

# Correlation Between Carotid Stenosis and Pulsatile Index Measured by Transcranial Doppler

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## ABSTRACT

**Background:** Carotid atherosclerosis is often mentioned as one of the main causes of stroke. Currently, embolization is considered the most common mechanism that causes ischemic strokes due to atherosclerotic lesions in the carotid artery. Transcranial Doppler (TCD) ultrasound provides relatively inexpensive, noninvasive, real-time measurement of blood flow characteristics and cerebrovascular hemodynamics within brain arteries. The pulsatile index measured by transcranial Doppler is a parameter that indicates the degree of elasticity of the blood vessels of the brain. **Objective:** The aim of this study is to determine the relationship between the value of the pulsatile index of the middle cerebral artery and the basilar artery in patients with carotid stenosis using transcranial Doppler and the value of the pulsatile index in relation to the degree of carotid stenosis. **Methods:** The study involved a total of 140 patients examined at the Color Doppler and Transcranial Doppler Department of the Neurology Department of the General Hospital "Prim Dr. Abdulah Nakas" Sarajevo. The patients were divided into two groups. The research was conducted in the General Hospital "Prim. dr. Abdulah Nakas" in Sarajevo at the Department for Color Doppler and Transcranial Doppler of the Department of Neurology and included patients examined in the period from February 2022 to December 2022. All patients underwent extracranial Doppler of the carotid arteries and transcranial Doppler of the middle cerebral artery and basilar artery. **Results:** The mean values of PI in ACM in the total sample were statistically significantly lower in patients with stenosis up to 50% compared to the average in patients with stenosis over 50%. Average values of PI in AB in the total sample were statistically significantly lower in patients with stenosis up to 50% compared to the mean values in patients with stenosis over 50%. **Conclusion:** Transcranial Doppler findings showed an increased pulsatile index in patients who had carotid stenosis greater than 50% compared to patients with mild carotid stenosis. The study showed that in clinical work it would be necessary to introduce the pulsatile index as an indispensable neurosonological parameter that would be included in the findings of the transcranial Doppler and thus objectify the potential risk of a cerebrovascular ischemic event.

**Keywords:** carotid stenosis, pulsatile index, extracranial Doppler, transcranial Doppler.

## 1. BACKGROUND

Atherosclerosis is a chronic disease of blood vessels, in which cholesterol and low-density lipoproteins accumulate at the inner wall of the vessels in the form of plaques, and the walls themselves become thicker and lose elasticity. Due to the accumulation of fat and deposits, the walls of blood vessels harden, lose elasticity and eventually narrow, which makes it difficult for blood to flow to the organs. Eventually, the blood vessel

can become completely blocked. If this disease is accompanied by a blood coagulation disorder, the susceptibility to thrombosis and ischemic organ damage increases (1). Carotid atherosclerosis is often cited as one of the main causes of stroke. Currently, embolization is considered the most common mechanism that causes ischemic strokes due to atherosclerotic lesions in the carotid artery. Thrombosis and low flow are other possible mechanisms. Carotid

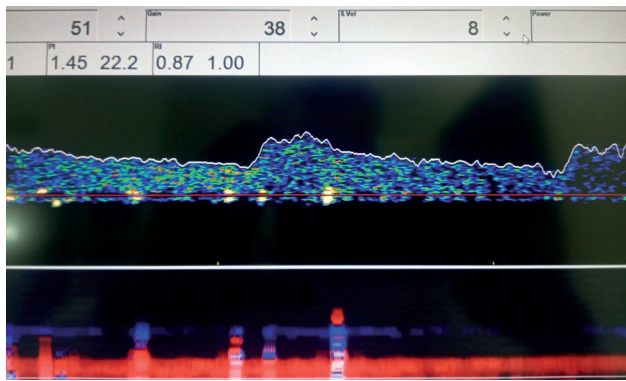


Figure 1. Transcranial Doppler ACM (PI values (1.45) in stenosis greater than 50%)

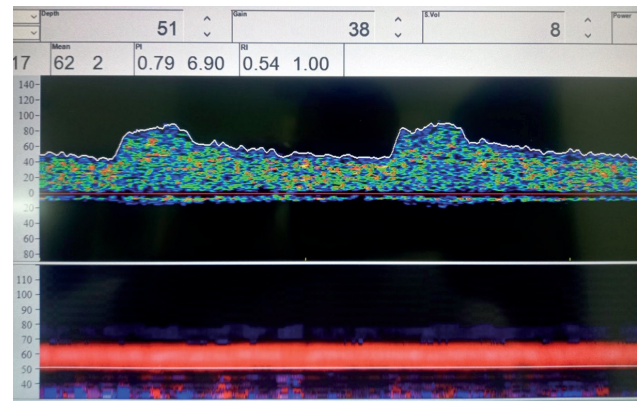


Figure 2. Transcranial Doppler ACM (PI value (0.79) for stenosis less than 50%)

