ORIGINAL RESEARCH

The acute and late effects of cigarette smoking on ocular hemodynamics

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Abstract

Aim: To investigate the acute and late effects of cigarette smoking on ocular hemodynamics.
Participants and methods: Seventy healthy participants who smoked less than 5 cigarettes a day were assessed. The ophthalmic artery, central retinal artery, and short posterior ciliary artery were examined by color flow Doppler imaging before smoking, immediately after smoking 1 cigarette, and 1 hour later. Peak systolic velocity, end-diastolic velocity, and average velocity were measured and the resistivity and pulsatility indices were calculated. In addition, intraocular pressure, systolic and diastolic blood pressure, and pulse rate were determined at each time point and mean blood pressure and ocular perfusion pressure were calculated.
Results: Values for systolic and mean blood pressure, pulse rate, and perfusion pressure were significantly higher immediately after smoking than before smoking or 1 hour after smoking. No significant smoking-induced changes were noted for intraocular pressure or diastolic blood pressure. In the ophthalmic artery, values for peak systolic velocity, end-diastolic velocity, average velocity, and pulsatility index were significantly higher immediately after smoking than before or 1 hour after smoking; however, for the short posterior ciliary artery, a corresponding elevation of peak systolic velocity was the only significant change observed. No statistically significant smoking-induced changes in blood flow parameters were detected in the central retinal artery.
Conclusion: This study has shown that cigarette smoking causes acute hemodynamic changes in the ophthalmic artery and, to a lesser extent, in the short posterior ciliary artery and the central retinal artery.

Key words: Color Doppler ultrasonography, Ocular physiology, Smoking

Introduction

Studies of cigarette smoking have become increasingly focused on the harmful effects of this practice in the community. Nicotine and carbon monoxide, the most harmful agents of more than 4000 active substances present in cigarette smoke, are 2 important agents that mediate the hemodynamic effects of cigarette smoke in the body.[1]

Smoking has diverse effects on blood flow in different organs. While causing an acute increase in cerebral and coronary blood flow, cigarette smoking decreases blood flow to the skin and placenta. The variation between organs in the blood flow response to smoking may reflect a difference in end-organ responsiveness to the absorbed products of tobacco smoke. Nicotine causes an increase in oxygen consumption in some organs. This is the principal mechanism cited for the acute increase in cerebral blood flow that occurs in humans after smoking.[2] A study of skin blood flow in smokers has revealed an increase in peripheral vascular resistance, which leads to a decrease in skin blood flow.[3] Carbon monoxide, which is released as a result of incomplete burning of a cigarette, constitutes 2% to 6% of cigarette smoke.[4] As carbon monoxide intake increases with cigarette smoking, blood carboxyhemoglobin levels also become elevated.[2] The affinity of carbon monoxide for hemoglobin

is far greater than that of oxygen. It thus reduces the capacity of the blood to carry and deliver oxygen, which may have a knock-on effect for blood flow.[1] Carbon monoxide shifts the oxygen hemoglobin dissociation curve to the left, and in so doing impairs the release of oxygen to the tissues.[2] Jensen et al determined that the oxygen level in subcutaneous tissue 30 to 50 minutes after smoking remained significantly low.[5] Morecraft et al determined that arterial blood flow in the distal arteries of a human upper extremity was reduced by up to 60% for 30 minutes after cigarette smoking,[6] while Bornmyr et al showed that smoking reduced finger skin blood flow over a 45-minute period.[7]

This is the first study in which color Doppler imaging (CDI) has been used to investigate the acute and late effects of cigarette smoking on ocular hemodynamics in healthy participants who smoked less than 5 cigarettes a day. CDI, which is a non-invasive, reliable, and reproducible method for qualitatively assessing hemodynamic changes in ocular and orbital vessels, was used to determine the effects of cigarette smoking on ocular circulation.

Participants and methods

In this study, which was performed between 1 May 1997 and 1 May 2003, in collaboration between the Department of Ophthalmology and the Department of Radiology, University of Harram, Sanliurfa, Turkey, the right eyes of 70 healthy smokers who smoked less than 5 cigarettes a day were examined. There were 30 women and 40 men, with a mean age of 32.7 years (SD, 9.6 years; range, 18 to 60 years).

