

Mean Blood Flow Velocities in Posterior Cerebral Arteries during Visual Stimulation

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Abstract

Changes of mean blood flow velocities (MBFV) in the posterior cerebral arteries (PCA) recorded during visual stimulation in a group of 51 healthy, right-handed volunteers are presented. There were 27 (52.9%) males and 24 (47.1%) females, aged 20–59 years (mean age: 36.98 years). Measurements were performed with a hand-held 2 MHz transcranial Doppler (TCD) probe through the temporal window, with the subjects' eyes open and closed, and while they were looking at constant and at flashing white light. In half of the subjects, first the right PCA was insonated and then the left PCA, while in the other half the reverse procedure was used. Statistical analysis was done using Wilcoxon's matched-pair signed-rank test. Mean MBFV value in the left PCA was 41.2 ± 8.6 cm/s (mean \pm SD) with eyes open, 27.8 ± 8.5 cm/s with eyes closed, 42.3 ± 9.1 cm/s while looking at constant white light, and 43.0 ± 9.6 cm/s while looking at flashing white light. Mean MBFV value in the right PCA was 41.7 ± 8.9 cm/s with eyes open, 28.2 ± 9.1 cm/s with eyes closed, 42.4 ± 8.8 cm/s while looking at constant white light, and 43.4 ± 9.2 while looking at flashing white light. Value differences for the left PCA, between eyes open and closed and between looking at constant white light and looking at flashing white light, were statistically significant ($p < 0.001$, $z = -6.2146$, and $p < 0.001$, $z = -3.4836$, respectively). For the right PCA, a value difference between eyes open and closed, and between looking at constant and flashing white light was statistically significant ($p < 0.001$, $z = -6.2146$ and $p < 0.001$, $z = -3.6928$), but there was no significant difference between eyes open and constant white light ($p = 0.03$, $z = -2.1693$). The results showed that simple visual stimulation had an effect on blood flow velocities in PCA and that it could be measured with TCD.

Key Words: Posterior cerebral artery, visual stimulation, TCD.

Introduction

THE PRIMARY VISUAL FIELDS of the cerebral cortex are located in both occipital lobes around the calcarine sulcus in Brodmann's area 17. The visual field is located mainly on the medial aspect of the occipital lobe, but at the apex of the occipital lobe the primary visual area extends partially into the lateral aspect of the occipital lobe. Around Brodmann's area 17, Brodmann's areas 18 and 19 function as associative visual areas, also called extracranial visual areas.

The brain receives arterial blood through the anterior (carotid) and posterior (vertebrobasilar) systems. The vertebrobasilar system consists of the left and right vertebral arteries, which fuse to form the basilar artery. The basilar artery, after a short course, divides into the right and left posterior cerebral arteries. The posterior cerebral arteries (PCA), emerging at the basilar artery bifurcation,

provide arterial blood supply for most parts of the occipital lobe. Primary and associative visual areas located in the occipital lobe also receive arterial blood by way of the posterior cerebral arteries (1, 2).

In 1982 Rune Aaslid (3) described an original method of visualizing and measuring blood flow velocities in the arteries at the base of the brain. This method, named transcranial Doppler (TCD), has several advantages over other methods of cerebral blood flow visualization and measurement. Cranial bones pose a barrier for intracranial ultrasound Doppler examination, because they weaken ultrasound waves. The problem of ultrasound weakening has been solved by using low-frequency (2 MHz), pulsed ultrasound, and by placing the probe on the thinnest part of the temporal bone, right over the zygomatic arch (the so-called temporal window). The reflected ultrasound waves have an acceptable signal-to-noise ratio.

TCD is noninvasive, harmless, painless, and relatively inexpensive. It provides data in real time and has optimal time resolution of the measurement. Measurement can be performed for as long and as frequently as needed. In recent years, TCD has been gaining more importance in the evaluation of cerebral hemodynamics, and it has many areas of diagnostic and research applications. TCD enables one to perform measurement of the effect

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of any mechanical manipulation or functional stimulation on intracranial circulation (4, 5), and has been used to measure blood velocities in basal cerebral arteries during functional stimulation of distinct brain regions (reading, writing, cognitive tasks, visual stimuli, etc.). Different functional tests and pharmaceutical substances have been used during TCD monitoring to assess the cerebral circulatory reserve (hypercapnia, hypoxia, acetazolamide, etc.) (6).

