Chapter 1: Medical ultrasound — germination and growth

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The earliest attempts to use ultrasound for medical diagnosis were in the late 1930s by the neurologist K.T. Dussik who tried to make 'hyperphonograms' of the head [1]. By the early 1950s a few more pioneers were beginning to explore other possibilities. The following 20 years transformed ultrasound into a recognized diagnostic method and the next 20 years into a common feature of modern medicine. The current range of applications described in this book are evidence of the apparent foresight of those early pioneers. At the time, however, it was far from clear where experiments with ultrasound would lead, or whether they were even of value. In the 1950s ultrasound could be likened to a tiny plant just unfolding its cotyledons from the soil, a stage at which it was unclear what it would become, let alone that it would develop into a major feature in the diagnostic 'garden'. It is all too easy from the viewpoint of the late 1990s to look at the well-established plant and describe a simple progression from germination to maturity. It is more difficult to imagine the environment of the 1940s, 1950s or even the early 1960s, when just a handful of machines existed, and then to extrapolate a few decades into the future. Particularly the future of the late 1990s when it is estimated that there are about 250000 machines in the world being used to perform nearly 250 million scans per year [2,3] (Fig. 1.1).

Achieving a clear understanding of the growth of a new technique and its effects requires considerable effort. The rewards to be aimed for are the development of an understanding of the medical, social, professional and commercial consequences of this aspect of technology, a reduction of myth and the recognition of the efforts of individuals, organizations and associations. Also it could lead to a better understanding of the conditions in which such germination and growth is possible. To do this requires sources of material, historical collections and archives. Over the last 10–20 years efforts have been made to establish these. In particular the American Institute for Ultrasound in Medicine (AIUM), the British Medical Ultrasound Society (BMUS) and the German Society of Ultrasound in Medicine (DEGUM) have established collections and archives.

Notably in 1988 Professor Barry Goldberg (Fig. 1.2) organized the first History of Medical Ultrasound Symposium (HMUS) in Washington, DC. As a result an archive was established and is now housed at the AIUM. This contains contributions from at least 70 pioneers from more than 15 countries in the form of written and pictorial material and recordings, both audio and video. Additionally, the work and lives of another 50 were described and acknowledged.

In 1995 the Wellcome Unit for the History of Medicine (WUHM), University of Glasgow, commenced a 3-year study of the developments which took place in Glasgow. This work is based on the resources of the BMUS collection and archives. Additional material is being acquired from a series of interviews being conducted by the WUHM with many of the pioneers, and their associates. Work on this large and increasing resource has been undertaken [4–6] and is planned to continue. A chronological listing of events is being assembled and this was used as the basis for the brief list of major events at the end of this chapter (Appendix 1).

The German collection was established in 1995 with the aim of collecting material from the early period of ultrasound with a special interest in the work which took place in the German-speaking countries of central Europe. More details of these collections are given at the end of this chapter (Appendix 2).

Apart from these collections and archives there are historical accounts, some written from personal experience [7–15]. Then there are the scholarly works such as the theses of Coste [2] and Koch [16]. Complementing these is a survey of the mature ultrasound industry by Blackwell [3] which contains factual and projected data for 1994–2000.

When reading of the efforts of the medical ultrasound pioneers between the late 1930s and the late 1960s the stories seem to be dominated by the development of equipment. This is especially evident in the frequency with which pictures of equipment appear. For example, in the Kodak booklet [17] there are 104 pictures, 73 show pieces of equipment, 25 show images and 23 pioneers. The equipment was usually developed from military or industrial instruments. From the military side came the technology of radar, which had developed rapidly during World War II, and in which the basic system is virtually the same as used in medical ultrasound. From industry came ultrasonic flaw detection developed to meet the particular needs of metal fabrication, from high pressure boilers to aircraft structures; ultrasound fulfilled the need for testing without the use of hazardous and time-consuming radiographic methods (B. Donnelly, 1996, interview in the I.H. Spencer, BMUS Collection and Archive).

