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Hemorrhagic Stroke in the Context of Anatomical Variations in the Circle of Willis - A Perspective on Neurological Rehabilitation

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Abstract

The pathology of stroke, either ischemic or hemorrhagic, with a growing incidence in the recent years, associates a long period of hospitalization, functional disabilities and an increased risk of death. There are mentioned in several studies correlations between variants at the level of the Anterior Communicating Artery (ACoA), the Posterior Communicating Arteries (PCoA), the Anterior Cerebral Arteries (ACA) and the Posterior Cerebral Arteries (PCA) and hemorrhagic stroke. In the case of a damaged area in the brain, it becomes important to make the missing connections with the non-affected areas. The left part of the brain controls speech. In stroke patients, when the left part of the brain is damaged, the right side takes over its function. The neurological rehabilitation in cases of stroke, either ischemic or hemorrhagic, requires long-term therapy, referring to physiotherapy associated with occupational therapy and psychotherapy, as well, besides the drug therapy and surgical interventions.

Keywords: Anterior communicating artery; Posterior communicating arteries; Anterior cerebral arteries; Posterior cerebral arteries; Neurological rehabilitation; Hemorrhagic stroke

Introduction

The pathology of stroke, either ischemic or hemorrhagic, with a growing incidence in the recent years, associates a long period of hospitalization, functional disabilities and an increased risk of death. In the current literature, there are relatively few studies that analyse the impact of anatomical variants of the circle of Willis (CoW) in the formation and evolution of hemorrhagic stroke, in the context of neurological rehabilitation. However, there are mentioned in several studies correlations between variants at the level of the Anterior Communicating Artery (ACoA), the Posterior Communicating Arteries (PCoA), the Anterior Cerebral Arteries (ACA) and the Posterior Cerebral Arteries (PCA) and hemorrhagic stroke. In the case of a damaged area in the brain, it becomes important to make the missing connections with the non-affected areas [1].

The left part of the brain controls speech. In stroke patients, when the left part of the brain is damaged, the right side takes over its function. The neurological rehabilitation in cases of stroke, either ischemic or hemorrhagic, requires long-term therapy, referring to physiotherapy associated with occupational therapy and psychotherapy, as well, besides the drug therapy and surgical interventions. Among the most common manifestations after a stroke episode are: motor disfunction regarding both upper and lower limbs, visual impairement and loss of memory and cognition of different degrees, depending on the affected areas in the brain. Neuroplasticity, as the adaptation of neurological cells in terms of functionability after a stroke event, becomes crucial in the healing process. In cases of motor impairement, the majority of patients become able to walk after neurorehabilitation, but there are needed multiple therapy sessions, the dose and the frequency of rehabilitation being important. Though, improving the walking function usually takes a shorter period of time than speech improvement, because the affected area of the brain responsible for speech function recovers more slowly. On the other hand, the therapeutical effects are rather limited in the chronic or subacute cases of stroke [2].

Material and Methods

We conducted an extensive research of the literature in order to identify studies that report the interrelation between anatomical variants in the circle of Willis and hemorrhagic stroke, in the context of neurological rehabilitation. The search was made in Google Scholar, ScienceDirect and PubMed using the following keywords: "hemorrhagic stroke, circle of Willis, variants" and "hemorrhagic stroke, neurological rehabilitation" in order to find up-dated articles on the mentioned topic, in English language only. Out of a total of 100 initially selected abstracts, we took into consideration only a number of 26 scientific articles, published over the last 20 years (2004-2024), that

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we considered to be most relevant for the topic, thus laying the basis for a descriptive literature review.

Results and Discussion

The circle of Willis and its anatomical variations

The CoW has been divided in two different parts: an anterior one, composed of ACoA and A1 precommunicating segments of the two ACAs and a posterior one composed of the P1 precommunicating segments of the two PCAs [3]. There are other Indian authors that consider a "classical" circle of Willis as symmetric bilaterally, in the shape of a "ring" of vessels [4]. Judging after its general external aspect, the circle of Willis can stand out as typical or atypical. The typical aspect of the circle of Willis has been described in several studies as having all its component arteries as well as its communicating segments present and of normal dimensions [5]. In terms of anatomical variations, the most common ones that are recurrently described in the actual literature are as follows: hipoplasia, duplication or triplication, fetal type artery, absence, fenestration.