atherosclerosis is often asymptomatic and does not cause any symptoms. Mild carotid stenosis generally ranges up to 50% blockage of the blood vessel, and a more severe form of stenosis ranges above 50% blockage of the lumen of the blood vessel (2). Transcranial Doppler (TCD) ultrasound provides relatively inexpensive, noninvasive, real-time measurement of blood flow characteristics and cerebrovascular hemodynamics within brain arteries. Transcranial ultrasound is based on the principle of the Doppler effect. According to this principle, ultrasound waves emitted from the Doppler probe are transmitted through the skull and reflected by the movement of red blood cells within the intracerebral vessels. The difference in frequency between the emitted and reflected waves, called the “Doppler shift frequency”, is directly proportional to the speed of moving red blood cells (blood flow velocity). Since the blood flow inside the vessel is laminar, the resulting Doppler signal actually represents a mixture of different Doppler frequency shifts that form a spectral representation of the velocity distribution of individual red blood cells on a TCD monitor (3). Carotid Doppler ultrasound is a popular tool for evaluating carotid artery atherosclerosis. Its two-dimensional gray scale can be used to measure intima-media thickness, which is a very good biomarker for atherosclerosis and can help in plaque characterization. Plaque morphology is associated with stroke risk (4).

## 2. OBJECTIVE

The aim of this study was to determine the relationship between the value of the pulsatile index of the middle cerebral artery and the basilar artery in patients with carotid stenosis using transcranial Doppler and the value of the pulsatile index in relation to the degree of carotid stenosis.

## 3. PATIENTS AND METHODS

### Participants

The study included a total of 140 patients examined at the Color Doppler and Transcranial Doppler Department of the Neurology Department of the General hospital “Prim Dr. Abdulah Nakaš” Sarajevo. The patients were divided into two groups. The first group is patients who have been verified to have mild carotid atherosclerosis, or stenosis of the artery up to 50% of the lumen and the second group were patients in whom stenosis over 50% of

the lumen of the blood vessel was verified. Inclusion criteria were all patients older than 18 years who were confirmed to have carotid stenosis by extracranial Doppler based on ultrasound parameters. The exclusion criteria from the study were patients under the age of 18, the presence of a more severe form of chronic obstructive disease, patients with high blood pressure greater than 180 mmHg in systole and greater than 110 mmHg in diastole, previous carotid artery dissection, head trauma and cerebral hemorrhage during the previous three months.

### Methods

The research was conducted in the General Hospital “Prim. dr. Abdulah Nakaš” in Sarajevo in the Cabinet for Color Doppler and Transcranial Doppler of the Department of Neurology and included patients examined in the period from February 2022 to December 2022. It was explained to all patients that the procedure is non-invasive like all the methods used during the research and that the data will be strictly confidential and used only for scientific purposes.

### Procedure and ethical considerations

The research was approved by the Ethics Committee of the General Hospital “Prim Dr. Abdulah Nakaš”.

### Measures

The research used a form that was specially designed and contained the following data: age, gender, ultrasound findings and neurosonological parameters of extracranial and transcranial Doppler. All patients underwent extracranial Doppler of the carotid arteries and transcranial Doppler of the middle cerebral artery and basilar artery. Extracranial

|        |               | Stenosis      |               |       | χ <sup>2</sup> | p     |       |
|--------|---------------|---------------|---------------|-------|----------------|-------|-------|
|        |               | Stenosis <50% | Stenosis >50% | Total |                |       |       |
| Gender | Male          | N             | 43            | 37    | 80             | 1.050 | 0.197 |
|        |               | %             | 61.4          | 52.9  | 57.1           |       |       |
|        | Female        | N             | 27            | 33    | 60             |       |       |
|        |               | %             | 38.6          | 47.1  | 42.9           |       |       |
| Total  | N             | 70            | 70            | 140   |                |       |       |
|        | %             | 100.0         | 100.0         | 100.0 |                |       |       |
| Age    |               | M±SD          | Min           | Max   | Z              | p     |       |
|        | Stenosis <50% | 65.09±9.01    | 34            | 82    | -0.549         | 0.583 |       |
|        | Stenosis >50% | 66.20±7.47    | 49            | 82    |                |       |       |
|        | Total         | 65.64±8.26    | 34            | 82    |                |       |       |