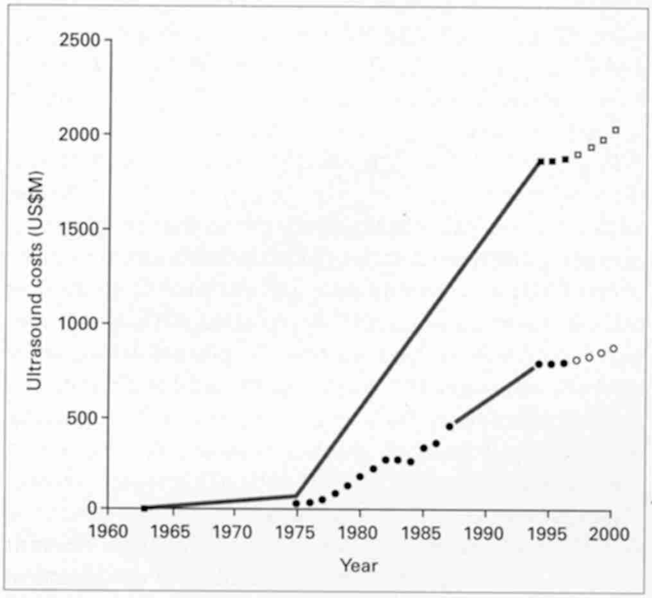

Fig. 1.1 The colossal expansion of the market from 1975 has been called 'the real-time boom'. This chart shows the World (■) and US domestic (●) markets for medical ultrasound in millions of US$. The 1975–87 points are from Coste [2] and for 1994–2000 from Blackwell [3] whose predicted figures are shown as unfilled symbols (World, □; US domestic, ○). The lines represent our interpolations and the 1963 point our estimate of the sales of KH Diasonographs.

But radar and flaw detectors did not have an obvious place in medicine. Who made the leap from these existing technologies to medicine? How did it happen? Someone must have planted the seed, or seeds, so that they could germinate. The existence of, in retrospect, such obviously suitable technology alone was insufficient; an initiator was needed.

Exploring the archives shows that in the majority of cases the initiator was a medical doctor. Making this connection between medicine and engineering was remarkable at a time when ultrasound was so little known, when there were few publications on ultrasound, or 'supersonics' as it was known in industry, and easily searched databases and bibliographies [18] were not available. It seems that the burden of a clinical problem prompted the question, can ultrasound help?

The question having been asked the next crucial element was the availability of a physicist or engineer, initially to discuss and advise and later to actively co-operate. To quote Hertz [9] '. . . at every point in this development [echocardiology] the engineering advance had to be carried to a certain stage before the apparatus could be used in medical research. Then the engineer had to wait until the physician had amassed enough experi-

Fig. 1.2 Exhibition at the History of Medical Ultrasound Symposium, Washington, 1988. Professor Barry B. Goldberg (left), Chairman of the Symposium organizing committee with Mr Tom Brown (see text) who is demonstrating the method of recording patient data and an ultrasound image using the Polaroid camera on the machine shown in Fig. 1.6. (Courtesy of the BMUS Historical Collection.)

ence to point out new possible improvements to the engineer'. Today such co-operation would not seem an unusual occurrence, just a normal activity of a department of medical physics. However, it was not always so; in the introduction to Koch's thesis [16] she states that she analysed 'the evolving relationships of one innovator, John Wild, and a medical community which was unaccustomed to dealing with research on machines'. In her conclusions she indicates some of the difficulties and explains the historical importance of the machines by saying of the individuals involved in research on ultrasound '[They] had to reconcile their differences of opinion about how research on ultrasound should be conducted and applied to clinical practice. As a result, the ultrasonic instrument was the crux of the relationship between individuals with very disparate interests, who might otherwise have nothing in common'.

Such relationships would be more likely to be successful if the medical practitioner had an interest in machines and the problems of invention and engineering. This carries with it the acceptance that invention does not work perfectly first time and that modification and adaptation will be needed. Wild is someone with that trait, and Koch described him succinctly and aptly as a 'tinkerer'.

Then there were deterrents to physicists, engineers or technologists moving into biology or medicine. Both may appear fuzzy and slippery subjects compared with the more defined and measurable world of engineering and technology. And the medical research community of the 1950s, at least in America, was not inviting. To quote Koch again [16] '. . . technological knowledge and the activities leading to its development were not valued—or at least were grossly undervalued compared with scientific knowledge . . .'.

