Intraoperative ultrasound arteriography with the “Coded Harmonic Angio” technique

Report of three cases

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The result of combining the ultrasound Coded Excitation method and an ultrasound contrast agent (UCA), the Coded Harmonic Angio (CHA) technique provides arterial images with exceptional spatial, temporal, and contrast resolution that are comparable to those produced by conventional digital subtraction angiography. The authors report on their experience with intraoperative ultrasound arteriography performed using the transdural CHA technique in three patients: one harboring a meningioma, another with a middle cerebral artery aneurysm, and a third with an arteriovenous malformation. The present study demonstrates how intraoperative cerebral ultrasound arteriography can be applied to assess the adequacy of neurovascular procedures without the presence of an experienced operator.

KEY WORDS • intraoperative ultrasound arteriography • Coded Harmonic Angio technique • contrast medium

With the advent of a new ultrasound technique, known as CHA (General Electric Medical Systems, Milwaukee, WI), UCAs can be imaged intraoperatively. Coded Harmonic Angio is an ultrasound imaging technique based on General Electric’s patented coded technology. Intravascular gas bubbles of UCA that have passed through the capillary bed of the lungs are used for imaging. Those bubbles whose sizes match the transmit frequency demonstrate a resonance in their vibrations and produce harmonics of the transmit frequency, whereas insonated brain parenchyma responds primarily at the fundamental frequency. Thus harmonic imaging dramatically improves the signal-to-noise ratio between brain parenchyma and intravascular UCA. Using the CHA technique, a decoder preferentially increases the sensitivity to harmonic returns from UCAs present in the vascular bed while simultaneously suppressing the return signal from stationary or near-stationary tissue. The decoder effectively removes almost all background tissue signals, resulting in an angiogram-like display. A combination of the Coded Excitation procedure and harmonic imaging, CHA provides real-time blood-flow images without diminishing spatial resolution and produces images that are comparable to DS angiograms.

Intraoperative angiography is useful in verifying the condition of major vessels during neurosurgical procedures; however, conventional direct intraoperative DS angiographic inspection has shortcomings such as invasiveness and expense. The intraoperative CHA technique is simple and less invasive and can be used to provide images of intracranial arteries through the craniotomy site. After injection of UCA, intravascular microbubbles generate enhanced harmonic signals and a real-time digital vascular image with increased contrast resolution is created. Using the CHA technique, researchers can identify the hyperechogenic tumor together with the intracranial arteries and blood vessels supplying the tumor. In fact, during the surgical procedure, real-time interaction between tumor and surrounding arteries is clearly visualized. We report our experience with intraoperative CHA studies.

Case Reports

Description of the Imaging Technique

In our study, we used the contrast agent Levovist (Schering Pharmaceutical Co. Japan, Osaka, Japan), an aqueous suspension of 99.9% galactose and 0.1% palmitic acid. We prepared a 300-mg/ml Levovist solution containing 12.5 to 20 × 10⁶ microbubbles of air, according to the manufacturer’s instructions. One intravenous bolus injection of 8.5 ml was administered at a dose of 5 ml/minute for each study.
All ultrasound imaging was performed using a LOGIQ 700 Expert Series ultrasound system (General Electric Medical Systems) with a 3-MHz convex transducer. Imaging was continuously recorded on videotape. The ultrasound probe was covered with coupling gel and placed within a sterile cover. An acoustic window was obtained through the craniotomy site, and the sheathed scanning head was placed on the dura. The probe was moved over the intact dura, providing real-time images of the lesion and surrounding anatomy. Three-dimensional images were reconstructed from these two-dimensional images. Duplex CHA ultrasonography was performed with and without intravenous administration of UCA.

The institutional review board at Osaka National Hospital approved the intraoperative ultrasound examinations performed with Levovist administration. Informed consent was obtained from each patient.

Summary of Cases

Over the past 5 months, we have used intraoperative CHA in seven neurosurgical procedures involving two patients with meningiomas, four with unruptured intracranial aneurysms, and one with an AVM. All patients underwent MR angiography and some also underwent DS angiography. The intraoperative CHA image was obtained at the craniotomy site following intravenous injection of UCA, unless otherwise indicated. The CHA image provided timely information concerning the presence of blood flow in arteries and, in the case of the AVM, in draining vessels. The spatial, contrast, and temporal resolution provided by the CHA technique was comparable to that of MR angiography or conventional DS angiography performed before the operation. The effect of UCA administration was observed approximately 1 minute after intravenous injection and continued for 5 to 6 minutes.

Our experience with the use of CHA in three cases of diverse lesions follows.

