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Improvement of cerebral circulation with the help of mouth guards (orthodontic appliances)

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Abstract. This study was conducted to determine the effectiveness of orthodontic appliances in improving cerebral circulation. The 24 participants of the study underwent a rheoencephalographic examination before and during the use of mouth guards. Its results analysed the changes in blood filling and blood flow in the brain vessels and evaluated the dynamics of treatment. According to the results of the study, insignificant, and slight positive treatment dynamics were detected in 58.33% of the subjects, no negative dynamics were detected, and no significant changes were recorded in 41.67% of the participants. This effect of orthodontic appliances on improving cerebral circulation is explained by the fact that by alleviating the symptoms of craniomandibular dysfunction, they affect the balance of the centre of gravity of the skull, reduce tension and spasm in the neck muscles, and protect the joints from mechanical irritation, which helps to reduce vascular tone and improves blood filling and blood flow in the masticatory muscles and jaw joint. The blood filling of the chewing muscles and jaw joint has no direct connection with the blood filling of the brain vessels, as these structures are supplied from different arteries, However, a decrease in vascular tone in the craniomandibular system and in the muscle bed of the cervical spine can affect blood pressure reduction and venous outflow in the jaw joint, which will indirectly improve cerebral circulation. The obtained results indicate that orthodontic problems can be factors of deterioration of blood filling and blood flow in the vessels of the brain, so the use of mouth guards is an effective method that should be used in the complex treatment of patients with cerebral circulation disorders

Keywords: craniomandibular dysfunction; masticatory muscles; jaw joint; blood pressure; venous outflow; carotid basins

INTRODUCTION

There are two main reasons for the importance of finding alternative approaches to improve cerebral circulation: the high prevalence of stroke, dementia, Alzheimer's disease, and other neurodegenerative diseases that affect the blood supply to the brain and the limited availability of existing treatments that are not always effective or have side

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effects. The potential advantages of using orthodontic appliances (mouth guards) to improve cerebral blood flow are the absence of side effects typical of traditional therapeutic methods and the possibility of improving cerebral circulation by reducing vascular tone due to the redistribution of masticatory pressure. To evaluate the potential of this method, it is important to conduct research to determine the biological mechanism of mouthguards' impact on improving cerebral circulation and to determine the level of their effectiveness and safety. As with any research related to the effectiveness of new therapies, there are a number of significant problems with studying the feasibility of using mouthguards to improve cerebral circulation. The first is the lack of scientific evidence on the effectiveness of their use in this area.

The few works related to this topic are mainly focused on identifying the correlation between the occlusal balance achieved with the help of certain orthodontic devices and certain indicators of brain functioning measured by instrumental methods. A study of the modification of cognitive functions caused by a functional orthodontic device was conducted by F. Pachì *et al*. [1]. Their results were based on observations of the electrical activity of the brain of 10 subjects. Cognitive functions, stress, arousal, and concentration were chosen as qualitative indicators for comparison, which, according to the results of observations, had significant differences between the three phases of the study (initial occlusion, occlusion changed by a functional orthodontic device and occlusion after removal of the device).

G. Sadvandi *et al*. [2] conducted a systematic review of the effect of experimental orthodontic tooth displacement on brain activation assessed by functional magnetic resonance imaging. The results showed that patients who used orthodontic separators experienced changes in the activation of brain areas associated with nociception, emotion, and cognitive functions.

Based on the observations of C. Kariya *et al*. [3], it was determined how the process of chewing, depending on the bite, affects cerebral blood flow. They analysed the cerebral blood flow measured by functional near-infrared spectroscopy during chewing. The results showed a correlation between jaw movement and cerebral blood flow, indicating an adverse effect of an anterior open bite on brain function. Despite the fact that all studies provide evidence of a correlation between dental occlusion and brain function, the limited size of their samples does not allow for definitive conclusions about the effectiveness of the method of improving cerebral blood flow through the impact on the bite.

Another problem with the study is the lack of understanding of the biological mechanisms by which orthodontic structures could affect cerebral circulation. P. Proff *et al*. [4] studied local vascularization during orthodontic tooth movement in a rat model. Using magnetic resonance imaging, the authors analysed the effect of orthodontic tooth movement on blood flow in the surrounding tissues and confirmed the hypothesis of increased perfusion in the areas of periodontal ligament tension during orthodontic tooth movement, but the relationship between local vascularization and cerebral blood flow was not established.

The relationship between the immune system and orthodontic tooth movement based on cellular and molecular mechanisms was analysed by Y. Gao *et al*. [5]. They investigated the mechanism of interaction of bone and soft tissue remodelling, cement resorption, orthodontic pain and relapse with immune cells and immunological active substance. And the interaction of cytokines in orthodontics was studied by F. Inchingolo *et al*. [6]. The results revealed the influence of cytokines on the cellular activity and metabolism of bone and soft tissue of the tooth through inflammatory processes and processes occurring due to tension and compression in the periodontal ligament. Although the activity of the immune system is related to the blood circulation process, the mechanisms of influence of orthodontic tooth movement on cerebral circulation have not been established in the above works.

An important problem of the study is the possibility of risks for patients using orthodontic constructions. I. Kumar *et al*. [7] emphasized the possible risk of orthodontic procedures for patients with cardiovascular diseases and blood coagulation disorders. G. Gökçe [8] identified allergic reactions and chronic fatigue syndrome among the side effects associated with orthodontic treatment. The risks that may affect cerebral circulation were not considered in these studies.

