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Effects of Smoking on Cerebral Circulation A TCD Study*

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*Department of Neurology, University Hospital Basel (Switzerland)**(Received December 3, 1994; Accepted March 16, 1995)***Abstract**

In 20 healthy subjects the right middle cerebral artery TCD Doppler shift was monitored over 10 minutes and on-line analyzed. During minutes 3, 4 and 5 the subjects smoked a cigarette of their choice making a deep inhalation every 20 seconds and respiring normally in between. Blood pressure and heart rate were externally measured every 30 seconds. Cigarette smoking significantly increased blood pressure, heart rate and flow velocity. The TCD pulsatility index increased only after smoking. Flow velocity dropped to an average of $94 \pm 8\%$ over postsmoking minutes 4 and 5. Repeated smoking spaced by several days done only in 1 subject so far having the middle cerebral artery Doppler signal recorded and analyzed bilaterally resulted in increased flow after smoking on one side and in decreased flow on the other. In conclusion the increase in heart rate and blood pressure and results indicate dilation of the cerebral resistance arteries during smoking followed by constriction of these vessels. The vasculature of one individual hemisphere may react differently on repeated smoking.

Key words; cardiovascular effects of smoking, cigarette smoking, impact of smoking onto brain circulation, transcranial Doppler sonography

Introduction

Cigarette smoking (CS) has been identified as a risk factor for carotid atherosclerosis¹⁾ and stroke²⁾. If it is associated to hypertension both risks seem to be increased^{3),4)}. Information of the acute effects of CS are scanty and contradictory^{5),6),7)}. The present study was undertaken to further investigate the pathophysiological problems involved.

Subjects and Methods

Study I: Twenty healthy smokers (9 m, 11 f, age 27–52 yrs, median 34 yrs), all hospital employees, participated in the study. Prior to the investigation the subjects refrained from smoking during at least one hour. Smoking was done in a sitting position. Cigarettes with a nicotine content of 0.2 to 1.2 mg were smoked. A probe holder based on the lockable ball joint principle and held in place by pairwise velcro locked elastic strips⁸⁾ was mounted on the head. The transducer placement, beam direction and gate depth were adjusted to monitor the right middle cerebral artery (MCA) Doppler signal from a tissue depth of 50 or 55 mm.

A TC64 2 MHz equipment (EME GmbH, D-Überlingen), was used for generating and a Biomac B108/K7 device (BIOMAC Engineering Ltd., CH-Frauenfeld), for on-line analyzing the Doppler signal. After steady state conditions were reached according to visual monitoring of the Doppler signal, registration on audio tape was started. Two minutes later the subject was given between his lips a burning cigarette of his choice from which for the following 3 minutes he took one deep inhalation every 20 seconds. Any head, face and arm movements which could change the quality of coupling and position of the probe were avoided.

At the beginning of minute 6, the cigarette was withdrawn, but Doppler shift registration and signal analysis continued for another 7 minutes. Throughout the experiment, blood pressure (BP) and heart rate (HR) were measured every 30 seconds at the left index using a Marshall finger sphygmomanometer (Omron Tateishi, Kyoto). Furthermore a printout of the TC64 EME device, including the display of the pulsatility index (PI) as averaged over the preceding 6 seconds was made every 30 seconds.

The results of the Doppler signal analysis were available im-

mediately after the individual investigations from a printout furnished by the Biomac equipment. On this document, mean velocity (v), Doppler signal power (p) as a measure of the MCA truncal calibre and the product of the 2 (FI=flow index) as a parameter of volume flow⁹) were shown. All were displayed as normalized to their average over the first minute of steady state. Additionally, their evolution in time and their average over 2 freely choosable time intervals A and B (minutes 3–5 and minutes 9, 10, respectively, in our study) were digitally indicated on the printout. (figure 1).

After termination of the experiments the baseline measurements and those of intervals A and B respectively were compared off-line to each other using the Wilcoxon matched pairs test.

