Innovation and Communication: Scientific Instrumentation Improving Patient Outcomes

Surgery is a messy business. While surgical procedures are often lifesaving, cutting through a patient's skin, drilling into their bones and slicing deep into their bleeding organs inevitably comes with risks of infection, injury and occasionally death. In recent years, biomedical engineers have provided improvements through new instruments, catheters and even robots that can reduce the impact of surgery on patients. But is it possible to manipulate or ablate tissue without cutting through the skin, or inserting any tools into the body at all: to perform surgery, without the surgery?

A major trend in medicine over the last few decades has been the replacement of open surgical procedures by minimally invasive techniques: either laparascopic surgery (replacing large incisions with small ones), or interventional procedures, where catheters are passed into the body, often via arteries. These techniques cause less collateral damage than open surgery, reducing recovery times and complications.[1]

This has been made possible through precision instruments and real-time imaging techniques, enabling doctors to manipulate and track objects using tools passed beneath the skin. For instance, instead of bypass surgery, many heart attack patients are now treated using a catheter passed through an artery into the heart, which can insert stents to open blocked vessels, while being tracked using a high-resolution X-ray fluoroscopy system. However, even though they reduce the risks of surgery, these approaches still carry risks of infection and damage from piercing the skin and inserting devices into the body.

But what if you could perform surgery on a patient without cutting into them *at all*? For some patients, this is now a reality.

Tremor, involuntary muscle contractions, usually in the hands, can have an appalling impact on someone's quality of life. Many people live for years with their hands shaking so violently that they're no longer able to eat, drink, or get dressed independently. There are two main causes of tremor, both of which originate in the brain. Parkinson's disease is due to the death of neurons in the basal ganglia, a part of the brain that controls movement (among other things). Essential tremor is more common, and is caused by a faulty motor circuit. While drug treatments generate some improvement, their effect is often limited.

Until recently, some of the only treatments involved drilling into someone's skull, and either burning away a bit of tissue ("cutting the wires" that provoke the tremor), or implanting electrodes to disrupt the faulty circuits with an electric current. The main target is the ventral intermediate (Vim) nucleus in the thalamus, right in the centre of the brain.

St Mary's Hospital in London is the only place in the UK that offers a completely non-invasive technique to replace this surgery on deep locations within the brain. Instead, they burn away the tissue by passing intense ultrasound waves through the skull.

The patient places their head inside a helmet containing 1,028 separately controllable transducers, each of which generates a sound wave. The pattern of excitation of these transducers allows the ultrasound to be focussed at a precisely defined point within the Vim nucleus, generating high sound intensities that heat up the tissue and deactivate it, leaving the rest of the brain untouched.[2,3]

This treatment needs a huge array of different technologies to come together in the form of complex instruments, scanners and software. The transducer helmet was developed by InsightTec, a company which has installed focussed ultrasound equipment for the brain at around 60 hospitals worldwide.

Before the procedure, the patient has a CT scan of the skull. Everybody's skull is a slightly different shape, and attenuates sound differently, and so this enables a computer to correct for this, to ensure the sound is focussed in the right place. They then lie inside an MRI scanner with their head in the transducer helmet. The brain is scanned to see the soft tissues, and the CT and MRI images are mapped together.

Once the clinicians have chosen the exact location they want to ablate, the computer takes this, combined with the data from the CT and MRI scans, and uses wave propagation algorithms to simulate how the ultrasound will be refracted or attenuated by the skull, before passing through the brain. This enables it to calculate exactly when each transducer needs to fire to ensure the beams meet up and focus at the right place. The location of the target region can be defined with a precision of well under one millimetre.[4]

The treatment takes place in stages, and the patient is constantly monitored for any adverse effects. A benefit of using MRI is that it can measure the temperature of tissues, to make sure the right parts are being heated. The temperature is increased only slightly at first, to around 40-45 degrees. This temporarily prevents the region from working properly, but does not cause any permanent changes. This phase enables clinicians to get a sense of what ablating that region will do to the patient before doing anything irreversible. The patient is assessed by a neurologist who sees if the tremor is improved; once they are satisfied, the temperature of the tissue is increased to 55-60 degrees, permanently deactivating it.

Treatment that might previously have required major neurosurgery can now be performed painlessly in an afternoon, with the patient lying back, awake, and getting up after a few hours suddenly able to go home and do normal activities of everyday life—eating, drinking, dressing yourself—independently for the first time in years.

While ultrasound will never replace every type of surgery, it has huge potential in the treatment of many other conditions. Similar ablation therapies are used to treat uterine fibroids, and are under investigation to treat cancer.[5] These procedures, like many others in modern medicine, are fundamentally driven by physics, engineering, and instrumentation, guided every step of the way by clinical expertise, and a clear patient need. Alongside pharmaceutical-based treatments, instrumentation has a vital part to play in the future of healthcare.

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1. Antoniou, S. A., Antoniou, G. A., Antoniou, A. I. & Granderath, F. A. Past, present, and future of minimally invasive abdominal surgery. *J. Soc. Laparoendosc. Surg.* **19**, 1–5 (2015).

2. Lipsman, N. *et al.* MR-guided focused ultrasound thalamotomy for essential tremor: A proof-of-concept study. *Lancet Neurol.* **12**, 462–468 (2013).

3. Elias, W. J. *et al.* A randomized trial of focused ultrasound thalamotomy for essential tremor. *N. Engl. J. Med.* **375**, 730–739 (2016).

4. Moser, D., Zadicario, E., Schiff, G. & Jeanmonod, D. MR-guided focused ultrasound technique

in functional neurosurgery: Targeting accuracy [J Ther Ultrasound. 2013;1:3]doi: 10.1186/2050-5736-1-3. *J. Ther. Ultrasound* **1**, 1–10 (2013).

5. Dick, E. A. & Gedroyc, W. M. W. ExAblate® magnetic resonance-guided focused ultrasound system in multiple body applications. *Expert Rev. Med. Devices* **7**, 589–597 (2010).

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