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Original Article

Diagnostic value of ambulatory blood pressure monitoring and transcranial color Doppler ultrasound combined with carotid artery ultrasonography in cerebral infarction

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Abstract: Objective: To determine the diagnostic value of ambulatory blood pressure monitoring (ABPM) and transcranial color Doppler ultrasound (TCD) combined with carotid artery ultrasonography (CAU) in patients with cerebral infarction. Methods: Fifty-three patients with cerebral infarction (observation group) admitted in Renmin Hospital of Wuhan University from January 2017 to January 2018, and 52 healthy individuals (control group) were enrolled for the study. The blood pressure (BP) parameters of the control and observation groups were measured and compared using ABPM. In addition, the patients with cerebral infarction were examined using three methodological combinations: (A) ABPM and TCD, (B) ABPM and CAU, and (C) ABPM and TCD combined with CAU, and the results were compared. Results: The 24 h mean systolic blood pressure (SBP), the 24 h pulse pressure (PP), the day mean SBP, the daytime PP, the night mean SBP and the night PP were significantly higher in the observation group compared to those in the control group. Among the patients with acute cerebral infarction, the A, B and C methods positively diagnosed 45, 47 and 51 cases, respectively. The detection rate of method C was significantly higher than that of methods A and B. In addition, the sensitivity, specificity, and positive predictive value of method C was also better than the other methods, and those of method B was better than those of method A. The negative predictive value of method A was better than that of B. Finally, there was no difference in the location of cerebral infarction detected by the three diagnostic methods. Conclusion: The use of ABPM and TCD combined with CAU can improve the detection rate and diagnostic accuracy of cerebral infarction, and offer a new method for its clinical diagnosis.

Keywords: Ambulatory blood pressure monitoring, transcranial color Doppler ultrasound, carotid artery ultrasonography, cerebral infarction

Introduction

Hypertensive patients are prone to cerebral infarction, which may lead to disability or even death. Therefore, an accurate and sensitive method is urgently needed for its timely diagnosis [1-3]. Previously, the clinical diagnosis of cerebral infarction was mainly done by digital subtraction angiography (DSA), which had good diagnostic value in cerebral artery lumen and wall lesions. However, DSA is an invasive and costly procedure, and can result in trauma to the patients, thereby limiting its use in clinical practice [4, 5]. Advanced imaging technologies like transcranial color Doppler ultrasound (TCD) and carotid artery ultrasonography (CAU) are highly promising in the diagnosis of cerebral infarction, and have been gradually incorporated in recent clinical practice. TCD has no side effects during detection, is highly safe and relatively economical [6, 7]. CAU is mainly used to detect the vascular diameter, plaques, and hemodynamics of the carotid artery. The combination of TCD and CAU can more accurately detect the lesions in intracranial blood vessels, and help patients with cerebral infarction receive timely treatment [8, 9]. Ambulatory blood pressure monitoring (ABPM) is a non-invasive method of measuring blood pressure (BP) in real time over a 24-hour period, which compensates for excessive BP variability [10, 11]. Only a few reports are available on the combination of these diagnostic methods in cerebral infarction. The aim of this study was to compare the diagnostic value of various combinations of ABPM, TCD and CAU in cerebral infarction.

Materials and methods

Patient data

A total of fifty-three patients (23 males and 30 females; average age 40.53±4.54 years) with cerebral infarction who were admitted in Renmin Hospital of Wuhan University from January 2017 to January 2018 were enrolled as the observation group and 52 healthy individuals as the control group (23 males and 30 females; average age 38.43±4.09 years). The patients were diagnosed with acute cerebral infarction by magnetic resonance angiography, and met all the clinical diagnostic criteria [12]. The inclusion criteria of the observation group were acute cerebral infarction diagnosis for the first time and compliance with medical personnel. Patients with mental illness, severe injuries in vital organs such as heart, liver and kidney, and upper gastrointestinal bleeding or ulcers were excluded. All subjects were aware of the clinical protocol and signed informed consent. The study protocol was approved by the Ethics Committee of Renmin Hospital of Wuhan University.

