Brain tissue perfusion monitoring using Sonopod for transcranial color duplex sonography

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KEYWORDS
Transcranial color duplex sonography; Transducer holder (Sonopod); Brain tissue perfusion; Acetazolamide vasoreactivity; Second harmonic imaging; Power modulation imaging

Summary
Objective: We have introduced and improved a transducer holder, named the Sonopod, for transcranial color duplex sonography (TCDS) monitoring via both temporal/foraminal windows (TW/FW). The objective is to clarify clinical usefulness and identify problems in TCDS-Sonopod monitoring during the evaluation of brain tissue perfusion.

Methods: Brain tissue perfusion monitoring was evaluated in 11 patients (ages 31–94, mean 66). After a bolus intravenous Levovist®, power modulation imaging (PMI) in all cases was evaluated in comparison with second harmonic imaging (SHI) in two cases at the diencephalic horizontal plain via the TWs on the basis of time–intensity curves (TICs) in five regions of interest (ROIs); bilateral basal ganglia (BG) and thalamus (Th), and contra-lateral temporal lobe (TL). After a SONOS5500 S3 transducer was installed in the Sonopod, acetazolamide (ACZ) cerebral vasoreactivity utilizing PMI was evaluated in 10 cases via the bilateral (five cases) and unilateral (five cases) TWs. A total of 30 TICs were evaluated before/after ACZ administration.

Results: (1) All patients could be monitored continuously by one examiner. (2) We confirmed that PMI proves superior to SHI in quantitative evaluation of the bilateral hemispheres via the unilateral TWs. (3) Brain tissue perfusion could be precisely quantified before/after ACZ in the same ROIs. (4) TIC base-line drifts during monitoring were observed in 4 (seven TICs) of 10 (30 TICs) patients. However, fixed-probe shifts during monitoring were easily readjustable and the TIC recovered to the base-line in all cases. (5) Due to re-fixation needed for contralateral TW monitoring, it was not possible to evaluate completely in the same ROIs.

Conclusions: TCDS-Sonopod monitoring succeeds in continuously and quantitatively evaluating precise and reproducible intracranial hemodynamics in the brain tissue.

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Introduction

Compared to conventional transcranial Doppler sonography (TCD), transcranial color duplex sonography (TCDS) is
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Transducer holder (Sonopod) for transcranial color duplex sonography (TCDS) monitoring. We have developed and improved the transducer holder (Sonopod) for TCDS monitoring (a and b).

Figure 1

Figure 2 TCDS-Sonopod monitoring in sitting position via both temporal (a) and foraminal (b) windows.

Material and methods

Brain tissue perfusion monitoring was evaluated in 11 patients (ages 31—94, mean 66). Details of patient demographics are shown in Table 1. After a 5 ml-bolus Levovist® injection (2.5 g, 400 mg/ml) via the antecubital vein, power modulation imaging (PMI) in all cases in comparison with

Table 1

<table>
<thead>
<tr>
<th>Total patients: n = 11</th>
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<tbody>
<tr>
<td>Causes of brain injury</td>
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<tr>
<td>Cerebral infarction</td>
</tr>
<tr>
<td>(atherothrombotic 5, lacunar 2, embolic 1)</td>
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<tr>
<td>Hypertensive putaminal hemorrhage</td>
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<tr>
<td>Ruptured anterior communicating aneurysm</td>
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<tr>
<td>Chronic subdural hematoma</td>
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<tr>
<td>Ages: 31—94 years (mean 66)</td>
</tr>
<tr>
<td>Gender: male 9, female 2</td>
</tr>
<tr>
<td>Monitoring (via temporal window)</td>
</tr>
<tr>
<td>Perfusion imaging</td>
</tr>
<tr>
<td>Power modulation imaging only</td>
</tr>
<tr>
<td>Second harmonic imaging and Power modulation imaging</td>
</tr>
<tr>
<td>Acetazolamide vasoreactivity test (bilateral 5, unilateral 5)</td>
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<tr>
<td>TIC base-line drift during monitoring</td>
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4 (7 TIC analyses)
second harmonic imaging (SHI) in the initial two cases were evaluated in the supine position via TWs (Fig. 3). Both imaging types were visualized by an integrated backscatter method. The transmitting and receiving frequencies of PMI and SHI were 1.7/1.7 MHz and 1.3/2.6 MHz, respectively. The investigation depth was 16 cm with a focus of 8 cm. Settings were mechanical index 1.6, system gain 75, and compression 70. ACZ cerebral vasoreactivity, before and after 500 mg Diamox® intravenous injection, was evaluated in 10 cases utilizing a SONOS5500 S3 transducer (Philips Electronics Japan, Ltd.) installed in the Sonopod. Time—intensity curves (TICs) on the diencephalic horizontal plain were evaluated before and after ACZ in five regions of interest (ROI); bilateral basal ganglia (BG) and thalamus (Th), and contra-lateral temporal lobe (TL). A total of 30 TICs with a duration of 10 min via the bilateral (five cases) and unilateral (five cases) TWs were analyzed before and after ACZ.

