Int J Clin Exp Med 2019;12(5):6441-6446
www.ijcem.com /ISSN:1940-5901/IJCEM0089677

Original Article

Evaluation of cardiotoxic effects with carbon monoxide poisoning by three dimensional speckle tracking imaging

Yanhua Cui[1], Jiping Yan[1], Quanbin Zhang[2], Junli Yu[2], Wenli Zhao[1], Xiaocheng Wang[3]

[1]Department of Ultrasound, Shanxi Provincial People's Hospital, Taiyuan 030012, Shanxi, China; [2]Department of Ultrasound, General Hospital of The Taiyuan Iron and Steel, Taiyuan 030008, Shanxi, China; [3]Department of Medical Record and Statistics, Shanxi Provincial People's Hospital, Taiyuan 030012, Shanxi, China

Received December 11, 2018; Accepted April 10, 2019; Epub May 15, 2019; Published May 30, 2019

Abstract: Objective: The aim of the current study was to investigate the cardiotoxic effects of carbon monoxide poisoning. Three-dimensional speckle tracking imaging (3D-STI) has been used in the literature to analyze left ventricular systolic function of patients with carbon monoxide poisoning. 3D-STI may be a potentially more sensitive technique. Methods: This prospective study included 36 hospitalized patients with carbon monoxide poisoning and 35 healthy volunteers were selected as the control group. All patients with carbon monoxide poisoning received 3D-STI examination at admission and at the time of 1 week after admission to the emergency department. Parameters were measured by 3D-STI technique which included the global longitudinal strain (GLS), global area strain (GAS), global circumferential strain (GCS) and global radial strain (GRS). Left ventricular ejection fraction (LVEF) was measured by Simpson's method. Peripheral blood was tested within 24 hours after admission and cardiac troponin I (cTn I) was measured. Femoral artery blood was collected at admission and one week after admission to the emergency department, and arterial blood gas analysis was performed to determine carboxy hemoglobin (HbCO). T-test or Wilcoxon rank-sum tests, Chi-square test, and Pearson correlation were performed for data analysis. Results: Compared to the control group, GLS and GAS were significantly lower at admission in patients with carbon monoxide poisoning ($P < 0.05$), but there was no significant difference between GCS, GRS, and LVFE at admission between the carbon monoxide poisoning group and the healthy control group ($P > 0.05$). HbCO and cTn I increased significantly at admission in patients with carbon monoxide poisoning ($P < 0.05$). There was no significant difference in GLS, GAS, GCS, GRS, LVEF, HbCO, and cTn I between the carbon monoxide poisoning group and the healthy control group at the time of 1 week after admission ($P > 0.05$). cTn I was negatively correlated with GLS and GAS, and GAS correlation ($r = -0.483$) was better than GLS correlation ($r = -0.345$). Conclusion: Heart is one of the most susceptible organs in carbon monoxide poisoning. Cardiotoxic effects with carbon monoxide poisoning can be evaluated early by 3D-STI technical. Left ventricular systolic dysfunction can be induced by carbon monoxide poisoning. GLS and GAS decreased with the increase of cTn I. Impairment of left ventricular function caused by carbon monoxide poisoning is reversible.

Keywords: Left ventricular systolic function, carbon monoxide poisoning, three-dimensional speckle tracking imaging

Introduction

Carbon monoxide is a colorless, odorless toxic gas. Excessive inhalation can lead to carbon monoxide poisoning [1]. Brain and heart are two of the most oxygen consuming organs in the body and they are always involved. Heart is a critical and susceptible organ in carbon monoxide poisoning. Myocardial involvement is common and is often associated with a higher risk of death [2-5]. Therefore, cardiac dysfunction caused by carbon monoxide poisoning is attracting more and more attention by researchers around the word. Three-dimensional speckle tracking imaging (3D-STI) can track the movement of myocardial spots in three-dimensional space and accurately assess the overall myocardial deformation. Compared with traditional methods, it is a potentially more sensitive technique to evaluate myocardial contractile function [6, 7]. In this study, the cardiotoxic effects of carbon monoxide poisoning were investigated via three dimensional speckle tracking imaging. Myocardial toxicity induced parameter changes of 3D-STI were studied in patients with carbon monoxide poisoning.

