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Original Article

The value of monitoring transcranial Doppler ultrasonography combined with electroencephalogram detection in carotid endarterectomy

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Abstract: Objective: To evaluate the value of monitoring transcranial Doppler ultrasonography (TCD) combined with electroencephalogram (EEG) detection in carotid endarterectomy. Methods: A total of 73 patients with carotid artery stenosis were monitored by TCD and EEG, and digital subtraction angiography (DSA) was performed as the gold standard for detection. Results: DSA examination revealed that there were 7 patients with mild stenosis, 46 patients with moderate stenosis, 12 patients with severe stenosis, and 8 patients with normal internal carotid arteries. TCD detection showed that in 70 patients, when the common carotid artery on the affected side was clamped intraoperatively, the blood flow velocity of the middle cerebral artery decreased by about 1/2, and that in the other 3 patients, the blood flow velocity of the middle cerebral artery decreased by 100%. EEG test found that 59 patients showed no obvious abnormalities in EEG (all $P>0.05$), and the other 14 patients showed potential neuronal differences as changes in the brain wave frequency, which was manifested as a decreased α wave frequency. The peak systolic velocity (PSV), mean velocity (MV), end diastolic velocity (EDV), and pulsatility index (PI) of the middle cerebral artery increased after surgery (all $P<0.05$). The internal diameter of patients' postoperative carotid artery stenosis was 4.62 ± 0.35 mm, which was significantly higher than the preoperative level ($P<0.05$). The positive rate and specificity of TCD combined with EEG detection in monitoring blood supply abnormalities were 93.17% and 82.35%, respectively; which were obviously higher than that of DSA, TCD and EEG tests alone (all $P<0.05$). Conclusion: The positive rate and diagnostic accuracy of TCD combined with EEG detection in monitoring cerebral blood supply abnormalities are higher than that of single detection, which is of great value in the prevention of complications in patients.

Keywords: Transcranial Doppler ultrasonography, electroencephalogram, carotid endarterectomy, monitoring value

Introduction

In recent years, the prevalence of cardiovascular and cerebrovascular diseases has been increasing in China, with 18.72% of the population suffering from different degrees of the diseases. The number of deaths due to this disease accounts for 41.72% of the total number of deaths, and arterial stenosis is a common clinical symptom [1]. Currently, studies have shown that carotid artery stenosis can affect the blood supply of intracranial arteries, so that the nutrients brought by the blood cannot meet the blood supply needs to the brain tissue. There are many methods for detecting arterial stenosis in clinical practice, such as digital subtraction angiography (DSA) and CT angiography (CTA) [2]. At present, CTA is a new method for the examination of vascular diseases, which is non-invasive to patients and has a high diagnostic value for arterial stenosis. However, this method is relatively complex and requires higher professional quality of clinicians [3]. DSA is an important method to evaluate arterial stenosis, but this method can cause certain trauma to patients. Besides, it is easy to induce complications such as vasospasms in patients, and its detection cost is relatively high [4].

Some studies have found that transcranial Doppler ultrasonography (TCD) is widely used in the diagnosis of vascular stenosis, and this method does not cause trauma to patients, and is simple to operate and less expensive [5]. Studies have found that TCD can more accurately assess the degree of intracranial vascular stenosis and blood flow in patients with cerebral infarction, so as to facilitate the adoption of targeted treatment methods for patients with vascular stenosis and improve the clinical treatment effects [6]. Electroencephalogram (EEG) is a crucial method to detect spontaneous bioelectricity in the brain and evaluate brain function [7]. In the early stage of cerebral infarction, the physiological structure changes of the brain tissue are not obvious, resulting in limited effects of detection methods such as DSA or TCD. Meanwhile, EEG can detect the abnormal brain waves in the patients' brain, so as to better reflect the physiological status of the brain tissue, which is conducive to improving the patients' outcome [8]. The purpose of this study was to explore the value of monitoring TCD combined with EEG in carotid endarterectomy.