The ocular and systemic history of each participant was recorded, and funduscopy, slit-lamp biomicroscopy, visual acuity, and refraction examinations were performed. All participants were free from systemic disease, including hypertension and peripheral vascular disease. No participant was taking systemic or ocular medication, drank alcohol excessively, or had ocular disease.[3] CDI examinations were conducted before smoking, immediately after smoking 1 cigarette, and 1 hour later. The participants were asked to avoid consuming drinks containing caffeine and smoking cigarettes for at least 24 hours prior to CDI examination. The procedure was explained to the participants and their consent was obtained.

Blood flow velocity was measured by the same doctor with a Doppler ultrasonography device (Eccocee-340A; Toshiba, Tokyo, Japan) using a 7.5-MHz multifrequency linear probe. The participants were placed in the supine position for at least 5 minutes prior to examination. Examinations of the ophthalmic artery (OA), central retinal artery (CRA), and short posterior ciliary artery (SPCA) were performed with the participants' eyes closed and their heads at 30° flexion.

Tests were carried out without putting any pressure on the eye, although gel was applied to the closed eyelids. Peak systolic velocity (PSV), end-diastolic velocity (EDV), and average velocity (AV) values were measured and the resistivity index (RI) and pulsatility index (PI) were calculated. RI was calculated as PSV minus EDV, divided by PSV. PI was calculated as PSV minus EDV, divided by AV. The intraocular pressure (IOP), systolic blood pressure (SBP), diastolic blood pressure (DBP), and pulse rate (PR) were determined at the fifth minute of CDI examination. IOP was determined using a Tono-Pen XL tonometer (Mentor, O & O, Norwall, USA) and SBP and DBP were determined by sphygmomanometry. Mean blood pressure (MBP) was calculated according to the following formula:

MBP = DBP + 1/3 (SBP-DBP).[8]

Ocular perfusion pressure (OPP) was calculated as follows:

OPP = 2/3 MBP-IOP.[9]

The data obtained were evaluated using the paired Student's t test.

Results

The mean IOP, SBP, DBP, MBP, OPP, and PR values of the participants are presented in **Table 1**. SBP, MBP, PR, and OPP values were significantly higher immediately after smoking 1 cigarette than the other measurements ($p < 0.05$). IOP and DBP values were not significantly different between the measurements (**Table 2**).

The PSV, EDV, AV, RI, and PI values from the OA, CRA, and SPCA of the participants and the statistical results obtained are presented in **Tables 3 and 4**. When the PSV, EDV, and AV values from the OA were compared with those of the 5-minute measurements, they were found to be

Table 1. Intraocular pressure, systolic, diastolic, and mean blood pressure, ocular perfusion pressure, and pulse rate before smoking and 5 minutes and 1 hour after smoking.

	Before smoking	After smoking	
		5 minutes	1 hour
Systolic blood pressure (SD) [mm Hg]	122.9 (14.8)	129.3 (11.9)	125.1 (12.8)
Diastolic blood pressure (SD) [mm Hg]	75.6 (9.6)	76.4 (9.0)	74.5 (9.4)
Mean blood pressure (SD) [mm Hg]	91.2 (8.4)	93.9 (7.7)	91.2 (8.7)
Pulse rate (SD) [beats/minute]	75.8 (7.1)	78.7 (7.2)	73.7 (7.3)
Intraocular pressure (SD) [mm Hg]	14.2 (1.8)	14.8 (1.8)	14.2 (1.8)
Ocular perfusion pressure (SD) [mm Hg]	50.8 (5.9)	52.2 (4.9)	50.8 (5.8)

Table 2. The p values for intraocular pressure, systolic, diastolic, and mean blood pressure, ocular perfusion pressure, and pulse rate before smoking a cigarette and 5 minutes and 1 hour after smoking a cigarette.

	Before smoking versus 5 minutes after smoking	Before smoking versus 1 hour after smoking	5 minutes after smoking versus 1 hour after smoking
Systolic blood pressure (SD) [mm Hg]	0.000	0.136	0.001
Diastolic blood pressure (SD) [mm Hg]	0.161	0.261	0.063
Mean blood pressure (SD) [mm Hg]	0.000	0.859	0.002
Pulse rate (SD) [beats/minute]	0.010	0.075	0.001
Intraocular pressure (SD) [mm Hg]	0.109	0.851	0.071
Ocular perfusion pressure (SD) [mm Hg]	0.003	0.999	0.019

Table 3. The mean values for peak systolic velocity, end-diastolic velocity, average velocity, pulsatility index, and resistivity index obtained from the ophthalmic artery, central retinal artery, and short posterior ciliary artery before smoking a cigarette and 5 minutes and 1 hour after smoking a cigarette.

