Pulsatile cerebral echo in diagnosis of brain death

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Conclusive diagnosis of brain death can be made by the demonstration of prolonged cessation of cerebral blood flow. This report describes a simple method to determine the presence or absence of the blood flow in the brain by recording the pulsatile midline echo on one channel of the electroencephalogram (EEG) or on any four-channel monitoring system in the intensive care unit. A firm transducer holder has been developed to eliminate artifacts caused by transducer motion. The pulsations of the midline echo are assumed to be the result of displacement of the midline structures by the arterial injection of each cardiac systole. Thus, the absence of these midline pulsatile echoes correlates with the absence of cerebral blood flow and, if the absence persists over 30 minutes in the presence of normal blood pressure, then the result is brain death.

Twenty-eight cases of clinical brain death with electrocerebral silence of EEG and 18 obtunded patients with various types of cerebral pathology were examined by the echo-pulsation technique. Twenty-six of the 28 cases showed no pulsation of the midline echo. The validity of the technique was documented in four cases by four-vessel cerebral angiogram.

Key Words • brain death • brain pulsation • cerebral blood flow • echoencephalogram • electroencephalogram

Almost all sets of criteria for cerebral death have been based upon deep coma, apnea, and electrocerebral silence (ECS) in the electroencephalogram (EEG). The determination of cerebral unresponsiveness and of apnea is somewhat imprecise, but at the bedside any response of the patient or respiratory effort is readily recognized. The interpretation of the EEG in cases suspected of cerebral death is complicated by three factors: technical inadequacies due to recordings in emergency rooms and intensive care units, misinterpretations in the reading of the record, and the validity of a single record of ECS as an indication of cerebral death.  

Since many European investigators consider brain death as total cerebral infarction due to the absence of cerebral circulation, some simple techniques for the determination of cerebral blood flow (CBF) seem appropriate and desirable as confirmatory tests. However, because the usual method of four-vessel angiography used to demonstrate CBF is invasive and risky in critically ill patients, physicians have been reluctant to routinely subject patients suspected of a dying brain to this technique. Indirect methods of determining CBF such as isotope bolus transit curves, retinal sludging, and rheoencephalography seemed promising, but their value is not yet established.
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This report describes a simple and noninvasive method to determine the presence or absence of the cerebral circulation, based upon the midline pulsatile echo that Leksell recognized as synchronous with the heart beat. It originates from distortion of the walls of the third ventricle as blood is driven into the intracranial cavity by cardiac systole. The echo-pulsation seen on the cathode ray screen becomes a quasi-sinusoidal wave when recorded on an inkwriter. LePetit, et al., have cinematographically observed the midline pulsatile echo and demonstrated that no pulsation can be seen in the absence of CBF. The technique described in this paper records the pulsatile echo in one channel of the write-out of an EEG or any other multi-channel recorder that may be available in the intensive care unit, so that simultaneous records of EEG, electrocardiogram (EKG), and the echo pulsations may be examined.

Materials and Methods

The ultrasonic pulsation signals recorded during this study were derived from an ultrasonic reflectoscope, which utilized a standard A-scope display to present the information, and a 2.0 mHz piezoelectric transducer.* This technique, the most common method in clinical use, has been described extensively. The recording of the pulsatile portion of the echo signal however, requires additional processing of the reflectoscope's electrical signals.

The familiar ultrasonic reflectoscope display is illustrated in Fig. 1 upper. This is an A-scope display of the detected video signals associated with an initial echo (I), midline echo (M), and a pulse (O), which corresponds to the echo reflected from the skull on the side opposite the transducer.

The pulsatile character of the echo is observed as a regular variation in the amplitude of the echo signal, typically the midline echo. Since an echo associated with a transmitted pulse has a given amplitude, the pulsation occurs as a relative change in amplitude of succeeding echoes. On the display, this is seen as a regularly occurring variation in the height of the echo signal, which, because of the rapid repetition rate, gives the illusion of being a variation in the height of the single displayed signal. If it were possible to observe these echoes in their true time sequence, they would appear as a sequence of pulses varying in amplitude at a frequency corresponding to the patient's heart rate as illustrated in Fig. 1 lower.