Systolic, diastolic and mean blood flow velocities are used to describe the flow in basal cerebral arteries. However, mean blood flow velocity (MBFV) has a greater physiological significance, since it has the least dependency on cardiovascular factors such as cardiac frequency and contractility, peripheral resistance, and aortic elasticity. Also, MBFV has a closer time correlation with perfusion than other values (7, 8).

Subjects and Method

Measurements of MBFV in the posterior cerebral arteries during simple visual stimulation in healthy volunteers are presented. Measurements of mean blood flow velocities of the posterior cerebral arteries were performed on 51 healthy right-handed volunteers, with a hand-held 2 MHz probe using a Transscan 3D EME TCD device, at the Laboratory of Cerebrovascular Diagnosis, University Department of Neurology, Sestre milosrdnice University Hospital in Zagreb, Croatia.

PCAs were identified and insonated¹ through the temporal window using a standard technique (9), while subjects had their eyes wide open and then closed; mean MBFV in the PCAs was measured. Then the subjects watched a rectangular source of white light (constant white light) placed at a distance of one meter in front of them for one minute; and MBFV in each PCA was measured. After a resting phase of two minutes, the light was turned on and off every second (flashing white light) for one minute; MBFV in each PCA was measured. In half of the subjects, the measurements were first performed on the right side and then on the left side, while in the other half, the measurements were first performed on the left side and then on the right side. Thus, each subject had MBFV measurements done in the right and left PCA with eyes wide open, eyes closed, and while looking at constant and at flashing white light.

Statistical analysis was done using nonparametric Wilcoxon's matched-pair signed-rank test, and analysis of variance was done with Bonferroni correction. Differences were considered statistically significant at a *p* value of less than 0.01 (*p*<0.01). Results are presented as mean \pm two standard deviations (SD).

Results

The study group consisted of 51 healthy right-handed volunteers, 27 (52.9%) men and 24 (47.1%) women, aged 20–59, mean age of 36.98 (SD=10.43) years.

MBFV in the left PCA was 41.2 ± 8.6 cm/s with the subjects' eyes wide open. Closing the eyes caused a drop of MBFV to 27.8 ± 8.5 cm/s, i.e., to 67.5% of the MBFV when their eyes were wide open. Wilcoxon's matched-pair, signed-rank test and analysis of variance with Bonferroni correction showed this difference to be statistically significant. While the subjects were looking at constant white light, MBFV was 42.3 ± 9.1 cm/s, i.e., 102.7% of the MBFV when their eyes were wide open, and while they were looking at flashing white light, MBFV was 43.0 ± 9.6 cm/s, i.e., 104.4% of the MBFV when their eyes were wide open. The differences for constant and flashing white light were found to be statistically significant with Wilcoxon's matched-pair, signed-rank test, but analysis of variance with Bonferroni correction did not show statistical significant difference. In the left PCA, the increase in MBFV while subjects were looking at constant white light was approximately twelve times smaller than the decrease in MBFV while they closed their eyes (2.7% to 32.5%). While they were watching the flashing white light, the increase in MBFV was approximately seven times smaller than the decrease in MBFV while the subjects closed their eyes (4.4% to 32.5%) (Table 1).