An additional problem may be created by the lack of a clear understanding of gender and age differences that may affect the results of using orthodontic appliances. When studying the impact of malocclusion on improving patients' oral health-related quality of life in adolescents, L. Schwarz *et al*. [9] found that the initial type of malocclusion has an impact on this indicator, while the gender and age of children do not correlate with it. Given that the participants of the study were adolescents, it was not possible to determine the differences in the impact of orthodontic treatment in different age groups based on its results.

Studying the relationship between the impact on oral health and personality profiles among orthodontic patients, A.A. Al. Nazeh *et al*. [10] determined that the impact of orthodontic treatment on oral health differs depending on the patient's gender. The results of the study were obtained in accordance with the methodology for assessing the profile of impact on oral health, which did not include determining the impact of orthodontic treatment on cerebral circulation or other indicators of brain function, so in the context of the tasks of this work, their use is incorrect.

The purpose of the study was to determine the effectiveness of the use of mouth guards to improve cerebral circulation. Its tasks were to conduct rheoencephalographic studies with a sample of patients, assess the dynamics of treatment and establish the biological mechanisms of the effect of orthodontic appliances on changes in cerebral circulation.

MATERIALS AND METHODS

To determine the effectiveness of using REHASPLINT mouthguards to improve cerebral circulation, rheoencephalographic studies of patients were conducted at the Kyiv Regional Mental Health Centre, a municipal non-profit enterprise of the Kyiv Regional Council, in Vorzel, from 1 to 29 March 2023. The instrumental examination was carried out using a digital rheoencephalograph, which recorded changes in the electrical resistance of the head tissues using sensors and provided the results in the form of graphs and tables. The patients were examined in a standard position. It assessed blood flow velocity and volume, vascular tone and vascular resistance. The study group consisted of 24 men with an average age of 28.5 years. The inclusion criteria were met by participants who had cerebrovascular disorders and needed to use orthodontic appliances (mouth guards) to solve orthodontic problems of varying severity or to protect the jaw during active or vigorous activity. The exclusion criteria excluded people under the age of 18 and those with contraindications to rheoencephalographic examinations: head injuries with damage to the skull bones, intracranial haemorrhages, acute infectious brain diseases, mental disorders, neurological disorders, epilepsy, severe cardiovascular diseases and hypertension. The study was conducted in accordance with the ethical standards that must be met in research involving human subjects, as outlined in the Declaration of the Helsinki Group of the World Medical Association [11]. All participants provided informed consent to participate in the study.

In accordance with the recommendations for the use of REHASPLINT orthodontic appliances, during the month of the study, the participants wore the aligners for 30 minutes 2-3 times during the day and throughout the night. They did not eat, drink or talk while wearing the aligners.

The first rheoencephalograph measurements were taken before wearing the mouthguard, and the second during the wearing. Significant changes in cerebral circulation indices were determined by the difference in blood filling in the basin of the superior middle artery (SMA), vascular tone in the SMA, tone of the main arteries in the SMA, tone of the resistance arteries in the SMA between the two measurements. Their determination was based on the relationship between the average blood flow velocity in the frontal lobe of the brain (FMs), the average blood flow depth in the frontal lobe of the brain (FMd), the average blood flow velocity in the parieto-occipital region of the brain (CMs), average blood flow depth in the parieto-occipital region of the brain (CMd) and vascular resistance (Oa), an indicator of low-frequency blood flow fluctuations associated with vasomotor activity (α1), an indicator of medium-frequency blood flow fluctuations associated with respiration (α2), an indicator of high-frequency blood flow fluctuations associated with the pulse wave (β), the volume of blood passing through the brain vessels per unit of time (Vo), an indicator of the ratio between blood flow volume and vascular resistance (R1), blood flow velocity in the brain capillaries (MKi), blood flow volume in the brain capillaries (MKd), the ratio between the frequency and duration of blood flow fluctuations (α/T), and the biological age of the vessels (BCA). Based on the analysis of the dynamics of treatment of each of the studied patients, the effectiveness of using REHASPLINT orthodontic appliances to improve cerebral circulation was determined. The method of descriptive statistics was used to process the data.

The biological mechanisms by which orthodontic appliances can affect cerebral circulation were determined based on the results of rheoencephalography and analysis of scientific sources in the relevant field. The sources were searched for in PubMed, Web of Science, Google Scholar and Scopus databases using the following keywords: "biological mechanisms associated with the occlusion process", "relationship between occlusion and cerebral circulation", "the effect of orthodontic structures on cerebral circulation", "relationship between occlusion and cerebral blood vessels", "the relationship between dental occlusion and vascular tone", "negative effects of malocclusion", "the impact of orthodontic structures on biological processes associated with the brain", "factors affecting cerebral circulation". The inclusion criteria were papers that contained relevant information on the subject of the study (theoretical studies related to the mechanisms of orthodontic pathologies, results of cerebral circulation measurements, assessment of cognitive function, assessment of quality of life, etc.), and the exclusion criteria were papers published before 2010.

RESULTS

According to the results of the rheoencephalographic examination, all the examined patients had cerebrovascular disorders of varying severity. A descriptive analysis of the examination results before and during the use of the orthodontic appliance (mouthguard) is given in Table 1.