Results

Hand-held monitoring utilizing PMI and SHI

Conventional SHI and PMI utilizing hand-held monitoring were compared in two cases. In the visualization of the contralateral hemispheres via the unilateral TWs, PMI was superior to SHI as shown in the upper panels of Fig. 4a and b. As shown in the lower panels of the quantitative TIC evaluations in both PMI and SHI, peak intensity (PI) in the contralateral hemisphere ROIs was lower than in the ipsilateral hemisphere ROIs. During hand-held monitoring, TICs were not always stable in all cases and drifted from the base-line due to patients’ movements as shown in the lower panels of Fig. 4.

Sonopod ACZ monitoring utilizing PMI

All patients could be fitted and monitored continuously by one examiner. Brain tissue perfusion could be precisely quantified before/after ACZ in the same ROI as shown in Fig. 5. Due mainly to patient’s movements, drifts from the base-line were observed in the TICs of 4 (seven TIC analyses)
out of 10 (30 TIC analyses) patients. However, fixed-probe shifts due to patients’ movements during monitoring were easily re-adjustable and the TICs could be returned to the baseline in all patients as shown in Fig. 6. Regarding contralateral TW monitoring in the five bilaterally ACZ examined patients, it was not possible to evaluate precisely in the same ROI locations due to Sonopod re-fixation.

Discussion

Transducer holder for TCD and TCDS

Transducer holders or probe fixation devices for conventional TCD monitoring have been introduced into clinical settings. Previously, for the examination of neonates, a hood-like probe fixation device via the transfontanellar window has been investigated [14]. Trials in adult patients have focused not only on the middle cerebral artery (MCA) via the TWs [7, 15], but also in the vertebrobasilar arteries via the FW for high intensity transient signals (HITS) monitoring [16]. More recently, a commercially available head-frame (Marc 600, Spencer Technologies) for monitoring via the TWs has been used for detection of recanalization in the MCA during tissue plasminogen activator studies [6]. Furthermore, a long-term ambulatory TCD monitoring device placed on a spectacle frame has been introduced for HITS detection in the MCAs via the TWs [9]. A modified head-frame combining two Spencer Technologies’ head-frames for both the TWs and FW has been tried for vasoreactivity tests [8].

Our TCDS transducer fixation device, the Sonopod, is able to monitor not only via the TWs, but also via the FW (Fig. 2). A further important advantage is long-duration stable TCDS monitoring that implies accurate quantitative measurements in the major cerebral arteries and brain tissue. Proposed criteria for probe-holding systems include ease of application, stability during patient movement, low-cost, compatibility with multiple probes, comfort and durability [7]. The durability of a prototype of this transducer, the Sonopod, has been proven, with no problems in our four-year experience. However, it is still so heavy that long-time TW monitoring in the sitting position will probably result in discomfort caused by fatigue of the neck muscles. This problem will be improved in changing materials from heavy stainless steel to light weight aluminum, titanium, or similar. For FW monitoring, the Sonopod is unable to be applied in a supine position, therefore patients should be instructed to lie down semi-laterally. It is necessary to tighten four screws during setup of the Sonopod and this may prove a slight time-consuming drawback while searching for appropriate location of vessels or anatomical places. In our experience however, we were usually ready for monitoring in around 5—10 min. Improvements of the Sonopod have been planned for the SONOS 5500 S3 transducer (Philips), compatibility with multiple probes and costs of marketing the products should be confirmed in the near future.

Comparison of SHI and PMI

Since the clinical introduction of transcranial ultrasound perfusion imaging of brain tissue, depth dependant ultrasound attenuation has been the most challenging problem for qualitative and quantitative evaluation [17, 18]. In our study, significant depth dependant PI attenuation on the TICs was observed in both image types, particularly in the contralateral hemisphere. In the pioneering work utilizing SHI with Levovist® by Postert et al. [17], not only PI but also the area under the TIC was shown to be significantly higher in the BG and white matter ROIs than in the Th ROI. Furthermore, SHI utilizing an alternative UCA (Optison) showed significantly higher Th ROI in the ipsilateral hemisphere than in the contralateral hemisphere [18]. More recent studies utilizing phase-inversion harmonic imaging (PIHI) utilizing Optison and SonoVue [19] showed typical depth dependant PI attenuation in the contralateral hemisphere rather than the ipsilateral hemisphere in bilateral or unilateral (ipsilateral) approaches. A bilateral approach utilizing PIHI [19, 20] has been suggested for evaluating contralateral hemispheres. Our previous study of ultrasound perfusion imaging also showed that PMI utilizing transient response high power images is superior to conventional SHI in evaluation of the contra-lateral cerebral hemisphere [21]. This study reconfirmed that result. However, limitations of the contralateral approach, e.g. shadowing [19], have been pointed out [5].

ACZ vasoreactivity utilizing PMI

In order to overcome the problems in quantifying brain tissue perfusion, e.g. depth dependant ultrasound attenuation, we have applied transcranial ultrasound perfusion imaging to the ACZ vasoreactivity test [10, 13]. In ACZ vasoreactivity tests, the same ROI placements before and after ACZ are very important for accurate quantification. From this point of view, the Sonopod is very useful for precise quantification of brain tissue perfusion.
Conclusions

TCDS-Sonopod monitoring succeeds in continuously and quantitatively evaluating precise and reproducible intracranial hemodynamics in the major cerebral arteries and brain tissue.

References