Materials and methods

General information

A total of 73 patients with carotid artery stenosis who received treatment in The Third Affiliated Hospital of Gansu University of Chinese Medicine from May 2017 to May 2018 were selected as the research subjects, including 60 males and 13 females, aged from 38 to 82 years, with an average age of 53.1±7.8 years. Among them, there were 68 patients with a history of hypertension, 27 patients with a history of diabetes, 41 patients with a history of hyperlipidemia, 30 patients with a history of coronary heart disease, and 59 patients with a history of smoking. According to the presence or absence of symptoms, 10 patients were classified as asymptomatic and 63 patients were classified as symptomatic. After admission, the degree of carotid artery stenosis was examined, it was found that there were 48 patients with the degree of stenosis less than 50%, 12 patients with the degree of stenosis ≥50% and <69%, and 13 patients with the degree of stenosis ≥69% and ≤99%. Inclusion criteria: Patients were diagnosed with carotid artery stenosis by DSA for the first time; patients with complete clinical data; patients with asymptomatic carotid stenosis who had a degree of stenosis more than 70%; patients with symptomatic carotid stenosis who had a degree of stenosis more than 50%. Exclusion criteria: Patients who did not have complete basic clinical data; patients with intracranial infection, moyamoya disease, hypertension, tumors and other diseases; patients with heart, liver, kidney and other important organ dysfunction; patients who were mentally abnormal or unstable. The general information data were comparable ($P>0.05$). All patients signed the informed consent, and this study was approved by the Ethics Committee of The Third Affiliated Hospital of Gansu University of Chinese Medicine.

Methods

All patients underwent TCD and EEG detections during the operation. The instrument used for TCD detection was a cerebrovascular Doppler ultrasound instrument (jointly produced by German DWL company and China Delikai EMS company), and the frequencies of the pulse probe was 4.0 MHz and 2.0 MHz. The 4.0 MHz pulse probe was used to detect vascular stenosis, while the 2.0 MHz pulse probe was used to detect preoperative or postoperative cerebral artery blood flow velocity or microembolic signals. The evaluated cerebral arteries mainly included the bilateral middle cerebral artery, anterior cerebral artery and posterior cerebral artery. The EEG test was performed in strict accordance with the international 16/20 lead method, followed by using 3 M mesh breathable tape to fix the patient's scalp to the electrode plate and amplifier to record the electrical activity of the patient's brain [4]. A video camera was used to record all the patients' activities within 4 hours. The TCD and EEG detections were operated by special personnel, and all standards, operation procedures, measurement units and statistical methods were unified.

When DSA was performed, the patients were instructed to take a supine position and expose the bilateral groin after conventional towel disinfection, and then local anesthesia was performed on the patients with 1% lidocaine (Guangzhou Hongcheng Biotechnology Co., Ltd.). The catheter sheath was inserted after successful percutaneous puncture, and 30 mg heparin was given to patients intravenously. Then, a single-curved catheter and double-J tube (Johnson & Johnson, USA) were used to perform angiography on the aortic arch and superior great vessels of the patients, and the contrast agent was iohexol (Yangzijiang Pharmaceutical Group Co., Ltd.). The patient's bilateral internal carotid artery status was visualized from the lateral, oblique, and ortho positions using a digital subtraction contrast machine.

Outcome measures

The degree of vascular stenosis caused by arteriosclerotic plaque was divided into 5 levels. If the carotid artery intima media thickness (IMT) <1.0 mm, the echo was not smooth, the peak systolic velocity (PSV) did not exceed 120 cm/s, and there was no stenosis, then it was recorded as level 1. When IMT >1.0 mm, and there were local bulging plaques and echoes of visible flat plaques, and PSV did not exceed 120 cm/s, the stenosis rate was 1%-15%, it was recorded as level 2. If the plaque was large, the PSV did not exceed 120 cm/s, the stenosis rate was 16%-49%, and the systolic window disappeared, then it was recorded as level 3. If the spectrum was widened, the stenosis rate was 50%-79%, and the PSV exceeded 120 cm/s, then it was classified as level 4. If all conditions of level 4 were met, and the blood vessel was completely blocked, the end diastolic velocity (EDV) <135 m/s, then it was classified as level 5 [5].