Object and method

Subjects

A prospective study was conducted. Thirty-six cases of carbon monoxide poisoning in Shanxi Provincial People's Hospital and General Hospital of the Taiyuan Iron and Steel from January 2017 to July 2018 were selected as the study group. Inclusion criteria were based on the guidelines for clinical treatment of carbon monoxide poisoning issued by the Minister of Health of China in 2012. None of the selected patients had a history of smoking. All patients were admitted to the hospital within 1 hour after intoxication. No hyperbaric oxygen or artificial ventilation was required. Oxygen was supplied through the mask and the oxygen flow rate was 2-5 L/min.

Thirty-five subjects were selected as healthy control group. The healthy control group subjects all came from a health check-up population in the medical center of the hospital. Echocardiogram, electrocardiogram, serological and physical examination were performed in the control group. With all of the above examinations, subjects with related diseases that could affect the structure and function of the heart were excluded in the healthy control group. This study was performed in accordance with the ethical standards established by the Shanxi People's Hospital ethics committee and approved by the committee. The subjects or their relatives have signed the informed consent.

Method

Echocardiography was performed using the color Doppler ultrasound diagnostic instrument produced by GE Company of America, the equipment type is Vivid E9. All data were collected by the same senior physician. All the subjects were in a left lying position, breathing evenly, and the examination room was quiet. Using 4V-D mode, the probe frequency was between 1.5 and 4 MHz and frame rate is greater than 25 frames/s. The standard apical four cavities were collected and the left ventricular 3D images were recorded continuously in 3 cardiac cycles. The left ventricular systolic function parameters were obtained by built-in software analysis: global longitudinal strain (GLS), global area strain (GAS), global circumferential strain (GCS), global radial strain (GRS).

The above four indicators can reflect the deformation of myocardium during the cardiac cycle, which are all strain indicators. The positive strain indicates the prolongation or thickening of the myocardium, while the negative strain indicates the shortening or thinning of the myocardium. The absolute value of strain represents the degree of myocardial deformation. Left ventricular ejection fraction (LVEF) was measured by Simpson's method.

Two milliliters of peripheral venous blood was extracted within 24 hours of admission, and the concentration of cTn I was measured. Arterial blood was collected at admission and 1 week after admission respectively, and blood gas analysis was performed to determine HbCO.

Statistical analysis

The SPSS 24.0 software (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Summaries according to patient characteristics are primarily descriptive. For continuous variables, all the data are expressed as means ± SD or median (interquartile range), depending on data distribution. Comparisons of indicators measured categorically are based on Chi-squared test. Comparisons between groups of indicators measured on a continuous scale are based on T-test or Wilcoxon rank-sum tests. Pearson Correlation Coefficient was used to analyze the correlation between cTn I and GLS or GAS. All P values reported are two-tailed and $P < 0.05$ was set as the level of significance.

Results

General data comparison

The study group was comprised of 19 males and 17 females, with the average age being (45.42 ± 7.13) years old, and an average body mass index of (21.61 ± 3.15) kg/m^2; Healthy control group has 18 males and 17 females, the average age was (44.79 ± 7.92) years old, and the average body mass index was (21.17 ± 3.23) kg/m^2. There was no significant difference in the gender composition, age composition and body mass index between the carbon monoxide poisoning group and the healthy control group (P = 0.935, 0.852, 0.472 respectively; all $P > 0.05$). The HbCO concentration in patients with carbon monoxide poisoning was (35.76 ± 9.43)%.

Comparison of parameters between the carbon monoxide poisoning group and the healthy control group at admission

Compared with the healthy control group, GLS and GAS were significantly lower at admission in patients with carbon monoxide poisoning (P = 0.026, 0.017 respectively; all $P < 0.05$), but there was no significant difference between GCS, GRS, and LVFE at admission between the carbon monoxide poisoning group and the healthy control group (P = 0.152, 0.087, 0.057 respectively; all $P > 0.05$). HbCO and cTn I increased significantly in patients with carbon monoxide poisoning at admission in patients with carbon monoxide poisoning (P = 0.001, 0.008 respectively; all $P < 0.05$). The details are shown in **Table 1**.

Comparison of parameters between carbon monoxide poisoning group and healthy control group after 1 week of admission

There was no significant difference in GLS, GAS, GCS, GRS, LVEF, HbCO and cTn I between the carbon monoxide poisoning group and the healthy control group at the time of 1 week after admission (all $P > 0.05$). The details are shown in **Table 1**. cTn I was negatively correlated with GLS and GAS, and GAS correlation (r = -0.483) was better than GLS correlation (r = -0.345).