Electronically this analysis may be made with a gating system illustrated in the functional block diagram in Fig. 2. The resulting signal may be recorded on any strip chart recorder, or oscillograph with sufficient slew capability to follow the rapidly changing portion of the signal, assuming proper sensitivity adjustment. It can also be recorded on an EEG pen writer, but the resulting curvilinear coordinate presentation is difficult to interpret. The gating method is sufficiently general to be applied to the various reflectoscope systems in current use and as many such gates as desired can be constructed to allow the simultaneous recording of the pulsatile component of two or more echoes.

FIG. 1. Upper: A-scope echogram with a gate interval indicated by arrows. I = initial echo, M = midline echo, O = opposite echo. Baseline scale: large markers represent 10-mm and small, 2-mm intervals. Lower: Formation of a typical pulsatile echo signal from gated echo pulse sequence.

*Ultrasonic reflectoscope and piezoelectric transducer manufactured by Sperry, Inc., Danbury, Connecticut.
S. Uematsu, T. D. Smith and A. E. Walker

Synchronizing

Trigger In

Delayed

Trigger

Generator

Gating Interval

Pulse Generator

Detected

Video

Electronic

Switch

Gated Echo

Out

Peak Detector and

Pulse Forming CKT

Low Pass

Filter

DC

AVG

Pulsatile Echo

Out

CKT: Circuit

DC Avg: Direct Current

Average

Adder Circuit

FIG. 2. Block diagram of typical gating and filtering system used to derive the pulsatile echo from a reflectoscope.

The equipment we used for most of the recordings in this study was a Model UM-729 Ultrasonic Reflectoscope manufactured by the Sperry Division of Automation Industries. The gating and peak detecting circuitry was provided by a unit that could be plugged into the Sperry reflectoscope. The subsequent processor was developed by one of us (T.D.S.) specifically for this study. A four-channel gating and processing system, developed by the author, was used with the Sperry ultrasonic reflectoscope to make the more recent recordings. In addition, a head band was fabricated to hold the transducer firmly to ensure stability.

The system was tested in 46 patients, three in stupor, 15 in coma, and 28 suspected of cerebral death on the basis of unresponsiveness, apnea, and isoelectric EEG (Table 1). Cerebral angiograms were carried out on four patients (Cases 3, 12, 25, and 26), two of whom had drug intoxication (Cases 12 and 26).

Results

In 10,000 patients with normal CBF, a pulsation of the midline echo has been invariably demonstrated.17 A normal pulsatile midline echo was present in all the normal, obtunded, and comatose patients and in two (Cases 8 and 9) of the 28 cases suspected of cerebral death. In the remaining 26 cases of cerebral death, the midline echoes did not pulsate. All four patients, who were suspected of brain death because of an absence of echo pulsation, and in whom angiograms were done, had nonfilling of the intracranial blood vessels.

Figure 3 is an example of normal echo-pulsation in a decerebrate patient with an

†Transigate E-550 unit manufactured by Sperry, Inc., Danbury, Connecticut.
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TABLE 1