Table 1. Analysis of the results of rheoencephalographic examination of patients before and during the use of orthodontic structures (caps)

Patient number	Data based on measurements before using caps			Assessment of the impact of orthodontic structures on cerebral blood circulation (assessment of treatment dynamics)
	Type of cerebral circulation disorder	Localization	The factor	
1	Slight violation of venous blood flow	Mostly in the carotid pools	Hypovolaemia	No significant dynamics were found
2	Violation of blood supply	From the right sides of the VBP and carotid basins	Increase in vascular tone	A slight positive trend is observed in terms of compensation of the left sections of the VBP and carotid basins at the expense of the right sections. A slight violation of blood supply on both sides persists
3	Violation of blood supply	In carotid basins from 2 sides	Increase in vascular tone	No significant dynamics were found
4	Violation of venous outflow	In VBP from 2 sides	Increase in vascular tone in the carotid basins from 2 sides	There remains a slight violation of venous outflow compared to previous examinations, positive dynamics were noted

Table 1. Continued

Patient number	Data based on measurements before using caps			Assessment of the impact of orthodontic structures on cerebral blood circulation (assessment of treatment dynamics)
	Type of cerebral circulation disorder	Localization	The factor	
5	Decreased blood supply	In VBP and carotid basins from 2 sides	Spasm of blood vessels	There is a slight improvement in the blood supply in the VBP and carotid basins on the right side
6	Marked violation of venous outflow	In VBP from 2 sides	Hypovolaemia and increased tone of blood vessels in VBP from 2 sides	Venous stasis remains. A positive trend is observed in the reduction of vascular tone on the left side of the left ventricle
7	Violation of blood supply	In VBP and carotid basins from 2 sides	Increase in vascular tone	No dynamics detected
8	Violation of blood supply	In VBP from 2 sides	Slight increase in blood vessel tone in VBP	A slight positive trend is observed in the reduction of vascular spasm in the VBP
9	A slight decrease in blood flow	In the VBP from 2 sides (on the left side of the pool, a decrease in blood supply is observed to a greater extent)	Spasm of blood vessels	On the right side of the VBP, the blood supply has recovered, on the left – it remains at the same level, but positive dynamics are observed.
10	Violation of venous outflow	In carotid basins from 2 sides	Increase in vascular tone	There is a slight improvement in blood filling in the VBP, venous stasis in the carotid basins remains at the same level
	Violation of blood supply	In VBP, it is directly proportional from 2 sides		
11	Violation of venous outflow	In VBP and carotid basins from 2 sides. Violation of venous outflow is greatest in the carotid artery	Hypovolaemia	There is normalization of vascular tone in the carotid basins from 2 sides and improvement of venous outflow, especially in the carotid basins
12	Violation of blood supply	In VBP and carotid basins from 2 sides	Increase in vascular tone	There is a slight improvement in blood flow in the carotid basins
13	Violation of blood supply	In VBP from 2 sides	Increase in vascular tone	There is a slight improvement in blood supply, but its deficiency still persists
14	Significant violation of blood supply	In VBP and carotid basins from 2 sides	Increase in vascular tone	There is a slight improvement in blood flow in the carotid basins
	Violation of venous outflow	It is present in all pools, but is most pronounced in the carotid		
15	Violation of venous outflow	In the carotid basins on both sides (mostly observed on the left side)	Hypovolaemia	Positive dynamics were noted due to partial compensation by the right carotid basin of the violation of venous outflow in the left basin
16	Significant violation of blood supply	In carotid basins from 2 sides	Increase in vascular tone	Sjight dynamics are observed, but the increased tone of blood vessels still remains
17	Slight violation of venous outflow	In VBP and carotid basins from 2 sides	Increase in vascular tone	Indicators of blood filling are within normal limits – the volume of blood in the vessels of the brain has normalised; venous outflow has improved, but its disturbances are still observed, which are insignificant and can be considered as a variant of the norm for a specific patient
18	Violation of blood supply	In VBP and carotid basins from 2 sides	Increase in vascular tone	No significant dynamics were found
19	Slight violation of blood supply	In carotid basins from 2 sides	Hypovolaemia	No significant dynamics were found
20	Violation of venous outflow	In VBP from 2 sides	Increase in vascular tone	No significant dynamics were found

Table 1. Continued

Patient number	Data based on measurements before using caps			Assessment of the impact of orthodontic structures on cerebral blood circulation (assessment of treatment dynamics)
	Type of cerebral circulation disorder	Localization	The factor	
21	Violation of blood supply	In VBP and carotid basins from 2 sides	Increase in vascular tone	No significant dynamics were found
22	Slight violation of venous outflow	In VBP from 2 sides	Hypovolaemia	No significant dynamics were found
23	Violation of blood supply	In carotid basins from 2 sides	Increase in vascular tone	No significant dynamics were found
24	Violation of blood supply	In VBP and carotid basins from 2 sides	Increase in vascular tone	No significant dynamics were found

Notes: VBP – vertebrobasilar pool
Source: compiled by the authors

A significant number of patients (13 patients/54.17%) who underwent rheoencephalographic examination, before the use of mouth guards (REHASPLINT orthodontic constructions), had blood filling disorders, two of them had minor disorders, one – significant; in one-third of the study subjects (8 patients/33.33%) had venous outflow disorders, two of which were mild and one severe; two patients (8.33%) had both disorders; one subject had a mild venous blood flow disorder. The main factors influencing these disorders were increased vascular tone and hypovolaemia. The localization of the disorders was determined in the carotid basins and/or the VBP on one or both sides. During the use of the mouthguard, the rheoencephalogram recorded positive dynamics of various intensities associated with improved cerebral circulation in 58.33% of patients, while in 41.67% of subjects, no changes were observed. In most cases, the positive dynamics were insignificant or mild. The dynamics of cerebral circulation improvement separately by different types of disorders are shown in Figures 1 and 2.

