Evaluation of the Cardiac Functions With Tissue Doppler Before and After Hyperbaric Oxygen Therapy of Patients Withcarbonmonoxide Poisoning

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Abstract

Objective: We aimed to determine whether systolic and diastolic functions of patients who presented to the pediatric emergency clinic because of carbonmonoxide poisoning and were treated with hyperbaric oxygen therapy, were examined with tissue doppler imaging method before and after the treatment.

Materials and Methods: Between January 2019-January 2021, 34 patients who presented to the pediatric emergency clinic because of carbonmonoxide poisoning and were treated with hyperbaric oxygen, and 34 healthy children who presented to the pediatric cardiology clinic as the control group were included. The study was performed prospectively.

Results: The mean age of patients was 10.95 ± 4.75 years. 21 patients (61.8%) were female. 21 patients (61.8%) presented with natural gas poisoning. The most common complaint at admission to the hospital was loss of consciousness with 41.2%. The mean carboxyhemoglobin of the patients after carbonmonoxide poisoning was found to be 21.70±6.45. After one session of hyperbaric oxygen therapy, the mean carboxyhemoglobin was found to be 0.74±0.34. The mean troponin-I level of the patients was 114.81±197.76 after carbonmonoxide poisoning and 42.32±118.36 after one session of hyperbaric oxygen therapy. In the tissue doppler imaging of the patients, the isovolemic relaxation time and myocardial performance index were higher in the group evaluated before hyperbaric oxygen therapy; ejection time was found to be shorter.

Conclusions: Systolic and diastolic dysfunctions were found in the cardiac evaluation of patients who presented with carbonmonoxide poisoning and were treated with hyperbaric oxygen. It has been demonstrated echocardiographically that this dysfunction is reversible with hyperbaric oxygen therapy.

INTRODUCTION

Severe cardiac involvement, ranging from mild and transient damage to necrosis and contractile dysfunction, was first described by Klebs in 1865 in patients with carbonmonoxide (CO) poisoning. Besides the hypoxic injury exacerbated by the high sensitivity of myocardial tissue to oxygen deprivation, increased contractility, decreased amount of coronary blood flow, and inhibition of cardiomyocyte respiration, CO causes additional myocardial injury mostly by cardiospecific mechanisms that can cause direct damage at the cellular or subcellular level [1]. Mild to moderate abnormalities in left ventricular structure, as well as the development of myocardial fibrosis, are another possible result of CO poisoning [2]. The ischemic damage to the heart and other highly oxygen-sensitive tissues is exacerbated by peripheral circulatory failure and hypotension that follows the deterioration of heart function. Cardiac decompensation also impairs tissue oxygenation and is the leading cause of death in severely CO poisoned patients [1,3].

Hyperbaric oxygen therapy (HBOT) is the treatment of choice for patients with significant CO exposure ADDIN CSL_CITATION {"citationItems":[{"id":"ITEM-1","itemData":{"author":[{"dropping-particle":"","family":"Thom","given":"Stephen R.","non-dropping-particle":"","parse-names":false,"suffix":""},

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MATERIALS AND METHODS

In this study, 34 patients who presented to the Pediatric Emergency Clinic because of CO poisoning and were treated with HBOT between January 2019-January 2021 were included. The patients were screened prospectively and their age, gender, clinical findings; 12-lead electrocardiography (ECG) findings, conventional echocardiography (ECHO) findings, hemogram, biochemistry, blood gas and cardiac markers detected before and after HBOT were recorded. Control ECHO and tissue Doppler (TD) imaging were performed approximately 4–6 hours after HBOT. The control group included in the study was selected from healthy individuals who presented to the pediatric cardiology clinic, and from a population similar to the mean age and gender distribution of the patient group.

Echocardiographic examination was performed using the 'GE Vivid S60N, United States' device and 3-MHz transducer. Early diastolic E waves and late diastolic A waves were measured with pulse wave Doppler. TD measurements were recorded from the lateral edge of the mitral and tricuspid annulus and from the septum. Velocities (e, a, s) and time intervals (isovolemic relaxation time (IVRT), isovolemic contraction time (IVCT), ejection time (ET)) were then obtained. Myocardial Performance Index (MPI) was calculated.