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age, Sex</th>
<th>Diagnosis</th>
<th>BP</th>
<th>EEG</th>
<th>Echo Pulsation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6, F</td>
<td>Reye's disease</td>
<td>140/120</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>2†</td>
<td>29, M</td>
<td>ACA aneurysm with intracerebral hematoma</td>
<td>150/72</td>
<td>ECS</td>
<td>0†</td>
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<tr>
<td>3</td>
<td>72, F</td>
<td>thrombosis, carotid artery</td>
<td>150/90</td>
<td>ECS</td>
<td>0</td>
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<tr>
<td>4</td>
<td>53, F</td>
<td>ruptured PCoA aneurysm</td>
<td>30/0</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>5†</td>
<td>56, M</td>
<td>parasagittal meningioma</td>
<td>100/60</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>23, F</td>
<td>coma of undetermined origin</td>
<td>140/80</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>7†</td>
<td>60, M</td>
<td>operative cardiac arrest</td>
<td>90/60</td>
<td>ECS</td>
<td>+</td>
</tr>
<tr>
<td>8†</td>
<td>64, F</td>
<td>ruptured ACA aneurysm</td>
<td>90/60</td>
<td>ECS</td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>51, M</td>
<td>head trauma</td>
<td>190/120</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>35, M</td>
<td>gunshot head wound</td>
<td>170/100</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>13, M</td>
<td>Reye's disease</td>
<td>80/50</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>12†</td>
<td>62, F</td>
<td>cerebral thrombosis</td>
<td>110/80</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>13†</td>
<td>29, M</td>
<td>gunshot head wound</td>
<td>80/50</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>14†</td>
<td>3, M</td>
<td>strangulation</td>
<td>140/100</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>15†</td>
<td>54, M</td>
<td>posterior fossa hematoma</td>
<td>150/100</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>16†</td>
<td>30, M</td>
<td>operative cardiac arrest</td>
<td>140/104</td>
<td>ECS</td>
<td>0</td>
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<tr>
<td>17</td>
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<td>multiple trauma</td>
<td>110/60</td>
<td>ECS</td>
<td>0</td>
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<tr>
<td>18†</td>
<td>10, M</td>
<td>head trauma</td>
<td>78/</td>
<td>ECS</td>
<td>0</td>
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<tr>
<td>19†</td>
<td>20, F</td>
<td>operative cardiac arrest</td>
<td>100/</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>20†</td>
<td>63, M</td>
<td>intracerebral hemorrhage</td>
<td>120/150</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>21†</td>
<td>54, F</td>
<td>subarachnoid hemorrhage</td>
<td>150/100</td>
<td>ECS</td>
<td>0†</td>
</tr>
<tr>
<td>22†</td>
<td>44, M</td>
<td>salicylate intoxication</td>
<td>160/80</td>
<td>ECS</td>
<td>0†</td>
</tr>
<tr>
<td>23†</td>
<td>24, F</td>
<td>head trauma</td>
<td>110/60</td>
<td>ECS</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>28, M</td>
<td>head trauma</td>
<td>120/60</td>
<td>ECS</td>
<td>0</td>
</tr>
</tbody>
</table>

*ACA = anterior cerebral artery; PCoA = posterior communicating artery; BP = blood pressure at the time of the pulsatile echography; ECS = electrocerebral silence; 0 = absence of echo pulsation; + = presence of echo pulsation.
†Diagnosis confirmed by autopsy.
‡Angiography showed no cerebral blood flow.

Acute subdural hematoma. In the upper trace is the EKG, in the second trace is an echo-pulsation, and the remaining traces are of the EEG's with biological activity (BA). The relationship of the echo-pulsation to the "PQR" complex of the EKG may be noted. Such records were seen in all of the normal, obtunded, and comatose patients, and in two of the patients suspected of brain death. The following cases were examples of patients with recordings indicating brain death.

Case 28

The recording in Case 28 showed the absence of a midline echo pulsation. This 28-year-old man never regained consciousness after evacuation of a left acute subdural hematoma and repair of a traumatic laceration of the abdominal aorta. At the time of the echo study, he was apneic and unresponsive; his pupils were fixed and dilated, without doll's eyes phenomena. His corneal reflexes were absent. Neither deep tendon nor plantar reflexes could be elicited. The EEG revealed electrocerebral silence. The top trace in Fig. 4 is the EKG; the second trace is carotid pulsation at the neck recorded by a Doppler flow meter; the third trace shows an absent echo pulsation of the third ventricle; and the fourth trace is the echo from the opposite internal table of the skull. Based on these findings, vasopressor agents were discontinued, but because of the family's wish the respirator

‡Doppler flow meter manufactured by Parks Electronics Laboratory, 12270 South West First, Beaverton, Oregon.

was not disconnected. His heart ceased beating 2 hours later.