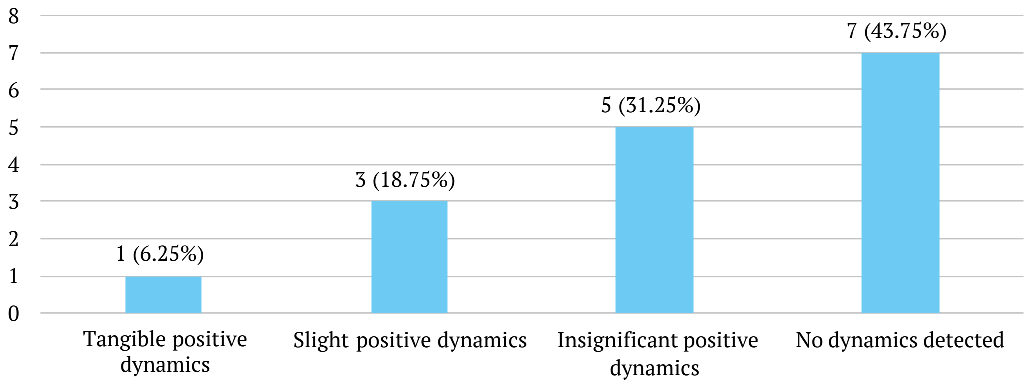

Figure 1. Dynamics of improvement of cerebral circulation in patients with blood filling disorders
Source: compiled by the authors

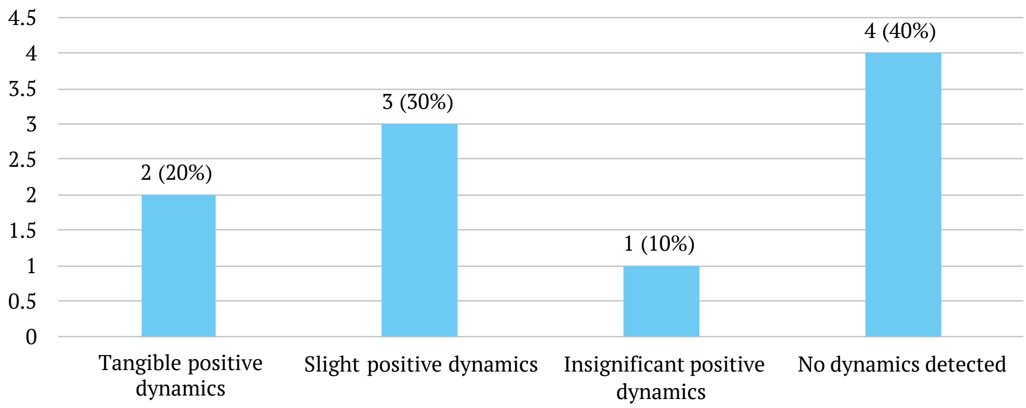

Figure 2. Dynamics of improvement of cerebral circulation in patients with venous blood flow disorders
Source: compiled by the authors

In 56.25% of patients with blood filling disorders, positive dynamics was observed due to the use of orthodontic appliances, in most of them (55.56%) it was insignificant, in one-third (33.33%) it was mild, and in 11.11% it was noticeable. The positive dynamics of the use of aligners in patients with venous outflow disorders was slightly better compared to patients with blood filling disorders (60% vs. 56.25%). Half of them had a mild improvement in outflow, one third had a significant improvement, and 16.67% had a slight improvement.

In none of the cases did the use of mouthguards as a treatment procedure lead to complete elimination of blood filling or venous outflow disorders. The main mechanisms of influence of orthodontic constructions on the positive dynamics in the restoration of normal cerebral circulation were a decrease in vascular tone, reduction of vascular spasm, compensation of blood filling or venous outflow disorders in one of the basins by another.

Analysing the results of rheoencephalographic examination, it is possible to assess the effectiveness and safety of the use of mouth guards (REHASPLINT orthodontic appliances) to improve cerebral circulation. The low level of dynamics of this treatment method indicates low efficiency. Therefore, it is inappropriate to use it for severe cases of cerebral circulation disorders. Instead, it can be effective for minor disorders of blood filling or blood flow or used as an adjunct to traditional treatments, provided that their combination is safe, which should be determined by a doctor. The use of mouth guards in combination with certain physiotherapeutic procedures, such as neck and head massage, may have potential. Given that no negative dynamics of treatment (deterioration of blood filling or blood flow during the use of mouthguards) was recorded in any of the cases, this method can be considered safe for use to improve cerebral circulation.

The development of craniomandibular dysfunction (CMD) involves biological processes associated with the dysfunction of one or more components of the craniomandibular system (CMS). Muscle dysfunction can occur under the influence of bruxism, stress or other factors that can lead to spasm and inflammation of the masticatory muscles, restriction of jaw movement, pain and discomfort, and changes in muscle tone or muscle structure. Joint dysfunctions can be manifested by inflammation of the articular disc, cartilage damage, and changes in the position of the articular head. The consequences of such disorders are pain, clicking, stiffness, restriction of movement, or dislocation of the jaw [12]. Among the neurogenic factors of CMD, the most common are trigeminal nerve dysfunction and changes in the level of neurotransmitters, in particular serotonin and dopamine, effects on nerve endings, and increased activity of the sympathetic nervous system [13].