Research data were analyzed in the IBM SPSS 25.0 (SPSS Inc., Chicago, IL, USA) statistical program. Descriptive findings in the study are shown with numbers, percentages, mean and standard deviation values. Whether the research data were normally distributed or not was examined according to the Shapiro Wilk test values. In determining the analysis tests to be used, the sample numbers of the groups

to be compared were taken into account, as well as the normality assessment. Non-parametric tests were used for group comparisons with less than 30 samples. The t test was used to compare two independent variables that met the parametric assumptions, and the Mann Whitney U test was used to compare two independent variables that did not meet the parametric assumptions. ANOVA test was used to compare more than two independent variables that met the parametric assumptions, and the Kruskal Wallis test was used to compare more than two independent variables that did not meet the parametric assumptions. Bonferroni-corrected p values were taken into account in multiple comparison tests. Paired t-test was used to compare two dependent (paired) variables that met parametric assumptions, and Wilcoxon signed-rank test was used to compare two dependent (paired) variables that did not meet parametric assumptions. Chi-square test was used to compare categorical variables. Values with $p < 0.05$ in the analyzes were considered statistically significant.

The study was conducted according to the recommendations set forth in the Declaration of Helsinki on Biomedical Research Involving Human Subjects. Written informed consent was obtained from the parents of each subject.

RESULTS

Of the 34 patients included in the study, 13 (38.2%) were male and 21 (61.8%) were female. The gender distribution of the control group was 16 (47.1%) boys and 18 (52.9%) girls. The mean age at diagnosis of the patients was 10.95 ± 4.75 years. The mean age of the control group was 10.55 ± 5.18 years. There was no statistically significant difference between the patient and control groups in terms of age and gender distribution. 21 patients (61.8%) were presented to the pediatric emergency department due to natural gas poisoning and 13 patients (38.2%) due to stove poisoning. The loss of consciousness in 14 patients (41.2%), dizziness in 12 patients (35.3%), vomiting in 7 patients (20.6%), and inability to walk in 1 patient (2.9%) were examined.

The test results of the comparison of cardiac enzyme parameters of the patient group before and after treatment are presented in Table 1. According to these findings, a statistically significant difference was found in the mean Troponin-I and Creatine Kinase-MB (CK-MB) levels ($p < 0.05$). It was observed that the mean B-type Natriuretic Peptide (BNP) of the patients before the treatment was higher than after the treatment, but there was no statistically significant difference.

Table 1
Comparison of Cardiac Enzyme Parameters of the Patient Group Before and After Treatment

Parameter	Median	Minimum	Maximum	Mean	SD	P
PrT-TROP	2,5	1,0	788,0	114,81	197,76	**0,026**
PsT-TROP	1,5	1,0	509,0	42,32	118,36	
PrT-CKMB	1,55	1,0	199,0	18,39	45,84	**0,04**
PsT-CKMB	1,42	0,26	5,41	1,62	0,90	
PrT -BNP	52	26	7721	350,26	1344,11	0,308
PsT -BNP	35	15	2390	122,62	404,25	

PrT: Pre-treatment, PsT: Post-treatment, TROP: Troponin-I, CKMB: Creatine Kinase-MB, BNP: B-type Natriuretic Peptide, SD: Standard Deviation, P: Pre-post treatment comparison

Left ventricular (LV) functions with TD of the patients before and after treatment and the control group were compared (Table 2). A statistically significant difference was found between the LVE, LVIRT, LVET, LVMPI variables before and after treatment ($p < 0.05$). It was determined that the post-treatment values in the LVE and LVET variables were higher than before the treatment, and the pre-treatment values in the LVIRT and LVMPI variables were higher than after the treatment. A statistically significant difference was found in the LVS, LVE, LVA, LVIRT, LVET and LVMPI variables in the comparison between the pre-treatment and control groups ($p < 0.05$). In LVE and LVET variables, the mean of the control group was higher than before the treatment; LVS, LVA, LVIRT and LVMPI variables were found to be higher than the control group before treatment. A statistically significant difference was found in the LVA, LVIRT, LVET and LVMPI variables in the comparison between the post-treatment and control groups ($p < 0.05$). LVET variable was higher in the control group than after treatment; LVA, LVIRT and LVMPI variables were found to be higher than the control group after treatment.