Case 26

The recording in Case 26 is an example of absent pulsatile echo. There was also angiographic verification of no CBF. This 44-year-old man was brought to the emergency room in delirium. His condition rapidly deteriorated so that he was comatose by the time he arrived on the ward. He became hyperpneic, resulting in respiratory alkalosis and then metabolic acidosis. He developed gastrointestinal bleeding, hypovolemic shock, and renal failure. Within 6 hours of admission, he stopped breathing and artificial ventilation was begun. He lost his brain-stem and deep tendon reflexes. An elevated serum salicylate (40 mg%, determined 24 hours after the admission) was considered indicative of intoxication.

There was an absence of the echo pulsation (Fig. 5, third trace) when the blood pressure (BP) was 160/80. Figure 5, lowest trace, is a control echoencephalogram showing midline pulsations from a normal individual. The EEG (channels 4 to 8) was read "possibly a flat record, but the possibility of traces of cerebral bio-electrical activity cannot be ruled out."

An aortic arch and selective right common carotid angiogram showed no intracranial flow of contrast material (Fig. 6). The internal carotid artery was not filled beyond the C-2 level, even at the end of 24 seconds.

Case 9

The recording in Case 9 showed a pulsatile echo in clinical brain death. This 51-year-old man entered the emergency room with an injury to the right orbit and right-sided seizures. He responded only to painful stimuli. Echoencephalography revealed a 9-mm displacement of the midline structures to the right. A large acute subdural hematoma overlying the entire left cerebral hemisphere and a lime-
FIG. 4. Case 28. Absence of a midline echo-pulsation. In spite of evacuation of an acute right subdural hematoma, cardiac arrest occurred 3 hours after these records were made. Traces from top: electrocardiogram, carotid pulsation (Doppler flow technique), absent pulsations of the midline, and of the echo from the opposite internal table of the skull. Time scale = 1 sec.

sized frontal intracerebral hematoma were evacuated. He remained unresponsive; his pupils were dilated and became non-reactive the next day. The bone flap was removed, and he was placed on a respirator. His blood pressure was difficult to maintain, and at times could not be determined. At the time of EEG, the blood pressure ranged from unobtainable to 90/40. The echoencephalogram, made over the right temporal bone opposite the craniotomy defect, had good pulsation in spite of the low blood pressure and a flat EEG.

The persistent echo-pulsation in this case may have been transmitted from the external carotid pulsation to the intracranial cavity through the large decompressive cranial defect.

Case 8

In Case 8, the recordings showed midline pulsations in a cerebral death suspect. This 64-year-old woman had a right frontal craniotomy for clipping of an anterior communicating aneurysm. On the evening of the surgery her right pupil began to be less responsive and to dilate. She was re-explored the following morning, and only a very thin layer of epidural blood was found. The possibility of a brain-stem infarction was suggested. Her BP was 160/100 at the end of the procedure, and she was kept on a respirator. Her pupils were unequal and non-reactive, and she moved her legs only to painful stimuli. Postoperatively, her BP could not be obtained and vasopressor agents only
restored it to 90/60. An EEG revealed a "flat" record, but an echogram showed good pulsations. One hour later the patient was pronounced cerebrally dead.

At autopsy the surfaces of the brain were dull and congested. The edematous brain was cut, and revealed that the hypothalamic area extending to the septum pellucidum, and the inferior mediofrontal cortex were necrotic. There was an area of hemorrhagic infarction in the left temporo-occipital area near the convexity.

The cause of the preservation of the pulsatile echo in the presence of a flat EEG in these Cases 8 and 9 may relate to the hypotensive state, poorly compensated by vasoressor drugs, for it is well known that the EEG is extremely sensitive to an arterial hypotension that may still cause intracranial pulsations.