Diagnostic procedures

CAU: The common carotid artery, external carotid artery and extracranial internal carotid artery were examined by color Doppler ultrasound along the anterior, posterior and lateral directions of the cervical root. The vascular diameter and intimal thickness of the carotid artery were determined, and plaque formation was observed. The angle of the sound beam and the blood flow was set at less than 60°C, and the probe frequency of nuclear magnetic frequency conversion was set to 5-10 MHz [13].

ABPM diagnosis: A dynamic blood monitoring device was used to test BP on the patient's upper arm. During daytime (6 a.m.-10 p.m.), measurements are taken every 15 minutes, and in the evening (10 p.m.-6 a.m.) every 30 minutes. The frequency of blood pressure measurements was higher than 70 in a day, and valid value rate was more than 90%. In order to obtain accurate BP values, the patients were instructed not to exercise excessively during the measurement period [14].

TCD diagnosis: Color Doppler ultrasound was used to analyze the blood flow of the anterior cerebral arteries, posterior cerebral arteries, internal carotid artery siphons, middle cerebral arteries, and intracranial vertebrobasilar arteries. The probe position and sampling frame direction were set appropriately. Plethysmography was used to detect MCA hemodynamic information [15].

Observation indices

Primary observation indices were the specificity and sensitivity of the following three different combinations of diagnostic methods: (A) ABPM and TCD, (B) ABPM and CAU, and (C) ABPM and TCD combined with CAU.

Secondary observation indices include BP parameters as measured by ABPM and cerebral infarction localization. The BP parameters were: 24 h mean systolic BP (24 h SBP), the daytime mean diastolic BP (24 h DBP), the 24 h pulse pressure (24 h PP), the day mean systolic BP (dSBP), the daytime mean diastolic BP (dDBP), the daytime pulse pressure (dPP), the night mean systolic BP (nSBP), the night mean diastolic BP (nDBP), the night pulse pressure (nPP), and morning peak blood pressure. The different locations of cerebral infarction were anterior circulation infarction, posterior circulation infarction and watershed infarction.

Evaluation criteria

TCD diagnosis indices for cerebral infarction: pulsation index ≥1.1 and resistance index ≥0.8 [16]. Carotid artery diagnostic indices were: intima-media thickness >0.9 mm, neck vascular peak systolic velocity >120.0 cm/s, and end diastolic velocity <40.0 cm/s [17]. ABPM indices for cerebral infarction were: 24-hour BP range <17.0/10.5 Kpa, the mean value during the day <18.0/11.0 Kpa, and the mean value at night <16.5/9.0 Kpa [18].

Statistical analysis

All data were analyzed with SPSS 19.0 software. Measurement data were expressed as mean ± standard deviation ($\overline{x}$±sd), and com-

Table 1. Demographic and clinical data

Group	Observation group (n=53)	Control group (n=52)	t/χ^2	P
Sex (male/female)	23/30	25/27	0.230	0.076
Age (year)	40.53±4.54	38.43±4.09	1.303	0.195
Smoking history (case)	15	3	9.636	0.002
Drinking history (case)	18	3	13.361	0.000
Hypertension (case)	33	4	34.918	0.000
Heart disease (case)	28	2	31.428	0.000
Nephropathy (case)	8	0	8.653	0.003

Table 2. Comparison of arterial BP parameters in patients of two groups (mmHg)

Index	Observation group	Control group	t	P
24 h SBP	137.86±12.31	111.13±11.63	11.453	0.001
24 h DBP	74.76±7.80	74.53±7.50	0.764	0.086
24 h PP	66.96±6.50	34.94±3.50	31.340	0.001
dSBP	129.85±12.11	119.87±12.81	9.652	0.001
dDBP	76.24±7.90	75.86±7.50	0.252	0.801
dPP	46.75±6.50	37.26±3.60	9.230	0.001
nSBP	125.44±11.70	101.55±12.83	9.986	0.001
nDBP	74.25±7.50	75.93±7.80	1.125	0.263
nPP	50.94±5.60	34.83±2.90	18.457	0.001
The morning peak BP	45 (84.91%)	2 (3.85%)	69.754	0.013

Note: 24 h SBP, 24 h mean systolic BP; 24 h DBP, the daytime mean diastolic BP; 24 h PP, the 24 h pulse pressure; dSBP, the day mean systolic BP; dDBP, the daytime mean diastolic BP; dPP, the daytime pulse pressure; nSBP, the night mean systolic BP; nDBP, the night mean diastolic BP; nPP, the night pulse pressure.