Table 2
Comparison of Tissue Doppler Echocardiography and Left Ventricular Functions of the patient group before treatment, after treatment in the patient group, and in the control group

Parameter	Minimum	Maximum	Mean	SD	P
PrT -LVS	5	15	9,59	2,27	P_1: 0,232
PsT -LVS	5	16	10,41	2,76	**P_2: 0,001**
C-LVS	7	13	9,26	1,52	P_3: 0,103
PrT -LVE	11	17	13,82	1,58	**P_1: 0,001**
PsT -LVE	10	21	17,03	2,41	**P_2: 0,001**
C-LVE	11	21	16,21	2,40	P_3: 0,201
PrT -LVA	6	13	9,38	1,84	P_1: 0,319
PsT -LVA	5	13	9,00	2,07	**P_2: 0,001**
C-LVA	4	9	6,74	1,26	**P_3: 0,001**
PrT -LVICT	30	65	48,21	9,97	P_1: 0,272
PsT -LVICT	25	61	50,26	7,64	P_2: 0,936
C-LVICT	34	60	48,41	7,42	P_3: 0,182
PrT -LVIRT	38	72	59,29	7,84	**P_1: 0,001**
PsT -LVIRT	33	57	47,26	5,43	**P_2: 0,001**
C-LVIRT	21	53	37,59	9,60	**P_3: 0,001**
PrT -LVET	161	320	233,79	38,29	**P_1: 0,001**
PsT -LVET	190	384	263,12	38,54	**P_2: 0,001**
C-LVET	248	358	287,41	22,83	**P_3: 0,002**
PrT -LVMPI	0,25	0,62	0,445	0,080	**P_1: 0,001**
PsT -LVMPI	0,25	0,48	0,376	0,061	**P_2: 0,001**
					P_3: 0,001

PrT: Pre-treatment, PsT: Post-treatment, C: Control group, LV: Left Ventricle, S: s velocity, E: e velocity, A: a velocity, ICT: Isovolemic Contraction Time, IRT: Isovolemic Relaxation Time, ET: Ejection Time, MPI: Myocardial Performance Index, SD: Standard deviation, P_1: Comparison of patient group before and after treatment, P_2: Comparison of the patient group with the control group before treatment, P_3: Comparison of the patient group after treatment with the control group

Parameter	Minimum	Maximum	Mean	SD	P
C-LVMPI	0,17	0,38	0,273	0,054	

PrT: Pre-treatment, PsT: Post-treatment, C: Control group, LV: Left Ventricle, S: s velocity, E: e velocity, A: a velocity, ICT: Isovolemic Contraction Time, IRT: Isovolemic Relaxation Time, ET: Ejection Time, MPI: Myocardial Performance Index, SD: Standard deviation, P_1: Comparison of patient group before and after treatment, P_2: Comparison of the patient group with the control group before treatment, P_3: Comparison of the patient group after treatment with the control group

Right ventricular (RV) functions with TD of the patients before and after treatment and the control group were compared (Table 3). Statistically significant difference was found between before and after treatment in RVIRT, RVET, RVMPI variables ($p < 0.05$). The RVET variable was higher in patients after treatment than in patients before treatment; RVIRT and RVMPI variables were found to be higher in pre-treatment patients than post-treatment patients. When the patients before the treatment were compared with the control group, a statistically significant difference was found between the two groups in the variables of RVICT, RVIRT, RVET and RVMPI ($p < 0.05$). RVICT, RVIRT and RVMPI variables were higher in pre-treatment patients than in the control group; the RVET variable was found to be higher in the control group than in the patients before the treatment. A statistically significant difference was found in the RVET and RVMPI variables between the patients after treatment and the control group ($p < 0.05$). The RVET variable was higher in the control group than in the post-treatment patients; the RVMPI variable was found to be higher in patients after treatment than in the control group.