The opening status of patient's arterial vessels was observed before operation, including the anterior and posterior communicating arteries and the lateral medial branch of external carotid arteries. When the anterior communicating arteries were closed, the blood flow velocity of anterior cerebral artery on the affected side was normal after surgery. When the posterior communicating arteries were closed, the blood flow velocity of the posterior cerebral artery on the affected side was significantly decreased and then tended to be normal, with symmetry on the left and right sides. In addition, when the lateral medial branch of carotid arteries were closed, the blood flow direction of the supratrochlear artery returned to normal. The pulsatility index (PI) of the patient was detected, and its value was notably increased. At the same time, the blood flow velocity was significantly increased by pressing the ipsilateral external carotid artery branch [6].

After surgery, if the blood flow velocity of the middle cerebral artery on the affected side far exceeded 140% of its baseline value, it can be considered as overperfusion, and the patient's blood pressure should be controlled to avoid the occurrence of cerebral hyperperfusion syndrome [7].

Statistical analysis

The data were analyzed with SPSS 18.0. The count data were expressed as cases/percentage (n/%) and evaluated by the χ^2 test. The measurement data were performed with a normality test by the Shapiro-Wilk method, those conforming to a normal distribution were expressed as mean ± standard deviation ($\overline{x}$ ± sd) and then analyzed by a t test. $P<0.05$ indicated that the difference was statistically significant.

Results

The result of DSA examination

DSA examination was performed on all research subjects, with 7 cases of mild stenosis, 46 cases of moderate stenosis, 12 cases of severe stenosis, and 8 cases of normal internal carotid arteries were found. See **Figure 1**.

The result of intraoperative TCD detection

TCD monitoring was performed in all patients during surgery. When the common carotid artery on the affected side was clamped in 70 patients, the blood flow velocity in the middle cerebral artery decreased by about 1/2, and the shunt tube was not placed, while in the remaining 3 patients, the blood flow velocity in the middle cerebral artery decreased by 100%, and a shunt tube was placed. As shown in **Figure 2**, the peak flow rate of the left middle cerebral artery (LMCA) was 212 cm/s, which was relatively fast, suggesting vascular stenosis in the LMCA. The peak flow rate of the right middle cerebral artery (RMCA) was normal.

Results of the EEG test

EEG test was performed in all patients before surgery. Among them, 59 patients showed no obvious abnormalities, and the other 14 patients showed changes in neuronal communication, which manifested as decreased α wave frequency. See **Figure 3**.

