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International Journal of Clinical Epidemiology

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Review Article

Cerebral Vascular Reactivity During Mental Activity

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Received Date: January 04, 2024 | Accepted Date: January 13, 2024| Published Date: January 25, 2024

Citation: Fliuryk S., Dremza I, Maksimovich N.Ye, Bon L.I, Borschevskaya T (2024), Cerebral Vascular Reactivity During Mental Activity, *International Journal of Clinical Epidemiology,* 3(1); **DOI:**10.31579/2835-9232/049

Abstract

The question of the effect of emotional stress on cerebral blood flow has both scientific significance from the stand point of analysis of various experimental and clinical data in this area, and practical significance for comparison of mental (psychoemotional) load with adaptation changes in cerebral blood flow and search for ways to optimize it.

Since during intense educational activity, accompanied by emotional stress, the likelihood of functional disorders of cerebral blood flow increases significantly.

The study of rheoencephalography changes in the research under conditions of emotional stress and the nature of these changes underline the importance of arterial intracranial vessel insolvency as one of the main causes of overload of the venous section of the cerebral circulatory system. It follows that in hypertensive crises headaches are more often and greater extent due to disturbances in the venous system of the brain than in the arterial system. Only a well-coordinated system of cerebral blood flow regulation, provided not only by metabolic, humoral, but primarily by nervous factors, can maintain adequate cerebral blood flow.

Keywords: brain; vascular reactivity; mental activity

Summary

The question of the effect of emotional stress on cerebral blood flow has both scientific significance from the stand point of analysis of various experimental and clinical data in this area, and practical significance for comparison of mental (psychoemotional) load with adaptation changes in cerebral blood flow and search for ways to optimize it.

Since during intense educational activity, accompanied by emotional stress, the likelihood of functional disorders of cerebral blood flow increases significantly [13].

The blood circulation of the organism is a complex self-regulating system with many different components responding to physical, chemical, physiological stimulus. This explains the fact that the same stimuli elicit a mosaic of responses often of opposite modality. In this regard, researchers have attempted to study changes in cerebral blood flow and elucidate the mechanisms of its autonomous regulation by modeling emotional stress. After all, among the many links of cerebral blood flow regulation, the mechanisms that ensure adequate changes in the tone of cerebral resistive arteries and promote normal function of exchange vessels - capillaries of the gray matter of the brain - are of special importance.No less significant are the mechanisms of optimization of regional venous blood outflow, because the appearance of even short-term functional signs of deterioration of regional blood outflow negatively affects the processes of transcapillary metabolism in nervous tissue[12].

Rheoencephalography (REG) is most often used as a method of studying cerebral blood flow, since this method allows quantitative assessment of the degree of blood filling of cerebral vessels, studying their tone and dilatation rate, secondly, it allows studying these changes in dynamics during emotional stress and after the end of stress. In addition, in comparison with blood pressure (BP) fluctuations and other indicators of the cardiovascular system, REG allows us to judge the degree of adaptation of intracranial vascular tone to the blood supply of mental load.

It is significant that the study of cerebral blood flow under conditions of emotional stress in healthy people and comparison of its changes in patients with arterial hypertension, which allows us to assess the degree of maladaptation and fatigue in persons of mental labor, makes it possible to study the adequacy of cerebral blood supply during mental work. Regulation of blood supply to such a complexly differentiated tissue as the brain is carried out mainly at three levels of cerebral circulation. With changes in total arterial pressure, this regulation is primarily carried out by the main arteries of the brain, which control blood flow to the brain in response to changes in intravascular pressure. Change of resistance in the system of main arteries is the most optimal mechanism of cerebral blood flow regulation, as normalization of blood flow extends simultaneously to the whole brain, which cannot be ensured by simultaneous response of pial and intracerebral vessels in different brain areas.

If the mechanism of the main arteries is imperfect due to some reasons or the blood pressure changes extremely sharply and intensively, the pial arteries come into action - the second stage of regulation of blood flow into the microcirculatory system of the brain. At the same time, brain capillaries, the walls of which are deprived of a muscular layer, are practically unable to actively change their lumen and do not participate significantly in the regulation of local blood flow[10].The principal difference in the mechanisms of constriction and dilatation of pial arteries from the same reactions of the main vessels is not the influence of changes in intravascular pressure on them, but the violation of adequate blood supply to the brain tissue, leading to significant changes in cerebral metabolism. In this regard, the reaction of pial arteries does not occur instantaneously, but with a significant latent period of 1-2 min.