Given that clinical medicine and physics had come together advances occurred most readily when the clinical problem related to the heart, the eye or the abdomen of a sick gynaecological patient. These are the regions of the body most amenable to ultrasound imaging. The heart is a well-defined structure of relatively simple form made more apparent by its dynamic nature. The eye being a simple structure, within the resolution of ultrasound, was also suitable and successful although it did present contact problems which required the use of water baths or bags or a steady hand placing the transducer directly onto the closed eyelid.

In retrospect it is clear that it was gynaecological patients, particularly those with large cysts or tumours who provided the most suitable subjects. In these patients the abdomen is almost entirely soft tissue or fluid ultrasonically similar to water. As the spine is positioned posteriorly, and the gas-containing bowel is commonly displaced by the mass, the two principal barriers to ultrasound are avoided. Later when pregnant patients were examined at mid or late term similarly obliging conditions existed. There could of course be fetal bone but being thin, soft and part of an easily recognizable structure this only served to enhance the images. The scale of the structures seen in these two groups of patients were also ideal as they were clearly resolvable even by the low frequency (1.5–2.5 MHz), poor resolution systems of the time. Furthermore, the deformable abdominal surface facilitated contact scanning.

In contrast the most unsuitable region was the head. This, however, in addition to Dussik's work mentioned above, attracted much attention in the early years, reflecting the many associated clinical problems. Unfortunately, in spite of considerable effort clinical value was difficult to establish [12,13]. Then X-ray computed tomography arrived and completely supplanted ultrasound. However, the technology has changed, Doppler and contrast enhancement have brought ultrasound back into the study of the head as evidenced by a recent congress on cerebral haemodynamics [19] in which there were 169 presentations, involving over 400 authors.

The crucial elements—an initiator with a clinical problem, ultrasonically suitable anatomy, co-operation with a physicist or engineer together with sponsorship and support—came together in varying ways in various places and over a number of years to allow 'germination' to occur. These are summarized Table 1.1. Less definable and not shown in the table, but perhaps of equal importance, was the strength of will to engage in the long haul of convincing a very sceptical medical community and of positively promoting this new technology.

As space does not allow inclusion of the stories from all of the centres, the events in Glasgow are taken as an example of ultrasound germination. The initiator was Ian Donald, the distended female abdomen presented the clinical problem, Tom Brown provided engineering insight and Kelvin Hughes (KH) supplied substantial support and facilities.

Ian Donald was born in 1910, a time of great advances in engineering and technology; the Wright brothers were at the height of their powers, Bleriot had recently flown the English Channel and Asdic, or Sonar as it became known, was developing. Ian Donald's sister Dame Allison Munro recalls (interview by I.H. Spencer, 1997 BMUS Collection and Archive) that as a child 'Ian was very good with his hands, boat building and things like that, and this man Hawkhurst, I think he was called, taught him something about electronics. . . . Ian built himself this wireless with a "cat's whisker", it was the first time I ever heard the wireless'. Later as a medical student he developed a device for bladder irrigation. As a registrar he developed a negative pressure ventilator for the newborn, and a spiroscope to

Table 1.1 A selection of initiators of research in ultrasound imaging; their speciality, when and where they began, region of application, initial objective, collaborators (individuals and firms/organizations) and how they came together