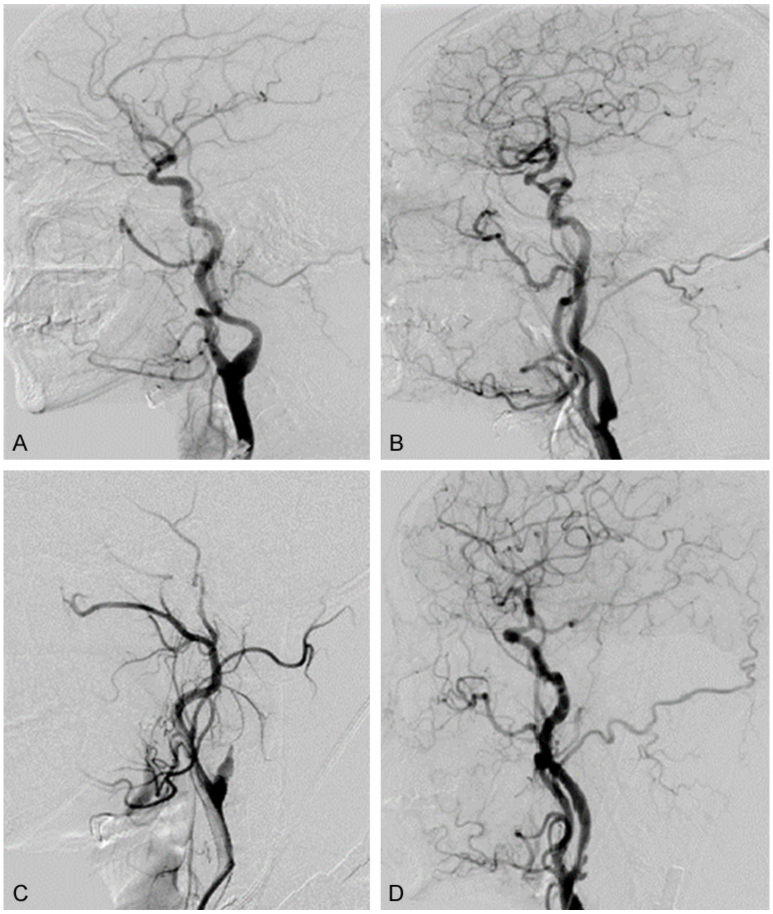

Figure 1. Representative DSA image showed stenosis degree of internal carotid artery. A. Normal internal carotid artery; B. Mild stenosis of internal carotid artery; C. Moderate stenosis of internal carotid artery; D. Severe stenosis of internal carotid artery; DSA, digital subtraction angiography.

Changes of blood flow velocity in the middle cerebral artery on the affected side

The PSV, MV, EDV and PI of the middle cerebral artery of patients increased after surgery (all P<0.05), indicating that the cerebral blood perfusion status of the affected side was improved to some extent. See **Table 1**.

Changes of the internal diameter at the site of carotid artery stenosis

The internal diameter of patients' postoperative carotid artery stenosis was 4.62±0.35 mm, which was significantly higher than the preoperative level (P<0.05), as shown in **Figure 4**.

Comparison of diagnostic performance among the three detection methods

The positive rate and specificity of TCD combined with EEG detection in monitoring blood supply abnormalities was 93.17% and 82.35%, respectively, which was notably higher than that of DSA, TCD and EEG detection alone (all P<0.05). See **Table 2**.

Discussion

Carotid endarterectomy is a commonly used surgical method for vascular surgical diseases. During the surgery, temporary interruption of the carotid artery on the affected side can further promote a decrease of cerebral perfusion. When the carotid artery is unblocked, it can cause more blood to flow into the cranium and induce a high perfusion state to the brain tissue, which is likely to lead to a stroke in patients [9]. Therefore, accurate and objective evaluation of cerebral perfusion in carotid endarterectomy has very important clinical value. TCD has high safety, reasonable cost and is easy to operate. It can be used repeatedly and can effectively grasp the internal blood flow conditions of patients. At the same time, it can display the lesion sites inside the human body, and the use of vascular ultrasound can effectively evaluate the status of patients undergoing carotid endarterectomy [10]. Some studies have found that EEG had a high sensitivity and specificity for cerebral ischemia detection (76.67% and 73.58%, respectively), which was conducive to the more accurate evaluation of brain function in patients [11, 12]. This study was designed to investigate the value of monitoring TCD combined with EEG detection in carotid endarterectomy.

Some studies have shown that TCD can accurately evaluate the changes in cerebral hemodynamics and collateral circulation, and can effectively evaluate the blood supply of intracranial brain tissue caused by decreased cerebral blood flow during carotid endarterectomy [13, 14]. In this study, TCD detection showed