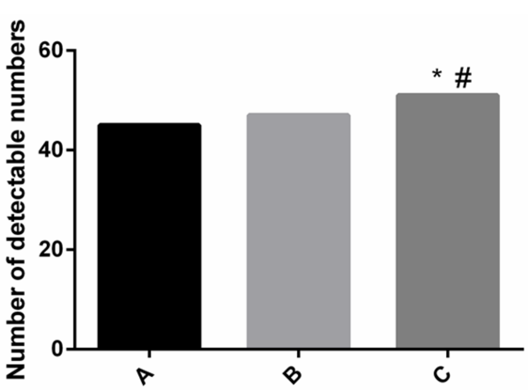

Figure 1. Comparison of different diagnostic methods. A-TCD joint ABPM; B-carotid artery ultrasound combined with ABPM; C-TCD and ABPM combined carotid artery ultrasound. Compared with A, χ^2=6.360, *P=0.012; compared with B, χ^2=4.157, #P=0.041.

pared using an independent sample t-test. Quantitative data were expressed as percentage and compared by the χ^2 test and Fisher's exact probability method. P<0.05 is considered statistically significant.

Results

Demographic and clinical data

The demographic characteristics of both groups have been described in the methods section, and summarized in **Table 1**. No significant difference was seen between the two groups in terms of age and gender. However, smoking history, drinking history, hypertension, heart disease and nephropathy were all significantly higher in the observation group compared to those in the control group (**Table 1**).

Comparison of arterial BP parameters in patients of two groups

The 24 h SBP, 24 h PP, dSBP, and dPP of the observation group were significantly higher than those of the control group (t=11.453, P=0.001; t=31.340, P=0.001; t=9.625, P=0.001; t=9.230, P=0.001 respectively). Furthermore, the nocturnal BP parameters of nSBP and nPP were also significantly higher in the observation group compared to those in the control group (t=9.986, P=0.001; t=18.457, P=0.001 respectively). No significant differences were seen in the 24 h DBP, dDBP and nDBP values between the two groups (all P>0.05). The morning peak BP was significantly higher in the observation group compared to that in the control group (P<0.05). See **Table 2**.

Comparison of different diagnostic methods

The combination A diagnosed 45 patients with acute cerebral infarction, 47 patients were diagnosed with B, and 51 patients with C. Therefore, the detection rate of C was significantly higher than that of A and B (χ^2=6.360, P=0.012; χ^2=4.157, P=0.041) (**Figure 1**).

Of the 45 positive cases detected by A, 43 were true positive and 2 were false positive,

Table 3. Comparison of different diagnostic methods (%)

Diagnostic methods	A	B	C
Sensitivity	81.13	86.79	96.23
Specificity	96.15	98.08	100.00
Positive predictive value	95.56	97.87	100.00
Negative predictive value	96.30	87.93	96.30
Misdiagnosis rate	3.58	1.92	0
Missed diagnosis rate	18.87	13.21	3.77
Diagnostic coincidence rate	88.57	92.38	98.10

Table 4. Comparison of different diagnostic methods for diagnosis location (n, %)

Diagnostic methods	Anterior circulation infarction	Posterior circulation infarction	Watershed infarction
A	20 (37.74)	15 (28.30)	10 (18.87)
B	20 (37.74)	18 (33.96)	9 (16.98)
C	23 (43.40)	17 (32.08)	11 (20.75)
χ^2	0.432	0.573	0.297
P	0.854	0.975	0.095

