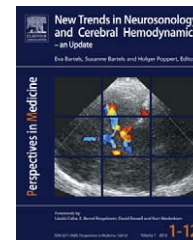




Bartels E, Bartels S, Poppert H (Editors):  
New Trends in Neurosonology and Cerebral Hemodynamics – an Update.  
Perspectives in Medicine (2012) 1, 362–365

journal homepage: [www.elsevier.com/locate/permed](http://www.elsevier.com/locate/permed)



## The role of color duplex sonography in the brain death diagnostics

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### KEYWORDS

Brain death;  
Transcranial Doppler  
sonography;  
Cerebral blood  
arrest;  
Confirmatory test

**Summary** In Russia brain death diagnostic is still under great public attention. In such environment confirmatory tests are absolutely necessary. Aim of our study is to investigate the cerebral blood flow in brain death using color-coded duplex sonography. The sonographic study of 20 patients with brain death was performed and included transcranial and extracranial color duplex sonography. All patients were untrepanized. The following parameters were measured – presence of reverberating flow, Vmax ranges.

**Results:** At baseline TCDS revealed both MCA in all patients, and the BA in 18 patients. Oscillating flow with Vmax  $-32 \pm 12$  sm/s in MCA was found. Reverberating flow in the proximal segment of ICA and in the V2 segment of VA was found in all patients. Vmax ranges were  $96 \pm 27$  sm/s in ICA and  $58 \pm 17$  sm/s in VA. After 6 h TCDS was successful in 16 patients. In all of 16 cases blood flow in the MCA as a systolic peak or reverberating flow was detected. Basilar system study was successful in 12 cases. In all vessels blood flow was as systolic peaks.

Extracranial ICA and VA were visualized in all cases. In the ICA and V2, V3 segments of the VA reverberating flow were detected. Vmax was  $47 \pm 25$  sm/s in ICA and  $35 \pm 17$  sm/s in VA. In BD color duplex scanning reveals oscillating flow or systolic spikes in distal ICA, VA, intracranial vessels. In TCDS, the most common finding is MCA with reverberating flow. The optimum combination is extracranial and intracranial scanning in the early stages of BD.

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### Introduction

The brain death (BD) is defined as the irreversible loss of function of the brain, including the brainstem, developing on the assumption of pulmonary ventilation and heart

beating. The BD is diagnosed in intensive care units (ICU) as a result of severe brain damaging and causes at least 10% of mortality in ICU in developed countries. Traumatic brain injury, malignant stroke, tumor, diffuse hypoxic–ischemic brain damage are supposed to be the main causes of BD. All these factors affect the brain and lead to brain edema and swelling, intracranial pressure increase, gradual reduction of cerebral perfusion pressure, decrease and termination of intracranial blood flow and necrosis of brain parenchyma up to 2nd cervical segment [1–3].

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According to the Russian National Guidelines of BD there are Diagnostic criteria for clinical diagnosis of BD [4]:

1. Defined cause irreversible deep coma.
2. Exclusion of complicating medical conditions that may confound clinical assessment (absence of hypothermia, drug intoxication, severe electrolyte and endocrine disturbance).
3. Systolic blood pressure  $\geq 90$  mm Hg.
4. Absence of brainstem reflexes.
5. Mydriasis with no response to the bright light.
6. Apnea with arterial  $pCO_2 \geq 60$  mm Hg.
7. The observation period of 6 and 24 h with the primary and secondary brain injury respectively.

In general, these criteria correspond to neurologic criteria for the diagnosis of brain death of American Academy of Neurology [2,5].

The following two confirmatory tests are approved for BD diagnosis in Russia:

1. Electroencephalography (EEG) – reveals no electrical activity of brain in BD patients.
2. Cerebral angiography – detects cerebral blood arrest in BD patients.

