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Original Scientific Paper

COMPUTATIONAL FLUID DYNAMICS IN PATIENTS WITH TRIGEMINAL NEURALGIA – A PRELIMINARY STUDY

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SUMMARY – Although earlier studies showed higher values of wall shear stress in neurovascular conflict, hemodynamic patterns in the blood vessel after microvascular decompression are unknown. This study aimed to analyze the hemodynamic features of the offending artery preoperatively and postoperatively using computational fluid dynamics. We retrospectively analyzed 11 patients with trigeminal neuralgia who were surgically treated in our department during 2022. All patients underwent pre- and postoperative computed tomography angiography. Hemoscope software was used for computational fluid dynamics analysis. This analysis included 11 patients, median age 71 years (54.5% of female patients). Superior cerebellar artery was the most common offending vessel. In all 11 patients, elevated values of wall shear stress were found in the area of neurovascular contact. Postoperatively, with improvement of the patient clinical status, there was also a decrease in wall shear stress. Computational fluid dynamics analysis of offending vessels in trigeminal neuralgia can be a useful tool in preoperative planning and in assessing treatment outcomes and prognosis.

Key words: *Computational fluid dynamics; Trigeminal neuralgia; Wall shear stress*

Introduction

Neurovascular compression syndromes such as hemifacial spasm and trigeminal neuralgia are chronic neuropathic pain conditions caused by vascular compression of the trigeminal nerve or facial nerve that can lead to partial demyelination of the nerve fibers and ultimately, result in abnormal impulse transmission and processing[1-4]. The hemodynamic forces that act on the blood vessel wall in the area where it is in contact with the nerve could perhaps provide additional information for better understanding of the pathophysiology of trigeminal neuralgia. Although the field of trigeminal neuralgia has been well-researched in the last two decades, some parts of the pathophysiology are still unclear.

In the last decade, computational fluid dynamics (CFD) has shown valuable application in the field of vascular neurosurgery[5-8]. Numerous hemodynamic parameters were studied, such as wall shear stress (WSS) and oscillatory shear index[7,9,10]. Several earlier studies investigated the benefits and usefulness of CFD in neurovascular syndrome[3,11,12]. Satoh *et al*. found that some patterns of the changes in preoperative WSS

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may correlate with the neurovascular contact region[12]. Another study performed by Tamer *et al*. suggested that at the contact site, high hemodynamic parameter values might indicate a neurovascular conflict zone[13].

However, we still do not know how hemodynamic parameters behave after surgery. To our knowledge, there are no studies comparing CFD and surgical results. Therefore, our study aimed to analyze CFD data and compare them with surgical outcomes.

Material and Methods

We performed a retrospective study of 11 consecutive patients undergoing endoscopic decompression of trigeminal neuralgia at the Department of Neurosurgery, Fujita Health University Bantane Hospital. Patient data were de-identified before analysis. Basic demographic data (age and gender) and neurologic admission status were collected. The radiological findings analyzed included location and site of neurovascular conflict and identification of the offending vessel. Barrow Neurological Institute Pain Scale (BNI-PS) was used to analyze pain intensity preoperatively and postoperatively. All operations were performed by the consultant neurosurgeon (F.K.) according to the previously published technique[14].

Computational fluid dynamics modeling

Computed tomography angiography (CTA) was performed preoperatively as a routine work-up and the day after surgery to evaluate the success of the procedure. CTA images were taken using a 320-row camera (Aquilion ONE; Canon, Tokyo, Japan) and processed using a Ziostation2 image-processing workstation (Ziosoft, Tokyo, Japan) to extract blood vessels. CFD images were created with Hemoscope software (Amin Corp., Minato Ward, Tokyo, Japan) according to the protocol published in our earlier publication[1]. For each offending vessel, we investigated instantaneous wall shear stress magnitude (WSSm) and streamline velocity and direction (SL).

Given that one of our hypotheses was that the WSS values were not equal in the entire blood vessel that had contact with the nerve, we divided the blood vessel into the proximal, contact and distal parts during the CFD analysis. All three parts were equally divided in all patients and their comparison was made preoperatively and postoperatively.

Statistical analysis

The Wilcoxon test was used to test differences in continuous variables between the two measurements. To examine the relationship between BNI and WSS values, we used Spearman's coefficient of correlation. The significance level was set at 0.05.

Results

Our study cohort included 11 patients with trigeminal neuralgia treated in our department. The population included 6 female and 5 male patients, median age 71 (range 41-77) years. In 6 patients, the neurovascular conflict was on the right side and in 5 patients on the left side. Superior cerebellar artery was the most common offending vessel (10 patients), while in one patient neurovascular conflict was between trigeminal nerve and anterior inferior cerebellar artery. Patient demographics and characteristics are summarized in Table 1.

Table 1. Baseline patient characteristics

Gender	
Female	6/11
Male	5/11
Age [years, median (minimum-maximum)]	71 (44-98)
Vessel	
Superior cerebellar artery	10/11
Anterior inferior cerebellar artery	1/11
Side	
Left	5/11
Right	6/11
Branch	
V1	3/11
V2	4/11
V3	3/11
Combined	1/11

The preoperative BNI pain score was IV in 7 patients and V in the remaining 4 patients. The median of BNI pain score was IV (IV-V) preoperatively. Postoperatively, there was an improvement in the BNI pain score in all patients, as shown in Figure 1.