Note: A-TCD joint AB PM; B-carotid artery ultrasound combined with ABPM; C-TCD and ABPM combined carotid artery ultrasound.

while of 60 negative cases, 50 were true negative and 10 false negative. Forty-six of the 47 positive cases detected by B were true positive and 1 was false positive, and of the 58 cases diagnosed as negative, 51 were true negative and 7 false negative. All 51 positive cases detected by C were true positive, and 52 of the 54 cases diagnosed as negative were true negative and 2 were false negative. Therefore, the combination C gave the best results in terms of sensitivity, specificity, positive predictive value, negative predictive value, misdiagnosis rate, missed diagnosis rate, and diagnostic coincidence rate (**Table 3**).

Finally, no significant differences were seen in the diagnostic rate of anterior circulation infarction, posterior circulation infarction and watershed infarction among the three methodological combinations (all P>0.05). See **Table 4**.

Discussion

Patients with cardiovascular diseases are prone to cerebral infarction, a potentially lethal condition with few emergency measures [19]. Timely diagnosis and treatment is therefore vital for the patients suffering from cerebral infarction. However, this condition is often difficult to diagnose quickly and accurately since the patient is in a state of confusion or shows poor compliance [20]. TCD and CAU have been recently used in the diagnosis of cerebral infarction, and have shown good diagnostic value. TCD can quickly determine the carotid artery medial thickness, plaque formation, and hemodynamic parameters in the vessel wall to predict the risk of cerebral infarction [21].

A healthy person's 24-hour blood pressure pattern follows a dipper shape, with peak values during the day, dropping to the lowest point at midnight, and then rising again after morning. This physiological variability can effectively protect the heart, brain and other organs [22]. If the nocturnal BP is too high, it leads to abnormal circadian rhythm, which is an important causative factor of cerebral infarction, and other cardiovascular and cerebrovascular diseases [23]. In this study, we found that the 24 h SBP, 24 h PP, dSBP and dPP of patients with cerebral infarction were significantly higher than those of the healthy controls, and the nSBP and nPP values also tended to be higher in the observation group. The non-dipper pattern, reduced circadian rhythm, and the overall increased BP indicated that patients with cerebral infarction were prone to abnormal BP. Real-time BP measurement through ABPM can provide a diagnostic basis for individualized medication and prevent nighttime spike in BP.

We found that combining ABPM, TCD and CAU had the best diagnostic value in acute cerebral infarction. ABPM has been used previously in monitoring BP in patients with cerebral infarction [24]. Gouda et al. showed that ABPM in patients with cerebral infarction helped track the BP-related changes, predict possible cardiovascular and cerebrovascular events, and help formulate the clinical regimens [25]. However, due to the high correlation between BP changes and cerebral infarction, ABPM can also be used for the auxiliary diagnosis of cerebral infarction patients [26]. Consistent with our hypothesis, Kolyviras et al. found that ABPM could predict the occurrence of atherosclerosis in patients, and played an important role in the diagnosis of cerebral infarction caused by atherosclerosis [27]. The combination of ABPM, TCD, and CAU may even be able to determine the cause of cerebral infarction accurately according to their individual diagnosis. However, we could not draw this conclusion in our study due to the lack of cerebral infarction cases with different causes.

The three diagnostic methods had similar diagnostic abilities for detecting cerebral infarction, such as anterior circulation, posterior circulation, and watershed areas. However, the number of cases positively diagnosed by the combination of ABPM, TCD and CAU was slightly bigger, indicating that both TCD and CAU have a good diagnostic value in cerebral infarction. TCD determines vascular stenosis and brain occlusion through hemorheology, and CAU assesses vascular stenosis mainly through the medial-adventitial spacing and intravascular plaque morphology [28]. Both TCD and CAU are non-invasive since they do not require the intravenous injection of contrast agents, which can improve patient comfort and is particularly suitable for patients with low immunity.

