INTRODUCTION

Brain death is defined as irreversible cessation of brain functions including the brain stem. The diagnosis is mainly clinical and includes irreversible coma, absence of motor responses to pain, absence of brain stem reflexes and apnea [19]. In most countries, confirmatory tests are not requested, except when clinical testing is inconsistent due to hypothermia, sedative drugs, anoxia or hemodynamic instability [16]. In some countries, confirmatory tests are mandatory including electroencephalography (EEG) recordings or cerebral angiography. However, EEG recordings may not be reliable when patients have received sedative drugs [11]; conventional angiography requires a trained team, and makes transportation of mostly intubated patients necessary. Spiral CT has been accepted as a diagnostic modality to establish brain death by French authorities in 2000. Other methods such as transcranial Doppler sonography [7], brain stem evoked potentials [9], bi-spectral monitoring [6], MRI [18], and cerebral blood flow studies [14] shorten the waiting period [10] and may be used to confirm the clinical diagnosis of brain death, but legally are not accepted as complementary examinations.

So far, only little data exists on the value of CT scanning for the diagnosis of brain death [2, 8, 13, 15]. Dupas et al. [8] compared two-phase spiral CT...
and conventional angiography in 14 brain-dead patients. The authors concluded, that two-phase spiral CT scans acquired at 20 and 60 sec after application of the contrast agent could demonstrate the absence of intracerebral blood flow in brain death. Despite the potential interest of spiral CT for the diagnosis of brain death, the literature does not provide accurate information about residual opacification of intracranial vessels on spiral CT in case of brain death.

The aim of this study was to assess the role of spiral CT for the diagnosis of brain death.

SUBJECTS AND METHODS

Patients

From December 2003 to November 2004, 15 consecutive patients (8 women, 7 women; mean age: 47.7 years, range: 16 to 62 years) were referred from the intensive care unit for a spiral CT to confirm the diagnosis of brain death prior to organ explantation. The causes of hospital admission included head trauma (6 cases), intracranial hemorrhage (5 cases), ballistic brain injury (1 case), cardiac arrest (1 case), suicide by hanging (1 case), and cerebral infarct (1 case).

For all included patients, clinical evaluation fulfilled all the criteria of brain death including: (1) total unresponsiveness to external stimuli including pain stimuli, (2) absence of all cranial nerve reflexes (pupillary reflexes, oculocephalic and vestibulo-ocular reflexes, facial sensory and motor responses, pharyngeal and tracheal reflexes).

Apnea Test

The absence of spontaneous breathing during an apnea test was demonstrated in all patients. For the apnea test, the target PCO2 was greater than 60 mmHg at 100% oxygenation at a rate of 6 L/min using a catheter placed at the level of the carina. Patients were observed for spontaneous respiratory movements under these conditions for 10 minutes.

Spiral CT

Spiral CT scans were performed on a 4-row multidetector scanner (Somatom Volume Zoom, Siemens, Erlangen, Germany) 2 to 24 hours (mean: 10.2 hours) after the apnea test. The spiral CT scans were acquired with a protocol similar to the one suggested by Dupas et al. [8] using two scanning phases. We first performed sequential scans in 10-mm sections without contrast material injection of the entire brain after acquisition of a lateral scout view. A total volume of 120 mL of nonionic contrast material (Omnipaque 350, Nycomed Imaging AS, Oslo, Norway) was then administered at a rate of 3 mL/sec using a power injector and a 20-gauge intravenous catheter inserted into the antecubital vein. Spiral scanning was started 20 seconds after the start of injection with 4×2.5 mm, pitch of 0.75, scan time of 16 seconds. Axial images were reconstructed at 10-mm increments every 5 mm. A low spatial frequency convolution algorithm was used. The window level was preset at 50 Hounsfield units (HU), with a width of 100 HU. This first scanning phase was used to ensure the correct administration of contrast media. A second acquisition using the same parameters was started 60 seconds after the start of injection to evaluate vessel opacification.

When CT findings suggested a persisting cerebral circulation, a second CT examination was performed 12 hours later.

Image Analysis

CT data were reviewed by two radiologists in consensus. Two groups of vessels were analyzed: (1) external carotid arteries to ensure the correct intravascular passage of contrast material. Observers compared the early phase with the late phase of spiral CT for the opacification of superficial temporal arteries and facial arteries, (2) intracranial vessels on the late phase at 60 seconds after injection to determine the intracerebral circulation. We analyzed the presence of enhancement in the middle cerebral arteries, the pericallosal arteries, the posterior cerebral arteries, the internal cerebral veins and the great cerebral vein. The horizontal (M1), sylvian (M2) and cortical (M3) segments of the middle cerebral artery (MCA) as well as both proximal segments (P1) of the posterior cerebral artery were assessed separately. Other intracranial vessels including the internal carotid artery, the intracranial vertebral artery, the horizontal segment (A1) of the anterior cerebral artery, the straight sinus and the superior sagittal sinus were not evaluated because previous studies reported the possible enhancement of these structures in brain-dead patients [8, 12].