Comparing the values of WSS on the three measured parts of the blood vessel using CFD, we noticed that the area of neurovascular contact had the highest WSS [mean 2.8 Pa (IQR 2.4-4.43 Pa)]. In addition, we observed a decrease in WSS in the area of neurovascular contact postoperatively (p=0.003) (Fig. 2). There was no correlation between BNI score and WSS, preoperatively or postoperatively.

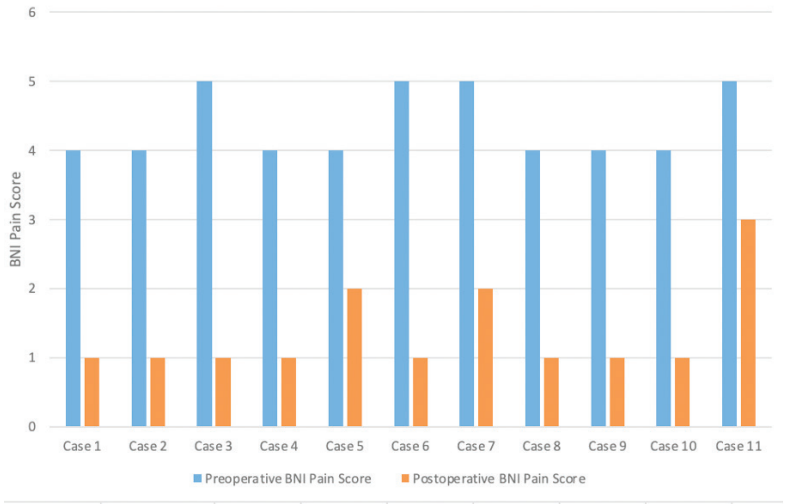

Fig. 1. Distribution of preoperative and postoperative Barrow Neurological Institute (p) pain scores.

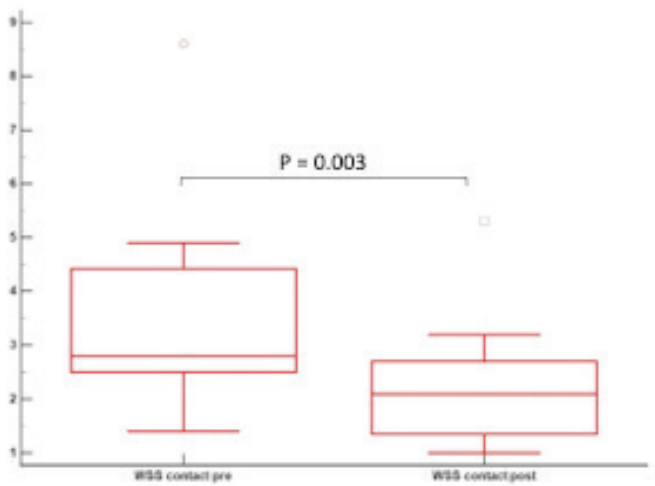

Fig. 2. Differences in the values of wall shear stress (WSS) preoperatively and postoperatively.

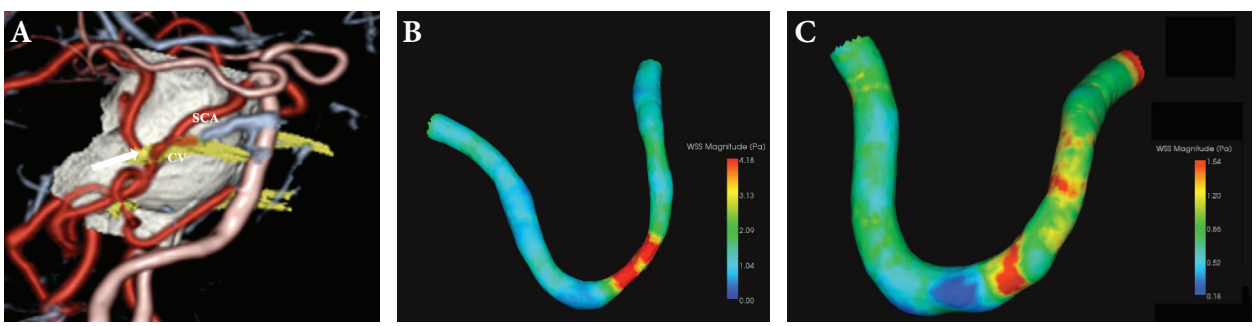

Fig. 3. (A) 3D fusion image showing the neurovascular conflict (arrowhead) between trigeminal nerve (CV) and superior cerebellar artery (SCA); (B) visualization of wall shear stress (WSS) in the computational fluid dynamics analysis (CFD). Preoperative CFD analysis showed that the WSS magnitude was elevated in the area of the neurovascular contact; (C) CFD analysis postoperatively showed lower WSS magnitude values than preoperatively.