Study II: One of the volunteers, a 48 years old, right-handed man without any CV risk factors who was consuming 30 cigarettes daily since 30 years was repeatedly examined to study the reproducibility of the effects. Smoking was limited to 1/2 cigarette, from which inhalations were carried out at ran-

dom during approximately 2 minutes. In order to also investigate possible side differences of the response, registration of the Doppler signal was accomplished simultaneously from both MCAs, using a technique described by us in an earlier paper¹⁰. The volunteer investigated in study II smoked cigarettes containing 1.2 mg nicotine (3 times), 0.2 mg nicotine (1 time) or carried out shame smoking of the latter without lightening (2 times). The individual tests were spaced by 1 to 2 weeks. An example of 2 printouts from the right and left side respectively is given in figure 2. Signal analysis was carried out on-line on the right, and off-line on the left side.

Results

The means and standard deviations of the individual parameters measured in study I are shown on Table 1.

MABP as averaged over the smoking period was by 7 mmHg and HR by 8 b/min higher than baseline ($p < 0.01$). PI remained at an average of 0.8 ± 0.1 as found in the baseline

Fig. 1 Study I. Smoking with unilateral monitoring and signal analysis of the MCA Doppler shift. Printout of a 52 yrs. old female volunteer. FI=flow index, v =mean spatial velocity, p =signal power. MABP=Mean arterial blood pressure, mmHg. FFT=Fast Fourier Transform.

Fig. 2 Study II. 49 yrs. old volunteer smoking 1/2 cigarette with simultaneous bilateral monitoring and signal analysis of the MCA Doppler shift. Printouts of first investigation contained in table 2 (a=right side, b=left side). For explanation of abbreviations see legends to Figure 1. FFT=Fast Faurier Transform.

Table 1. Averages of cardiovascular and cerebral flow parameters during the baseline, smoking and postsmoking periods.

	HR b/min	MABP mmHg	PI	v %	p %	FI %
baseline	74.1 ± 8.6	87.5 ± 11.2	0.82 ± 0.08	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0
	**	**	ns	**	ns	ns
smoking	82.1 ± 12.3	94.5 ± 9.3	0.80 ± 0.11	105.1 ± 7.4	99.4 ± 10.0	105.5 ± 16.0
	ns	**	*	**	ns	*
postsmoking	86.6 ± 12.1	88.5 ± 8.9	0.84 ± 0.11	93.8 ± 7.7	98.5 ± 12.9	95.5 ± 13.6

*=difference significant at 5%, **=at 1% level. ns=difference not significant.

(presmoking) period. There was no significant change in p and only a non-significant increase by 5.5 ± 16.0% of FI. A postsmoking decrease of this latter amounting to 4.5 ± 13.6% proved to be significant ($p < 0.05$).

There was no significant correlation of the individual parameters to the nicotine content of the cigarette smoked. However, the cardiovascular response tended to be more marked with cigarettes containing ≥ 0.7 mg than with those containing < 0.7 mg nicotine.

Table 2 shows the results of study II.

No FI value beyond 92–112% was seen in the 2 shame smoking experiments and in the one carried out with a low (0.2 mg) nicotine content cigarette. Astonishingly the rise of FI% which was regularly observed when the volunteer smoked a high (1.2 mg) nicotine content cigarette was always unilateral. It did however not have a constant lateralization, occurring on the right side in 2 and on the left side in 1 of the 3 measurements. Mean FI calculated on these sides for the whole smoking period ranged from 113.1 to 122.6%. The postsmoking value remained well over 100% on the homolateral side while contralaterally it was 89.2, 90.5 and 95.1%, respectively.

Discussion

In order to minimize the risk of coughing on inhalation and thereby possibly causing TCD artefacts, smokers only were included in our investigation. For the same reason all subjects participating in study I smoked the cigarette they were in the habit of smoking. These selection criteria made allowance for a wide range of nicotine content of the cigarettes smoked.

Like other authors^{11)–15)} we found a moderately increased MABP HR during CS. MABP increased by an average of 7 mmHg from its baseline values to those measured during smoking and decreased to almost baseline thereafter. Both

Table 2. Results of 4 smoking and 2 shame smoking tests in a 48 year old volunteer. Tests 3, 4 and 5, 6 were carried out successively. All others were spaced by 2 weeks. Smoking abstinence before tests 1, 2, 3, 5: 1 hour.