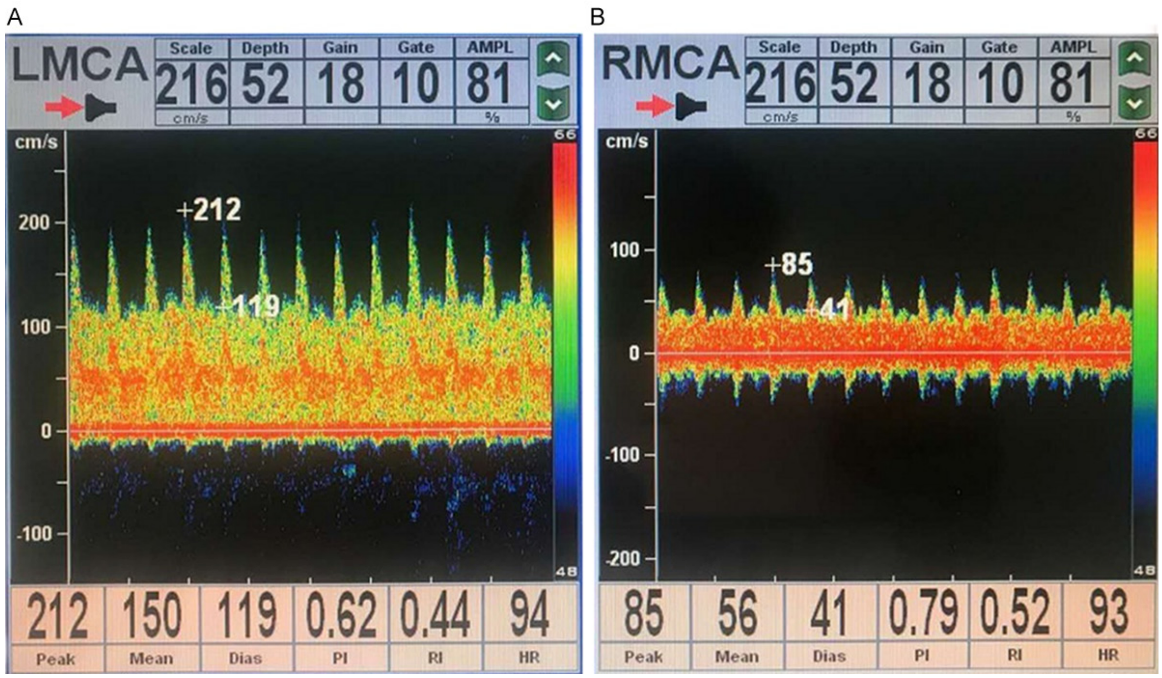

Figure 2. Velocity of middle cerebral artery during opening of the common carotid artery. A. The TCD result of left middle cerebral artery (LMCA); B. The TCD result of right middle cerebral artery (RMCA).