For each vessel, observers indicated if the vessel was assessable or not. An artery or a vein was judged not assessable when artifacts, massive hemorrhage or major brain edema prevented accurate image interpretation. When the vessel was judged assessable, observers indicated if the vessel enhanced or not.

RESULTS

Image interpretation

Of 15 patients referred for spiral CT to evaluate clinically suspected brain-death, vessel analysis at 60 seconds after contrast material injection showed that the M1 segment of the MCA was assessable in all cases. Ballistic artifacts, major edema or hemorrhage prevented visualization of the pericallosal arteries in two patients, and the M1 segment of the MCA in two. The internal cerebral veins were judged not assessable in five patients and the great cerebral vein in one.

External carotid artery

To ensure correct application of the contrast agent, the branches of the external carotid artery were carefully evaluated. The branches of the
external carotid arteries were opacified in all patients at both 20 and 60 seconds after application of contrast media. We found it easier to assess the opacification of the facial artery in front the maxillary sinus (figure 1) compared to the superficial temporal artery close to the temporal bone. A qualitative comparison between the first phase and the second phase of spiral CT did not show any differences.

Intracranial vessels

When the vessels were judged assessable, the major branches of the circle of Willis were frequently opacified (table I, figures 2 and 3). The M₁ segment of the MCA was opacified in seven patients, whereas enhancement of the M₃ branches of the MCA occurred in one patient only (table I, figure 4). The M₂ segments of the MCA were never enhanced bilaterally. The great cerebral vein was opacified in one patient (figure 5), whereas the internal cerebral veins never showed enhancement in brain death.

DISCUSSION

Our study showed that the absence of opacification of the cortical segment of the MCA in both hemispheres and the absence of internal cerebral vein enhancement constitute the best CT criteria for

<table>
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<tr>
<th>Vessels</th>
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<th>Both side</th>
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<tbody>
<tr>
<td>PCA-P₁/P₂</td>
<td>0</td>
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</tr>
<tr>
<td>ACA-A₂</td>
<td>4</td>
<td>0</td>
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<td>MCA-M₁</td>
<td>2</td>
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<td>MCA-M₂</td>
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<td>0</td>
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<td>ICV</td>
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<tr>
<td>GCV</td>
<td>1</td>
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Abbreviations: PCA-P₁/P₂ = perimesencephalic segments of the posterior cerebral artery, ACA-A₂ = pericallosal artery, MCA-M₁ = horizontal segment of the middle cerebral artery, MCA-M₂ = sylvian segment of the middle cerebral artery, MCA-M₃ = cortical segment of the middle cerebral artery, ICV = internal cerebral vein, GCV = great cerebral vein, NA = not applicable.
FIG. 3. – Patient with right subdural hematoma responsible for major mass effect. Precontrast spiral CT (a) and 60-second phase of spiral CT after contrast material injection (b). Spiral CT findings at 60 seconds after contrast media injection showed opacification of the pericallosal artery (arrow) whereas the cortical segments of the middle cerebral arteries are not enhanced.

FIG. 4. – Brain-dead patient with massive intracranial hemorrhage. Pre-contrast spiral CT (a) and spiral CT after contrast media injection (b). The post-contrast scan demonstrates opacification of a few cortical branches of the left middle cerebral artery (arrows).

FIG. 5. – Patient admitted for a head trauma. Precontrast spiral CT (a) and 60-second phase of spiral CT after contrast material injection (b) show opacification of the horizontal segment of the middle cerebral arteries (arrows) and the great cerebral vein (arrowhead).