MBFV in the right PCA was 41.7 ± 8.9 cm/s when the subjects had their eyes wide open. Closing the eyes caused a drop of MBFV to 28.2 ± 9.1 cm/s, i.e., to 67.6% of the MBFV when they had their eyes wide open. Wilcoxon's matched-pair, signed-rank test and analysis of variance with Bonferroni correction showed this difference to be statistically significant. While the subjects were looking at constant white light, MBFV was 42.4 ± 8.8 cm/s, i.e., 101.7% of the MBFV when their eyes were wide open; and while looking at flashing white light, MBFV was 43.4 ± 9.2 cm/s, i.e., 104.1% of the MBFV when their eyes were wide open. The difference for constant white light was not statistically significant, with both Wilcoxon's

¹ Insonation is the method used in Doppler ultrasound in which the angle between the Doppler ultrasound beam and the direction of blood flow in the vessel is examined by means of Doppler ultrasound probe.

TABLE 1
Mean Blood Flow Velocities in Left Posterior Cerebral Artery during Visual Stimulation

	Mean blood flow velocity mean \pm 2 SD (cm/s)	%	Statistical Significance	
			Wilcoxon's matched-pair signed-rank test	Analysis of variance with Bonferroni correction
Eyes wide open	41.2 \pm 8.6	100.0		
Eyes closed	27.8 \pm 8.5	67.5	z = -6.2146 p < 0.001	t=14.008, p<0,001
Constant white light	42.3 \pm 9.1	102.7	z = -3.4836 p < 0.001	t=1.201, ns
Flashing white light	43.0 \pm 9.6	104.4	z = -3.7693 p < 0.001	t=2.102, ns

ns = non-significant

matched-pair, signed-rank test and analysis of variance with Bonferroni correction, while the difference for flashing white light was statistically significant with Wilcoxon's matched-pair, signed-rank test and not with analysis of variance with Bonferroni correction. In the right PCA, the increase in MBFV while subjects were looking at constant white light was approximately 19 times smaller (1.7% to 32.4%) than the decrease in MBFV when their eyes were closed. While watching the flashing white light, the increase in MBFV was approximately 8 times smaller than the decrease in MBFV while the subjects closed their eyes (4.1% to 32.4%) (Table 2).

There was no statistically significant difference in MBFVs between the left and right PCAs with the subjects' eyes wide open, closed, or while looking at constant or flashing white light, with both Wilcoxon's matched-pair, signed-rank test and with analysis of variance with Bonferroni correction (Table 3). However, distribution of values and results in all groups was not normal, i.e., dis-

tribution of all values and results was not Gaussian. Therefore, it was expected that parametric statistical analysis (analysis of variance with Bonferroni correction) would show only coarse, and not subtle, differences between groups. On the other hand, nonparametric statistical analysis (Wilcoxon's matched-pair, signed-rank test) showed only slight differences between groups.

Discussion

Vision is probably the most important sense in humans. And light is a stimulus that can be easily and precisely applied and controlled. Therefore, the application of light stimuli to the organs is a convenient method for performing different kinds of potentially important experimental research.

Many authors have recorded changes of blood flow velocities with TCD in the posterior cerebral arteries during visual stimulation (4, 10–15). Most of these studies report a decrease in blood flow velocities when the eyes were closed and an increase

TABLE 2
Mean Blood Flow Velocities in Right Posterior Cerebral Artery during Visual Stimulation

	Mean blood flow velocity mean \pm 2 SD (cm/s)	%	Statistical Significance	
			Wilcoxon's matched-pair signed-rank test	Analysis of variance with Bonferroni correction
Eyes wide open	41.7 \pm 8,9	100.0		
Eyes closed	28.2 \pm 9.1	67.6	z = -6.2146 p < 0.001	t=14.802, p<0,001
Constant white light	42.4 \pm 8.8	101.7	z = -2.1693, ns	t=0.837, ns
Flashing white light	43.4 \pm 9.2	104.1	z = -3.6928 p < 0.001	t=1.909, ns

ns = non-significant

TABLE 3

Mean Blood Flow Velocities in Left and Right Posterior Cerebral Arteries during Visual Stimulation (Mean \pm 2 Standard Deviations)