CMD has several mechanisms of action on blood vessels. Spasms of the masticatory muscles, a common symptom of CMD, can negatively affect blood circulation. Spasmodic masticatory muscles can mechanically compress blood vessels localised in the CMS area, leading to a decrease in blood flow, and prevent venous outflow from the head and neck, causing venous congestion. At the same time, spasms of the masticatory muscles can mechanically compress the nerves, damaging nerve fibres and disrupting the transmission of signals to the blood vessels, which leads to vascular dysfunction and impairs their ability to regulate blood flow. Prolonged pain, as a result of constant spasm of the masticatory muscles, affects the sensitization of nerve endings, developing hypersensitivity to stimuli, which can lead to excessive vasoconstriction in response to minor stimuli, thus exacerbating vasoconstriction [14].

Inflammation of the joints and muscles, which is also common in CMD, can negatively affect blood vessels. It can provoke endothelial damage and the release of chemicals that constrict blood vessels, including endothelin-1 [15]. This process is accompanied by a change in vascular tone and can lead to a violation of their ability to regulate blood flow, increasing vasoconstriction. The inflammation-induced release of vasoactive substances (prostaglandins and leukotrienes), which have the ability to constrict or dilate the vessel, can lead to blood flow instability and impaired blood pressure regulation [16]. Using its own mechanisms of influence on platelets, clotting factors, fibrinogen and the fibrinological system, inflammation can lead to coagulation disorders (increased risk of blood clots) and cause circulatory disorders and damage to inflamed tissues [17, 18].

CMD can have a certain effect on blood vessels through neurogenic factors. The mechanisms of such effects include changes in the activity of the sympathetic nervous system, effects on nerve endings that regulate blood flow, and effects on the central nervous system and the noociceptive system, which is responsible for the perception and processing of pain signals [19]. In most cases, the main factors of influence are spasms or inflammation of the masticatory muscles and joints caused by bruxism, joint deformity or other CMD factors, but additional negative effects are caused by psycho-emotional factors, including stress and anxiety, and medication side effects of certain drugs, such as antidepressants, non-steroidal anti-inflammatory drugs, hormones, etc [20].

The masticatory muscles and jaw joint are supplied with blood from different arteries. The masticatory artery is the largest artery supplying the masticatory muscles, branches from the carotid artery and divides into a deep branch supplying the medial masseter, lateral masseter and temporalis muscles, and a superficial branch supplying the masseter and buccal muscles [21]. The temporalis and buccal muscles are supplied by the parotid artery, and the bicuspid and hyoid muscles by the deep neck artery. The arteries supplying the jaw joint include the superior maxillary artery, which supplies the articular disc and capsule of the jaw joint; the middle meningeal artery, which supplies the articular process of the temporal bone and the articular fossa of the zygomatic bone; and the ascending pharyngeal artery, which supplies the posterior capsule of the jaw joint [22, 23]. Depending on the individual anatomical features, the blood supply to the masticatory muscles and jaw joint may vary, but in most cases, the general blood supply to these components of the CMS corresponds to the described one.

There are several small connections (anastomoses) between the arteries of the CMS and the arteries of the brain, which allow blood to flow in small amounts from one system to the other, but they do not have a significant effect on the blood supply to the brain [24]. The arteries supplying the jaw joint and masticatory muscles do not have a direct connection to the cerebral vessels. They are part of the external carotid artery, which is one of the two main branches of the carotid basin, a network of arteries that supplies blood to the face, neck, and scalp, and the blood supply to the brain is carried out through the internal carotid arteries, which are also part of the carotid basin, and the arteries of the vertebrobasilar system [25].

The effect of decreased blood flow in the masticatory muscles or jaw joint on cerebral circulation deterioration may be exerted by indirect mechanisms. Reduced blood flow in the masticatory artery can be a factor in increasing blood pressure, which can lead to cerebral blood flow deterioration due to reduced perfusion pressure, narrowing of the arteries and a decrease in the volume of blood circulating in the body [26, 27]. Spasm-induced mechanical compression of the vessels passing through the masticatory muscles can lead to a decrease in blood flow to the brain. Damage to nerve fibres caused by muscle spasm or inflammation can lead to disruption of nerve signals and become a factor in reducing the ability of blood vessels to regulate blood flow in the masticatory muscles and jaw joint, which can cause changes in blood pressure. When analysing the mechanisms of the impact of CMD on cerebral circulation, it should be noted that there is no direct connection between the arteries of the CMS and the brain, so impaired blood flow in the masticatory muscles and jaw joint may have a minor impact on cerebral circulation mainly through the impact on blood pressure.

Another reason for the deterioration of blood circulation in CMD is impaired venous outflow. Its main factor is mechanical compression of the veins in the jaw joint, which occurs due to displacement or curvature of the articular disc; spasm of the masticatory muscles; reduction of space in the jaw joint due to changes in the position of the articular head; swelling as a result of inflammation of the jaw joint; formation of cuspid growths caused by degenerative changes associated with arthritis; anatomical features of the structure of the venous canals that affect their width; severe impact or dislocation of the jaw [28]. Impaired venous outflow in the jaw joint area has a direct impact on the outflow of blood from the brain. The deep venous network collects blood from the muscles, bones, and skin of the face, including blood from the jaw joint, and flows into the jugular vein, which draws blood from the head and neck and then flows into the superior vena cava [29]. The submandibular plexus, located under the lower jaw, connects to the deep venous network and other plexuses that drain blood from the brain. Impaired venous outflow in the jaw joint can lead to blood stasis in these plexuses and compression of the jugular vein, which will impede blood flow from the brain and provoke an increase in intracranial pressure, nerve damage, and cerebral circulation [30].