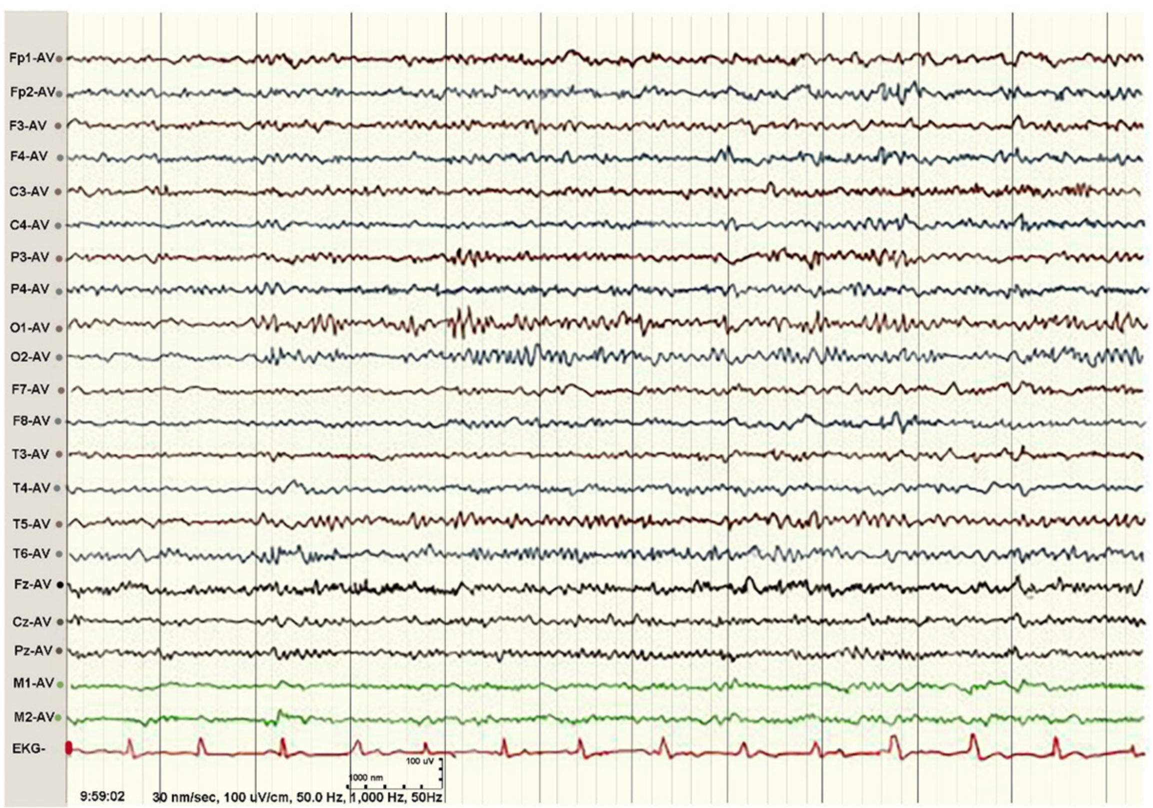

Figure 3. The result of EEG test. EEG, electroencephalogram.

Table 1. The changes of blood flow velocity in the middle cerebral artery of patients on the affected side

Methods	PSV (cm/s)	MV (cm/s)	EDV (cm/s)	PI
After anesthesia	45.53±12.71	34.51±8.64	23.56±8.31	0.63±0.12
After surgery	72.58±13.24	52.47±9.26	46.53±10.27	0.75±0.16
t	12.593	12.116	14.856	5.126
P	0.000	0.000	0.000	0.000

Note: PSV: peak systolic velocity; MV: mean velocity; EDV: end diastolic velocity; PI: pulsatility index.

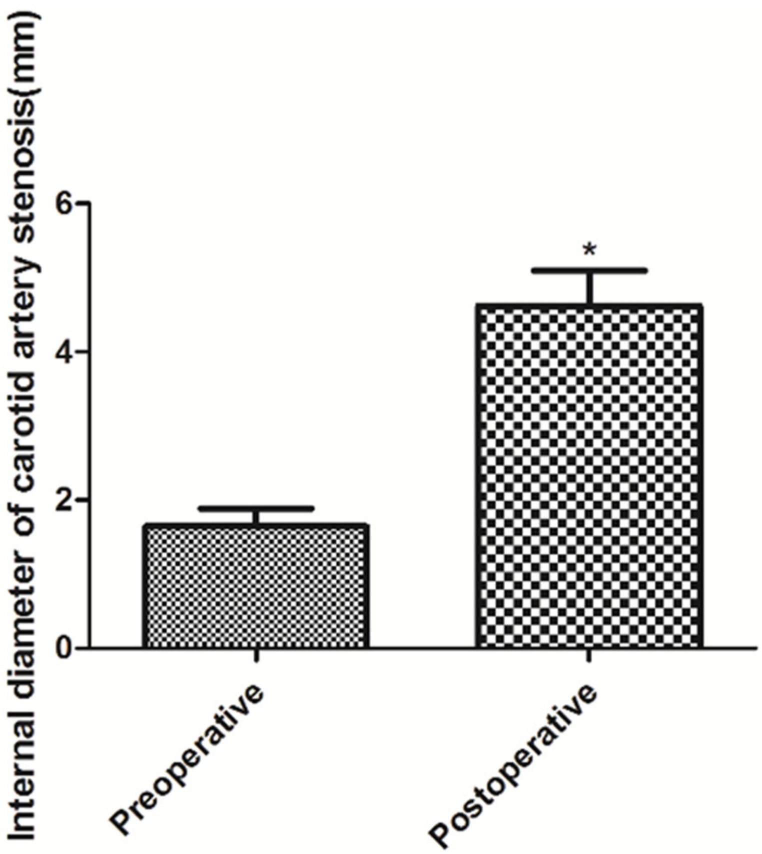

Figure 4. The internal diameter at the site of carotid artery stenosis. Compared with preoperative level, *P<0.05.