Hipoplasia refers to a diameter of an artery that is less than 1mm, with the exception of PCoAs and ACoA [4]. Fenestration is the type of anatomical variant described by the presence of two arterial canals for a singular vascular route [6]. Duplication or triplication of an artery refer to the presence of suplimentary arteries. The fetal type artery can be either partial, defined by a PCoA diameter that is less than 1 mm and the P1 segment of the PCA less than 1 mm, or total, when the PCoA diameter is greater than 1 mm and the P1 segment of PCA is missing. The absence is an anatomical variation referring to some arteries that are practically missing from the configuration of the vascular circle[4,6].

Risk factors associated to hemorrhagic stroke formation, in the context of anatomical variants in the circle of Willis

The main cause of stroke development at the level of the CoW is represented by the thrombotic occlusion, secondary to atherosclerosis**.** The most frequent areas of its development is at the bifurcation of PCAs. Principal risk factors for the development of stroke, either ischemic or hemorrhagic, are high blood pressure and atherosclerosis, under the condition of Internal Carotid Artery (ICA) occlusion and bilateral PCoA hipoplasia/aplasia (absence of the vessel lumen) [7]. The hipoplasia of the ipsilateral Vertebral Artery (VA) is an additional risk factor to the presence of PCoA hipoplasia, because it increases the arterial pressure within the controlateral vertebral artery in the case of hypertensive patients. Frontal haematoma can appear in the case of patients presenting unilateral PCoA hipoplasia or aplasia, in the context of an elevation of blood pressure within the carotidian system, due to the fact that blood cannot communicate with the vertebral-basilary system for depressurizing the CoW. The unilateral partial fetal type PCA that has anastomosis with the basilary artery through a very thin arterial branch can determine the formation of a right hemispheric paradoxal infarction, if the patient presents systemic atherosclerosis, complicated with ulcerations and calcifications and high tensional values. After thrombolysis, the blood penetrates the infarction zone and this way the hemorrhagic stroke is produced. Acute pancreatitis can determine a metabolic encephalopathy, but also a fatal intracerebral hematoma [8]. In a study published in 2018, Mukherjee et al. suggests that the presence of anatomical variants in the CoW can lead to a change in the microembolic circulation at the level of the constituent arteries in the circle and can have as effect the development of infarction in some distal areas of the brain, less common [9]. The hipoplasic arteries present a patent lumen, therefor, in the absence of stenosis at the level of big proximal arteries, the communicating arteries do not affect the blood flow volume to the brain, unless there are several risk factors involved such as: hypertension, atherosclerosis, insulin-requiring Type-2 diabetes mellitus, hemorrhagic acute pancreatitis, hepatic cirrhosis or disseminated intravascular coagulation [10]. It is documented in literature that chronically elevated tensional values that lead to a higher risk of cardiovascular pathology have most commonly stress as main trigger [11].

The connexion between anatomical variants in the circle of Willis and hemorrhagic stroke development

The current literature presents just few studies on the variations of the CoW in relation to aneurysmal development and the rupture. Changes in the haemodinamics of a vessel in the CoW, due to anatomical variations, can influence the formation and rupture of such an aneurysm [12], in addition to capillary frailty. A study from 2012, in which there were investigated over 100 patients presenting ACoA and PCoA aneurysms, revealed the fact that the presence of anatomical variants was highly associated with the rupture of intracranial aneurysms [13].

A recent Romanian study, in which there were analized the causes of death in patients with bilateral hipoplasia of the PCoA, concludes that extended stroke could be correlated with this association of variants, especially when it associates a systemic pathology or the occlusion of an important artery assuring the irrigation of the brain [14].

In a Chinese radiology study published in 2019, in which there were analyzed over 200 patients presenting aneurysms at the level of CoW, both univariate and multivariate analysis highlighted the fact that the presence of fetal-type PCoA increased twice the risc of rupture of the aneurysm formed at the ICA-PCoA junction [15].

