Seismic imaging technology could deliver finely detailed images of the human brain

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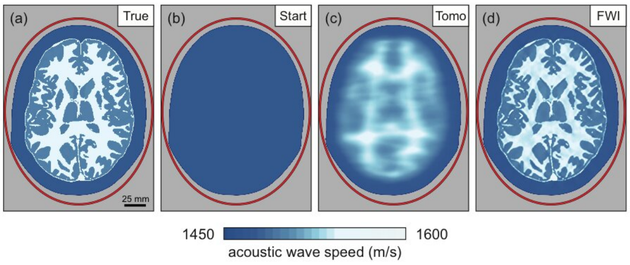


Inversion of data from a brain outside the skull. a)A 2D model of acoustic wave speed in the naked brain without the skull. The red ellipse shows the transducer positions; the grey region is masked and held fixed during the inversions.b)Homogeneous model used to begin inversion. c)Result of ultrasound computer tomography. The resultant model is accurate but has poor spatial resolution. d)Result of ultrasound full-waveform inversion. The resultant model is now both accurate and spatially well resolved. Credit: Imperial College London

The Imperial College London and UCL researchers say their proof-of-concept study, published today in *npj Digital Medicine*, paves the way for the development of high-fidelity clinical imaging of the human brain that could be superior to existing technology.

Unlike existing brain imaging methods like MRI, CT and PET scanning, the technology could be applied to imaging any patient, and could be suitable for the continuous monitoring of high-dependency patients. It could be delivered by a relatively small device, which would also potentially make it portable via ambulance and enable fast investigation in advance of arrival to hospital.

The researchers are confident the technology will be safe as sound waves are already used for ultrasound scanning and this technology uses similar sound intensities. Ultrasound cannot easily penetrate through bone, whereas the new device, which is designed to be worn like a helmet, is able to overcome this barrier.

The new approach is of special value in patients investigated for stroke—the second commonest cause of death and commonest cause of adult neurological disability—where rapid, universally applicable, high-fidelity imaging is essential.

Lead author Dr. Lluís Guasch, of Imperial's Department of Earth Science and Engineering, said: "An imaging technique that has already revolutionised one field—seismic imaging—now has the potential to revolutionise another—brain imaging."

Professor Bryan Williams Director NIHR UCL Hospitals Biomedical Research Centre, which partly funded the research, said: "This is an extraordinary and novel development in brain imaging which has huge potential to provide accessible brain imaging in routine clinical practice to evaluate the brain in head trauma, stroke and a variety of brain diseases.

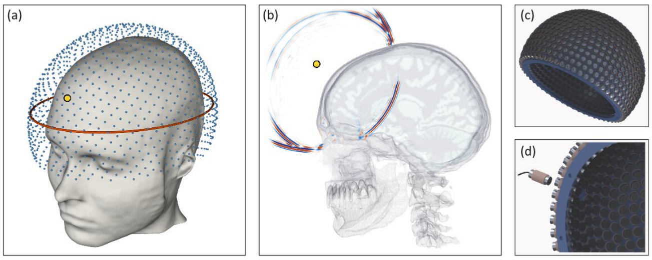
"If this lives up to its promise it will be a major advance. It is also a fabulous illustration of how the collaboration between engineers and clinicians, using methods from another sphere of science, can bring ground-breaking innovation into medical care ."

Transcending disciplines

Earth scientists use seismic data and a computational technique called full waveform inversion (FWI) to map the inside of the earth. Seismic data from earthquake detectors (seismometers) are plugged into FWI algorithms that extract 3-D images of the Earth's crust that can be used to predict earthquakes and search for reservoirs of oil and gas.

Now Imperial researchers have adapted this approach to medical imaging, developing a method that uses sound waves with the ultimate aim of producing high-resolution images of the brain.

They built a helmet lined with an array of acoustic transducers that each sends sound waves through the skull. The ultrasound energy that propagates through the head is recorded and fed via the helmet into a computer. FWI is then used to analyse the reverberations of the sound throughout the skull, constructing a 3-D image of the interior.



a)Three-dimensional array of transducers used for data generation and subsequent inversion. Each transducer acts as both a source and a receiver. The red ellipse shows the location of the two-dimensional array used to generate the data for Fig. 2 and 4.b)A snapshot in time of the wavefield generated by a source transducer located at the position indicated by the small yellow circle, computed via numerical solution of the 3D acoustic wave equation. The wavefield is dominated by strong reflections from the skull, and by intracranial transmitted energy travelling across the brain; Supplementary Video 1 shows the full wavefield propagating in time.c)Prototype helmet containing 1024 transducers held rigidly in a 3D-printed framework. In the prototype device, the framework is customised to provide an accurate fit to an individual subject, and filled with water. In portable clinical devices, the sensors move radially, and contact the patient via sonographic gel. d)Close up of sensor connections in the prototype. Credit: Imperial College London

The researchers tested their helmet on a healthy volunteer and found that the quality of the recorded signals was sufficient for the algorithm to generate a detailed image, and they are confident the scattered energy from the brain will be interpretable.

Using computer modelling, they also found they could obtain high-resolution images with sound frequencies low enough to penetrate the skull at safe intensities.

They created detailed computer simulations based on the properties of different types of human brain tissue to establish that sound waves would be effective for composing high-resolution images of the brain.

Dr. Guasch said: "This is the first time FWI has been applied to the task of imaging inside a human skull. FWI is normally used in geophysics to map the structure of the Earth, but our collaborative, multidisciplinary team of earth scientists, bioengineers and neurologists are using it to create a safe, cheap and portable method of generating 3-D ultrasound images of the human brain."

Potential clinical use

Magnetic Resonance Imaging (MRI) is generally the best method for obtaining high-resolution images of the brain, and its use is currently essential to the investigation of many neurological disorders including stroke, brain cancer, and brain injury.

Nonetheless, MRI requires large, complex, expensive, non-portable machines cooled to three degrees above absolute zero, and it cannot be used on patients for whom the presence of metallic implants or foreign bodies cannot be scrupulously ruled out. This makes emergency use in patients with potentially altered consciousness, such as those suspected of stroke, difficult or impossible.

The researchers say that if it proves successful in human trials, their device will overcome these obstacles.

Study co-author Professor Parashkev Nachev, of UCL, said: "This is a vivid illustration of the remarkable power of advanced computation in medicine. Combining algorithmic innovation with supercomputing could enable us to retrieve high-resolution images of the brain from safe, relatively simple, well-established physics: the transmission of soundwaves through human tissue.

"The practicalities of MRI will always limit its applicability, especially in the acute setting, where timely intervention has the greatest impact. Neurology has been waiting for a new, universally applicable imaging modality for decades: full-waveform inversion could well be the answer."

Next, the researchers will build a new prototype for live imaging of normal human brains as the first step to a device that could be evaluated in clinical contexts.

More information: "Full-waveform inversion imaging of the human brain" by Lluís Guasch, Oscar Calderón Agudo, Meng-Xing Tang, Parashkev Nachev and Michael Warner, published 6 March 2020 in *npj Digital Medicine*.
www.nature.com/articles/s41746-020-0240-8

Provided by Imperial College London

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