Angiography is believed to reduce the observational period only and does not substitute to any clinical criteria of BD. According to the Russian National Guidelines on Diagnostics of Brain Death, ultrasound confirmatory tests are being investigated and can not be recommended for BD diagnosis, at the same time, all over the world ultrasound tests are the 3rd in order of sensitivity and frequency for BD diagnostics [6,7]. Transcranial Doppler (TCD) is notably desirable in patients in whom specific components of clinical testing cannot be reliably performed or evaluated such as barbiturate brain protection, hypothermia or face trauma [8–10].

Our department has gained experience in ultrasonography in clinical and confirmatory tests, 438 cases of BD were diagnosed since January 1995 to December 2010 [11]. The diagnosis of BD was confirmed by TCD and EEG. Color duplex sonography (CDS) was started to be performed in 2009.

We initiated a prospective observational study of the extra- and intracranial artery CDS in BD diagnostics in 2009. 20 patients with BD have been enrolled in the study up to December 2010. The study was approved by Local Ethic Committee of Moscow State University for Medicine and Dentistry in 2008.

The aim of the study was

- to investigate whether CDS of both extra- and intracranial arteries increases sensitivity of the test in patients with BD compared with CDS of intracranial arteries alone;
- to clarify CDS criteria of circulatory blood arrest.

## Materials and methods

The study was started in Moscow hospital intensive care units in 2009 and has still been going on.

20 patients with BD due to traumatic brain injury and intracranial hemorrhage were included in the study and

**Table 1** Systolic velocity ranges in extra- and intracranial arteries.

Systolic velocity	ICA (sm/s)	VA (sm/s)	MCA (sm/s)	BA (sm/s)
1st exam	96 ± 27	58 ± 17	32 ± 12	38 ± 9
2nd exam	47 ± 25	35 ± 17	15 ± 8	21 ± 7

underwent a sonographic study which included color duplex sonography (CDS) of extracranial and intracranial arteries.

BD was diagnosed according to the Russian National Guidelines of BD. The average age of patients was  $25 \pm 5.4$  years. The average time from ICU admission to BD development was  $27 \pm 6.5$  h. The diagnosis of traumatic brain injury and intracranial hemorrhage was detected by computer tomography at the admission. All the patients had severe diffuse brain injury with the transverse and axial dislocation. Craniotomy was not carried on.

The sonographic study was performed according to the Rules of Task Force Group on Cerebral Death of Neurosonology Research Group of the World Federation of Neurology [12].

The following criteria of the test were mandatory:

1. The investigation of anterior and posterior circulation.
2. Bilateral visualization of intracranial internal carotid artery branches.

The study was conducted on a portable device Sonosite Micromaxx (USA) with broadband transducers L5–10 MHz, P1–5 MHz twice: at baseline after assessment of clinical criteria of BD and 6 h later. Presence of reverberating flow, Vmax ranges, presence of midline shift in B mode were also measured.

## Results

At baseline CDS revealed both MCA (right and left) in all 20 patients, both ACA in 16 patients and BA in 18 patients. Oscillating flow with Vmax  $-32 \pm 12$  sm/s in MCA was found.

Data of extra- and intracranial artery and blood flow rates are presented below (Tables 1 and 2).

A midline shift 4–10 mm in B-mode was noted in 13 patients and it made artery differentiation difficult.

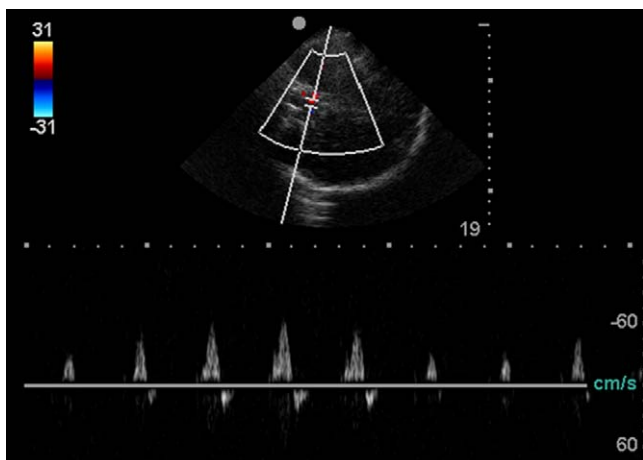
Reverberating flow in the proximal segment of ICA and in the V2 segment of VA was found in all patients.