Test No.	Period	MABP, mm Hg	Flow Index, % R	% L	Nicotine, mg/Cig.
1	baseline	103.0 ± 4.9	100.0	100.0	1.2
	smoking	105.0 ± 3.1	121.5	92.8	
	postsmo.	102.8 ± 3.4	121.5	89.2	
2	baseline	99.4 ± 2.3	100.0	100.0	0.2
	smoking	99.8 ± 1.5	104.7	95.6	
	postsmo.	96.5 ± 4.0	101.9	92.0	
3	baseline	98.8 ± 4.7	100.0	100.0	0.0
	smoking	97.4 ± 4.8	95.4	101.9	
	postsmo.	94.8 ± 1.3	103.7	98.8	
4	baseline	99.4 ± 1.7	100.0	100.0	1.2
	smoking	110.8 ± 2.8	122.6	103.2	
	postsmo.	114.0 ± 1.6	107.6	95.1	
5	baseline	89.2 ± 10.7	100.0	100.0	0.0
	smoking	99.0 ± 5.1	93.3	111.4	
	postsmo.	102.0 ± 2.2		102.0	
6	baseline	102.8 ± 7.6	100.0	100.0	1.2
	smoking	106.2 ± 5.6	94.4	113.1	
	postsmo.	100.0 ± 1.6	90.5	108.8	

changes were statistically significant. There was a tendency of the cardiovascular response to be more marked with cigarettes having a high than those having a low nicotine content.

Similarly to Cruickshank et al⁷⁾ and Kodaira et al¹⁵⁾, we found an increased MCA flow velocity (v) during and a decreased one after CS. Velocity being inversely related to the cross sectional area of the artery at the measuring site but directly to the calibre of the resistance arteries, a truncal constriction as well as a dilation of the small branches of the MCA could therefore theoretically be the reason.

However CS caused no change of the Doppler signal power

(p), proportional to the cross sectional area at the measuring site. On the other hand PI, generally considered as an index of resistancy, did not change significantly between baseline and CS but showed a moderate increase after smoking. It appears therefore as likely that the increase in v during CS was due to the increase in blood pressure while the reason of the decreased v observed in the postsmoking period was caused through constriction of the resistance arterioles.

The unilaterally increased FI during CS, and the contralateral decrease of this parameter in the postsmoking period observed in study II were rather unexpected findings. They can however not be discussed before more data, allowing a statistical analysis, are available. On reviewing the results of study I we found 6 cases where mean FI as averaged over the smoking period, was below 100%, and where the postsmoking value was clearly decreased. It is well possible that in these cases CS increased flow on the left side which was not investigated in this study.

Our findings in study II demonstrating different responses of the right and left MCA systems respectively are well compatible with those of Cruickshank et al.⁷⁾. These authors examined CBF in 6 volunteers immediately after each of 3 smokings of 1 cigarette spaced by 2 hours. After the first smoking period CBF was more reduced in the left than in the right hemisphere in 4 of them. The same side difference of the response was found in 5 of the 6 cases on the second but only in 3 of them on the third smoking. One case showed bilateral CBF reduction after all 3 cigarettes, which was more marked on the right than on the left side.

The minimum abstinence of smoking of 1 hour only before the investigation may have been too short for measuring the relative changes of the TCD flow parameters caused through CS. Baseline level of the blood nicotine values was not reached even 2 hours after smoking a cigarette in the series of Cruickshank et al.⁷⁾, and there was a clear cumulation of this value over 3 cigarettes smoked at that interval. As a consequence neither the cross-section of the MCA trunk nor the calibre of the MCA resistance arteries at the time zero may have represented a true baseline status in our experiments. Our measurements may therefore have been carried out in vasoconstriction or vasoparalysis.

Logically it must be recommended that any future TCD investigation studying the acute effects of CS be carried out in the early morning before the first cigarette has been smoked. In order not to miss possible delayed responses it would also appear to be important to extend such an investigation to

more than just 12 minutes. The limit of 12 minutes set for our studies had been chosen just tentatively to make the TCD test as practicable as possible. Simultaneous bilateral TCD-monitoring including signal power measurements should be feasible from the experience made since the begin of our studies over periods of 30 or even more minutes without difficulties.

Conclusion

In conclusion, the increase of blood pressure and heart rate through CS known from earlier investigations have been confirmed in our study. As to MCA volume flow whose relative changes are measured with FI there was a statistically non-significant probably pressure passive increase during smoking and a significant decrease, most likely attributable to the constriction of small resistance arteries, thereafter. There seems to be a side difference of both responses which may however be reversed on following smoking sessions.

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