

Recording brain activity with laser light

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A Caltech professor, in collaboration with researchers at the University of Southern California, has demonstrated for the first time a new technology for imaging the human brain using laser light and ultrasonic sound waves.

The technology, known as photoacoustic computerized tomography, or PACT, has been developed by Lihong Wang, Bren Professor of Medical Engineering and Electrical Engineering, as a method for imaging tissues and organs. Previous versions of the PACT technology have been shown capable of imaging the inner structures of a rat's body; PACT is also capable of detecting tumors in human breasts, making it a possible alternative to mammograms.

Now, Wang has made further improvements to the technology that make it so precise and sensitive that it can detect even minute changes in the amount of [blood](#) traveling through very tiny blood vessels as well as the oxygenation level of that blood. Since blood flow increases to specific areas of the brain during cognitive tasks—blood flow will increase to the visual cortex while you are watching a movie, for example—a device that shows blood concentration and oxygenation changes can help researchers and medical professionals monitor brain activity. This is known

as [functional imaging](#).

"In breast imaging you just want to see blood vessels because they can reveal the presence of a tumor [tumors secrete chemicals that stimulate blood vessel formation]" Wang says. "But the functional change in imaged brain activity is only a few percent change in the baseline signal. That's more than an order of magnitude harder to measure."

Previously, this kind of imaging was conducted only with [functional magnetic resonance](#) imaging (fMRI) machines, which use radio waves and magnetic fields that are 100,000 times stronger than the Earth's [magnetic field](#) to monitor blood oxygen levels. The machines work well, and are a mature technology, but they have some disadvantages. For one, they are very expensive, costing as much as a few million dollars each. Another downside is that the intense magnetic fields created by the machine require special precautions, as iron-containing objects like some medical tools, as well as surgical implants, can be pulled with great force by the machine." An MRI machine also requires the patient to be placed inside a narrow tube while they are being imaged, which can be uncomfortable for people with claustrophobia.

In contrast, Wang's technology is much more simple, inexpensive, and compact, and does not require the patient to be placed inside the machine.

It works by shining a pulse of laser light into the head. As the light shines through the scalp and the skull, it is scattered through the brain and absorbed by oxygen-carrying hemoglobin molecules in the patient's red blood cells. The energy that the hemoglobin molecules pick up from the light causes them to vibrate ultrasonically. Those vibrations travel back through the tissue and are picked up by an array of 1,024 tiny ultrasonic sensors placed around the outside of the head. The data from those sensors are then assembled by a computer algorithm into a 3D map of blood flow and oxygenation throughout the brain.

To test the technology in humans, Wang worked with Jonathan Russin, assistant professor of clinical neurological surgery at the Keck School and associate director of the USC Neurorestoration Center; Danny J Wang, Professor at USC Institute for Neuroimaging and Informatics; and Charles Liu, professor of clinical neurological surgery at the Keck School and director of the USC Neurorestoration Center.

After severe traumatic brain injury, some patients undergo a decompressive hemicraniectomy, a life-saving procedure whereby a large portion of the skull is removed to control pressure due to brain swelling. Liu and Russin work with many such patients at Rancho Los Amigos National Rehabilitation Center in Downey, California, where Liu serves as chief of innovation and research. After recovering from an acute injury, but before skull reconstruction surgery, select patients participated in this study to determine how well the imaging technology works.

"A hurdle we still need to overcome is the skull," Wang says. "It's an acoustic lens, but it's a bad one, so it distorts our signal with attenuation as well. It's like looking outside through a wavy window," he says. "But they have a population of patients who have had hemicraniectomies. They are missing a part of their skull, so we can image them."

"Neuroimaging is central to the development of new treatment paradigms, and this demonstration is a very important step toward developing an impactful new tool to complement current approaches such as MRI-based techniques," Russin says.

Liu agrees, adding that "many of the most exciting therapeutic approaches for functional restoration involve neuromodulation strategies that cannot be studied in the MRI environment, and we look forward to using this new technology to better understand and refine our treatments. Many of the participants in this study may ultimately require new treatments, so this is a terrific way to help develop a tool to ultimately benefit them."

To image a patient, the research team shaves their head (a step Wang says they are trying to

eliminate) so the laser light can illuminate their scalp. The patient then lies down on a table with their head partially resting in a bowl that contains the laser source, the ultrasonic sensors, and water. The water acts as a "mediator," acoustically coupling the sensors to the surface of the scalp and allowing them to pick up signals efficiently, Wang says. It is analogous to the gel that is placed on the skin when a patient gets an ultrasound.

Going forward, Wang says research will need to focus on solving the issues caused by the hair and the skull. He said it might be possible to avoid shaving a patient's head if optical fibers can be used to deliver the [laser light](#) pulses between hair follicles on the scalp. And he also hopes to eventually use the technology on patients who have intact skulls.

"We need a way to counter the distortion caused by the skull," he says, adding that such a corrective "lens" will most likely be a more powerful data-processing algorithm that can compensate for the distortion when it assembles an image.

A paper describing the technology, titled, "Massively parallel functional photoacoustic computed tomography of the [human brain](#)," appears in the May 31 issue of the journal *Nature Biomedical Engineering*.

More information: Shuai Na et al, Massively parallel functional photoacoustic computed tomography of the human brain, *Nature Biomedical Engineering* (2021). [DOI: 10.1038/s41551-021-00735-8](https://doi.org/10.1038/s41551-021-00735-8)

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