Discussion

The most common cause of trigeminal neuralgia is trigeminal nerve compression by vascular structures[2]. According to the European Academy of Neurology guidelines on trigeminal neuralgia, microvascular decompression is recommended as first-line surgery in patients where neurovascular contact with morphological changes has been demonstrated[3]. Although various neuroradiological tools have been proposed in recent years to visualize neurovascular contact, 3D magnetic resonance imaging provides the best spatial resolution and multimodal image fusion can be used in clinical practice[4-6].

Due to the compression of the nerve and vessels, the vessels can adhere to the nerve, which can cause morphological changes[7]. Hemodynamic forces may also contribute to the pathogenesis of classic trigeminal neuralgia[8]. Devor *et al*. report on the presence of focal axonopathy and demyelination at the site of trigeminal nerve entrapment in a patient with trigeminal neuralgia[9].

With the development of neuroradiological tools, CFD has enabled simulation of blood flow in realistic models. Although in the last 20 years, it has mostly been used in research on the formation, growth and rupture of aneurysms, over the past few years, CFD has also been introduced in the investigations of neurovascular syndromes[1,10-12]. Although several hemodynamic parameters were previously published, it is considered that WSS plays a key role in the interaction between the nerve and the wall of the small vessel[8].

Satoh *et al*. report that the magnitude of the WSS increases along the neurovascular contact[7]. Our study confirmed that the contact area had the highest WSS preoperatively compared to the proximal and distal parts of the vessel.

The effect of WSS on the blood vessel walls depends on the magnitude, geometry and characteristics of the blood vessel[13]. These parameters can be different in blood vessels affected by atherosclerotic plaques. Hemodynamic patterns in atherosclerotic blood vessels have been well investigated[15,16].

A study in an animal model showed that atherosclerotic blood vessels had different atherosclerotic alterations[17]. Previous studies have reported that high WSS can cause remodeling of blood vessels. Satoh *et al*. also report that deformation of the luminal geometry might be responsible for increasing WSS[7]. All our patients had higher WSS values preoperatively, but there was no correlation with the severity of symptoms.

To our knowledge, this is the first study comparing preoperative and postoperative hemodynamics in trigeminal neuralgia. In our study, there was a recovery of WSS postoperatively. All our patients postoperatively had lower WSS values in addition to better clinical status and lower BNI values. Compared with the proximal and distal parts of the blood vessel, we found a slightly higher pressure postoperatively at the site where there was neurovascular contact (Fig. 3). However, postoperative WSS was lower compared to preoperative results. Future studies should investigate pressure values in the offending vessel postoperatively and during follow-up.

Limitations

Our study had some limitations. First, we performed a retrospective study which may not have completely reflected the natural disease course. The small sample size in our study may also have affected the reliability of the results. In addition, we used the Hemoscope-v1.5 (Tokyo) software, which was primarily made to assess the perianeurysmal environment. During surgery, the blood vessel was mobilized due to decompression, which also may have affected the hemodynamic conditions inside the blood vessel.

Conclusion

Although there were high WSS preoperatively, we noticed that a lower WSS was observed postoperatively, in addition to a postoperatively better BNI pain score, especially in the area of neurovascular decompression. CFD could serve as an additional diagnostic tool in preoperative planning, as well as for evaluating treatment outcome. The utility of CFD in the cases of trigeminal neuralgia recurrence should be investigated.

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Sažetak

RAČUNALNA DINAMIKA FLUIDA KOD BOLESNIKA S NEURALGIJOM TRIGEMINUSA – PRELIMINARNO ISTRAŽIVANJE

D. Jankovic, K. Sasaki, K. Kralik, M. Nakipuria, K. Fuminari i *Y. Kato*

Iako su ranije studije pokazale veće vrijednosti stresa smicanja zida u neurovaskularnom kontaktu, hemodinamski obrasci u krvnim žilama nakon mikrovaskularne dekompresije nisu poznati. Cilj istraživanja bio je analizirati hemodinamske značajke krvne žile koja je u kontaktu s trigeminalnim živcem prijeoperacijski i poslijeoperacijski primjenom računalne dinamike fluida. U opservacijskoj retrospektivnoj studiji analizirano je 11 bolesnika s trigeminalnom neuralgijom koji su kirurški liječeni na našem odjelu tijekom 2022. godine. Kod svih bolesnika je prijeoperacijski i poslijeoperacijski učinjena CT angiografija intrakranijskih krvnih žila. Za analizu računalne dinamike fluida primijenjen je program Hemoscope. U svih 11 bolesnika utvrđene su povišene vrijednosti smičnog naprezanja zida krvne žile u području neurovaskularnog kontakta. Poslijeoperacijski je s poboljšanjem kliničkog statusa bolesnika došlo i do smanjenja vrijednosti smičnog naprezanja zida krvne žile. U zaključku, analiza oštećenih krvnih žila u trigeminalnoj neuralgiji pomoću računalne dinamike fluida može biti koristan alat u prijeoperacijskom planiranju i procjeni ishoda liječenja i prognoze.

Ključne riječi: *Računalna dinamika fluida; Smično naprezanje zida; Trigeminalna neuralgija*