In addition to affecting the blood vessels localised in the CMS, dental occlusion disorders lead to an imbalance in the musculoskeletal system. This occurs due to a shift in the centre of gravity of the skull and loss of support from the dental arches due to changes in the position of the temporomandibular joint. This imbalance leads to an increased load on the neck muscles to hold the head in a new position, which provokes spasms and changes in their tone and causes vertebral displacement. Such a cascade of mechanical processes triggered by a change in the position of the temporomandibular joint causes a change in the biophysics of blood vessels and nerves that are surrounded by the neck muscles. The mechanism of such changes is that under the influence of increased muscle load, the vessels located in the muscle bed of the cervical spine are compressed, resulting in a decrease in their diameter, and, accordingly, a decrease in blood flow and an increase in blood pressure. This leads to a decrease in the volume of blood filling and difficulty in the outflow of blood from the head. The use of orthodontic appliances aimed at fixing the correct position of the jaws allows balancing the centre of gravity of the skull, reducing the load on the neck muscles and eliminating vascular compression, and therefore normalizing haemodynamics – restoring the tone and diameter of blood vessels in accordance with the needs of the body and return blood pressure to the physiological norm.

Thus, by affecting masticatory muscle dysfunction and jaw joint position changes, CMD can be a factor in cerebral circulation deterioration. The use of mouthguards alleviates the symptoms of CMD by reducing muscle tension and spasms, protecting the joints and altering sensory information. Thanks to its shape, the REHASPLINT orthodontic appliance is able to correct the correct position of the lower jaw, thus reducing the load on the masticatory muscles and temporomandibular joint and reducing occlusal pressure, which helps to relax the muscles, reduce spasm and eliminate pain. As a joint protector, the mouthguard creates a cushioning effect by absorbing part of the chewing pressure, which helps protect the articular cartilage and other structures of the jaw joint from damage. At the same time, the smooth surface of the orthodontic appliance reduces friction between the teeth, eliminating the source of discomfort. An important function of the mouthguard is neuroproprioceptive stimulation – it can provide sensory information about the position of the lower jaw, helping to restore the balance of the centre of gravity of the skull, reprogramme muscle activity and reduce spasm and pain. This function is further enhanced by the mouthguard's ability to reduce nociceptive stimulation in the mouth. Having an understanding of the mechanism of the impact of aligners on cerebral circulation, it is possible to analyse the results of a rheoencephalographic study in more detail – to determine what the therapeutic effect of the orthodontic appliance is and why it turned out to be insignificant.

The therapeutic effect of using orthodontic appliances is to relax the masticatory muscles and protect the joints, reduce vascular spasm and tone, and reprogramme muscle activity through sensory information about the position of the lower jaw. These mechanisms have a direct effect on improving blood filling and venous outflow in the CMS area, and an indirect effect on improving blood circulation in the brain.

To analyse the therapeutic effect, it is important to separate cases of impaired blood filling and venous outflow, as they have different mechanisms of influence on cerebral circulation. A slight or mild therapeutic effect was found in subjects who had blood-filling disorders on one or both sides of the VBP and/or carotid basins before the procedure, due to the fact that the arteries supplying the jaw joint and masticatory muscles do not have a direct connection to the cerebral vessels. Although the external carotid artery, which includes the arteries supplying the jaw joint and masticatory muscles, and the internal carotid artery, which supplies the cerebral vessels, branch off from the common carotid artery, they do not have a direct connection to each other. An indirect effect on the blood flow to the brain can be caused by an increase in blood pressure as a result of increased vascular tone in the masticatory muscles or jaw joint. Blood pressure has a significant impact on the blood supply to the entire body. By increasing the strength of heart contractions, it can increase blood filling, and by increasing blood flow resistance and capillary permeability, it can temporarily reduce it [31]. Hypovolaemia can also be a factor in lowering blood pressure, as fluid deficiency leads to a decrease in the volume of blood circulating in the body [32]. Impaired venous outflow in the CMS has a direct impact on the outflow of blood from the brain, as it is carried out through the only way – through the jugular vein.

Summing up the results of the rheoencephalographic study and analysis of the biological mechanisms of the effect of orthodontic appliances on cerebral circulation, it can be noted that the use of mouth guards is an appropriate and effective way to improve cerebral blood flow in cases where its disorders are caused by the effect of CMD symptoms on the vessels of the masticatory muscles and jaw joint.

DISCUSSION

Analysing the results of the study, which revealed the low effectiveness of the impact of mouthguards in improving cerebral circulation, it is worth noting that their primary task is to eliminate orthodontic pathology of moderate or mild severity. The impact of such pathology causes significant local discomfort for the patient, but does not have a significant immediate effect on the body as a whole. However, like any problem without proper attention and treatment, orthodontic dysfunctions can worsen over time and affect other body systems. In this case, by alleviating the symptoms of CMD, aligners improve the blood filling of the vessels of the masticatory muscles and jaw joint, and help to establish venous blood flow in the CMD area. Therefore, their insignificant effect, recorded at a certain moment, can be beneficial in the future, inhibiting the development of negative factors (impaired blood filling and/or venous congestion), which, when aggravated, can cause greater harm to cerebral circulation.

