Sound effects

A sensor that uses acoustics to measure the impact of kidney stone treatment has the potential to improve the care of thousands of patients

KIDNEY STONES are a major health problem, affecting hundreds of thousands of people in the UK each year. Many of these cases require medical treatment, which until relatively recently usually involved surgery. Since the mid-1980s, this has been mostly superseded by a method using intense shock waves to bombard the stone from outside the body, breaking it up so that the fragments can be passed in urine or dissolved quickly with drugs.

However, this technique, called extracorporeal shock wave lithotripsy or ESWL, is effective only when the shock waves hit the stone repeatedly and reliably. Unfortunately, the clinicians who deliver the treatment have no way of knowing whether this is happening. Acoustics and ultrasound expert Prof Timothy Leighton, of Southampton University, put together a research consortium to solve this problem. The results of their research have won this year's sector collaboration award for medical and healthcare research.

Each ESWL treatment involves sending 3,000 shock waves into the body, but although X-rays can be used every so often during the treatment, the patient's movement can easily move the stone away from the focus of the shock waves, so they hit healthy tissue. Moreover, the clinicians have no way of monitoring whether the shocks are breaking up the stone, even if they are on target.

If the stone doesn't break up, the treatment has to be repeated. This is rather common — 30–50 per cent of ESWL patients need repeat treatment. If the stone does break early, the treatment still continues, risking unnecessary damage as the shockwaves hit healthy tissue.

Leighton, whose work covers a huge range of ultrasound applications, from chemistry to zoology, has been intrigued by this problem for some time. 'I was working with Andrew Coleman at St Thomas' Hospital in the late 1980s,' he said. 'Andrew had built a desktop lithotriptor, for research purposes rather than using on patients, and he'd made a passive acoustic sensor to have a look at some of the signals it produced.'

At the time, Leighton was working on cavitation — the collapse of bubbles that are formed from shock waves travelling through a liquid — and was particularly interested in the flashes of light caused by the heat generated in the bubble as it collapsed. 'We got together around 1990 and took light emission measurements from Andrew's desktop lithotriptor. We worked out that the passive acoustic signals he was measuring were coming from the bubble collapse. Once we'd made that connection, we thought it would be a good idea, somewhere down the line, to use this phenomenon to monitor how the lithotriptor was working on a patient.'

But the journey from that concept to a finished device was a long one. 'I knew Precision Acoustics well, and got them on board right from the start, bringing their inventiveness, time and materials into the project, and we got a grant from the Engineering and Physical Sciences Research Council,' said Leighton.

The project had two parts: Leighton, Coleman and Dr Andrew Hurrell from Precision Acoustics worked on designing a sensor and using it to obtain passive acoustic measurements from a small sample of patients, while two PhD students used computational fluid dynamics (CFD) simulations to work out what the signals might mean. 'There was a big fundamental gap in understanding how the cavitation in the body generates the signals we were hearing, and what that

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Breaking up is hard to do: shock wave treatment on kidney stones can be hit and miss

meant in terms of whether the stone is breaking up,' said Leighton. 'The CFD started with in-body scenarios, then worked out what sort of sound those events would make once they'd travelled through the human body. The medical technique, of course, has to work backwards, deriving from the signal what it actually means.'

What happens inside the body is complicated. As the 100MPa shock wave hits the kidney stone, it causes shear and compression waves in the stone, which can make it fracture, chip and splinter. This gives rise to blast waves that can exceed 1GPa, which travel through the various tissue types of the body out to where the sensor is placed on the skin.

The team had to start with direct experiments with spherical bubbles in water, explained Leighton, then extend that to simulating non-spherical bubbles hitting irregularly shaped kidney stones in a complex environment. To complicate matters still further, CFD works only on fluids, so another algorithm had to be developed to calculate how the signal just below the skin would sound once it travelled through the soft substance and into the sensor.