	Left PCA (cm/s)	Right PCA (cm/s)	Statistical Significance	
			Wilcoxon's matched-pair signed-rank test	Analysis of variance with Bonferroni correction
Eyes wide open	41.2 \pm 8.5	41.7 \pm 8.9	$z = -1.0867$, ns	$t = 0.815$, ns
Eyes closed	27.8 \pm 8.5	28.2 \pm 9.1	$z = -0.9940$, ns	$t = 0.0215$, ns
Constant white light	42.3 \pm 9.1	42.4 \pm 8.8	$z = -0.1688$, ns	$t = 0.450$, ns
Flashing white light	43.0 \pm 9.6	43.4 \pm 9.2	$z = -0.8252$, ns	$t = 0.622$, ns

ns = non-significant

in velocities when the eyes were open as well as when various visual stimuli were used. However, the percentage of increase or decrease varies considerably according to different authors. Some of them recorded smaller, and others greater changes in blood flow velocities. These differences could be the result of the different methods of visual stimulation used by the various authors.

There are many mechanisms presumed to play a significant role in the autoregulation of cerebral blood flow, which is definitely increased by changes in metabolic activity. Cerebral blood flow is directly or indirectly coupled with the metabolic activity of the brain (vasoneural coupling). In many instances, significant differences in the regional cerebral blood flow may exist when distinct parts of the brain have increased metabolism (16, 17).

Since the visual cortex in the occipital lobes receives its blood supply almost exclusively from the posterior cerebral arteries, (2) all changes in the arterial blood flow due to differences in the metabolism of the visual cortex neurons are reflected in the arterial blood flow of the posterior cerebral arteries. Thus, changes in the blood flow of the posterior cerebral arteries could indirectly reflect changes in the metabolism of the visual cortex neurons. In the present study, MBFV was measured in the posterior cerebral arteries while the subjects were exposed to simple visual stimuli (opening and closing their eyes, and looking at constant and flashing white light). When their eyes were closed, there was a significant decrease of MBFV in the right and left posterior cerebral arteries. On the other hand, when they were looking at a constant white light, there was an increase in MBFV in both posterior cerebral arteries: in the left PCA, the increase was significant, while in the right PCA, the increase did not reach statistical significance. While they were looking at a flashing white light, there was a significant increase in MBFV in both PCAs.

These changes in MBFV support the concept of vasoneural coupling, i.e., the coupling of cerebral metabolism and brain blood flow. According to this concept, when the eyes are closed, the metabolism of the visual cortex significantly decreases, because there are fewer visual stimuli conducted through visual paths and therefore less visual information to process, thus explaining the decrease in MBFV recorded in the posterior cerebral arteries. On the other hand, when the eyes are looking at constant and flashing white light, there are more visual stimuli and therefore more visual information to process, thus enhancing the metabolism of the visual cortex, resulting in the increase in MBFV recorded in the posterior cerebral arteries.

However, the increase in MBFV, while the subject is looking at a constant white light was approximately 12–19 times smaller than the decrease in MBFV when both eyes were closed. The increase in MBFV while they were looking at a flashing white light was 7–8 times smaller than the decrease in MBFV when both eyes were closed. This could imply that most of the visual cortex neurons are metabolically active when the eyes are open, and that additional stimulation with constant white light causes only a slight additional increase in the metabolism of the visual cortex neurons. However, stimulation with a flashing white light caused an additional increase in MBFV, reaching statistical significance.

Also, from the results of this study it could be speculated that there might be some differences between the right and left occipital visual cortexes, since there was a statistically significant increase in MBFV in the left PCA, but not in the right PCA during stimulation with constant white light, but there was a statistically significant increase in MBFV in both PCAs during stimulation with a flashing white light. Also, it could be speculated that stimulation with a flashing white light could be more appropriate for detecting subtle changes in flow velocities in the PCAs. However, additional

studies are needed to confirm these hypotheses.

This study showed TCD to be a very good method for measuring changes in the blood flow of basal cerebral arteries. TCD can measure changes in the brain activity in the area supplied by the posterior cerebral arteries indirectly, harmlessly and noninvasively, with high temporal resolution, as frequently and as long as necessary. These features make TCD an excellent method for the assessment of blood flow in the basal cerebral arteries.

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