The third active link in the regulation of cerebral blood supply is the precortical arteries. However, their reaction is dominated by vasoconstrictor influences, and vasodilatation in case of systemic decrease in BP is significantly weakened. Intracerebral arteries do not respond to any BP disturbances by active change of their tone. The factor providing instant control over cerebral circulation, before the onset of metabolic changes, is primarily nervous regulation. The influence of humoral factors is rather an intermediate link in the realization of vasoactive influence on cerebral vessels, changing the sensitivity of the latter to nervous influences. Nervous regulation of cerebral blood flow is manifested in normal conditions also mainly at the level of the main arteries; mainly carotid arteries. When the latter are denervated, vertebral arteries are unable to prevent a significant increase in blood flow in the villous circle in case of an increase in systemic BP. As for the role of smooth muscle elements in the active change of the vascular lumen, the degree of myogenic component manifestation in cerebral blood flow is estimated by researchers ambiguously. A smaller number of them are in favor of the dominance of the myogenic component in the regulation of vascular tone. It is considered that the realization of stretching and contraction of vascular smooth muscles in response to changes in intravascular pressure is insufficient and unimportant in the regulation of cerebral blood flow, in which humoral and nervous factors are of primary importance. Muscular compartments of cerebral arteries in physiologic limits are not kept in a state of expansion from changes in intravascular pressure, because they are able to give only a short-term response to sudden stretching, which is not observed in the norm. However, in pathological conditions, when there is a disturbance of innervation of carotid arteries, the increased role of miogenic component of vascular reaction in the brain becomes the most likely, especially in patients with weakened autonomic reactions.

Endothelium plays an important role in the regulation of vascular lumen. One of the important effects of endothelial dysfunction is the increased sensitivity of arterial wall receptors to vasoconstrictors or physical factors causing vasoconstriction [11].

Rheoncephalographic study of hemispheric blood flow under emotional stress allowed us to make sure of extremely high rate of change in the character of vascular tone and blood flow of the brain depending on the level of productivity of mental activity not only in healthy people, but also in patients with arterial hypertension (AH). The presence of the disease imposes certain regularities on the manifestation of vascular responses, and among patients with AH cerebral blood supply largely depends on the state of vascular regulation mechanisms. The use of REG in clinical and experimental practice allows to capture rapid not only interhemispheric, but also regional hemodynamic changes.

Rheoencephalography (REG) is a method of assessing the functional state of cerebral vessels, based on the registration of changes in the electrical resistance (impedance) of tissues and is caused by pulse vascular oscillations [14].

The use of frontomastoidal (hemispheric) REG leads in the study of cerebral hemocirculation under emotional stress allows us to focus primarily on the features of regulation of carotid artery tone because of the rapid dynamics of changes in systemic BP. Even just visual assessment and calculation of rheographic curve amplitude provide quite convincing data on the nature of mental activity and the degree of emotional stress on cerebral blood flow and possible mechanisms of its changes.