Discussion

There are three components in a pulsatile echo: 1) rise time, 2) latency time, and 3) amplitude. The rise time is the interval between the attainment of 10% and 90% of the amplitude; it is thought to represent the injection of the blood into the cranium by a cardiac contraction. The latency time is the interval from the Q wave of the EKG to the rising point of the pulsatile echo. This represents the time from the onset of cardiac contraction to the arrival of arterial blood in the intracranial cavity. These times are not influenced by the position or direction of the transducer nor of the sound beams. The amplitude, measured from the baseline to the peak of the wave, may be affected by the slightest alteration of the direction of sound beams which may be caused by movement of the transducer. The sources of the pulsa-
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Fig. 6. Case 26. Right carotid angiogram showing failure of contrast material to enter the skull at the end of 24 seconds. Aortic arch injection demonstrated the absence of intracerebral circulation from the internal carotid and vertebral arteries.

tion may be divided into two groups: 1) structures supplied with blood by the internal carotid artery (walls of the third ventricle, septum pellucidum, vascular complex of Sylvian fissure, carotid siphon, and lateral ventricle); and 2) structures supplied by the external carotid artery (dura mater, temporal muscle, and scalp).

Hyperventilation or the position of the body (such as supine, standing, and sitting) can effect the amplitude of the pulsatile echo. Clenching the teeth and contraction of facial muscles may also influence its amplitude. The latency time of the echo-pulsation may be prolonged as a falling BP significantly decreases the velocity of blood flow. A decreased amplitude is observed when the BP falls sufficiently to lessen the pulsatile movement at interphases. An arterial hypertension particularly associated with atherosclerosis, may increase the velocity of the blood flow, which in turn shortens the rise and latency times. It is reported that elevated intracranial pressure decreases the amplitude of the pulsatile echo, shortens the rise time and prolongs the latency time.

Obviously, pathological changes in the region of the third ventricle, such as contusion, hemorrhage, or tumor will change the configuration of the midline echo and interfere with its pulsation. Arnold, et al., have shown such a non-pulsatile midline pathological echo with preserved pulsation of the lateral ventricle. The diffusion of the midline echo in this case may have masked its pulsatile character. For this reason, in the presence of a pathological midline echo, pulsations from other intracranial structures should be interpreted as indicating CBF.

Uniform changes in the consistency of cerebral tissues, severe anemia, dehydration, inflammatory processes, or cerebral edema, may not significantly affect the echo. In liquefication of the brain during mortification, there may be a total absence of echoes. This finding is less common in cerebral death than the absence of the pulsation of the persistent midline echo.
The dissociated findings of an isoelectric EEG and a pulsating midline echo, may be explained either by assuming that the irreparably damaged brain still has some cerebral circulation or that the EEG disappears as the result of a fall in perfusion pressure which can still be detected by echograms. One of us (A.E.W.) has observed biological activity of the EEG to reappear when vasopressors elevated the BP to near normal levels.\textsuperscript{18,19} In the two cases in which dissociated findings were noted in this series, the arterial pressure was fluctuating from imperceptible to shock levels. This severe hypotension apparently maintained perfusion of the brain at a level inadequate to sustain neuronal activity, but sufficient to produce a shock wave detectable by echoencephalography.

We suggest that two examinations of pulsatile echography be made at 15- to 30-minute intervals before it is concluded that the pulsation of the midline echo is absent. This not only doubly substantiates the absence of the pulsation, but it also indicates an arrest of CBF for a period that assures the nonviability of the brain.

**Summary**

Because clinical signs of absent brain function even when associated with electrical silence in the EEG are equivocal evidence of cerebral death, the demonstration of loss of cerebral circulation, even for a few minutes, adds a certainty of neuronal death in a short time. Angiographic evidence of an absent cerebral circulation alone is adequate proof of cerebral death, but the technique requires four-vessel angiography with some attendant risk. The indirect evidence afforded by the absence of pulsation of midline and other intracranial echoes (in the presence of a normal BP), is theoretically indicative of no cerebral circulation, and is a preferable means for the confirmation of a dead brain that is simple, noninvasive, reliable, and practical.

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