Table 3
Comparison of Tissue Doppler Echocardiography and Right Ventricular Functions of the patient group before treatment, after treatment in the patient group, and in the control group

Parameter	Minimum	Maximum	Mean	SD	P
PrT -RVS	3	21	12,09	4,20	P_1: 0,359
PsT -RVS	10	19	12,76	2,13	P_2: 0,120
C-RVS	8	18	11,88	2,30	P_3: 0,091
PrT -RVE	6	22	15,53	3,34	P_1: 0,451
PsT -RVE	10	27	16,03	3,11	P_2: 0,296
C-RVE	11	20	15,21	2,32	P_3: 0,350
PrT -RVA	3	16	8,79	2,71	P_1: 0,301
PsT -RVA	6	14	9,38	2,16	P_2: 0,200
C-RVA	6	13	8,82	1,93	P3: 0,242
PrT -RVICT	4	76	50,79	16,03	P_1: 0,064
PsT-RVICT	30	85	56,00	12,84	**P_2: 0,001**
C-RVICT	38	68	50,71	6,12	P_3: 0,089
PrT -RVIRT	26	65	47,65	10,76	**P_1: 0,014**
PsT-RVIRT	24	58	42,12	8,97	**P_2: 0,001**
C-RVIRT	27	58	45,41	7,33	P_3: 0,170
PrT -RVET	177	320	232,76	34,54	**P_1: 0,035**
PsT -RVET	157	366	250,09	35,03	**P_2: 0,001**
C-RVET	211	346	292,47	26,90	**P_3: 0,001**
PrT-RVMPI	0,27	0,59	0,423	0,089	**P_1: 0,018**
PsT-RVMPI	0,19	0,51	0,379	0,071	**P_2: 0,001**
					P_3: 0,001

PrT: Pre-treatment, PsT: Post-treatment, C: Control group, RV: Right Ventricle, S: s velocity, E: e velocity, A: a velocity, ICT: Isovolemic Contraction Time, IRT: Isovolemic Relaxation Time, ET: Ejection Time, MPI: Myocardial Performance Index, SD: Standard deviation, P_1: Comparison of patient group before and after treatment, P_2: Comparison of the patient group with the control group before treatment, P_3: Comparison of the patient group after treatment with the control group

Parameter	Minimum	Maximum	Mean	SD	P
C-RVMPI	0,16	0,38	0,257	0,065	

PrT: Pre-treatment, PsT: Post-treatment, C: Control group, RV: Right Ventricle, S: s velocity, E: e velocity, A: a velocity, ICT: Isovolemic Contraction Time, IRT: Isovolemic Relaxation Time, ET: Ejection Time, MPI: Myocardial Performance Index, SD: Standard deviation, P_1: Comparison of patient group before and after treatment, P_2: Comparison of the patient group with the control group before treatment, P_3: Comparison of the patient group after treatment with the control group

Statistically significant difference was found in IVSS, IVSE, IVSA, IVSICT, IVSIRT, IVSMPI variables when comparing interventricular septum (IVS) functions before and after treatment ($p < 0.05$) (Table 4). IVSS, IVSE, IVSICT variables were higher after treatment than before treatment; IVSA, IVSIRT and IVSMPI variables were found to be higher before treatment than after treatment. A statistically significant difference was found in the IVSE, IVSIRT, IVSET and IVSMPI variables in the comparison of the patients before the treatment and the control group ($p < 0.05$). IVSE and IVSET variables were higher in the control group than in the patients before treatment; IVSIRT and IVSMPI variables were found to be higher in patients before treatment than in the control group. A statistically significant difference was found in the IVSIRT, IVSET and IVSMPI variables in the comparison of the patients after treatment and the control group ($p < 0.05$). IVSET variable was higher in the control group than the patients after treatment; IVSIRT and IVSMPI variables were found to be higher in patients after treatment than the control group.

