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Evaluation of brain oxygenation using near-infrared spectroscopy (NIRS) in patients with hypertensive crisis

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Abstract

Aim: Hypertension is one of the most common health problems in the world, and brain oxygenation changes depending on blood pressure increase. Near-infrared spectroscopy is a non-invasive technology that measures regional tissue oxygenation through photons. The main objective of our study is to investigate whether brain oxygenation changes in hypertensive conditions by using this new technology.

Methods: The patients who have acute neurological damage and presented to the hospital due to hypertensive attack, were included in our study. Intravenous antihypertensive treatment was initiated. During the treatment, NIRS measurements and blood pressure values at 0th, 15th, 30th, and 60th minutes were recorded.

Results: There was a statistically significant difference between the initial measurement of the diastolic blood pressure and the oxygenation of both the right and left lobes of the brain ($P < .05$).There was a negative correlation between the initial measurement of diastolic blood pressure and oxygen values of both lobes of the brain. In addition, there was no correlation between these measurements and oxygenation.

Conclusion: Diastolic blood pressure changes in hypertensive attacks affect brain oxygenation. It is difficult to state that NIRS can be used as a monitoring tool in the acute phase of hypertensive attacks.

Keywords

near infrared spectroscopy, hypertensive crisis, brain oxygenation, oxygen saturation, diastolic blood pressure

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Introduction

Hypertension (HT) is one of the major health problems worldwide.[1] Hypertension is observed in 1.13 billion people worldwide and is responsible for 6% of adult deaths in the world.[2] Approximately 95% of the patients with hypertension have no known cause.[3] The pathogenesis of hypertensive emergencies is thought to result from the sudden increase in systemic vascular resistance. Vascular resistance can be increased by decreasing the lumen diameter or the number of arteries, or by increasing the length of the arteries.[4] Hypertensive crisis is one of the frequent causes of emergency admission in patients with uncontrolled hypertension (HT), which can be symptomatic or asymptomatic due to acute blood pressure elevation, accompanied by end organ damage. Parameters such as heart rate (HR), mean arterial pressure (MAP) and arterial oxygen saturation (SaO_2) used during standard monitoring are known to be not always sufficient to show tissue oxygenation.[2]

Near-infrared spectroscopy (NIRS) is a non-invasive technology which continuously monitors regional tissue oxygenation. NIRS is used to evaluate oxygen saturation of the brain and other tissues (such as muscle, liver and lung).[4] NIRS (NIR; near-infrared; wavelength 700-1100nm) is a technique in which the amount of Near-Infrared light absorption by chromophore molecules [oxyhemoglobin (O_2Hb) and deoxyhemoglobin (HHb), cytochrome-c oxidase (CCO), myoglobin, etc.] is measured while passing through tissues.[5] Although there are various restrictions regarding cerebral NIRS, it has been reported that it can show silent periods of cerebral ischemia and play an important role in maintaining brain functions.[6] Diffuse optical spectroscopy (DOS) and diffuse optical imaging (DOI) are methods that aim to examine biological tissues non-invasively by using visible and near-infrared light. Three different DOS/DOI can be used during the applications. These are called continuous wave, frequency-domain and time-domain.[7] In our study, we used continuous wave DOS/DOI method.

The main objective of our study was to investigate whether we can detect brain oxygenation changes in hypertensive conditions using the NIRS method. We think that with this method, we can continuously monitor the brain oxygenation of our patients and predict the pathological conditions that may develop.

Materials and Methods

Study Design

This is a prospective, analytical and cross-sectional study. Our study was carried out between July and September 2019 in the emergency medicine clinic of University of Health Sciences, Prof. Dr. Cemil Tascioglu City Hospital. The patients were included in the study after receiving local ethics committee approval and patient consent. Although the majority of the presenting patients are green zone patients, an average of 2 patients with hypertensive crisis are treated every day. These patients are treated according to JNC's hypertension guideline recommendations and algorithms.

Patient Selection

77 patients above 18 years of age were included in our study. 23 of these patients were excluded from the study since they were found to have intracerebral hemorrhage, infarct and intracerebral mass. Patients without neurological damage (Traumatic Brain Injury-Aneurysm, Spontaneous Subarachnoid or Intracranial Bleeding), those without acute Cerebrovascular Syndromes (Ischemic cerebrovascular event, Transient Ischemic Attack) and patients with hypertensive attack during admission (headache, dizziness, etc.) were included in our study. Patients under 18 years of age, those with acute neurological damage, patients with intracranial pathologies mentioned in the inclusion criteria, and those allergic to the antihypertensive treatment to be given were excluded from the study.