Table 1. Comparison of gender and age according to groups

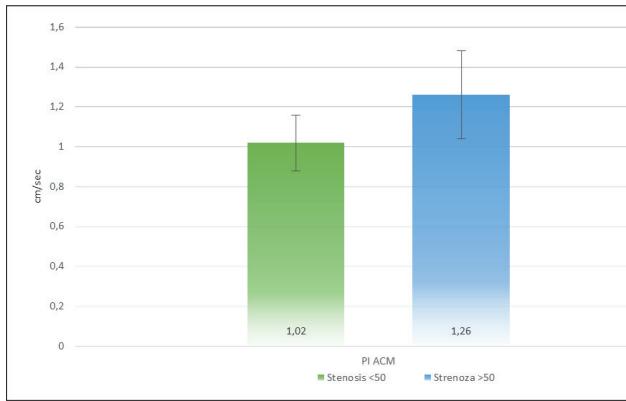


Figure 3. Comparison of mean PI ACM values according to the degree of carotid stenosis

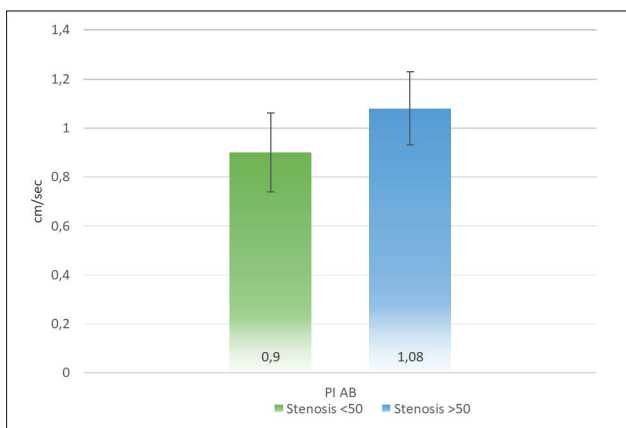


Figure 4. Comparison of mean PI AB values according to the degree of carotid stenosis

Doppler was performed on a Toshiba Xario 100 device with an 11 Mhz probe, manufactured in 2016, Japan. Transcranial Doppler was performed on a DWL Multidop T device with a 2 Mhz TCD probe, year of manufacture, 2021, Germany.

#### Statistical analysis

The results of the analysis are presented in tables and charts by the number of cases, percentages, arithmetic mean with standard deviation and range of values. Testing of differences between categorical variables was performed using the chi-square test, while differences between continuous variables were tested using the non-parametric Mann-Whitney test. Testing of correlation relationships was performed using Spearman's rank correlation test. The analysis was performed using the statistical package IBM Statistics SPSS v 25.0.

## 4. RESULTS

The sample was homogenous regarding the gender distribution with a slightly higher prevalence of male patients in the group with stenosis below 50% - 61.4% compared to 52.9% of women.

The patients in the group with carotid stenosis over 50% were slightly older with a mean age of  $66.20 \pm 7.47$  years compared to the patients with stenosis below 50% and mean age of  $65.09 \pm 9.01$  but without statistically significant difference (Table 1).

The mean values of PI in ACM in the total sample were  $1.13 \pm 0.22$  cm/sec and were statistically significantly lower ( $p < 0.05$ ) in patients with stenosis up to 50% with an average of  $1.02 \pm 0.14$  cm/sec compared to the mean value in patients

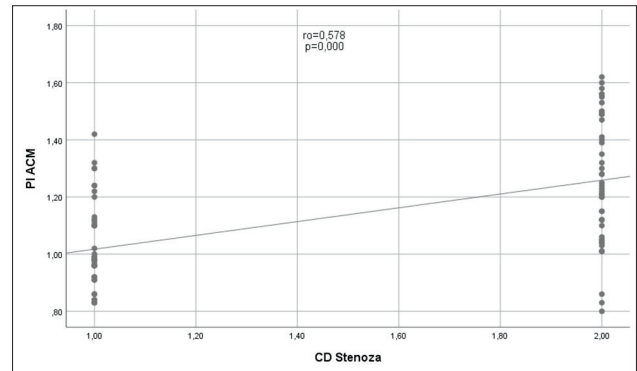


Figure 5. Correlation between blood flow velocity in the PI ACM and degree of carotid stenosis

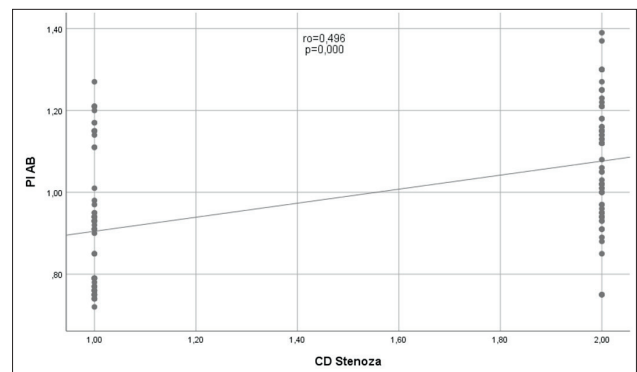


Figure 6. Correlation between blood flow velocity in the PI AB and degree of carotid stenosis

with stenosis over 50% -  $1.26 \pm 0.22$  cm/sec (Figure 3).