Table 4
Comparison of Tissue Doppler Echocardiography and Interventricular Septum Functions of the patient group before treatment, after treatment in the patient group, and in the control group

Parameter	Minimum	Maximum	Mean	SD	P
PrT -IVSS	5	17	7,74	2,55	**P_1: 0,012**
PsT -IVSS	5	14	9,32	2,43	P_2: 0,682
C-IVSS	6	14	8,68	2,04	P_3: 0,249
PrT -IVSE	8	16	12,06	2,10	**P_1: 0,001**
PsT -IVSE	11	19	14,62	1,97	**P_2: 0,030**
C-IVSE	11	19	14,00	2,07	P_3: 0,174
PrT -IVSA	4	13	8,26	2,27	**P_1: 0,004**
PsT -IVSA	4	11	6,82	1,38	P_2: 0,172
C-IVSA	5	12	6,85	1,84	P_3: 0,374
PrT-IVSICT	30	58	43,21	8,43	**P_1: 0,001**
PsT-IVSICT	25	68	52,56	9,81	P_2: 0,079
C-IVSICT	34	58	46,24	5,89	P_3: 0,190
PrT-IVSIRT	30	65	51,03	8,81	**P_1: 0,001**
PsT-IVSIRT	34	58	45,38	6,42	**P_2: 0,001**
C-IVSIRT	19	55	39,47	8,87	**P_3: 0,030**
PrT -IVSET	134	316	247,56	43,61	P_1: 0,218
PsT -IVSET	183	289	237,82	26,27	**P_2: 0,001**
C-IVSET	146	314	262,41	36,14	**P_3: 0,036**
PrT-IVSMPI	0,24	0,59	0,416	0,074	**P_1: 0,002**
PsT-IVSMPI	0,26	0,48	0,366	0,051	**P_2: 0,001**
					P_3: 0,001

PrT: Pre-treatment, PsT: Post-treatment, C: Control group, IVS: Interventricular Septum, S: s velocity, E: e velocity, A: a velocity, ICT: Isovolemic Contraction Time, IRT: Isovolemic Relaxation Time, ET: Ejection Time, MPI: Myocardial Performance Index, SD: Standard deviation, P_1: Comparison of patient group before and after treatment, P_2: Comparison of the patient group with the control group before treatment, P_3: Comparison of the patient group after treatment with the control group

Parameter	Minimum	Maximum	Mean	SD	P
C-IVSMPI	0,19	0,38	0,271	0,051	

PrT: Pre-treatment, PsT: Post-treatment, C: Control group, IVS: Interventricular Septum, S: s velocity, E: e velocity, A: a velocity, ICT: Isovolemic Contraction Time, IRT: Isovolemic Relaxation Time, ET: Ejection Time, MPI: Myocardial Performance Index, SD: Standard deviation, P_1: Comparison of patient group before and after treatment, P_2: Comparison of the patient group with the control group before treatment, P_3: Comparison of the patient group after treatment with the control group

DISCUSSION

Despite normal coronary arteries, right and left ventricular dysfunction may occur in patients with CO poisoning [6]. Acute CO exposure causes a direct negative inotropic effect, causing an increase in left ventricular end-diastolic pressures and a decrease in stroke volume [7]. However, persistent myocardial dysfunction has also been reported after acute CO poisoning. In a study in which patients with CO poisoning participated, ECHO was performed and BNP and COHb levels were measured in all patients and it was observed that left ventricular ejection fraction (LVEF) showed a negative correlation with COHb level and CO exposure time [8]. It was concluded that the degree of left ventricular dysfunction depends on COHb levels and CO exposure time [7]. In combination with conventional ECHO, TD ECHO is an accepted, practical, safe and non-invasive method for diagnosing left and right ventricular systolic and diastolic functions. A few studies have demonstrated that even mild CO poisoning causes acute adverse effects on left and right ventricular function in adults, which can be demonstrated by ECHO [9]. Prolonged exposure to CO or high COHb levels are associated with transient myocardial injury, usually lasting less than 24 hours and manifested by a decrease in LVEF.

Typical presenting complaints after CO poisoning include headache, dizziness, and nausea [10]. In our study, it was determined that the most common finding during admission was loss of consciousness. Since patients who underwent HBOT were included in our study, it is not surprising that the most common complaint at presentation was loss of consciousness. It can be thought that this situation is related to the fact that loss of consciousness is a common treatment indication for the application of HBOT.