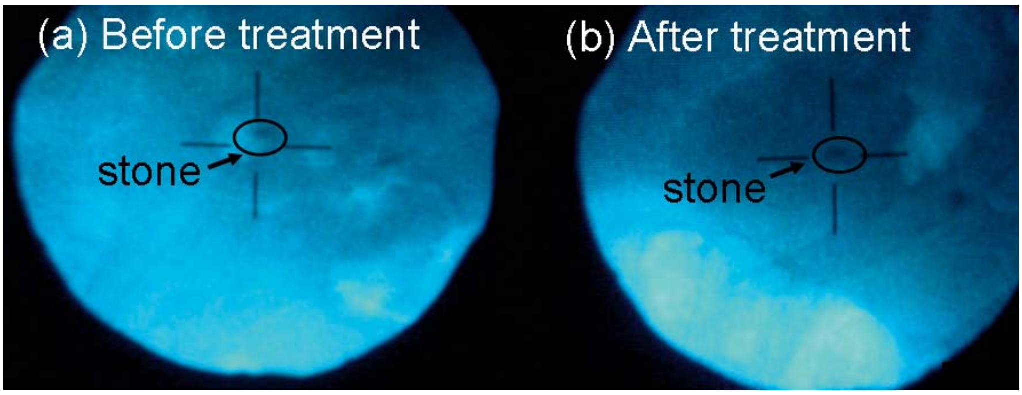
At the same time, the other team was working on prototype sensors. 'The CFD gave us loads of information on what processes generate what sort of sounds, and the work at the hospital and with Precision Acoustics told us what sort of device, measuring what bandwidths and signal noises, and with what sensitivities, we would need,' said Leighton. 'We built four sensors, refining each time, and we ended up with a unit about the size of a 50p piece and 1cm thick, housed inside a perspex case, which plugs into a simple laptop.'

The software to analyse the signal was another tricky problem. All the complexity of the signal had to be boiled down to a simple result: was the stone breaking up or not?

'Once you start working on real patients, it gets complicated; there are fat people, thin people, and they all give a different signal,' said Leighton. 'We worked out that there were two crucial parameters. When the shock hits the stone, if you have good cavitation and good effect on the stone, you get two echoes back. We needed the time lag between the first and second signal, and the ratio of the amplitudes of the signals. That ratio normalises for fat and thin people.'

The team received another grant for a clinical trial, in which a non-specialist nurse used the equipment to monitor therapy. Her results were compared with the opinion of the specialist operating the lithotriptor, who had access to X-ray and ultrasound imaging. The passive sensor predicted 18 out of 19 successful treatments on 79 patients, while the lithotriptor operator could predict only seven.

No stone unturned: the passive acoustic sensor, below, that could revolutionise kidney stone therapy



ALSO SHORTLISTED

Respiratory aids and prosthetic lungs
The subject of a three-way technology transfer partnership between Haemair, Swansea University and Swansea NHS Trust, this project is developing respiratory aids that do not use the patient's lungs, allowing him to rest and recover from surgery or illness. Haemair is running tests on its first prototype.

Nanomagnetic gene transfection
Delivering foreign DNA into cells using nanoparticles driven by magnetic fields is the goal of nanoTherics, a spin-off from research at Keele University and the University of Florida. The technique could lead to fast, effective treatments for genetic disorders such as cystic fibrosis.

Leighton is confident that the device, which is being manufactured by Precision Acoustics, has great potential for reducing the number of ESWL treatments, thereby cutting costs, improving patient care and increasing the lifetime of lithotriptor machines, which would need to perform fewer operations. Several groups have bought the device to perform larger clinical trials, and he hopes that the companies producing lithotriptor machines might be persuaded to include the sensors in their equipment.

'I like to see things through to a practical application,' said Leighton, 'whether that's something that can be mass-produced or something that will give some key one-off measurement. But I always start with the fundamental physics and simple equations. Then, when you're halfway down, you know that your assumptions aren't violating the original physics.'

Leighton and his colleagues are keen to see the technology distributed as widely as possible.

'The team wants to balance the need to support the commercial development with the ethical need to ensure that its benefits are made widely available to sufferers around the world,' he said. 'The partners — the university, Precision Acoustics and Guy's and St Thomas' — are willing to accept a reduction in the financial return as a trade-off.'