Vmax ranges were  $96 \pm 27$  sm/s in ICA and  $58 \pm 17$  sm/s in VA respectively.

Reverberating and oscillating flow of intracranial and extracranial artery are presented in Figs. 1–4.

**Table 2** Visualization frequency of extra- and intracranial arteries ( $n = 20$ ).

N = 20	MCA	ACA	PCA	BA	VA V2	ICA prox
1st exam	20	16	15	18	20	20
2nd exam	16	11	5	12	20	20



**Figure 1** Reverberating flow in MCA in case of brain death.

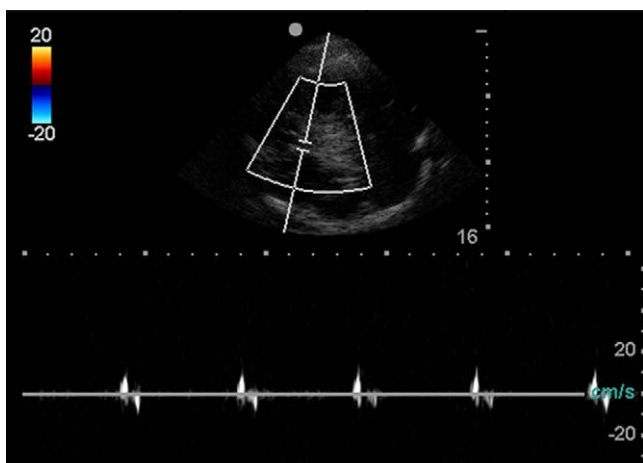
After 6 h TCCS was successful in 16 patients. In all of 16 cases blood flow in the MCA as a systolic peak or reverberating flow was detected.

Extracranial ICA and VA were visualized in all cases. In the ICA and V2, V3 segments of the VA reverberating flow were detected.  $V_{max}$  was  $47 \pm 25$  cm/s in ICA and  $35 \pm 17$  cm/s in VA. Spontaneous echo contrast in ICA and bulb was observed in 14 cases.

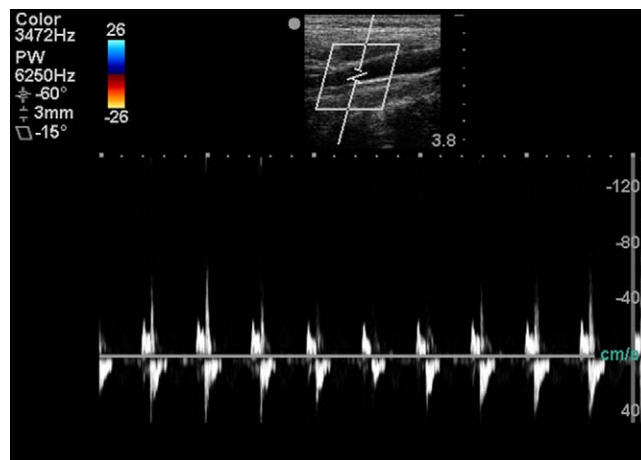
Thus, the sensitivity of the method in extra and intracranial study was 100%. The separate holding TCD in early sensitivity was 90%, at a later date from the time of clinical brain death sensitivity decreased to 80%.