Discussion

Carbon monoxide poisoning occurs occasionally in daily life. Incomplete combustion of carbonaceous substances may produce carbon monoxide [8]. It is a potentially fatal form of poisoning, which can cause myocardial toxicity, and cause cardiac autonomic nervous system dysfunction [9-12]. It can be manifested as angina pectoris, arrhythmia, cardiomyopathy, ventricular systolic dysfunction, heart failure and myocardial infarction, and even cardiogenic shock and sudden death. Especially in patients with coronary heart disease, there is a greater risk of infarction and arrhythmia [3, 13]. Cardiac dysfunction in some patients with carbon monoxide poisoning is reversible [14]. The occurrence of myocardial damage has been used as a predictor of long-term adverse events in carbon monoxide poisoning [15]. Mild myocardial hypoxia, direct effects of carbon monoxide and ischemia-reperfusion injury can lead to myocardial injury and cardiac dysfunction [15-17]. Among them, mild myocardial hypoxia is most closely related to cardiac function changes associated with carbon monoxide poisoning. Coronary artery stenosis may not be the main cause of carbon monoxide cardiomyopathy [18]. The affinity of carbon monoxide gas to hemoglobin is about 240 times than that of oxygen [19], The oxygen carrying capacity of hemoglobin decreased and the oxygen dissociation curve shifted to the left. Moreover, carbon monoxide hemoglobin formed by carbon monoxide poisoning can lead to difficulty in dissociating hemoglobin from oxygen and aggravate tissue hypoxia.

Previous studies have documented changes in serology and electrocardiogram caused by carbon monoxide poisoning, but the quantitative assessment of cardiac function changes caused by carbon monoxide poisoning by echocardiography is rare. 3D-STI is a new technique of echocardiography, which has been developed in recent years. By tracking the acoustic speckle motion of myocardial tissue in three-dimensional space, the deformation of the myocardium was evaluated accurately, and myocardial contractile function was evaluated quantitatively [20-23]. Many studies have reported application of two-dimensional speckle tracking to evaluate left ventricular systolic function [24-27]. Compared with 2D-STI, 3D-STI has no angle dependence. It can reflect the whole movement and deformation of myocardium and evaluate the changes of myocardial function more accurately. Compared with 2D-STI, the time required for examination was significantly reduced, with good repeatability and less bias [6, 7].

In this study, GLS and GAS in carbon monoxide poisoning were lower than that of the healthy control group at admission. The difference was statistically significant ($P < 0.05$), indicating

Table 1. Comparison of parameters between the carbon monoxide poisoning group and the healthy control group

Group	GLS (%)	GAS (%)	GCS (%)	GRS (%)	LVEF (%)	HbCO (%)	cTn I (ng/ml)
Healthy control group	-20.13 ± 2.37	32.71 ± 2.82	-18.47 ± 2.58	44.29 ± 4.13	63.52 ± 4.54	1.69 ± 0.27	0.03 ± 0.01
Study group at admission	-16.86 ± 2.07*	28.19 ± 3.11*	-18.03 ± 2.34	43.90 ± 4.28	62.67 ± 4.36	35.76 ± 9.43*	0.11 ± 0.06*
Study group after 1 week of admission	-19.82 ± 1.95	31.67 ± 2.15	-18.26 ± 2.51	44.17 ± 4.25	62.86 ± 4.49	1.66 ± 0.45	0.03 ± 0.02

*$P < 0.05$ versus Healthy control group.

that carbon monoxide poisoning could lead to the decrease of left ventricular systolic function. However, the difference of LVEF in the two groups was not significant at admission ($P > 0.05$). In this study, the LVEF measured by Simpson's method failed to reflect the decrease of left ventricular systolic function in time. The sensitivity of GLS and GAS was higher than that of LVEF which was measured by Simpson's method, so that GLS and GAS can reflect the decrease of left ventricular systolic function at the early stage in carbon monoxide poisoning patients. There was no significant difference in GCS and GRS between carbon monoxide poisoning group and healthy control group at the time of admission ($P > 0.05$). Among the parameters of 3D-STI, GAS, and GLS are more accurate and more sensitive than GCS and GRS in reflecting the early cardiac contractile function changes in patients with carbon monoxide poisoning.