Table 2. Comparison of diagnostic performance among the three detection methods

Methods	Positive	Negative	Positive rate/%	Specificity/%
DSA	64	9	87.67	72.32
TCD	62	11	84.93	71.54
EEG	55	18	75.34	74.66
TCD combined with EEG	68	5	93.17$^{*,\#,\&}$	82.35$^{*,\#,\&}$

Note: DSA: digital subtraction angiography; TCD: transcranial Doppler; ultrasonography; EEG: electroencephalogram. Compared with DSA, *P<0.05; compared with TCD, $^{\#}$P<0.05; compared with EEG, $^{\&}$P<0.05.

that in 70 patients with intraoperative occlusion of the common carotid artery on the affected side, the middle cerebral artery blood flow velocity decreased by about 1/2, while in the remaining 3 patients, the middle cerebral artery blood flow velocity decreased by 100%. Additionally, studies have found that TCD can accurately assess the presence or absence of plaques, the hemodynamics station in the blood vessels and the stenosis rate of the internal carotid artery by detecting blood flow filling and the hemodynamic changes caused by stenosis can be measured by color flow imaging, which was consistent with this study [15].

EEG can accurately detect the electrical activity of patient's brains and help clinicians to determine the correlation between abnormal brain waves and clinical manifestations, which is of great significance for the diagnosis and differential diagnosis of cerebral ischemia [16]. In this study, EEG tests found that 59 patients showed no obvious abnormalities, and the other 14 patients showed changes in electrical potential differences in brain cells, presenting as abnormal α frequency waves. A study found that the frequency band of the α wave changed greatly in most patients with cerebral ischemia, which was consistent with this study [17]. In another study, it was shown that EEG is highly sensitive to ischemia in the intracranial brain tissue of patients, with a sensitivity up to 73.42%, which helps to better assess the degree of vascular stenosis [18].

Some studies have found that the consistency of CTA and TCD in the diagnosis of mild arterial stenosis was not good, while the consistency in the diagnosis of moderate and severe arterial stenosis was high [19, 20]. This study also analyzed the monitoring results, and the results showed that the positive rate and specificity of TCD combined with EEG detection in monitoring blood supply abnormalities of patients were 93.17% and 82.35%, respectively; which were significantly higher than that of DSA, TCD and EEG detection alone, suggesting that TCD combined with EEG detection had a higher monitoring efficiency. Moreover, a study found that the sensitivity and specificity of TCD for detecting arterial stenosis can reach 81.26% and 84.73%, respectively, which was in good agreement with DSA, but there was still a certain level of misdiagnosis rate [21]. This suggests that TCD combined with EEG detection can improve the evaluation of intracranial blood supply in patients undergoing carotid endarterectomy. However, TCD and EEG tests also have certain limitations in the assessment of carotid stenosis or occlusion. These two detection methods cannot analyze the texture of atherosclerotic plaques in the arterial wall, and cannot display whether there are ulcers or other morphological conditions. Besides, they are not very effective in diagnosing patients with mild arterial stenosis, thus limiting doctors' comprehensive understanding of patients' disease information. Therefore, in order to further improve the treatment effect for patients' disease, it can be combined with other technological means such as CTA or magnetic resonance angiography for detection.

In summary, the positive rate and diagnostic accuracy of TCD combined with EEG detection in monitoring cerebral blood supply abnormalities are higher than that of single detection, which is of great value in preventing complications in patients.

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Disclosure of conflict of interest

None.

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