Cerebral Oximetry Measurements

The socio-demographic data (age, gender, admission date and time) of the patients were recorded. The first blood pressure measured at rest was recorded. The treatment of all patients was initiated immediately according to the current hypertension treatment guidelines. INVOS 5100C Cerebral Somatic Oximeter monitor was used. NIRS measurements were performed with electrodes attached to the bilateral frontal region. In this application, a source with low frequency modulation such as a light-emitting diode or a continuous-intensity laser and a detection device that can detect these attenuations are used. It measures the balance between oxygen delivery and oxygen consumption in the tissue, called fractional tissue oxygen extraction.[7] After cleaning the patient's frontal area, the physician placed the probes. The NIRS values measured in the meantime were called as $RrSO_2$ in the right lobe of the brain and $LrSO_2$ in the left lobe, and the first measurements were accepted as zero-minute measurements. The medication used in the treatment of the patients were randomly selected according to their comorbidity history. Blood pressure, brain right and left lobe oxygenation were recorded simultaneously at the fifteenth minute of the treatment. All measurements were recorded simultaneously with the blood pressure measurement at the 0th, 15th, 30th and 60th minutes.

Ethical Approval

The study was approved by the local ethics committee.

Statistical Analysis

Descriptive statistics were used primarily for all the study data. Repeated Measures were tested with Analysis of Variance. Time-dependent changes of numerical variables were analyzed with Friedman Test. Mann Whitney U test was used to analyze the differences between the measurement values of the two groups. Spearman Correlation Test was used to analyze whether there was a correlation between the time-dependent changes of two different numerical variables. The difference between time-dependent measurements was analyzed using the Kruskal Wallis Test. *P* value of 0.05 was considered significant. Analyses were performed using SPSS 18.00 (SPSS, Chicago, IL).

Reporting Guidelines

This study was reported in accordance with the STROBE guideline.

Results

A total of 54 patients were included in our study. 19(35.2%) of the patients were female and 35(64.8%) male. Of 54 patients, 33(61.1%) had Hypertension, 15(27.8%) had Diabetes Mellitus, 12(22.2%) had Ischemic Heart Disease, 11(20.4%) had Chronic Renal Failrue, and 11(20.4%) had Chronic Obstructive Pulmonary Disease. In antihypertensive treatment, esmolol was used in 9(16.7%) patients, nicardipine in 9(16.7%) patients, and nitroglycerin in 36(66.7%) patients.

The mean SBP of the patients during admission was 208.94 ± 13.33 (range: 180-250), DBP 108.91 ± 11.82 (range: 85-150); in this case, the mean right hemisphere RsO_2 was 58.52 ± 8.96 (range: 44-79) and the mean left hemisphere LsO_2 was 58.93 ± (range: 47-81). Measurements at 15, 30, and 60 minutes are shown in Table 1.

15th minute, 30th minute and 60th minute measurements of SBP were found to be lower than the first SBP measurement ($P < .001$).

Table 1. Descriptive Statistics for Numerical Variables

	n	Avg ± SD	Range	Q1	Q3
AGE	54	62.19 ± 13	35-84	53	73
SBP	54	208.94 ± 13.3	180-250	200	218
SBP_15	54	193.87 ± 12.4	160-221	186	200
SBP_30	54	183.69 ± 12.6	146-211	175	192
SBP_60	54	173.07 ± 10.2	140-198	168	179
DBP	54	108.91 ± 11.9	85-150	102	116
DBP_15	54	103.22 ± 11.8	80-140	95	112
DBP_30	54	96.87 ± 11	80-135	88	102
DBP_60	54	91.5 ± 9.2	75-126	83	95
RrSO2	54	58.52 ± 9	44-79	51	65
RrSO2_15	54	59.17 ± 9.1	42-73	51	65
RrSO2_30	54	57.98 ± 8.6	43-78	50	65
RrSO2_60	54	57.57 ± 9.6	42-81	49	65
LrSO2	54	58.93 ± 8.4	47-81	52	64
LrSO2_15	54	59.48 ± 8.2	48-75	53	66
LrSO2_30	54	59.28 ± 8.1	45-77	52	65
LrSO2_60	54	59.35 ± 8.9	44-77	52	67
0.dk MAP	54	142.2 ± 10.7	121.33-183.3	135	149.6
60.dk MAP	54	118.69 ± 8.6	97.3-150	112	123.3
Decrease	54	16.43 ± 4.5	9.7-30.5	13.3	18.5

In addition, 30th minute SBP was found to be lower than the 15th minute SBP, while the 60th minute SBP was found to be lower than the 30th minute SBP ($P < .001$) No statistically significant difference was found in time-dependent changes in both values (Table 2).

