ON THE COORDINATED CHANGES IN THE BLOOD SUPPLY OF THE BRAIN AND EXTREMITY WHICH OCCUR DURING THE PROCESS OF FALLING ASLEEP

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Research on the circulation of such organs as the muscles and digestive glands shows that their blood supply clearly relates to their condition of activity.

The problem concerning the changes in the cerebral blood supply which are associated with the various degrees of brain activity is more complicated.

There are observations that, when the brain is active, its blood supply usually increases, for example, under the influence of light, sound or other stimuli [4]. Information on the blood supply of the brain during sleep is extremely contradictory. Along with data to the effect that both narcotic and natural sleep are attended by contraction of the cerebral vessels [11,14], there are also observations that the cerebral vessels dilate during sleep [6,18]. These diametrically opposed opinions can be explained by the fact the observations were done at different periods of sleep, on different subjects and, finally, with different methods.

Most of these methods – studying the circulation in the circle of Willis, plethysmography of the brain, observing the surface vessels of the brain through a trephined window – are meant for use in short experiments, and, therefore, the experimental study of this problem is difficult, until recently being limited to observations on people with a cranial defect [5].

EXPERIMENTAL METHODS

We had studied the changes occurring in the blood supply of the brain during natural sleep in a long-term experiment on a dog [12] by means of a plethysmographic method developed in our laboratory [1].

We fastened a special plug in a trephined window of the cranium with a branch tube for connection wi a Marey's capsule. In a series of experiments, two plugs were simultaneously connected with the recording system and were placed diagonally at opposite poles of the cranium to allow for mutual compensation of the intracranial pressure with certain movements of the animal's head.

Since there is a close connection between the cerebral and the peripheral blood supply [3, 4, 18], we recorded a plethysmogram of an extremity at the same time, for which purpose we used a simple air plethysmograph, similar in form to the recently proposed water plethysmograph for an extremity [9].

The experiments were done on five dogs, Jack, Barbos, Gray, Ryzhik and Kakvas. All the dogs were trained to lie on a bench, and they easily fell asleep and after the removal of external stimulations.

EXPERIMENTAL RESULTS

The process of falling asleep was clearly shown by the kymogram (Fig. 1) in all of the experiments: the level of the brain plethysmogram rose, and the amplitude of the pulsations increased, while the level of the extremity plethysmogram, on the other hand, fell. The curve, moreover, became wavy. That these changes were not connected with the movements of the dog is shown by the fact that the rod registering the movements of the head and extremity drew a horizontal line (Fig. 1).

A similar picture was observed in all of the experimental animals during medicamental sleep as well as natural sleep. The advent of morphine sleep was characterized by the same typical discrepancy between the cerebral and pheripheral plethysmograms and by an increase in their oscillation. However, these changes were temporary when effected by morphine, and were only observed at the beginningof the narcotic's action. In natural sleep, they occurred regularly each time the dog fell asleep after being repeatedly awakened.

The fact shown in these experiments that, simultaneously, the flow of blood to the brain is intensified while the peripheral blood supply is reduced can therefore be considered characteristic to the process of transition from the state of being awake to that of sleep.

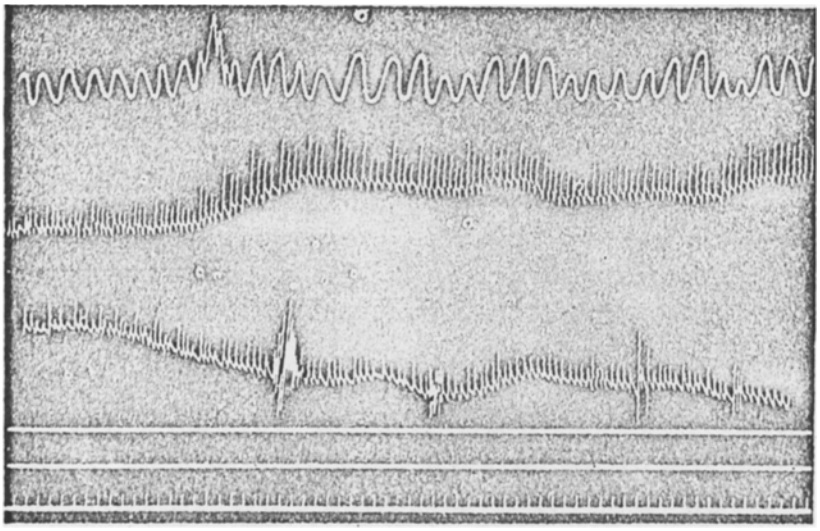

Fig. 1. Coordinated changes in the blood supply of the brain and extremity during the process of falling asleep (in the dog Jack).
Curves from top to bottom show: respiratory movements, plethysmogram of brain, plethysmogram of extremity, movements of head, movements of extremity, indication of time (in 2 second marks).