Artery assessed	Before smoking	After smoking	
		5 minutes	1 hour
Ophthalmic artery			
Peak systolic velocity (SD) [cm/second]	39.9 (5.8)	41.4 (5.5)	39.7 (6.0)
End-diastolic velocity (SD) [cm/second]	10.2 (2.6)	11.0 (2.4)	9.8 (2.7)
Average velocity (SD) [cm/second]	18.8 (3.6)	20.1 (2.8)	18.3 (3.6)
Resistivity index (SD)	0.74 (0.07)	0.73 (0.05)	0.75 (0.07)
Pulsatility index (SD)	1.70 (0.44)	1.54 (0.32)	1.68 (0.41)
Short posterior ciliary artery			
Peak systolic velocity (SD) [cm/second]	12.4 (2.8)	13.4 (2.9)	12.3 (3.2)
End-diastolic velocity (SD) [cm/second]	4.9 (1.6)	5.2 (2.1)	4.7 (1.6)
Average velocity (SD) [cm/second]	7.3 (2.5)	7.9 (2.5)	7.3 (2.5)
Resistivity index (SD)	0.58 (0.16)	0.61 (0.10)	0.62 (0.07)
Pulsatility index (SD)	1.12 (0.54)	1.13 (0.41)	1.10 (0.31)
Central retinal artery			
Peak systolic velocity (SD) [cm/second]	10.9 (1.9)	12.1 (2.0)	11.8 (2.1)
End-diastolic velocity (SD) [cm/second]	3.9 (1.0)	4.1 (0.9)	4.0 (0.9)
Average velocity (SD) [cm/second]	6.4 (1.4)	6.2 (1.2)	6.6 (1.3)
Resistivity index (SD)	0.66 (0.09)	0.65 (0.09)	0.65 (0.08)
Pulsatility index (SD)	1.36 (0.65)	1.26 (0.32)	1.22 (0.35)

significantly higher than those of the before and 1 hour after smoking measurements ($p < 0.05$). For the blood flow velocities obtained from SPCA, a significant difference was determined only for PSV at 5 minutes post-smoking ($p < 0.05$). No statistical significance was determined for blood flow velocity values obtained from the CRA. When a statistical comparison was performed for PI and RI values, only the PI value of the OA was significantly lower for measurements taken after 5 minutes ($p < 0.05$).

Discussion

The heart rate, which immediately accelerates during smoking, decelerates within a few minutes and returns to its baseline value.[2] This might be explained by the acceleration of the heart rate due to the nicotine absorbed and by the substitution of the paradoxical decrease in the late period. In the present study, the PR was elevated soon after smoking 1 cigarette, an increase that has been attributed to activation of the sympathetic nervous system. An acute elevation of SBP was also observed after smoking. Vasoconstriction causes an increase in SBP, and nicotine causes vasoconstriction by excitation of sympathetic ganglia and increased release of catecholamines.[10,11]

Although cigarette smoking is known to cause hemodynamic changes in the systemic circulation, its effects on ocular circulation are controversial. Morgado et al showed that acute smoking caused a reduction of retinal blood flow,[1] whereas Robinson et al determined that macular capillary leucocyte velocity increased immediately after smoking 1 cigarette.[2]

Rajanapongpun et al showed that an amount of nicotine equivalent to one-third of that present in a cigarette increased OA flow velocity measured soon after adminstration.[12] Langhans et al measured blood flow in the retina and optic nerve head before and after applying 100% oxygen over a period of 5 minutes.[13] These authors determined that there was a significant difference in reduction in the blood flow velocities of smokers and non-smokers, which was

Table 4. The p values for peak systolic velocity, end-diastolic velocity, average velocity, pulsatility index, and resistivity index obtained from the ophthalmic artery, central retinal artery, and short posterior ciliary artery before smoking a cigarette and 5 minutes and 1 hour after smoking a cigarette.