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the diagnosis of brain death. Contrast enhancement of the great cerebral vein, the pericallosal artery, the posterior cerebral artery, and the proximal segment of the MCA on late series, acquired at 60 seconds after contrast material injection does not seem to be a reliable indicator of brain death. Diagnosis of irreversible loss of brain function is clinically established by demonstrating coma, brainstem areflexia and apnea. An apnea test with PCO$_2$ monitoring is required to stimulate the respiratory centers. It includes a disconnection of the ventilator, a delivery of 100% oxygen inside the tracheal cannula and the measurement of PaCO$_2$ after 10 minutes observation before reconnecting the ventilator. No spontaneous breathing may be observed during the disconnection period while the threshold of maximal stimulation of the respiratory center in the medulla oblongata is set at a PCO$_2$ of 60 mmHg [20]. The protocol used for apnea testing varies between different countries [21]. Because the irreversibility of the clinical status may sometimes be uncertain, most countries require a second clinical evaluation at various time intervals whereas a confirmatory test is mandatory in other countries including the Netherlands, Italy, Luxembourg and France [10]. The clinical criteria for “brainstem death” ensure that “whole-brain death” is present. Young et al. argue, that if the brainstem is selectively damaged or if brainstem function cannot be adequately assessed clinically, ancillary tests are needed to confirm whole-brain death with certainty. Therefore they even demand tests of whole-brain perfusion to reliably diagnose brain death [22].

Dupas et al. [8] suggested to perform an early spiral CT at 20 seconds after injection in order to ensure correct administration of the contrast media. In the present study, the early phase scans showed a similar appearance of major extracranial carotid arteries branches when compared to a scanning phase acquired at 60 seconds after application of the contrast agent. Our data suggest that the scanning protocol could be limited to a single, late phase of spiral CT and that the correct intravascular passage of contrast media after injection can be confirmed by paying special attention to the facial artery in front of the maxillary sinus.

The cortical segment of the MCA was always assessable whereas the internal cerebral veins were judged not assessable in seven patients. This was explained by the appropriate contrast of images at the level of the centrum ovale whereas brain oedema or intracranial hemorrhage could prevent accurate image analysis at the level of basal cisterns.

Of 15 patients that clinically fulfilled all the criteria of brain death including apnea testing, one pericallosal artery remained opacified on the late series in four patients, the posterior cerebral arteries in one and the great cerebral vein in one. In the study of Dupas et al [8], only the proximal segment of the MCA and the pre-communicating segment of the anterior cerebral artery were irregularly opacified on the late series, which was explained by “stasis filling” [12]. The pericallosal arteries and the great cerebral vein did not enhance on late series in brain-dead patients. However, other reports using conventional angiography [1, 4] or Xenon CT studies [3, 5] have demonstrated stasis of the contrast agent within the vertebrobasilar and carotid systems despite the constant absence of capillary filling and venous drainage. Braun et al. [4] assessed the value of intravenous angiography in 140 brain-dead patients and showed a persistent vertebrobasilar slow flow at 60 seconds after injection with a venous circulation in nine patients. All these patients met the criteria of brain death including cessation of brain-stem functions. The authors suggested that the cerebellar tentorium has a protecting role against increased intracranial pressure and that the circulatory arrest initially affects first the cortical branches of the carotid arteries, then the proximal branches of the circle of Willis and finally the posterior fossa. Our data corroborate these findings, confirming that the absence of bilateral opacification of the distal branches of the MCA represents one of the best parameters for the diagnosis of brain death. Only one patient in our series presented with residual opacification of a few distal branches of one MCA. The opacification of the great cerebral vein in one patient may be explained by residual slow flow into the vertebo-basilar system as reported by Braun et al. [4]. The absence of opacification of the internal cerebral veins seems to be the most sensitive and specific parameter for the diagnosis of brain death demonstrating the supratentorial circulatory arrest but the small diameter of these veins, their orientation and their location explain that they may be sometimes difficult to analyze.

There are limitations to the present study. Conventional angiograms for comparison purposes have not been performed due to logistic difficulties. Yet, comparison between techniques remains difficult. It has been shown that opacification of intracranial arteries at conventional angiography depends on the technique and the protocol used. When an intra-arterial injection is performed, the high pressure has the contrast media passively enter the intracranial arteries [17]. The higher sensitivity of spiral CT in the detection of vascular contrast enhancement, when compared to conventional angiography, could on the other hand lead to a better detection of intracranial vessels on spiral CT. Other non-invasive techniques such as transcranial Doppler sonography could have been used to corroborate clinical findings but we did not have the opportunity to perform this examination at that time. Our current protocol includes both Doppler sonography and bi-spectral recordings without mobilizing the patient in order to choose the most appropriate moment to perform spiral CT and to avoid repeated CT examinations.

CONCLUSION

Spiral CT can be used to demonstrate cessation of intracerebral circulation in brain death. The absence of bilateral opacification of the cortical branches of
the MCA and the absence of opacification of the deep cerebral veins constitute the most reliable CT criteria of brain death.

Acknowledgements: C. A. Taschner, M.D. was supported by a grant of the Swiss National Science Foundation, funded by the L. + Th. Laroche-Stiftung, Basel, Switzerland.

References