There was a statistically significant difference between the first measurement of DBP and the oxygenation of both the right and left lobes of the brain ($P < .05$). As diastolic blood pressure decreased, brain oxygenation increased. There was a moderate negative correlation between the first measurement of DBP and $RrSO_2$_0th and $LrSO_2$_30th minutes, and a slight negative correlation with other rSO_2s. It was seen that the higher the initial measurement of DBP, the lower the oxygenation of the brain detected. Except for the 15th minute value of the left lobe, there was a weak negative correlation between the 30th minute measurement of DBP and the oxygenation of both the right and left lobes of the brain, which was statistically significant. No statistical significance was found between all measurements of SBP and both right and left brain oxygenation. Moreover, there was no correlation between these measurements and oxygenation (Table 3).

Discussion

According to the results of our study, although there was a relationship between diastolic blood pressure changes and brain oxygenation, no relationship was detected in terms of systolic blood pressure changes. We are of the opinion that diastolic blood pressure changes will affect cerebral autoregulation and change brain oxygenation. Evaluation of cerebral autoregulation (CA) is often used in experimental investigations and in the diagnosis, monitoring or prognosis of cerebrovascular disease; however, despite the widespread use and references of static CA, a valid "normal" CA amount has not been clearly defined. Lucas et al. described the first clear examination of static CA over a wide range of blood pressure in healthy people. They evaluated blood pressure from the radial artery, middle cerebral artery blood flow by ultrasound and cerebral oxygenation by NIRS. With the pharmacological agents they administered, they evaluated the relationship between cerebral blood flow and cerebral oxygenation in hypertension and hypotension cases.[8]

Table 2. Time-Dependent Change of LrSO2 and RrSO2

X	*n*	Median	Min-max	Q1	Q3	*P*
LrSO2	54	58	47-81	52	64	.658
LrSO2_15	54	59.5	48-75	53	66	
LrSO2_30	54	58	45-77	52	65	
LrSO2_60	54	58	44-77	52	67	
RrSO2	54	58	44-79	51	65	.099
RrSO2_15	54	61	42-73	51	65	
RrSO2_30	54	57.5	43-78	50	65	
RrSO2_60	54	57	42-81	49	65	

It was analyzed with the Friedman Test.

In previous studies on cerebral oxygenation, no relationship was established between blood pressure and middle cerebral artery (MCA) diameter i.e. cerebral blood flow.[9] However, after years, a study that opposed these studies argued that the blood-brain barrier would be disrupted, and cerebral blood flow and cerebral autoregulation would change in case of hypertension. The main limitation of all these studies was that MCA diameter measurements were not reliable. In none of these studies, MCA blood flow was measured by ultrasound. Lassen et al. argued that brain blood flow did not change when MAP was between 60-150 mm Hg. They claimed that the arterioles in the brain stabilized the brain blood flow by adapting to the MAP changes.[10] Lucas et al. conducted the most important study in this regard. In this study similar to our study, MCA current was evaluated with ultrasound and brain oxygenation with NIRS. They found that as the MAP increased MCA current also increased, but brain oxygenation decreased.

Our study is the largest-scale study in the literature evaluating brain oxygenation in blood pressure changes. Although the physiological mechanism of cerebral autoregulation is not fully understood, we think NIRS technology is effective in non-invasively measuring dynamic cerebral autoregulation and we consider it may be useful in the management of patients under anesthesia, intensive care patients and diseases such as stroke where cerebral blood flow and oxygen supply are important. Our main expectation was that the saturation that we evaluated from both lobes of the brain would be lower in the patients with hypertension, and saturation would be increased as the hypertensive condition improved. Indeed, we observed this in many of the patients. However, the difference was not big enough to create any statistical significance. Therefore, we believe that the best way to prove the hypothesis of our study is to measure the saturation of our patients with hypertension in the case of hypertension and when their basal blood pressure values are reached.