CO poisoning can cause reversible or irreversible myocardial damage through myocardial hypoxia and direct toxic effects. In our study, a significant decrease was observed in Troponin-I and CK-MB levels, which were measured at admission, after one session of HBOT. It was observed that there was a decrease in BNP level after one session of HBOT, but this decrease was not significant. It has been shown in previous studies that there may be an increase in myocardial enzymes [11]. In the study of Kalay et al., it was shown that cardiac abnormalities improved rapidly in patients with high cardiac markers in CO poisoning. It has been stated that BNP is a sensitive marker to define cardiac dysfunction and negatively correlates with LV dysfunction [8]. In the study of Ozyurt et al. in children with CO poisoning, Troponin-I and CK-MB levels were found to be elevated, and it was stated that there was a statistically significant

decrease in both enzyme levels after 24 hours [9]. In a study conducted by Cha et al. in 2015 with adult patients, it was found that creatine kinase (CK), CK-MB, Troponin-I and BNP levels were higher in patients with myocardial injury than in the group without myocardial injury [12]. In our study, the significant decrease in patients' Troponin-I and CK-MB levels after one session of HBOT suggests that cardiac involvement in CO poisoning is related to the rapid response to treatment. In the follow-up of patients whose cardiac enzyme elevation continued after one session of HBOT, enzyme levels were found to regress to normal, and no cardiological complications were observed in any of the patients. The lack of sufficient decrease in BNP levels after HBOT, which was high at the first admission, suggests that although BNP is a cardiac sensitive marker, it is related to the fact that it is an indicator of left ventricular enlargement rather than left ventricular systolic dysfunction.

Echocardiography is a preferred method in diastolic function studies because it is a noninvasive method and can be applied easily [13]. In a study by Henry et al, global LV dysfunction and regional wall abnormality were found in 57% of the patients who applied due to CO poisoning, and right ventricular dysfunction was found in 34% of the patients [14]. In our study, TD parameters were compared by dividing them into 3 regions as LV, RV and IVS. It was observed that diastolic dysfunction developed after CO poisoning in all 3 regions of the patients and there was a significant improvement in these findings after one session of HBOT. However, when the data of the patient group after HBOT were compared with the control group, it was found that diastolic dysfunction continued compared to the control group. In addition, in the examination of these regions, the fact that ET was shorter at admission than after treatment and in the post-treatment patient group compared to the control group indicates that systolic dysfunction has developed. It is observed that systolic dysfunction also improved with one session of HBOT, but continued compared to the control group. In the literature, studies on the evaluation of the effects of CO poisoning on diastolic functions in children with TD are limited. In the study of Ozyurt et al. with CO poisoning in children, low mitral E wave velocity and high left ventricular MPI values were found in patients. A statistically significant difference was found in the MPI values of the patients before and after admission, and it was shown that left ventricular systolic and diastolic dysfunction in the patients could resolve spontaneously without HBOT [9]. In the study of Ciftci et al. on adult patients exposed to mild CO poisoning, left ventricular systolic dysfunction was not found. In this study, it was found that MPI did not change significantly after mild CO poisoning, but was significantly higher after CO poisoning than 1 week after poisoning [15].

CONCLUSION

When we classified our study according to the COHb level, it showed that moderate CO poisoning may also have negative effects on the systolic and diastolic functions. The reason for this situation can be shown as the sensitivity of myocardial tissue to CO inhalation in children. We showed that the negative effects of CO poisoning on the myocardium were significantly regressed after one session of HBOT compared to the pre-treatment period, using the TD method in which regional myocardial functions can be evaluated. However, when the post-treatment group was compared with the control group, it was observed that the effect still continued. Since control imaging was performed in the early period after

HBOT, it is thought that diastolic deterioration continues and complete recovery has not occurred yet. It should not be forgotten that systolic and diastolic dysfunction can be seen in patients presenting with CO poisoning, even without elevated cardiac enzymes or ECG disturbances.

STUDY LIMITATIONS

Our study is the first to evaluate cardiac functions with TD ECHO in children who presented with CO poisoning and needed HBOT. The limitation of this study is the relatively small number of patients included in the study. Long-term follow-up of the patients could not be performed. It is thought that the findings will completely return to normal in the long-term follow-up. Detailed cardiac function could not be evaluated with advanced cardiac imaging systems such as cardiac magnetic resonance imaging due to difficulties in application, expensive examination and time constraints.