## Discussion

Brain death is a clinical diagnosis and neurologic criteria are still the main valid in BD diagnosis. However BD diagnosis has a comprehensive ethic value and on the one hand, there are some patients in whom specific components of clinical testing cannot be reliably performed or evaluated. Thus new maximal accurate, fast and safe test for BD diagnosis are required. On the other hand, frequently spontaneous and reflex movements, face trauma make difficulties of the BD diagnostics that is why additional



**Figure 2** Systolic spikes in MCA in case of brain death.



**Figure 3** Reverberating flow in ICA (extracranial) in case of brain death.

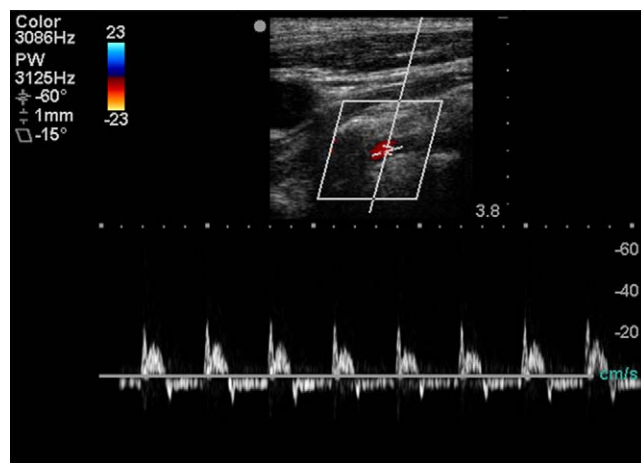
confirmatory tests are considered to trend in unclear cases. Moreover, significant restriction of observational period or complete rejection of re-examination for BD diagnosis is discussed when confirmatory tests are performed [2,8,13].

All the tests for BD diagnosis perfectly have to be:

- feasible at the bedside;
- survey should not take much time;
- should be safe for the examinee, and a potential recipient of donor organs as well as performing their medical staff;
- to be sensitive, specific, reproducible and protected from external factors.

Color duplex scanning is the test which satisfies better than others to the requirements listed above. The great advantage of duplex scanning compared with the blind Doppler in BD is an opportunity of direct visualization of the lumen, which facilitates the diagnostics.

The most important is the qualitative analysis of the spectrograms with the definition of specific patterns of oscillating or reverberating flow, indicating the development of circulatory blood arrest. Quantitative parameters, including



**Figure 4** Reverberating flow in VA (V2 extracranial) in case of brain death.

systolic velocity, the index of Gosling, volumetric flow rate are more unsteady than qualitative ones and in patients with BD depend generally on two factors – level of systolic blood pressure and intracranial pressure during the investigation [6,14–16]. Although there are some reports that showed that a decrease in the total volume of cerebral blood flow below 100 ml/min is in line with 100% mortality [17,18].

As it was shown in our study, the combination of intracranial and extracranial tests increased the sensitivity of the study up to 100%. The sensitivity of isolated transcranial color duplex scanning was lower and depended on the time when the test was carried on in patients who had their clinical symptoms developed. The maximum sensitivity was 90% when the test was performed in the early period and decreased to 80% when the investigation was done 6 h after the symptom manifestation.

In addition, another factor which makes difficulty in interpretation of ultrasound data is previous extensive resection craniotomy in neurosurgical patients. In this case, the intracranial pressure is usually much lower. Here TCD is supposed to prolong the period when diagnosis of BD will be established. Although in any case, the typical ultrasound picture of circulatory blood arrest is developed with the lapse of time [19].

Cerebral angiography remains a “gold standard” of diagnostics in angiology. It should be noted that in cases with craniotomy, even when cerebral angiography was performed, there is flow of contrast into the cranial cavity, which makes the interpretation of the clinical data difficult [20–23].

BD is a clinical diagnosis and any confirmatory tests are auxiliary. The diagnosis of BD cannot be based only on confirmatory tests and neurologic criteria assessment is required.

## Conclusions

CDS of patients with BD reveals oscillating flow or systolic spikes in distal ICA, VA, intracranial vessels and spontaneous echo contrast in proximal ICA. In TCD, the most common finding is MCA with reverberating flow. There are some difficulties in detection of basilar system and it depends on the time of BD manifestation.

The optimum combination is extracranial and intracranial scanning in the early stages of BD.

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