The mean values of PI in AB in the total sample were  $0.99 \pm 0.17$  cm/sec and were statistically significantly ( $p < 0.05$ ) lower in patients with stenosis up to 50% with an average of  $0.90 \pm 0.16$  cm/sec compared to the average in patients with stenosis over 50% -  $1.08 \pm 0.15$  cm/sec.

Correlation analysis indicate that there are statistically significant correlation between the blood flow velocities in the PI ACM ( $r = 0.578$ ) and PI AB ( $0.496$ ) with the degree of carotid stenosis, indicating the higher probability of stenosis over 50% (Figure 5 and 6).

## 5. DISCUSSION

The purpose of this study is to investigate the association between carotid stenosis determined by extracranial Doppler and pulsatile index (PI) of the middle cerebral artery and basilar artery. Our study shows that elevated PI measured by transcranial Doppler is associated with a greater degree of carotid stenosis, which may suggest that patients with a greater degree of stenosis have more severe damage to the endothelium of the intracranial cerebral circulation. These findings support the hypothesis that PI reflects the degree of downstream resistance in the intracranial circulation and that the pulsatile index is elevated when signs of cerebral small vessel disease are present. In a similar study, Kidwell et al. retrospectively compared TCD-derived PIs and MRI manifestations of SVD in 55 consecutive patients who underwent TCD and brain MRI studies 6 months apart during a 2-year period. They found correlations between PI MCA and MRI measures in PVH, DWMH, lacunar disease, and combined PVH/DWMH/lacunae. The correlation between pontine ischemia and vertebrobasilar PIs was

significant (5). The presence of risk factors such as diabetes and hypertension affect cerebral atherosclerosis and several studies have confirmed the association of diabetes with increased PI (6). Certain studies have confirmed the association of small blood vessel disease with elevated PI (5, 7). Studies have also confirmed the association between the degree of pulsatility of brain blood vessel walls and PI with aging and dementia (8, 9). We show that in patients with AIS, plaque severity is associated with MCA PI, with a connection between severe plaque morphology and increased MCA PI. The most likely explanation is that severe carotid stenosis above 50% associated with small intracranial artery disease due to common pathophysiological mechanisms. Indeed, carotid plaques were shown to be associated with lacunar stroke in the population-based Rotterdam study (10). High-grade precerebral carotid stenosis was significantly associated with reduced PI in the middle cerebral artery distal to the stenosis or occlusion.

Additionally, we find no difference in PI between normal carotid arteries (without stenosis) or low-grade stenosis. This finding is consistent with earlier studies in patients undergoing endarterectomy (11-13). In an earlier study, middle carotid artery PI was associated with increased systolic blood pressure, lower diastolic blood pressure, and increased pulse pressure. An increase in heart rate and blood pressure is associated with reduced elasticity of large arteries (14). TCD findings of diffusely elevated PI may suggest previously undiagnosed ischemic disease of small vessels and prompt the search and treatment of underlying vascular risk factors (15). At high values, PI becomes highly specific but less sensitive. For example, in our data, an MCA PI of 0.83 or higher indicates combined hemispheric small vessel disease with about 96% specificity. According to this study, the analysis of the sensitivity of certain neurosonological parameters to the presence of carotid stenosis shows that the pulsatile index (PI) measured in the anterior cerebral circulation (ACM) is the most sensitive neurosonological parameter in patients with carotid stenosis with a sensitivity of 99.1%. The analysis also showed that the pulsatile index of the basilar artery (AB) is sensitive up to 87.2% in patients with carotid stenosis. In the future, this information can help us in screening patients with a high pulsatile index for the purpose of preventing stroke and transient ischemic attack. Future studies will be needed to determine whether serial TCDs are a useful measure of disease progression or the effectiveness of therapeutic interventions.

## 6. CONCLUSION

Transcranial Doppler findings showed an increased pulsatile index in patients who had carotid stenosis greater than 50%, which may suggest previously undiagnosed ischemic disease of small blood vessels and encourage the search and treatment of underlying vascular risk factors. The study showed that in further clinical work with neurological patients, it would be necessary to introduce the pulsatile index as an indispensable neurosonological parameter that would be included in the findings of the transcranial Doppler and thus objectify the potential risk of a cerebrovascular ischemic event. The pulsatile index could also be used as one parameter in the assessment of further treatment of carotid stenosis, considering the risk factors of patients and complications of surgical treatment and stenting of the carotid artery. Additional studies are needed to determine the association between carotid stenosis determined by extracranial

Doppler and pulsatile index measured by transcranial Doppler.

- **Author Contribution:** All authors are contributed in the entire process of the study, including the preparation, data collection, analysis, as well as conceptualized the study and for the publication of this original article.
- **Conflict of Interest:** There are no conflict of interest regarding the publication of this article.
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