Table 1. Correlation between blood pressure and brain oxygenation

		RrSO2 0th	RrSO2 15th	RrSO2 30th	RrSO2 60th	LrSO2 0th	LrSO2 15th	LrSO2 30th	LrSO2 60th
SBP	*r*	0.036	0.151	0.202	0.131	0.04	0.046	0.069	0.123
	p	.795	.275	.144	.346	.776	.742	.622	.375
SBP_15	*r*	–0.192	–0.05	–0.037	–0.058	–0.17	–0.149	–0.182	–0.138
	p	.163	.718	.791	.678	.22	.282	.189	.32
SBP_30	*r*	–0.232	–0.182	–0.105	–0.104	–0.21	–0.248	–0.232	–0.165
	p	.091	.187	.451	.453	.128	.07	.091	.233
SBP_60	*r*	–0.238	–0.196	–0.16	–0.09	–0.191	–0.256	–.273*	–0.17
	p	.083	.156	.248	.519	.166	.062	.046	.218
DBP	*r*	–.432**	–.358**	–.350**	–.387**	–.355**	–.355**	–.435**	–.387**
	p	.001	.008	.009	.004	.008	.008	.001	.004
DBP_15	*r*	–.286*	–0.205	–0.217	–0.236	–0.267	–0.188	–.269*	–0.261
	p	.036	.137	.115	.086	.051	.174	.049	.057
DBP_30	*r*	–.345*	–.320*	–.281*	–.309*	–.340*	–0.267	–.281*	–.300*
	p	.011	.018	.04	.023	.012	.051	.04	.028
DBP_60	*r*	–0.195	–0.102	–0.138	–0.099	–0.186	–0.072	–0.14	–0.106
	p	.158	.462	.319	.478	.179	.603	.313	.448
0th MAP	*r*	–0.266	–0.165	–0.142	–0.213	–0.212	–0.201	–.280*	–0.221
	p	.052	.234	.305	.122	.124	.146	.04	.109
60th MAP	*r*	–0.241	–0.141	–0.163	–0.11	–0.205	–0.127	–0.196	–0.132
	p	.079	.309	.24	.428	.138	.362	.157	.34

It was analyzed with the Spearman correlation test.

Limitations

The most important limitation of our study is that the basal blood pressure of the patients is not known. When we reach the target blood pressure values in these patients who have low basal blood pressure and present with hypertensive crisis, the patients may still be in a hypertensive state. If brain oxygenation of the patients were measured in hypertensive state and when it reached normal basal values, brain oxygenation measurements could be different. Since our main objective was to use NIRS to monitor brain oxygenation in the acute phase of hypertensive crises, we made our measurements up to 1 hour. We believe that our hypothesis will be supported by long-term NIRS monitoring. Another limitation was that carotid Doppler flow was not measured. Proving the difference between the carotid Doppler ultrasound findings during the attack and blood pressure reduction would have made our study stronger.

Conclusion

According to the findings of our study, diastolic blood pressure changes in hypertensive attacks affect brain oxygenation. It is difficult to state that NIRS can be used as a monitoring tool in hypertensive attacks in the acute phase. However, further research with long-term NIRS monitoring in these patients may support our hypothesis and reveal that NIRS can be used as a monitoring method.

Declarations

Animal and Human Rights Statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No animal or human studies were carried out by the authors for this article.

Informed Consent

Informed consent was obtained from all participants.

Data Availability

The datasets used and/or analyzed during the current study are not publicly available due to patient privacy reasons but are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that there is no conflict of interest.

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None.

Abbreviations

CA: Cerebral autoregulation
CCO: Cytochrome-c oxidase
DBP: Diastolic blood pressure
DOI: Diffuse optical imaging
DOS: Diffuse optical spectroscopy
HHb: Deoxyhemoglobin
HR: Heart rate
HT: Hypertension
$LrSO_2$: Left regional cerebral oxygen saturation
MAP: Mean arterial pressure
MCA: Middle cerebral artery
NIR: Near-infrared
NIRS: Near-infrared spectroscopy
O_2Hb: Oxyhemoglobin
$RrSO_2$: Right regional cerebral oxygen saturation
SaO_2: Arterial oxygen saturation
SBP: Systolic blood pressure

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