In conclusion, ABPM can accurately measure BP in real time and detect any abnormalities in its circadian rhythm, and the combined use of TCD and CAU can improve the diagnosis rate of cerebral infarction. The combination of all three techniques can be used as an effective and accurate auxiliary diagnostic method for cerebral infarction, and can be incorporated in routine clinical practice. The disadvantage of this study was that neither technique was examined individually for the diagnosis of cerebral infarction.

Disclosure of conflict of interest

None.

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References

[1] Zhang MJ, Pan XD, Liu M, Li JJ and Liu LP. Analysis of risk factors of patients with progressive cerebral infarction and hypertension. World Journal of Complex Medicine 2017; 3: 10-12.

[2] Chen H. Clinical analysis of hypertension complicated with cerebral infarction and the relationship between high homocysteine levels. Guide of China Medicine 2017; 15: 11-12.

[3] Hollander M, Bots ML, Del Sol AI, Koudstaal PJ, Witteman JC, Grobbee DE, Hofman A and Breteler MM. Carotid plaques increase the risk of stroke and subtypes of cerebral infarction in asymptomatic elderly: the rotterdam study. Circulation 2002; 105: 2872-2877.

[4] Zeng DH. Young and middle-aged and elderly patients with cerebral infarction DSA analysis of the distribution of cerebral artery stenosis. Journal of Hunan Normal University (Medical Science) 2016; 13: 49-50.

[5] Wang C. Role of CUS Combined with TCD and DSA in diagnosis of cerebral infarction. Modern Hospital 2016; 16: 1614-1616.

[6] Wu HT, Luo WQ and Huang ZY. The value of transcranial Doppler ultrasound combined with neck vascular ultrasound on the diagnosis of cerebral infarction. Journal of Minimally Invasive Medicine 2016; 11: 61-63.

[7] Chen L and Zhang ZY. Analysis of diagnostic value by color Doppler ultrasound for carotid plaque in senile cerebral infarction patients. Chin Prac Med 2016; 11: 28-30.

[8] Zhang H, Zhang HL, Liang HF and Yong XY. Application analysis of the carotid artery ultrasound in carotid artery disease in patients with cerebral infarction and hypertension. Clinical Research and Practice 2017; 2: 3-5.

[9] Wang Y, Zhang HB, Chen B, Ma J, Fan MZ and Zhang TS. Carotid artery ultrasound evaluation on asymptomatic cerebral infarction in elderly patients. Chinese Journal of Control of Endemic Disenaces 2016; 31: 1087-1089.

[10] Lin YF, Ji XD, Gong ZY and Zang DW. Correlation study of abnormal circadian rhythm of blood pressure with carotid plaque and PWI in acute cerebral infarction and hypertension patients. Drug Evaluation 2017; 14: 37-40.

[11] Herrera EL, Michea L, Toro L, Alban N, Contreras D, Paccot M, Escobar M. Concordance between the blood pressure profile (BPP) and ambulatory blood pressure monitoring (ABPM) for the diagnosis of high blood pressure (HBP) in primary health care. Journal of Hypertension 2018; e175.

[12] Nael K, Knitter JR, Jahan R, Gornbein J, Ajani Z, Feng L, Meyer BC, Schwamm LH, Yoo AJ, Marshall RS, Meyers PM, Yavagal DR, Wintermark M, Liebeskind DS, Guzy J, Starkman S, Saver JL and Kidwell CS. Multiparametric magnetic resonance imaging for prediction of parenchymal hemorrhage in acute ischemic stroke after reperfusion therapy. Stroke 2017; 48: 664-670.

[13] Dominika H, Demosthenes D, Björn K, Martin B and Anders W. Simplified ultrasound protocol for the exclusion of clinically significant carotid artery stenosis. Upsala Journal of Medical Sciences 2016; 121: 165-169.

[14] Etyang AO, Warne B, Kapesa S, Munge K, Bauni E, Cruickshank JK, Smeeth L and Scott JA. Clinical and epidemiological implications of 24-hour ambulatory blood pressure monitoring for the diagnosis of hypertension in Kenyan adults: a population-based study. J Am Heart Assoc 2016; 5: 1-9.