Analysis of REG in healthy people during verbal counting under conditions of emotional tension has very dynamic changes in the shape of rheographic waves from the beginning of the working period to its end. In the initial state, the REG is predominantly waves with steeply ascending anacrotic part, pointed or slightly rounded apex, well-defined dicrotic dentition located at the level of the middle or upper third of the catacrota, shallow incisura. In a smaller number of cases, the apexes of REG are rounded or bifurcated. During emotional load the shape of the RER apex does not change significantly in contrast to patients with AH. Only its slight smoothing or rounding is noted. Changes in cerebral hemocirculation during visual evaluation of REG are manifested mainly in the shift of the dicrotic spike level without a significant change in its shape. A distinct shift of the dicrotic dentition to the lower third, in some people up to the base of the wave, can be regarded as an adequate decrease in vascular tone during the period of the tentative reaction. By the middle of the working period, the level of the dentition rose to the top, the dentition itself tended to smoothing, which, in the presence of almost unchanged amplitude of REG, may indicate a decrease in venous outflow, manifested, perhaps, as a consequence of changes in the character and rhythm of breathing, reaching by this time the greatest shifts. By the end of the working period, the level of the dicrotic dentition was established at the initial level, remaining the same in the recovery period. Thus, the change in the form of hemispheric REG in healthy people under conditions of emotional stress is quite dynamic, characterized by rapid recovery and indicates well expressed compensatory-adaptive mechanisms of cerebral hemocirculation. Unfortunately, frontomastoidal REG leads do not provide an opportunity to assess changes in regional blood flow in the involved functional areas of the brain (frontal and sensomotorial), while radioisotope studies allow us to detect blood flow enhancement in them during activation of mental activity. However, this not reduce the importance of REG in the study of the influence of emotional load, since comparison of the reaction of healthy people with patients with AH in this situation reveals more severe disorders of cerebral hemocirculation, associated mainly with blood flow through the internal carotid arteries. Under physiological conditions, an increase in functional or metabolic activity in some brain regions is accompanied by a decrease in the activity of surrounding regions, so that the total oxygen saturation of the brain and, consequently, its blood supply remain constant.Since AH is an important factor in the reduction of local cerebral blood flow. Normalization of systemic AP level, even in the case of adequate control of AH using different classes of antihypertensive drugs, is not able to ensure the proper level of cerebral perfusion and preservation of brain tissue volume [9]. In this regard, the total quantitative changes of blood flow in the brain correlate mainly with disturbances in the systemic hemocirculation, the detection of which is necessary for adequate therapy of patients with AH. Thus, in patients with AH, characteristic changes in the REG form are changes in the pattern of its apex, indicating an increase in vascular tone and the level of displacement of the dicrotic onde. Due to the discrepancy between clinical and functional diagnostic data, it becomes insufficient to establish only the fact of decreased or increased vascular tone and changes in cerebral blood flow. It becomes possible to use REG to identify mechanisms determining vascular tone in order to find ways of correction in case of their violation. To date, quite complex, highly labile mechanisms of vascular regulation in such pathologies as AH, migraine, atherosclerosis have been studied [8]. The degree of blood filling of cerebral vessels largely depends on the ability of vessels to active constriction or dilatation in response to external factors. Therefore, it may not always be reasonable to consider the fact of cerebral vascular tone increase in patients with AH at early stages of the disease as a negative effect, if this phenomenon is accompanied by an increase in cardiac output and BP, which may be aimed at maintaining phenomenon is accompanied by an increase in cardiac output and BP. Rather angiospasm is pathologic, leading to a decrease in cerebral blood flow velocity in a part of patients in the early stages of AH. Accession of atherosclerotic vascular changes in AH sharply impairs the ability to adequate regulation, resulting in a clearly linear relationship between cerebral blood perfusion and changes in cardiac output, more often in the downward direction.

Quantitative changes of REG allow to estimate more accurately the dynamics of changes in blood flow rate and to find out possible mechanisms of regulation of cerebral vascular tone in given conditions mental activity [15]. The index determining the rate of arterial vessels dilation and, therefore, testifying mainly of to the changes in vascular tone plays a great role here. Its fluctuations are influenced by the elasticity of the vascular wall, the degree of its elasticity, cardiac output, blood flow rate.

Thus, it is impossible to ignore changes in cardiac activity and activity of vascular reactions. As AH progresses, the elasticity index of arterial vessels does not decrease.

The rheoencephalographic index (RI), an index indicating the value of cerebral blood flow, also depends on a large number of factors - stroke volume, changes in blood flow rate, peripheral resistance, blood viscosity, elasticity of the vascular wall and other reasons. Therefore, static determination of RI (at rest) can give, unfortunately, only an indirect idea of the state of cerebral blood flow, not taking into account the tendency to increase or decrease cerebral blood flow in patients with AlH depending on the stage of the disease, which is associated with differences in individual mechanisms of cerebral blood flow regulation. Multiphase in the development of AH at different stages of the pathogenesis of hypertensive or depressor links don't give the opportunity to assess REG indicators as something stable. That is why various functional tests, in particular with the creation of emotional tension, which allow to observe shifts in the change of cerebral blood flow conditions, become invaluable. However, it is RI that carries clear statistically reliable differences in healthy individuals and patients with AH at baseline and has no reliable differences at the peak of psychoemotional load. It can be noted that a decisive factor in assessing the compliance of brain hemodynamic shifts may be an initially low cerebral blood flow that doesn't meet the brain's needs for mental activity, such as in hypertensive patients.

This means that in half of AH patients negative emotions arising during mental activity cause unfavorable changes in cerebral blood supply, caused not only by weakening of intracranial vessels regulation, but also by interference of external factors, in particular by changes in heart activity, one of the reasons for high vascular resistance in cerebral vessels during mental activity is a local increase in blood viscosity. Extreme lability of these processes observed in patients with AH during the period of performance of a relatively short time load is determined only by the initial state of hemodynamics due to the predominance of cardiac output or peripheral resistance in patients with AH becomes insufficient.

It is also necessary to know the change in the ratios of these factors. This conclusion becomes important because the measures directed against hypertensive reaction depending on individual features of vascular manifestations to negative emotions should include differentiated effects on vascular tone or cardiac activity.