Artery assessed	Before smoking versus 5 minutes after smoking	Before smoking versus 1 hour after smoking	5 minutes after smoking versus 1 hour after smoking
Ophthalmic artery			
Peak systolic velocity (SD) [cm/second]	0.045	0.528	0.038
End-diastolic velocity (SD) [cm/second]	0.042	0.291	0.000
Average velocity (SD) [cm/second]	0.028	0.344	0.001
Resistivity index (SD)	0.557	0.319	0.069
Pulsatility index (SD)	0.020	0.789	0.012
Short posterior ciliary artery			
Peak systolic velocity (SD) [cm/second]	0.522	0.691	1.197
End-diastolic velocity (SD) [cm/second]	0.161	0.477	0.680
Average velocity (SD) [cm/second]	0.199	0.454	0.069
Resistivity index (SD)	0.412	0.501	0.990
Pulsatility index (SD)	0.245	0.102	0.408
Central retinal artery			
Peak systolic velocity (SD) [cm/second]	0.012	0.833	0.021
End-diastolic velocity (SD) [cm/second]	0.267	0.250	0.066
Average velocity (SD) [cm/second]	0.077	0.851	0.059
Resistivity index (SD)	0.169	0.077	0.605
Pulsatility index (SD)	0.875	0.821	0.631

statistically more significant for the smoking group. Kaiser et al determined that for chronic smokers, the blood flow velocities in the OA, measured at least 1 hour after the last cigarette smoked, were higher than corresponding values for non-smokers.[4]

In this study, the PSV, EDV, and AV values of the OA 5 minutes after smoking were found to be elevated more than the other measurements. Changes in blood flow velocities during CDI measurement may be influenced by several factors. Local hypoxia causes changes in the blood flow of ocular tissues, which are very sensitive to oxygen deficiency.[14] To supply oxygen to the tissues, vasodilatation, a regulatory mechanism that operates when there is a relative oxygen deficiency, is provoked and thus blood flow velocity increases.[4,5] In addition, increases in OA flow velocities may reflect increases in SBP.[12]

In this study, there were no significant differences between PSV, EDV, AV, PI, and RI values of the CRA. That cigarette smoking demonstrates different hemodynamic effects on ocular vessels could be explained by the ocular autoregulation mechanism.[13] Despite varying conditions, the autoregulation mechanism maintains the constancy of ocular blood flow. Among the factors that have an effect on the autoregulation mechanism are local metabolites, which affect the autoregulation mechanism by means of oxygen and carbon monoxide. The effects of vasoconstrictive and vasodilative mechanisms that constitute the autoregulation mechanism on the vascular structures are balanced, so that dysfunction of either mechanism is compensated by the other. The autoregulation mechanism has different effects on the OA, CRA and SPCA.[15] The vasodilatory effects of lower oxygen tension and other autoregulatory factors are likely to affect the CRA, and SPCA, possibly counteracting the vasoconstriction in the OA. The relative partial pressures of carbon monoxide and oxygen in retinal circulation have a regulating effect on retinal blood flow by means of the autoregulation mechanism. For the blood flow velocities obtained from SPCA, a significant difference was determined only for the PSV. SPCA is affected by the autoregulation mechanism.[16] Morgado et al reported that retinal vessels were more resistant because of the autoregulatory mechanism to the vasoconstrictive effects of smoking in the acute period and the vasodilative effects in the late period.[1]

The OA was sensitive to the hemodynamic changes caused by nicotine in the early period. The CRA and SPCA may be less sensitive to the effects of cigarette smoking than the OA, which might be a result of the CRA and the SPCA not being under the direct effect of sympathetic innervation and/or the autoregulation mechanism, which is stronger in the OA. Although the role of the autonomic nervous system in the retinal circulation is not completely known, it is thought that autonomic nervous system receptors are present in the OA, but are not present in the CRA and the SPCA.[17]

This study has shown that cigarette smoking causes acute hemodynamic changes in the OA and, to a lesser extent, in the SPCA. The effects of cigarette smoking on the vascular system have led to its recognition as a risk factor in various ocular disorders. This study suggests that the potential effects of cigarette smoking on the development of pathologies related to ocular circulation are worthy of further investigation.

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