How safe is medical ultrasound?

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Ultrasound is being used increasingly in medical diagnosis and treatment of the human body but how safe is it?

For example, in the 1970s and 1980s about one in every 2,000 children was diagnosed with autism but today it is about one in every 150. Is this a result of ultrasound scanning of foetuses or changes in diagnosis of autism? Today, ultrasound is being used ever more widely in medicine from finding heart defects and detecting osteoporosis to targeted delivery of drugs and helping to relieve the symptoms of Parkinson's disease with implanted transmitters in the brain.

The applications of ultrasound fall into two groups: echo-detection and material processing but the physics of the propagation of ultrasound is the same in both groups. Ultrasound is a mechanical pressure-wave that is conveyed by a material; when there is a change in material property there is nearly always some reflection of ultrasound from the interface. It is the reflection that is exploited in echo-detection and it is the pressure of the wave that is exploited in material processing.

It is because the physics of propagation is the same in both groups of applications that we should never forget that an application intended to be echo-detection can also be material processing and vice-versa. A good example is ultrasonic medical imaging, which is intended to be echo-detection but can inadvertently become material processing.

There have been concerns for many years that ultrasound used to image unborn babies could damage the babies. I worked back in the late 1980s on a project sponsored by the National Physical Laboratory to create a 2-dimensional image of the pressure field of an ultrasonic transducer. The important feature of the project was to have very fine spatial definition of the pressure field. Of concern then was that phased-arrays of transducers were being used to generate images of foetuses, with the ultrasound from each transmitter transducer focused at the same point to maximize pressure there so that the return echoes would contain more information about the point focused upon. Manufacturers were making ultrasound equipment with finer and finer resolution, which requires finer and finer focusing of ultrasonic energy with more energy put into a smaller volume of the foetus. Of particular concern was this energy concentration in the brain of the foetus. Phased-arrays work by scanning the focus throughout the body and brain of the foetus to build-up an image so the whole body and brain, consequently, the whole body and brain of the foetus gets the high pressure treatment. The scanning process means that the highest pressure is maintained fleetingly at each point followed by a lower pressure but each point gets the high pressure several times a second to create a moving image of the foetus.

Ultrasound is absorbed in most materials but to a varying degree; when ultrasound is absorbed its energy is converted into another form of energy and this is nearly always heat

(which is arguably still ultrasound). The higher the ultrasound pressure at a point the more heat can be generated there. A curious feature of ultrasound is non-linear propagation, in which the compression half-cycle of the ultrasound wave travels faster than its twin rarefaction half-cycle. Non-linear propagation changes the variation with time of an ultrasonic wave and, for example, it turns a sine-wave into a saw-tooth-wave where the sharp leading-edge of the saw-tooth can have an extra high pressure peak. It's the material conveying the ultrasound that is creating the non-linear behaviour, the human body in this case, and non-linear propagation means that the peak compressive pressure at the focal point can be higher than expected and less predictable. Consequently, non-linear pressures are an important source of uncertainty in medical ultrasound scanners.

Designers of medical ultrasound scanners have been aware of the capacity of their instruments to cause damage to the human body. By generating a high enough temperature with ultrasound, cells in the body can be disrupted and killed. There are scanners on the market that can work in an imaging mode and then switch to increase the pressure to kill cells (HIFU). Cancer can be treated this way, with the imaging mode used to find cancer tumours and the high pressure mode used to kill the cancer cells in the tumour.

Many of us will come to rely upon the ingenuity of designers of such systems to prolong or improve our lives. But we must never forget the question of what ultrasonic pressure is safe to use on particular human tissue? Returning to foetal scanning, it was thought back in the 1980s, when I was working to image the pressure field with high spatial definition, that the brains of baby boys might be more sensitive to ultrasound than girls'. The incidence of autism is more common in boys than girls – is this a sign of cause and effect or a thought-provoking correlation?

More recently I have been working on using ultrasound to cut through bone. It's interesting that the conversion of ultrasound into heat is important in this processing application too because if enough heat is generated then bone gets cooked (or burnt) and a burnt bone-surface will not re-grow new bone and fuse with an adjacent bone surface. I may need an operation myself in the next few weeks to restore normal breathing through my nose after it was broken in a schoolyard brawl when I was 14 years old. The surgeon has told me he will use ultrasound tools to sculpt the bones in my nose. I'll let you guess what thoughts have passed through my mind!

Designers of medical ultrasonic equipment need a handbook to tell them what pressure can be used safely in different parts of the human body. These handbooks are international standards, which I work with frequently, but standards always lag behind innovations in the technology and our knowledge of the subject. The situation is not perfect so that concerns for safety in this field are not likely to disappear in the near future.

Meanwhile, I have learnt that some designers are trying to bring down the price of ultrasound scanners so that concerned mothers can buy one and use it at home to scan their own babies during pregnancy. How often will a nervous mother use the scanner on her unborn child – could frequent scanning result in a higher incidence of damage to foetuses? HIFU has also been taken-up for cosmetic surgery to process skin and to remove fat. It

sounds marvellous but what happens to the processed cells, what do they become? Can the process cause mutations in genes?

Maybe it’s time to sell medical ultrasonic equipment with health warnings like cigarettes.