When fetal-type PCoA is present, it is associated with the presence of a P1 segment of the ACP that is smaller in diameter than the contralateral homologous artery. A hipoplasic VA is associated with a higher risk of atherosclerosis in the posterior circulation and, therefor, there would be a higher incidence of stroke in this region in the case of this type of anatomical variant [16]. In Germany, there has been investigated by Harati et al. the co-occurence of hipoplasia/aplasia/atresia of the VA, the aplasia of the Postero-Inferior Cerebellar Artery (PICA) and the aneurysms formed at the junction between the VA and PICA. The study concluded that VA hipoplasia on one side alone represents a risk factor for aneurysm formation on the opposite side to hipoplasia [17]. In a recent Turkish study there has been mentioned that when co-existing, the fetal-type variant of PCoA and hipoplasia of the A1 segment of ACA imply a higher rate of ACoA aneurysm rupture [18]. Therefor, the concomitant presence of anatomical variants, such as hipoplasia and fetal-type, in both anterior and posterior parts of the CoW imply more often the formation and rupture of aneurysms in the CoW.

In the case of fetal PCA, the controlateral hemispheric cerebral infarction is formatted, the "paradoxal" infarction as it is called in the specialty literature, having as risk factors hypertension and atherosclerosis. From a clinical point of view hipoplasia and aplasia of PCoA are very significant. The hipoplasic or aplasic PCoA can compromite the capacity of the CoW to assure collateral circulation [19]. The clinical significance of anatomical variants is shown especially in the case of an atypical model of stroke. In the context of big arteries occlusion or severe stenosis, the communicating arteries become crucial. In this context, the caliber of communicating arteries is inversely proportional with the risc for stroke development. The smaller this caliber of these arteries is, the smaller the blood flow carriage capacity becomes [20].

It seems that AcoA fenestration represents a predictive risk factor of death for hemorrhagic stroke, because aneurysms can develop at this level. At the same time, the anatomical variants of AcoA, in the form of hypoplasia, fenestration and absence of the vessel, represent a predictive factor of mortality risk for multiple, infra- and supratentorial ischemic strokes.

There are also reports of associations between the presence of anatomical variants of AcoA and the development of aneurysms at the level of the anterior AcoA-ACA complex and their rupture, which often leads to the death of those patients [21].

It appears that hypoplasia of the A1 segment of the ACA in the pediatric population is predominantly associated with headaches and dizziness, which may play a role in the incidence of neurological diseases in later life. The mechanism of these symptoms may be represented by progressive cerebral ischemia [22]. It is documented in literature that neurological symtoms in children usually appear in pathologies that affect the brain, primarly, but, in some cases, it is important to exclude other gastrointestinal disorders such as the caeliac diasease [23].

Neurological rehabilitation and treatment in the case of hemorrhagic stroke patients, in the context of variants in the circle of Willis

Hemorrhagic stroke, in both of its presentations, either as intracerebral hemorrhage (ICH) or subarachnoid hemorrhage (SAH) represents a medical emergency and treatment must be initiated immediately.

Regarding the emergency treatment for hemorrhagic stroke, it must control the bleeding and should diminish the accumulated fluid in the brain, that would act as raised pressure at this level.

After the effectuation of a CT-scan to correctly establish the diagnosis, in the context of symptoms that differ depending on the affected areas in the brain from headache and vomiting (subarachnoid hemorrhage) to seizures, aphasia, hemianopia and sensorimotor deficts, there is usually indicated surgical therapy in order to remove the blood and lower down the brain pressure [24]. This may involve: surgical clipping, coiling or endovascular embolization, surgical removal of arteriovenous malformations (AVM), in case of the presence of an aneurysm as stroke main leading cause or radiosurgery. The drug therapy is usually administered for underlying conditions and pathologies such as hypertension, any possible trigger factor for hemorrhagic stroke development and also for other conditions, considered the effects of stroke such as seizures or raised intracranial pressure. Hemostatic treatment also becomes important to avoid the extension of hematoma [24].

The post-stroke rehabilitation is even more complex than so far mentioned procedures and consists of an inter-pluridisciplinary team of healthcare professionals: a neurologist, a psychiatrist, physiotherapists, occupational therapists, a psychotherapist, a speech therapist, rehabilitation nurses and social workers. The majority of clinical guidelines say that the sooner the intensive rehabilitation is done, the better it is for the patient, in terms of outcome [24]. Usually it takes up to several month to rehabilitate after hemorrhagic stroke, but the period varies in connexion to the affected brain territories, duration and intensity of rehabilitation procedures [25].