The concentrations of cTn I and carboxy hemoglobin in the patients with carbon monoxide poisoning were higher than those in healthy control group ($P < 0.05$). GAS and GLS were negatively correlated with cTn I, and the correlation of GAS ($r = -0.483$) was better than GLS ($r = -0.345$). GAS is more sensitive to the decrease of systolic function in the left ventricle. Maybe this is because GAS reflects the overall movement of longitudinal and circular movements of the myocardium. However, GLS reflects the overall situation of longitudinal myocardial motion.

One week after admission, there was no significant difference in GAS, GLS, HbCO, and cTn I between carbon monoxide poisoning group and healthy control group ($P > 0.05$). It showed that within one week after carbon monoxide poisoning, the left ventricular systolic function recovered and showed a reversible change. The increase of cTn I caused by carbon monoxide poisoning gradually decreased to the normal level with recovery of left ventricular systolic function, and the concentration of carbooxy hemoglobin could also be restored to a normal level within one week after admission.

Conclusion

Carbon monoxide poisoning can lead to cardiac systolic dysfunction. Three-dimensional speckle tracking imaging can be used to identify and quantitatively assess cardiac systolic dysfunction caused by carbon monoxide poisoning.

Disclosure of conflict of interest

None.

Address correspondence to: Xiaocheng Wang, Department of Medical Record and Statistics, Shanxi Provincial People's Hospital, Taiyuan 030012, Shanxi, China. Tel: (+86) 0351-4960114; E-mail: buyi21shiji@163.com

References

[1] Bleecker ML. Carbon monoxide intoxication. Handb Clin Neurol 2015; 131: 191-203.
[2] Ciftci O, Gunday M, Caliskan M, Gullu H, Dogan R, Guven A and Muderrisoglu H. Mild carbon monoxide poisoning impairs left ventricular diastolic function. Indian J Crit Care Med 2013; 17: 148-153.
[3] Lippi G, Rastelli G, Meschi T, Borghi L and Cervellin G. Pathophysiology, clinics, diagnosis and treatment of heart involvement in carbon monoxide poisoning. Clin Biochem 2012; 45: 1278-1285.
[4] Ozyurt A, Karpuz D, Yucel A, Tosun MD, Kibar AE and Hallioglu O. Effects of acute carbon monoxide poisoning on ECG and echocardiographic parameters in children. Cardiovasc Toxicol 2017; 17: 326-334.
[5] Park JS, Seo KW, Choi BJ, Choi SY, Yoon MH, Hwang GS, Tahk SJ, Choi SC, Min YG and Shin JH. Various echocardiographic patterns of left ventricular systolic dysfunction induced by carbon monoxide intoxication. Cardiovasc Toxicol 2016; 16: 361-369.
[6] Amzulescu MS, Langet H, Saloux E, Manrique A, Slimani A, Allain P, Roy C, de Meester C, Pasquet A, Somphone O, De Craene M, Vancraeynest D, Pouleur AC, Vanoverschelde JL and Gerber BL. Improvements of myocardial deformation assessment by three-dimensional speckle-tracking versus two-dimensional speckle-tracking revealed by cardiac magnetic resonance tagging. J Am Soc Echocardiogr 2018; 31: 1021-1033.
[7] Seo Y, Ishizu T, Atsumi A, Kawamura R and Aonuma K. Three-dimensional speckle tracking echocardiography. Circ J 2014; 78: 1290-1301.
[8] Omaye ST. Metabolic modulation of carbon monoxide toxicity. Toxicology 2002; 180: 139-150.
[9] Jung YS, Lee JS, Min YG, Park JS, Jeon WC, Park EJ, Shin JH, Oh S and Choi SC. Carbon monoxide-induced cardiomyopathy. Circ J 2014; 78: 1437-1444.

