An Historical Perspective on Medical Ultrasound

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1. The history of ultrasonics lacks the drama of Rontgen's discovery of x-rays, but in all other respects it is part of the history of medical physics. The world-wide sales value of medical ultrasonic equipment is estimated to exceed seven billion dollars this year. About one third of all medical imaging is performed using ultrasound. My own career was in medical ultrasound so, when Slavik Tabakov suggested that Medical Physics International would be interested to cover the history of ultrasonics, I couldn't refuse. This turned out to be a larger project than I had anticipated.

2. The results of our efforts were published in 2020 and 2021 in two special issues of MPI. These are freely available on line at www.mpijournal.org/history. Part one describes the origins of ultrasonics during the first half of the twentieth century, up to the time when medical ultrasonic imaging emerged. During this time, physicists and engineers also developed approaches to ultrasonic metrology, and three of the chapters in Part 1 deal with these developments.

http://www.mpijournal.org/pdf/2021-SI-05/MPI-2021-SI-05.pdf

In Part 2, the period from about 1950 onwards, describes how ultrasonic methods entered clinical use. There are, of course, a number of similar articles already in the literature and on-line on this topic. However, most of these have been written from a clinical point of view. In contrast, we have tried to emphasise the contributions of the physicists and the engineers who designed, built and improved these ultrasonic techniques. In the rest of my talk I will give you a whistle-stop overview of some of the content of these two special issues.

http://mpijournal.org/MPI-v09SIi06.aspx

3. By the end of his life, the French physicist Paul Langevin was highly honoured in France. He is laid to rest in the Pantheon in Paris. Picasso sketched his portrait, shown here. He was a lifetime friend of Marie Curie and of Albert Einstein. Walter Cady, from Weslyan University, in his 1946 book Piezoelectricity called Langevin the 'originator of the science and art of ultrasonics'. Using x-cut quartz Langevin had created the first ultrasonic piezoelectric pulse-echo system, for submarine detection during World War I. Following the first war there was little widespread interest in ultrasonics. This graph shows how publications took off after about 1930, counted from the citations in a 1939 ultrasonics textbook

The few developments in the 1920s can all be traced directly to Langevin. The first example is that of the American physicist Robert Wood, who visited Langevin's laboratory during the war. Later, funded by investment Banker and amateur scientist Alfred Lee Loomis, explored the physical, chemical and biological effects of powerful ultrasonic beams in Loomis' personal laboratory at Tuxedo Park. They called them 'death rays'.

A second example is that of Charles Florisson. He was Langevin's engineering collaborator during the war and went on the develop the first ultrasonic depth sounder for merchant shipping, shown in this 1923 magazine cover. Together they also created an ultrasonic beacon for navigation in fog, first installed at Calais harbour.

Under Langevin's guidance, Robert Boyle had led the British war-time development on what the British Navy then called asdics (later called Sonar). After the war he returned to his native Canada where he published widely on acoustic cavitation and ultrasonic metrology.

The fourth example was a medical physicist. Frank Lloyd Hopwood was appointed professor of physics at St Bartholomew's Hospital Medical School in London in 1924. He had worked on underwater acoustics during the war, when he heard of Langevin's work. This trace shows the inhibition that he observed of nerve conduction during ultrasonic exposure.

So these four physicists, in the USA, France, UK and Canada, all drew inspiration from Langevin's pioneering work, and each took some interest in the bioeffects of ultrasound.

4. As I said, for Part 1, Kevin Martin and I looked at the origins of ultrasonic metrology. Langevin's first measurements were of total acoustic power, which he measured using the radiation force exerted on a reflecting target. One device, the tortion balance, is shown on the right. But in order to make measurements at sea he needed something more robust, and designed the quartz hydrophone shown here in the centre. The charge is connected directly to the grid of a triode, giving a very high impedance and so the necessary sensitivity. At the same time several physicists exploited the optical diffraction caused by ultrasound in order to visualise beam structure. You can see one lovely example from this time, shown on the left. All three techniques have modern equivalents, and are now used for ultrasonic standards, for safety and for calibration.

5. Ultrasonics first entered clinical practice in 1939 with the advent of ultrasonic therapy, pioneered by the Seimens physicist Reimar Pohlmann in Berlin. The late 1940s saw a huge expansion in ultrasonic therapy. This 1949 advertisement for Dr Born's equipment was typical of more than a dozen manufacturers operating at this time. At this stage, resonant quartz plates were still being used, but were about to be replaced by ferro-electric ceramics.

6. Moving on to Part 2, the first clinical chapter was written by Norman McDicken and Carmel Moran from Edinburgh. They showed how the technology developed from A-mode and cardiac M-mode to a variety of automated and semi-automated scanning techniques, some shown here. Top right is the Octoson, developed by George Kosoff at the Commonwealth Ultrasonics Institute in Sydney Australia: Bottom left is Norman McDicken's own 'spinner', a mechanical scanner with 4 transducers, Centre is an intraoesophageal rocking transducer for cardiac scanning. Finally, arrays were introduced in the late 1970s, opening the way for dynamic focussing and beam-steering.

7. Two of the chapters in Part 2 are rather unusual. They describe in detail the engineering design and commercial development of two particular scanners. The first, developed by Tom Brown with the obstetrician Ian Donald in Glasgow, is described by Tony Whittingham, medical physicist now retired from Newcastle. It was this unique commercial scanner that first established obstetric ultrasound as a useful clinical tool. These images are part of the archive recording this development. And, of interest to the serious historian, Tony added an appendix containing the full service and operating manuals.

8. The second chapter about a commercial scanner is by the only US contributor, Tom Szabo from Boston University. As a past employee of Hewlett Packard, he was in an ideal position to write this unique account of how a team of engineers worked to create arguably the first successful high-end phased array cardiac scanner. A range of novel engineering techniques had to be developed, including methods for dicing ceramic materials, and the exploitation of new digital techniques for beam-forming and signal processing.

9. Initially, Doppler techniques developed in parallel with imaging. At first the Doppler shift in a continuous beam of ultrasound cased by flowing blood, was interpreted using analogue spectral analysis of short recorded epochs. Peter Hoskins from Edinburgh University shows how the pulsed Doppler was eventually merged with pulse-echo imaging, to form the now-familiar integrated ultrasonic scanning systems, created from both phase and amplitude of the returning echoes

10. Finally, complementing the more widespread diagnostic use of ultrasonics, Gail ter Haar from the Institute of Cancer Research in London writes about the historical developments that underpin modern surgical uses, in High-Intensity Focussed Ultrasound or HIFU, staring with the work of the Fry brothers at Indianapolis.

11. All these developments in medical ultrasound find their origin in the pioneering work of Paul Langevin. This year, 2022, marks the 150th anniversary of his birth in January 1872. As a result, we have initiated several projects to remember his life and work to add to the content of the MPI Special Issues that I have just outlined.

Duck F. Paul Langevin (1872-1946): The father of ultrasonics. *MPIJ* 2022;10:84-91

Duck F. ‘A piece of stone, two plates of tinfoil’ Paul Langevin and ultrasonics. *Physics Today* 2022(4) in press.

André Langevin. *Paul Langevin, my father* (in English translation). EDP sciences. 2022 in press.