The aneurysms of the ACoA are documented to happen most frequently, representing the cause of 40 % of the subarachnoid hemorrhages after aneurismal rupture [26]. Aneurysms located in this arterial region of the CoW are usually related to visual defects, rarely, though, leading to complete loss of vision. ACA strokes on the other hand have a low prevalence in population, but, despite this fact, they cause severe disability such as: motor, cognitive and behavioral disorders [27]. In these latter mentioned cases, there are indicated either upper or lower limbs exercises which can be part of both physiotherapy and occupational therapy and the intervention of a behavioral therapist [27].

In the United States and Australia, there is documented a decrease of neurological rehabilitation outcomes in post-stroke survivors, down to 13% to 31%. In a recent article published in Singapore, there is evidence of very good rehabilitation outcomes in a group of 215 patients, with a fast post-stroke recovery at 12.5 weeks after the event occurred. The study involved a multidisciplinary healthcare team and focused more on the rehabilitation intensity, rather than on its duration and it took into consideration variables such as ethnicity, stroke lesion type, cognitive impairement, recurrent stroke, depression and social support that were concluded to be independent prediction factors in the context of post-stroke recovery. The literature mentiones severity of paralysis, proprioception, sitting balance, apraxia and hemianopia as markers for functional rehabilitation [27]. In post-stroke patients, physiotherapy and occupational therapy exercices for both upper limbs and lower limbs become crucial, especially post ACA aneurismal ruptures and post SAH [28].

According to the Agency for Integrated Care Singapore, some recommendations for the upper limb exercices consist of: lifting the arm to shoulder level, bending and straighten elbows, forearm turning, turning palms up and down alternatively, bending wrists from side to side, in 3 sets of 20 every day, on a regular basis. Some of the recommendations for the lower limbs exercices are as follows: knee exercices, using stronger leg for support, straightening the weaker leg, weight shifting in standing position, calf stretch with towel, hamstring stratch. Mindfulness exercices can also help improve the states of post-hemorrhagic stroke patients and these consist of visualization, but body movement as wel [28].

In an American study from Boston, there have been mentioned the clinical signs, in the case of PCA hemorrhagic stroke: sensory, motor, balance, visual (optic ataxia, simultagnosia, achromotopsia and palinopsia) and both cognitive disorders (prosopagnosia) and neuropsychiatric manifestations (hallucinations, confusion, agitation and delirium) [29].

In a recent longitudinal study from Columbia University, New York, presenting the rehabilitation outcomes for 11 patients with ICH, after a six month period from the onset, there are highlighted as rehabilitation techniques used in medical practice: “environmental enrichment”, “skilled reach training”, “constraint-induced movement therapy” and “aerobic training” (25). The authors mention that patients underwent a complex rehabilitation programme comprising medical and nursing support, physical exercise for 3 hours a day, occupational and speech therapies. During the period of this programme, there were taking place weekly discussion meetings in order to establish the outgoing progress and the further steps to consider. The outcomes of the programme were satisfactory involving: better behavior in patients and increased neuroplasticity [25].

Conclusion

The current research shows the interrelation between variations in the circle of Willis and hemorrhagic stroke development, with a focus on neurological rehabilitation. Gaining information on recovery and rehabilitation in these cases could be useful for the patients’ families,

so that they continue to monitor their beloved ones' evolution after coming back from medical centres or hospitals. The study also provides an insight into the anatomical underlyimg aspects of this pathology, becoming useful for neurologists, radiologists, internal medicine and family medicine practitioners, as well as for anatomists. It is noticeable that professional neurological rehabilitation can have a major impact on the outcomes of recovery in post-hemorrhagic stroke patients, if there is applied the right dose and time of specific recovery exercices and therapy. The final outcome of the neurological rehabilitation therapies has a focus on neuroplasticity, by brain stimulation and functional recovering, after a hemorrhagic stroke event.

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Conflict of Interest

None

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