[10] Liu SD, Shen Q, Lv C, Zhang P, Yu H, Yang L and Wu L. Analysis of combined detection of N-terminal pro-B-type natriuretic peptide and left ventricular ejection fraction in heart function in patients with acute CO poisoning. Am J Emerg Med 2014; 32: 1212-1214.
[11] Saracoglu E, Vuruskan E, Kilic S, Cekici Y, Onur B, Arslan Y, Kilic E and Aykut O. Predicting cardiotoxic effects of carbon monoxide poisoning using speckle tracking echocardiography. Cardiovasc Toxicol 2018; 18: 175-183.
[12] Vural C, Dinleyici EC, Kosger P, Bolluk O, Kilic Z and Ucar B. Evaluation of cardiac autonomic function using heart rate variability in children with acute carbon monoxide poisoning. Cardiol Young 2017; 27: 1662-1669.
[13] Rose JJ, Wang L, Xu Q, McTiernan CF, Shiva S, Tejero J and Gladwin MT. Carbon monoxide poisoning: pathogenesis, management, and future directions of therapy. Am J Respir Crit Care Med 2017; 195: 596-606.
[14] Lee JH, Kim HS, Park JH, Kim MS, Sun BJ, Ryu S, Kim SS, Jin SA, Kim JH, Choi SW, Jeong JO, Kwon IS and Seong IW. Incidence and clinical course of left ventricular systolic dysfunction in patients with carbon monoxide poisoning. Korean Circ J 2016; 46: 665-671.
[15] Cha YS, Kim H, Hwang SO, Kim JY, Kim YK, Choi EH, Kim OH, Kim HI, Cha KC and Lee KH. Incidence and patterns of cardiomyopathy in carbon monoxide-poisoned patients with myocardial injury. Clin Toxicol 2016; 54: 481-487.
[16] Abass MA, Arafa MH, El-Shal AS and Atteia HH. Asymmetric dimethylarginine and heart-type fatty acid-binding protein 3 are risk markers of cardiotoxicity in carbon monoxide poisoning cases in Zagazig university hospitals. Hum Exp Toxicol 2017; 36: 247-255.
[17] Hashemzaei M, Barani AK, Iranshahi M, Rezaee R, Tsarouhas K, Tsatsakis AM, Wilks MF and Tabrizian K. Effects of resveratrol on carbon monoxide-induced cardiotoxicity in rats. Environ Toxicol Pharmacol 2016; 46: 110-115.
[18] Cha YS, Kim H, Lee Y, Kwon W, Son JW, Youk H, Kim HI, Kim OH, Park KH, Cha KC, Lee KH and Hwang SO. Evaluation of relationship between coronary artery status evaluated by coronary computed tomography angiography and development of cardiomyopathy in carbon monoxide poisoned patients with myocardial injury: a prospective observational study. Clin Toxicol 2018; 56: 30-36.
[19] Wu PE and Juurlink DN. Carbon monoxide poisoning. CMAJ 2014; 186: 6.
[20] Li L, Zhang PY, Ran H, Dong J, Fang LL and Ding QS. Evaluation of left ventricular myocardial mechanics by three-dimensional speckle tracking echocardiography in the patients with different graded coronary artery stenosis. Int J Cardiovasc Imaging 2017; 33: 1513-1520.
[21] Lo Iudice F, Petitto M, Ferrone M, Esposito R, Vaccaro A, Buonauro A, D'Andrea A, Trimarco B and Galderisi M. Determinants of myocardial mechanics in top-level endurance athletes: three-dimensional speckle tracking evaluation. Eur Heart J Cardiovasc Imaging 2017; 18: 549-555.
[22] Muraru D, Niero A, Rodriguez-Zanella H, Cherata D and Badano L. Three-dimensional speckle-tracking echocardiography: benefits and limitations of integrating myocardial mechanics with three-dimensional imaging. Cardiovasc Diagn Ther 2018; 8: 101-117.
[23] Wang D, Zhang L, Zeng Q and Xie M. Assessment of left ventricular performance in heart transplant recipients by three-dimensional speckle tracking imaging. Medicine 2017; 96: e8129.
[24] Chan J, Shiino K, Obonyo NG, Hanna J, Chamberlain R, Small A, Scalia IG, Scalia W, Yamada A, Hamilton-Craig CR, Scalia GM and Zamorano JL. Left ventricular global strain analysis by two-dimensional speckle-tracking echocardiography: the learning curve. J Am Soc Echocardiogr 2017; 30: 1081-1090.
[25] Deveci M, Uncuoglu Aydogan A, Altun G, Kayabey O, Tugral O and Babaoglu K. Left ventricular mechanics are affected in children with celiac disease: a study based on two-dimensional speckle tracking echocardiography. Echocardiography 2017; 34: 1339-1346.
[26] Ma W, Liu N, Tong M and Zhou H. Evaluation of left ventricular function in uremic patients by speckle tracking imaging. Cell Biochem Biophys 2015; 73: 577-580.
[27] Moaref A, Faraji M and Tahamtan M. Subclinical left ventricular systolic dysfunction in patients with metabolic syndrome: a case-control study using two-dimensional speckle tracking echocardiography. ARYA Atheroscler 2016; 12: 254-258.