At seeming similarity of hemodynamics in the brain of healttry and patients with AH, there are also fundamental differences. In the former, brain activity is supported by the active reaction of cerebral vessels, while in the latter the level of blood filling of intracranial vessels largely depends on intravascular pressure. Moreover, the intensity of cardiac output decrease was directly proportional to the intensity of cerebral blood flow decrease.

It should be noted that insufficiency of cerebral blood supply can develop not only in such pathology as atherosclerosis, hypertensive disease, etc., but also in healthy people under stressful mental activity, emotional excitement, especially in conditions of hypodynamic lifestyle. Exbaustion of reserves of active vasoconstriction and dilatation leads to deepening of cerebral ischemia, which in tum reflexively changes heart activity [3]. Cerebral blood flow is no longer able to be maintained by vascular regulation and remains at the same level only due to increased cardiac output and increased BP, as well as the change of autoregulatory type of cerebral blood supply to the systemic-circulatory type. Less intensive production of catecholamines in such patients disturbs the processes of their utilization, adequacy of cardiovascular system reactions, leading to paradoxical reactions, when in response to the presentation of increased load the external work of the heart decreases [1,2]. Moreover, the correlation of these indices with RI suggests that in healthy people the processes of compensation of cerebral blood supply are sufficiently provided by myogenic component with active vasodilation. In this connection excessively sharp increase of cardiac output causes proportional increase of cerebral blood flow intensity. Even a small increase in cardiac output is accompanied by an increase in cerebral blood flow. However, this reaction is accompanied by different changes in vascular tone. In one case, the tone is significantly increased, preventing excessive blood flow into the cranial cavity. In the other case, the tone is unchanged, as well as blood flow. This kind of reaction is physiologically justified, as it contributes to a greater blood supply to the brain at its initially low value. Headaches occurring in this case, are unstable in localization (in the temporal, frontal or occipital regions) or non-localized character in the form of a feeling of bloating, heaviness in the head. They are often accompanied by insomnia. More often the appearance of pains is associated with fatigue after any kind of work, in some patients with AH they acquire the character of squeezing "hoop" and pressing pains with the greatest intensity in temporal and occipital regions. In contrast to other groups of patients here headaches were accompanied by a sensation of heavy pulsation in the occipital region, accompanied by a feeling of staggering, shroud before the eyes, dizziness, noise in the head. AH patients are characterized by: marked irritability, a sense of unmotivated longing, fear, sleep disturbance. Hypertensive crises in them are predominantly cerebral variant. Passive vascular reactions to changes in cardiac output, observed in the group, are the main mechanism of headache pathogenesis, as the weakening of vasoconstriction leads to an increase in intracapillary pressure. The consequence of this increase is the development of chronic interstitial cerebral edema, which in turn weakens metabolic processes in brain tissue [4-7]. Quickly arising fluctuations of blood pressure, characteristic for emotional tension, lead to failure of autoregulatory processes with loss of stability of vascular tone. Fall of intravascular pressure in this case leads to a decrease in tonic tension of intracranial arterial walls, which cannot but resist the suddenly increased arterial pressure.

Having analyzed studies, cerebral blood flow in patients with chronic cerebral insufficiency by radioisotope method, it was noticed that in normotensive patient's regional blood flow was lower than in hypertensive patients, whereas in healthy people it remained constant regardless of fluctuations in total pressure. Reaching a certain upper limit of arterial pressure in the presence of disruption of active changes in cerebral vascular tone, leading to aggravation of plasma transudation through the capillary wall, is the basis of vascular dysregulation. One of the compensatory mechanisms of cerebral blood supply in AH is overestimation of the lower level of blood pressure, which reduces cerebral blood flow. The limits of pressure fluctuations, within which autoregulatory processes are not necessarily involved, are considered to be 60-160 mm Hg, for healthy people - 100-130 mm Hg. Insufficiency of compensatory increase in vascular tone at intravascular pressure increase leads to venous outflow obstruction.

The study of rheoencephalographic changes in the research under conditions of emotional stress and the nature of these changes underline the importance of arterial intracranial vessel insolvency as one of the main causes of overload of the venous section of the cerebral circulatory system. It follows that in hypertensive crises headaches are more often and greater extent due to disturbances in the venous system of the brain than in the arterial system. Only a well-coordinated system of cerebral blood flow regulation, provided not only by metabolic, humoral, but primarily by nervous factors, can maintain adequate cerebral blood flow.

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