An observational study of the effect of the mandibular resting position on cerebral circulation and physical balance was conducted by T. Heit *et al*. [33]. The researchers' observational study involved 9 participants, seven of whom were healthy male athletes and two were women with multiple sclerosis. Cerebral blood flow was measured while the subjects clenched their teeth on both jaws using transcranial Doppler. The results of the observation showed that the physiological position of the lower jaw at rest can affect the increase in blood flow to the brain. The conclusions of scientists can be compared with the results of this study, as the use of orthodontic appliances is aimed at eliminating certain defects and bringing the jaws closer to their physiological position. Therefore, it is worth agreeing with the results of the authors and noting that for further research on the effect of orthodontic appliances on improving cerebral circulation, it would be advisable to partially use the methodology proposed by Canadian scientists, namely the use of transcranial Doppler to measure cerebral blood flow, given the accuracy and informativeness of the procedure.

The search for a link between dental occlusion and brain activity was conducted by S.S. Ulloa *et al*. [34] in their work. Scientists have found that bite changes can affect the sensorimotor cortex of the brain, so it would be fair to assume that occlusion plays a pivotal role in the development of anxiety and stress and even Alzheimer's disease or senile dementia. The authors emphasise the importance of continuing research in this area to find out how much brain functioning changes, which parts of the brain are affected by malocclusion, and what biological mechanisms contribute to this. Despite the different objectives of the study by S.S. Ulloa *et al*. [34]and the present study, both have a common aspect – confirmation of the influence of jaw position on brain function. To a certain extent, the results of the study confirm the authors' theoretical assumptions, noting that impaired venous outflow can lead to increased intracranial pressure and nerve damage, which can cause many neurological disorders, as well as anxiety and stress.

The impact of tooth loss on cognitive function was studied by P. Galindo-Moreno *et al*. [35]. After analysing data from two US national health surveys based on a total sample of 102,291 people, the researchers found that the number of teeth in the mouth directly affects the cognitive status of a person. At first glance, the work may seem to have little to do with the results of this study, but it also develops the concept of the relationship between occlusion and brain function. Given that the use of the REHA-SPLINT mouthguard can help reduce the pressure on the gums and jaw associated with tooth loss, thus reducing the risk of further tooth loss, it can be assumed that orthodontic appliances have an indirect effect on improving cognitive function.

When evaluating the effectiveness of using mouth guards as a way to improve cerebral circulation, it is important to pay attention to individual patient characteristics such as age, gender, and health status. Children have more pliable skull bones and more elastic blood vessels than adults. Therefore, it is likely that orthodontic appliances will have a greater impact on children's cerebral blood flow. It should be added that children, in most cases, do not have concomitant diseases typical of middle-aged and elderly people, which can be additional factors in orthodontic pathologies and cerebral circulation deterioration.

The difference in the effect of orthodontic structures on cerebral circulation in men and women may be explained by their anatomical differences between the masticatory muscles and the jaw joint. The temporalis muscle, masseter muscle, and medial pterygoid muscle are typically larger in men than in women, which may result in greater chewing force in men. The masticatory muscles in men may have a more pronounced shape than in women. The distribution of muscle fibres in the masticatory muscles may differ between the sexes, thus affecting the nature of their chewing movements. In men, the articular fossa of the temporal bone and the condylar fossa of the mandible are usually larger than in women. The articular fossa of the temporal bone in men is more rounded and the condylar fossa of the mandible is more conical, while in women the articular fossa is more oval and the condylar fossa is more rounded. These differences in the size and shape of the parts of the articular structure may explain the greater mobility of the male jaw. Also, the articular cartilage in men is usually thicker, and the ligaments that hold the jaw joint in place are stronger than in women, which affects the greater resistance of male joints to certain irritations. These anatomical differences indicate that men's jaws are subjected to greater stress due to the force of chewing, which leads to greater compression of blood vessels, but at the same time they are also more resistant to technical stimuli, which reduces the risk of mechanical pressure on the arteries and veins in the occlusion area. Thus, the anatomical difference between the masticatory muscles and the jaw joint in women and men is not likely to have a significant impact on the evaluation of the effectiveness of orthodontic appliances in improving cerebral circulation. Instead, it can be affected by factors that lead to orthodontic pathologies. These include contact sports, facial injuries of varying severity, and other activities that can cause damage to the jaw vessels, which are usually more common in men. The study involved mainly young and middle-aged men, so it was not possible to analyse the effect of orthodontic appliances on cerebral circulation separately between women and men in this case. G. Kummer *et al*. [36] analysed the impact of gender on the results of orthodontic treatment based on an analysis of published studies. According to the authors, only a small proportion of published clinical trials included an assessment of the gender impact on treatment outcomes. In a quarter of those that took into account gender-specific effects, the impact of gender on the effectiveness of orthodontic treatment was reported. It is worth agreeing with the authors' conclusions about the importance of analysing the study groups taking into account not only age or physiological characteristics, but also the gender of the participants.

The effectiveness of the use of caps to improve cerebral circulation is also influenced by the health status of the subjects. Diseases of the cardiovascular system (hypertension, atherosclerosis, coronary heart disease, arrhythmias, heart failure), diabetes mellitus, hypercholesterolaemia, obesity, sleep apnoea, and inactive lifestyle, smoking and alcohol abuse are independent factors of cerebral circulation deterioration, so without a systematic approach to treatment or lifestyle changes, reducing pressure in the vessels of the lower jaw and improving their blood filling and blood flow will not significantly affect cerebral circulation.