In order to investigate the feasibility of such an "antagonistic" effect on the vessels of the brain and extremity from the standpoint of the vasomotor center, we conducted short experiments on dogs, stimulating the floor of the fourth ventricle at the places corresponding to the situation of the vasomotor center mechanisms [10]. We found that by stimulating certain portions of the floor of the fourth ventricle, one could reduce the blood supply of the extremity, while increasing the blood supply of the brain. Since the medulla oblongata was exposed when the cranium was opened, the conditions for plethysmography had sharply deteriorated. We therefore recorded the pressure in the circle of Willis in these experiments in order to determine the blood supply of the brain. The curve (Fig. 2) shows that the blood supply of the brain increased (rise of pressure in the circle of Willis), while the blood supply of the extremity decreased; arterial pressure in the animal changed slightly at the same time. This suggests the presence of a central nervous mechanism which redistributes the blood between the vessels of the brain and extremity in the way observed in our experimental dogs as they fell asleep.

The works of many authors have shown the great dependency of the cerebral blood supply on the concentration of carbon dioxide [13, 16, 17 and others]. The inhalation of air with a 10% content of carbon dioxide doubles the cerebral blood supply, while hyperventilation can reduce by half the natural flow of blood through the brain [15].

These and numerous other works concerning the dilatation of the cerebral vessels under the influence of carbon dioxide are particularly important in the light of the data obtained by A. A. Kedrov and A. I. Naumenko [5] and their notion that carbon dioxide is physiologically important to the regulation of the tonicity of the cerebral vessels.

According to A. A. Kedrov and A. I. Naumenko, "the intracranial neurovascular apparatus possesses a special reactivity to a surplus of carbon dioxide." At the same time, the amount of carbon dioxide in both the alveolar air and the blood is known to increase during the process of falling asleep.

This suggests that carbon dioxide activates the mechanism which, as we observed, increases the cerebral blood supply while the animal is falling asleep when the excitability of the brain stem is reduced [8, 12].

We conducted special experiments to test this effect of carbon dioxide. The head of a dog was enclosed in a transparent case made of thin plastic. Air containing 4-5% carbon dioxide was fed into the case from a 100-liter Douglas bag. The percent of carbon dioxide was controlled by a Golden gasometric analyzer. The plethysmograms of the brain and extremity recorded while the animal was in a tranquil state and under conditions of a surplus of carbon dioxide showed changes in the blood supply similar to those observed during the process of falling asleep. That carbon dioxide participates in the "sleep" redistribution of the blood is further indicated by the fact that respiratory changes (see Fig. 1) occurred almost simultaneously with the coordinated changes in the blood supply of the brain and extremity observed during the development of natural sleep.

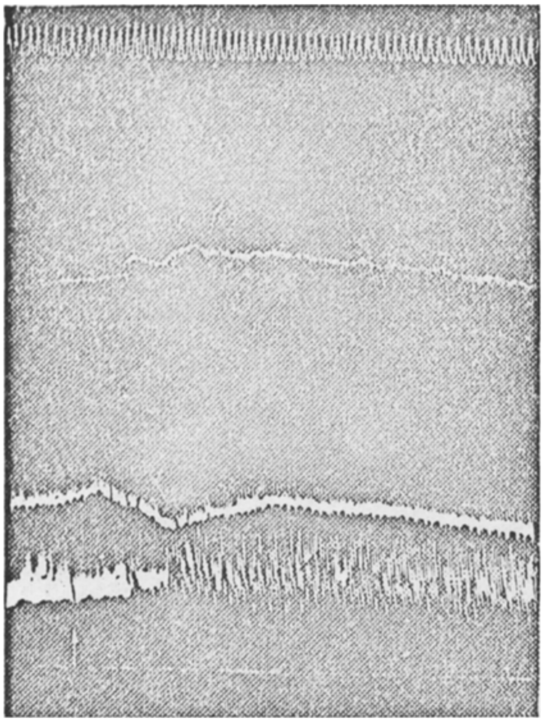

Fig. 2. Coordinated changes in the blood supply of the brain and extremity with stimulation of the floor of the fourth ventricle in a short experiment on a dog. The arrow shows the moment of stimulation with an induced current (distance of 230 mm between the induction coils). Curves from top to bottom show: respiratory movements, blood pressure in circle of Willis, plethysmogram of extremity, blood pressure in carotid artery.

SUMMARY

Long experiments were performed on 5 dogs. Changes in the blood supply of the brain and extremity during natural sleep and that induced by morphine were recorded by plethysmography. Coordinated changes were found in the blood supply of the brain and the extremity in the process of falling asleep, i.e., the blood supply of the brain was increased while the blood supply of the extremity reduced. It was demonstrated that such redistribution of the blood depended on the activity of the vasomotor center. Short experiments were performed on dogs with electric stimulation of the vasomotor center in the area of the fourth ventricle. Coordinated changes in the blood supply of the brain (increased pressure in the circle of Willis) and in the extremity (decrease of the plethysmogram) were recorded. Besides, data were obtained that the nervous mechanism of redistribution of the blood during sleep is influenced by carbon dioxide. In long experiments on dogs which were kept in the atmosphere, containing 4-5% of carbon dioxide, the same coordinated changes were found in the blood supply of the brain and extremity as during the process of falling asleep.

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