Case 1. This 56-year-old woman was admitted to the hospital with a loss of hearing in the right ear and right facial numbness. Magnetic resonance imaging with contrast medium infusion revealed a large enhanced lesion that was located in the apex of the right petrous pyramid and clivus and extended forward into the right middle fossa, which was suggestive of a petroclivotal meningioma (Fig. 1 left). Digital subtraction angiography performed before the operation revealed a hypervascular extraxial tumor (Fig. 1 right). A subtemporal craniotomy was performed and an acoustic window was obtained for intraoperative ultrasonography. Using B-mode ultrasound, we determined that the tumor was a hyperechoic lesion. Intravenous injection of UCA increased the Doppler signal-to-noise ratio; however, enhanced backscatter in the blood resulted in overwriting of the vessel walls and appeared as a blooming of Doppler signals on duplex images. The intraoperative CHA technique provided a sufficient signal-to-noise ratio for visualization of the circle of Willis, even without UCA administration (Fig. 2 upper). After injection of UCA, pulsatile flow from the circle of Willis and arterioles adjacent to the tumor was clearly demonstrated because of the increased signal-to-noise ratio (Figs. 2 lower and 3).

Case 2. Using MR angiography, we found that this 68-year-old woman had an incidental aneurysm of the right middle cerebral artery. A frontotemporal craniotomy was made for the pterional approach and an acoustic window was obtained. The spatial resolution obtained using intraoperative CHA in this case was comparable to that of the MR angiogram obtained before the operation (Fig. 4).

Case 3. This 69-year-old man presented with an intracerebral hematoma sustained 2 months previously. He was referred to our institution for resection of the lesion. Preoperative DS and MR angiograms demonstrated a small AVM in the left occipital lobe (Fig. 5 left and center). An
occipital craniotomy was made and an ultrasound examination was performed. Use of the intraoperative CHA technique revealed both the feeding arteries and the nidus of the AVM (Fig. 5 right), although preoperative MR angiography had failed to demonstrate the nidus.

**Discussion**

The present study demonstrates our first experiences using intraoperative cerebral ultrasound arteriography. Because the CHA technique is used chiefly to visualize the harmonics derived from intravascular UCA, vascular images can be obtained with exceptionally high resolution, comparable to those obtained using DS angiography. With the new technologies of ultrasound Coded Excitation and UCA, intraoperative ultrasound arteriograms obtained using the CHA technique can be applied to assess the adequacy of neurovascular procedures.

Conventional B-mode ultrasonography has proved to be useful in defining the extent of brain tumor, and color Doppler flow imaging adds information about blood vessels. Nevertheless, the vascular images provided by conventional duplex ultrasonography are often fuzzy, difficult to interpret, and not as clear as those provided by DS angiography. Because color Doppler flow images demonstrate lower resolution, superimposing them onto a B-mode image will result in some overwriting of vessel walls, which can conceal subtle lesions in the vessel under study. With the administration of a UCA, duplex images in the color flow overlay are inevitably displayed as overshadowing the true flow data. A major limitation of ultrasound is that it is extremely operator dependent, particularly in comparison with DS angiography. In the current study of the CHA technique, we found that these shortcomings are dramatically improved using the Coded Excitation method and the harmonic frequencies generated by the UCA. Because the CHA technique provides exceptional spatial, temporal, and contrast resolution, an experienced operator is not necessary to perform the technique. During surgery, a neurosurgeon who is not experienced in ultrasonography can perform ultrasound arteriography and obtain excellent images comparable to those obtained using conventional angiography. Coded Harmonic Angio may be used to document complete obliteration of lesions, such as aneurysms and cerebral AVMs, or to verify normal filling of the surrounding vasculature. Overall, we have found real-time CHA studies to be helpful for localization of arteries in a variety of neurosurgical procedures, and so far we have clearly identified every lesion in which ultrasound was attempted.
When administered by an intravenous bolus, UCA reaches the arterial circulation in sufficient concentrations for CHA-aided visualization of small arteries. The pulmonary circulation, nitrous oxide anesthesia, and positive-pressure ventilation do not appear to be significant limiting factors for the harmonic imaging of intravascular microbubbles. As reported in the literature3 and according to our experience, the intraoperative ultrasound CHA technique is safe and effective in a variety of situations. The ultrasound system required for CHA is a general purpose device and can be shared by other surgical or ultrasound diagnostic departments such as those dealing with hepatic diseases. Instead of needing the bulky C-arm of a DS angiographic system, one only needs to apply the convex ultrasound transducer to the dural surface to enable the CHA study. Finally, given the amount of money required to purchase a machine that performs at the level of state-of-the-art imaging systems, one could easily purchase a top-of-the-line ultrasound device without the need for renovations and alterations to the operating room.7 The definite advantages of ultrasonography over other imaging modalities are its availability, portability, and low cost. This article provides useful information regarding the new role of ultrasound technology in neurosurgical navigation.

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References


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