In general, orthodontic problems have a significant impact on other body systems. Depending on their complexity, such an impact can manifest itself quickly or, on the contrary, have a cumulative effect. It is worth noting that dental occlusion disorders are often the result of a congenital defect rather than external factors. This problem was analysed by S. Kahn *et al*. [37] in their study. The main problem of the jaw epidemic, as the authors of the article called the problem of dental occlusion, they consider not genetic factors, but, despite the too limited time period for full evolutionary changes. Agreeing with the authors' conclusions, it is important to emphasise that the study of the impact of evolutionary changes on the anatomical features of the jaws is an essential component for understanding the causes and mechanisms of dental occlusion disorders and finding methods to eliminate them, in particular with the help of orthodontic appliances.

In addition to evaluating the effectiveness of mouth guards in improving cerebral circulation, this study has revealed biological mechanisms linking cerebral blood flow and blood flow to the masticatory muscles and jaw joint. Using the connection of such seemingly different structures made it possible to expand the number of methods for influencing the blood filling and blood flow of the brain vessels. Since the way to effective treatment is to take into account and eliminate all possible causes that affect the development of the pathological process, the use of mouth guards in a systemic approach to improving cerebral circulation is an effective and justified means that at the same time meets the principles of personalised medicine.

CONCLUSIONS

Rheoencephalographic studies conducted to determine the effectiveness of the use of mouth guards to improve cerebral circulation revealed a slight and mild positive trend in 58.33% of patients, in 41.67% – no significant changes were recorded, and no negative effects were recorded in any of the 24 subjects. This effect and its intensity are explained by the therapeutic effect of orthodontic appliances, which is to alleviate the symptoms of CMD. These symptoms include muscle dysfunction, which leads to spasms and inflammation of the masticatory muscles, changes in muscle tone, muscle structure, and restriction of jaw movement; joint dysfunction, which causes inflammation of the articular disc, cartilage damage, and changes in the position of the articular head. Spasms and inflammation of the masticatory muscles and jaw joint as factors of mechanical compression of blood vessels and nerves in the CMS area lead to changes in vascular tone and impaired blood flow regulation (decreased blood filling in this area and impaired venous outflow). Reduced blood filling in the vessels of the masticatory muscles and jaw joint does not have a direct impact on changes in the cerebral circulation, as these structures are supplied through various arteries of the carotid basin, but it can affect the increase in blood pressure, reducing the total volume of circulating blood and thus worsening the blood filling in the brain vessels. Disruption of venous outflow in the jaw joint has a direct impact on the same process in the brain, as it is carried out through the only way – through the jugular vein. The effect of orthodontic appliances (aligners) on improving cerebral circulation is achieved by restoring the balance of the centre of gravity of the skull, reducing muscle tension, spasms and joint protection, which leads to a decrease in vascular tone and improved blood circulation in the masticatory muscles and jaw joint.

The effectiveness of orthodontic appliances in improving cerebral blood flow and blood flow makes it possible to recommend their use in a systemic approach to the treatment of patients with cerebral circulatory disorders requiring orthodontic treatment. The limitation of the study was the insufficient gender and age representativeness of the sample. Therefore, to extend the results obtained, the main direction of further research may be to analyse the effectiveness of orthodontic appliances in improving cerebral circulation, taking into account gender and age anatomical differences in patients.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Покращення мозкового кровообігу за допомогою кап (ортодонтичних апаратів)

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Анотація. Дана робота була проведена з метою визначення ефективності впливу ортодонтичних апаратів на покращення кровообігу головного мозку. 24-ом учасникам дослідження було проведено реоенцефалографічне обстеження до та під час використання кап. За його результатами аналізувалися зміни кровонаповнення та крововідтоку в судинах головного мозку та оцінювалась динаміка лікування. За результатами досліджень незначна та легка позитивна динаміка лікування була виявлена в 58,33 % досліджуваних, негативної динаміки виявлено не було, в 41,67 % учасників суттєвих змін не зафіксовано. Такий ефект ортодонтичних апаратів на покращення церебрального кровообігу пояснюється тим, що, полегшуючи симптоми краніомандибулярної дисфункції, вони впливають на збалансування центру ваги черепа, зменшення напруги та спазму в м'язах шиї, а також забезпечення захисту суглобів від механічних подразнень, що сприяє зниженню тонусу судин та покращує кровонаповнення та крововідтік в жувальних м'язах та щелепному суглобі. Кровонаповнення жувальних м'язів та щелепного суглоба не має прямого зв'язку з кровонаповненням судин головного мозку, так як дані структури живляться з різних артерій, проте зниження тонусу судин в області краніомандибулярної системи та в м'язовому ложі шийного відділу хребта здатне впливати на зниження артеріального тиску та налагодження венозного відтоку в щелепному суглобі, що опосередковано впливатиме на покращення церебрального кровообігу. Отримані результати вказують на те, що ортодонтичні проблеми можуть бути чинниками погіршення кровонаповнення та крововідтоку в судинах головного мозку, тому використання кап є ефективним методом, який доцільно використовувати в комплексному лікуванні пацієнтів з порушеннями церебрального кровообігу

Ключові слова: краніомандибулярна дисфункція; жувальні м'язи; щелепний суглоб; артеріальний тиск; венозний відтік; каротидні басейни