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Tiny particles, big impact: towards less invasive brain stimulation

Living with a brain disorder often means relying on medication that does not work for everyone and, in some cases, surgery. EU-funded researchers are now investigating whether nanotechnology could one day offer a safer, less invasive alternative.

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For decades, treating serious brain disorders has often meant making a difficult trade-off. Symptoms could be relieved, but usually at the cost of invasive surgery and implanted electrodes that stay in the body for life.

“Having wires in your body isn’t ideal,” said neuroscientist Mavi Sanchez-Vives, head of the Systems Neuroscience group at the IDIBAPS research institute in Barcelona, Spain. “Yet for many patients, it has been the only option.”

That paradigm may now be beginning to shift. Sanchez-Vives is leading a three-year EU-funded research initiative called META-BRAIN that runs until December 2026.The team is exploring new ways to interact with the brain by combining nanotechnology, ultrasound and advanced brain monitoring.

Bringing together scientists and clinicians from leading research institutions across Europe, including Austria, Cyprus, Italy, Spain and Switzerland, the META-BRAIN team is developing wireless, minimally invasive ways to restore brain activity. They are using nanotechnology to interact with neurons remotely – without permanent implants or open brain surgery.

A growing neurological burden

Neurological disorders are one of the greatest health challenges of our time and the leading cause of illness and disability worldwide. In Europe alone, 165 million people suffer the effects of brain disorders such as Parkinson’s disease, stroke, epilepsy, depression, anxiety and traumatic brain injury.

“These disorders are based on neural pathologies and are often associated with alterations in brain rhythms and activity patterns,” explained Sanchez-Vives.

Available treatments remain limited. Drug therapies do not work for all patients and can cause significant side effects. Surgical approaches, such as deep brain stimulation, require electrodes to be implanted deep inside the brain to block or regulate faulty signals.

“Some patients live with these implants for decades,” said Sanchez-Vives. “But they come with risks and complications. We need better options.”

Wireless interaction with the brain

To address this need, the META-BRAIN research team is exploring minimally invasive ways to control neural activity remotely and precisely.

“The main goal is to investigate new forms of wireless interaction with the brain,” she said. “We want to achieve high-precision control using nanotechnology as an interface.”

While non-invasive brain stimulation methods already exist, they have important limitations. Some lack the ability to precisely target specific regions of the brain, while others cannot reach deeper structures.

“That is why we need approaches that are both non-invasive and capable of targeting any part of the brain,” Sanchez-Vives said.

To do this, the researchers are exploring two different but complementary ideas. One uses carefully focused ultrasound waves to stimulate the brain from outside the body. The other relies on nanoparticles that can be guided and activated using magnetic fields, referred to as magnetoelectric nanoparticles.

Tiny particles acting as wireless electrodes

The magnetoelectric nanoparticles have emerged as a particularly promising avenue, said Marta Parazzini, director of research at the Institute of Electronics, Information Engineering and Telecommunications of Italy’s National Research Council (CNR) in Milan.

In simple terms, magnetoelectric nanoparticles – many times smaller than the width of a human hair – convert magnetic signals into electrical ones, the same type of signals used by neurons to communicate. When exposed to an external magnetic field, they generate a local electric field, effectively acting like wireless electrodes.

“They can be injected without surgery and controlled remotely using magnetic fields,” said Parazzini. “Because they are so small, their application can be extremely precise.”

Laboratory experiments have already shown that these nanoparticles can be activated in a controlled way using external magnetic fields. Crucially, they are capable of both stimulating and inhibiting neural activity.

“This gives us many therapeutic possibilities,” Parazzini said. “It allows us to fine-tune brain stimulation rather than simply switch neurons on or off.”

Treating the brain without surgery

In the long term, the researchers envision applications that could fundamentally change how neurological injuries and disorders are treated.

For example, after a serious accident, a patient with traumatic brain injury could be brought to hospital and undergo detailed brain imaging. Based on this scan, clinicians could inject magnetoelectric nanoparticles directly into the affected regions, in quantities tailored to the individual patient.

“These decisions could be guided by personalised computational models of the brain,” said Parazzini.

Once in place, the nanoparticles could be activated externally, for instance, using a helmet-like device to restore healthy activity patterns and steer damaged tissue back towards normal physiological function.

“The idea is to intervene immediately, without opening the skull or implanting hardware,” Parazzini said.

“We could treat the injury immediately and possibly even avoid surgery. This method would be much safer, faster and less intrusive. That is the dream.”

From lab to life-changing applications

So far, the META-BRAIN team has conducted extensive experiments in brain tissue and is now moving towards in vivo studies in rodents. Human trials will not take place within the scope of the project, although the researchers plan to run computational simulations using a human brain phantom, a very detailed 3D model of the brain.

If successful, the technology could eventually lead to more effective treatments for a wide range of neurological and neuropsychiatric conditions. Parkinson’s patients might regain smoother movement, epilepsy patients could achieve better seizure control, and people with complex psychiatric disorders could benefit from more targeted therapies.

Beyond treatment, the technology may also help restore or compensate for lost senses. In cases where sensory pathways are damaged, magnetoelectric interfaces could one day help replace or bypass broken connections – potentially offering new options for certain forms of blindness or other sensory loss.

Uncharted territory

Despite the promise, the researchers are keen to emphasise that the work is still at an early stage.

“It will be a long process before this technology reaches patients,” said Sanchez-Vives. “We first need to thoroughly understand how these particles behave in the brain and how to control them safely and effectively.”

Still, the potential is undeniable.

“It is fascinating to see that such small particles can have such a big impact on neurons,” she said. “We are exploring completely new territory – but one that could eventually transform how we treat brain disorders.”

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More info

- [META-BRAIN (CORDIS)]

- META-BRAIN project website
- EU support for research and innovation on brain health