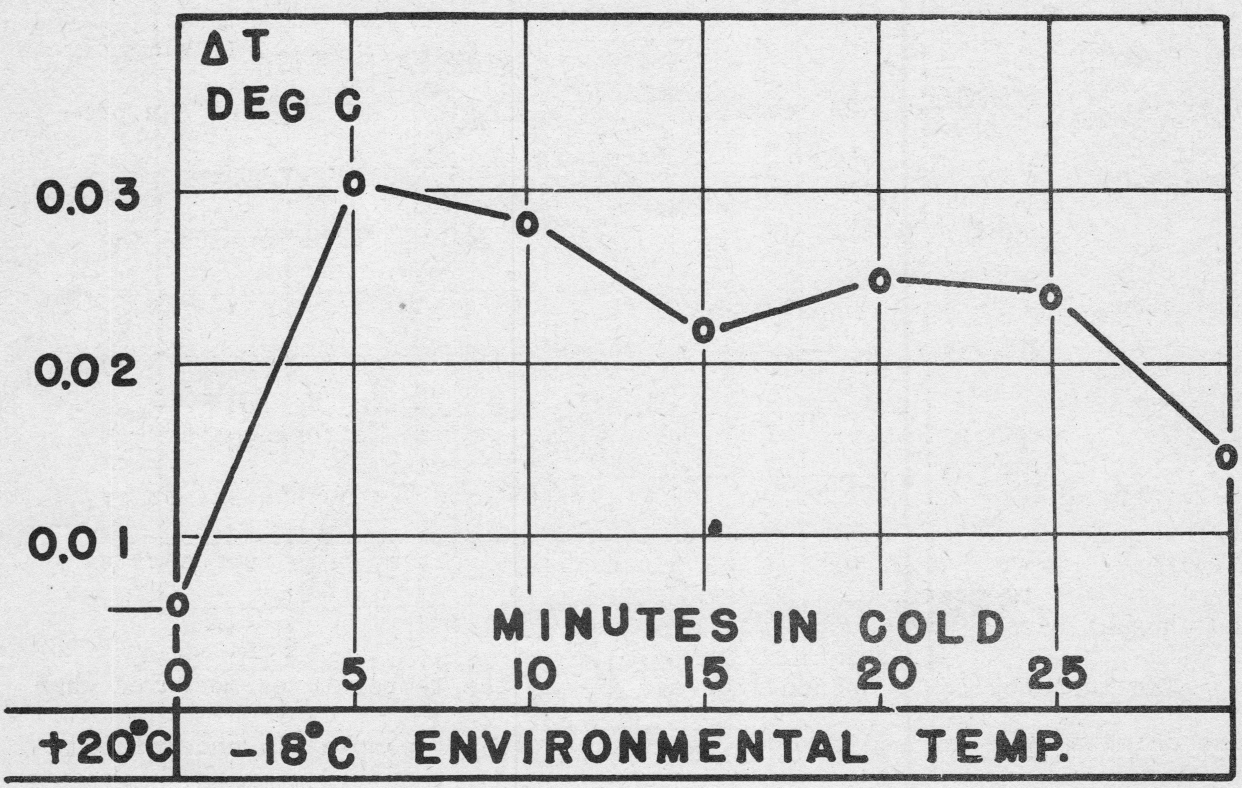

Figure 2. The relationship between the temperature difference of the pulmonary artery blood and left atrial blood and the length of exposure to the cold environment of -18° C. The values represent averages of 12 experiments and are taken over successive five-minute periods.

fluctuate slightly and in most cases fall; the rectal temperatures, nevertheless, remained well above those of the pulmonary artery blood.

DISCUSSION AND CONCLUSION

It was observed in nine out of twelve of the experiments performed that the pulmonary artery blood temperature was slightly above that in the left atrium when the animals were in an environment of 20° C., indicating that there was but little cooling of the blood as it passed through the lungs. In three dogs the atrial blood temperatures were higher than the pulmonary artery temperatures indicating heating of the blood in the lungs. This would indicate that pulmonary blood as it flows through the lungs can receive heat from adjacent warm structures, such as the heart and respiratory muscles, or it can lose heat to the respired air. Ordinarily, blood cools slightly, but during eupnea in a "comfortable" environment the gain in heat can predominate.

It has been recognized for some time that the rectal temperature in the normal animal is somewhat above that found in the greater vessels. It was found that the average difference as disclosed in this work was 0.275° C. There are, however, irregularities in the temperature difference between pulmonary artery and rectum. In one of the 12 experiments the pulmonary artery was found to be 0.05° C. warmer than the rectum, this representing an unusual case.

The tendency for a sudden increase in all the temperatures measured when the animals were exposed to cold environment is not completely understood. The animal body places into operation a rapidly acting protective mechanism, the duty of which is to aid in the thermostability of the physiological interior of the body. Two animals failed to show this type of reaction. The first was a short-coated animal; it was believed that this animal was unable to compensate for the radiation heat loss. The second animal was abnormal in that it persisted in panting during the experiment.

The rectal temperature appeared to increase steadily when an animal was subjected to cold environment. After approximately ten minutes of exposure, there was some fluctuation in the rectal temperature; this was thought to be due to shivering. The course of the rectal temperature from the time shivering began depended upon whether or not the animal was able to compensate for his heat loss by heat production; in most instances he was not able to compensate, and the rectal temperature fell.

The difference between the pulmonary artery blood temperature and that of the atrium appeared to be greatest immediately after the experimental animals had been placed in the cold environment. This difference was seen to decrease as the animal continued to endure the cold. It appears that the animal body has a protective device that comes into operation to reduce the heat loss through respiration.

These experiments substantiate the fact that the upper respiratory tract is remarkably efficient in warming the inspired air.

SUMMARY

a. The rectal temperature was usually higher than the blood temperature of the pulmonary artery and the left atrium under conditions of an environment of 20° C. and -18° C.

b. The pulmonary artery blood temperature was higher than that of the left atrium in environments of 20° C. and -18° C. This difference was in the order of 0.01° C. in an environment of 20° C. and 0.03° C. in an environment of -18° C. with animals in the reclining state.

c. When animals in an environment of 20° C. were suddenly exposed to an environment of -18° C., there was an increase for a short period of time in the pulmonary artery blood temperature, the left atrial blood temperature, and the rectal temperature.

d. The cooling effect of the respiration of cold air upon the blood in the pulmonary circulation is small; the upper respiratory passages are very efficient in warming cold air before it influences the temperature of the pulmonary capillary network when the animal is in the resting state.

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USAF School of Aviation Medicine
Distribution Number 1893
March 1953

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