Declarations

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Ahmet B2urak Şimşek], [Hazım Alper Gursu] . The first draft of the manuscript was written by [Ahmet Burak Şimşek] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Compliance with Ethical Standards

The authors have no relevant financial or non-financial interests to disclose.

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All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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References

1. Lippi G, Rastelli G, Meschi T, Borghi L, Cervellin G. Pathophysiology, clinics, diagnosis and treatment of heart involvement in carbon monoxide poisoning. Clin Biochem. 2012;45(16–17):1278–85.
2. Thom SR, Fisher D, Xu YA, Garner S, Ischiropoulos H. Role of nitric oxide-derived oxidants in vascular injury from carbon monoxide in the rat. Am J Physiol. 1999;276(3):984–92.
3. Andre L, Boissiere J, Reboul C, Perrier R, Zalvidea S, Meyer G, et al. Carbon monoxide pollution promotes cardiac remodeling and ventricular arrhythmia in healthy rats. Am J Respir Crit Care Med. 2010;181(6):587–95.

4. Thom SR, Mendiguren I, Hardy K, Bolotin T, Fisher D, Nebolon M, et al. Inhibition of human neutrophil beta2-integrin-dependent adherence by hyperbaric oxygen. Am J Physiol. 1997;272(3):770–7.
5. Thom SR. Antagonism of carbon monoxide-mediated brain lipid peroxidation by hyperbaric oxygen. Toxicol Appl Pharmacol. 1990;105(2):340–4.
6. Hampson NB, Piantadosi CA, Thom SR, Weaver LK. Practice recommendations in the diagnosis, management, and prevention of carbon monoxide poisoning. Am J Respir Crit Care Med. 2012;186(11):1095–101.
7. Garg J, Krishnamoorthy P, Palaniswamy C, Khera S, Ahmad H, Jain D, et al. Cardiovascular abnormalities in carbon monoxide poisoning. Am J Ther. 2014;25(3):339–48.
8. Kalay N, Ozdogru I, Cetinkaya Y, Eryol NK, Dogan A, Gul I, et al. Cardiovascular effects of carbon monoxide poisoning. Am J Cardiol. 2007;99(3):322–4.
9. Ozyurt A, Karpuz D, Yucel A, Tosun MD, Kibar AE, Hallioglu O. Effects of Acute Carbon Monoxide Poisoning on ECG and Echocardiographic Parameters in Children. Cardiovasc Toxicol. 2017;17(3):326–34.
10. Nelson LS, Lewin NA, Howland MA, Hoffman RS, Goldfrank LR, Flomenbaum NE. Carbon Monoxide. In: Goldfrank's Toxicologic Emergencies 9th Edition. 2011. p. 1658–71.
11. Satran D, Henry CR, Adkinson C, Nicholson CI, Bracha Y, Henry TD. Cardiovascular manifestations of moderate to severe carbon monoxide poisoning. J Am Coll Cardiol. 2005;45(9):1513–6.
12. Cha YS, Cha KC, Kim OH, Lee KH, Hwang SO, Kim H. Features and predictors of myocardial injury in carbon monoxide poisoned patients. Emerg Med J. 2014;31(3):210–5.
13. Gunal N, Bilgic A. Diyastolik Fonksiyonlar: Diyastol fizyolojisi, fonksiyon bozuklukları ve ekokardiyografi ile değerlendirilmesi. Arch Turkish Soc Cardiol. 1997;25(1):54–64.
14. Henry CR, Satran D, Lindgren B, Adkinson C, Nicholson CI, Henry TD. Myocardial injury and long-term mortality following moderate to severe carbon monoxide poisoning. J Am Med Assoc. 2006;295(4):398–402.
15. Ciftci O, Gunday M, Caliskan M, Gullu H, Dogan R, Guven A, et al. Mild carbon monoxide poisoning impairs left ventricular diastolic function. Indian J Crit Care Med. 2013;17(3):148–53.