[15] Brunser AM, Mansilla E, Hoppe A, Olavarria V, Sujima E and Lavados PM. The role of TCD in the evaluation of acute stroke. J Neuroimaging 2016; 26: 420-425.

[16] Wang LJ, Chen Y, Chen LM and Xing YQ. Different evaluations between transcranial Doppler ultrasonogrphy and magnetic resonance imaging for the ischemic stroke. Neuropsychiatry (London) 2018; 8: 663-668.

[17] Camerlingo M, Casto L, Censori B, Ferraro B, Gazzaniga GC and Mamoli A. Transcranial Doppler in acute ischemic stroke of the middle cerebral artery territories. Acta Neurol Scand 1993; 88: 108-111.

[18] Adrián MJ, Sobrino J, Alvarez R, Ribera L, Rodriguez E, Torres M and Coca A. A007: ambulatory blood pressure monitoring in acute stroke. American Journal of Hypertension 1999; 12: 148.

[19] Wu X, Chen YH, Lin HS, Cai MY, Cheng Y and Wang X. Correlation analysis of cardiovascular risk factors, cerebral infarction area and cognitive dysfunction in Qi-Xu-Xue-Yu stroke patients. Med Innov China 2016; 13: 5-8.

[20] Huang J, Zhang P, Zhou SX, Shen YJ, Xie WX and Zou L. Diagnosis value of lipoprotein(a) in cerebral infarction. Int J Lab Med 2018; 39: 429-431.

[21] Huang ZX and Li TT. Correlative study between carotid atherosclerotic plaque and cerebral infarction. Chinese Imaging Journal of Integrated Traditional & Western Medicine 2016; 14: 246-247.

[22] Zhou L, Deng Y, Gong J, Chen X, Zhang Q and Wang J. Epicardial adipose tissue volume a diagnostic study for independent predicting disorder of circadian rhythm of blood pressure in patients with essential hypertension. Cell Mol Biol (Noisy-le-grand) 2016; 62: 1-7.

[23] Wang W, Gao C, Yu C, Liu S, Hou D, Wang Y, Wang C, Mo L and Wu J. No association between elevated total homocysteine levels and functional outcome in elderly patients with acute cerebral infarction. Front Aging Neurosci 2017; 9: 70.

[24] Tsivgoulis G, Pikilidou M, Katsanos AH, Stamatelopoulos K, Michas F, Lykka A, Zompola C, Filippatou A, Boviatsis E, Voumvourakis K, Zakopoulos N and Manios E. Association of ambulatory blood pressure monitoring parameters with the framingham stroke risk profile. J Neurol Sci 2017; 380: 106-111.

[25] Gouda M, Abdelwahab HA and Gad M. Can ambulatory blood pressure monitoring solve the conundrum of true cryptogenic stroke? International Journal of Cardiovascular Research 2017; 6.

[26] Mistry EA, Mistry AM, Nakawah MO, Khattar NK, Fortuny EM, Cruz AS, Froehler MT, Chitale RV, James RF, Fusco MR and Volpi JJ. Systolic blood pressure within 24 hours after thrombectomy for acute ischemic stroke correlates with outcome. J Am Heart Assoc 2017; 6.

[27] Kolyviras A, Manios E, Georgiopoulos G, Michas F, Gustavsson T, Papadopoulou E, Ageliki L, Kanakakis J, Papamichael C, Stergiou G, Zakopoulos N and Stamatelopoulos K. Differential associations of systolic and diastolic time rate of blood pressure variation with carotid atherosclerosis and plaque echogenicity. J Clin Hypertens (Greenwich) 2017; 19: 1070-1077.

[28] Knoka E, Trusinskis K, Narbute I, Briede I, Sondore D, Strenge K and Erglis A. Vulnerable plaque characteristics assessed by iMAP-intravascular ultrasound and the association with C peptide in prediabetic patients with stable coronary artery disease. Atherosclerosis 2017; 263: e145-e146.