Initiator (year work began)	Place of study	Speciality	Part of body	(a) First reason for interest in ultrasound (b) Knowledge of other work	Co-operation Co-worker(s) Firm/organization	How they met and other notes
Dussik, K.T. (1937)	Salzburg, Austria	Neurology	Head	(a) Seeking method of visualizing non-calcified brain tumours (b) Had learnt that ultrasound was used for finding fish and non-destructive testing	Dussik, F. (physics)	Brothers
Denier, A. (1946)	France	Physiotherapy		(a) To produce images of interior body structures (b) —		
Howry, D.H. (1948)	Denver, CO	Radiology	Neck, limbs	(a) Wanted to make a soft tissue 'X-ray' (b) —	Bliss, W.R. (eng) Posakony, G. (eng)	
Wild, J.J. (1949)	Minneapolis, MN	Surgery	Bowel	(a) To detect malignancy in bowel by measurement of bowel wall thickness. 'Wild was trying to demonstrate to other surgeons the difference between obstruction of the bowel and paralysis' (b) From Finn Larsen (Honeywell) designer of radar simulator using ultrasound for US Navy	Neal, D. (eng) Reid, J. (eng) US Navy	
Edler, I. (1953)	Lund, Sweden	Cardiology	Heart	(a) Need for a method of detecting mitral regurgitation. co-operation with Lars Leksell (b) Only learned later of work in USA	Hertz, H. (physics) Siemens	Edler said he sought out Hertz who says they met by chance. The first echocardiogram was recorded October 1953
Donald, I. (1954)	Glasgow, UK	Obstetrics/ gynaecology	Female abdomen	(a) To differentiate between cyst and tumours (b) Donald had heard J.J. Wild talk about ultrasound, Brown said didn't know of Howry's work	Brown, T.G. (eng) MacVicar, J. (obstetrics/ gynaecology) Kelvin Hughes Ltd	As described in text
Leksell, L. (1955)	Lund, Sweden	Neurology	Head	(a) — (b) By co-operation with Edler and Hertz		
Mundt, G.H., Hughes, W.F. (1956)		Physicians	Eye		Smith Kline Precision Inc.	
Kossoff, G. (1959)	Melbourne, Australia	Physics	Obstetrics	(a) Garrett quotes diagnosis of placenta praevia as aim (b) At start did not know of Donald's work in Glasgow	Garrett, W.J. (obstetrics/ gynaecology) Robinson, D.E. (eng.) Comm. Acoustic Labs	
Kratochwil, A. (1964)	Austria	Obstetrics/ gynaecology	Obstetrics/ gynaecology	(a) As alternative to radionuclides for placental localization (b) In head	Kretz, C. (eng) KretzTechnic	

eng, engineering.

aid his studies of neonatal breathing. During World War II, as a member of the medical branch of the Royal Air Force, he became aware of the development of radar. Possibly this awareness was increased to some extent because his sister worked with Robert Watson-Watt the radar pioneer. Later while Reader in Obstetrics at the Hammersmith Hospital, London, Donald heard of the medical possibilities of ultrasound from a lecture by a surgeon, J.J. Wild (Fig. 1.3), who had been experimenting in Minneapolis since 1949 [20]. Initially, Wild had been seeking a means of measuring bowel wall thickness and had contacted Finn Larsen, a physicist, who had designed a radar simulator using 15 MHz pulsed ultrasound. This consisted of a water tank containing a relief map of a land area; this was scanned by an ultrasound transducer which simulated the radar antenna. By the time Donald heard him speak, Wild's interest had moved to using the whole echo pattern to differentiate one tissue from another.

Some time after Wild's lecture Donald was appointed to the Regius Chair of Midwifery at Glasgow University. On his arrival in Glasgow in 1954 Donald had in his own words '. . . a rudimentary knowledge of radar and a continuing childish interest in machines, electronic and otherwise—or what my wife would refer to as my "toys" [7]'; altogether a suitable background for being involved in invention and development. In his clinical practice he was commonly faced with grossly distended female abdomens and the problem of making a differential diagnosis. By chance one of his patients was the wife of a Director of Babcock and Wilcox (now Mitsui Babcock) a major firm in Glasgow's heavy engineering industry. This contact led to a visit to their works on 21 July 1955 with a quantity of cysts and tumours removed during operations that morning. These were 'tested' using the company's ultrasonic flaw detector. As a camera was not available the A-scan traces were sketched by the company artist; Donald related that '. . . these [results] were beyond my wildest dreams and clearly showed the difference between a fibroid and an ovarian cyst'.* The Babcock equipment had been manufactured by KH, also in Glasgow, and through this connection Ian Donald visited Professor Mayneord at the Royal Marsden Hospital, London. Mayneord had been using a KH Mk2 flaw detector (Fig. 1.4) in an attempt to examine the brain through the intact skull, but as was later recognized this presented major difficulties. Thus it is no surprise that Donald formed the view '. . . that they knew a good deal about the subject, enough in fact to be thoroughly discouraged' [7] and that soon after it was agreed that Mayneord's apparatus could be loaned to Donald.

Kelvin Hughes had interests other than ultrasound and were installing an experimental shadowless lamp in Donald's operating theatre in the Western Infirmary in Glasgow (WIG) where one of the KH staff heard that 'The doctor was using a flaw detector on people'. Later he mentioned this to his colleague Tom Brown, a young design engineer, who that evening phoned Professor Donald. He later described this 'as the most fateful telephone call I ever made', but it was the start of a fruitful and exciting period. Brown visited Donald at the WIG and found that

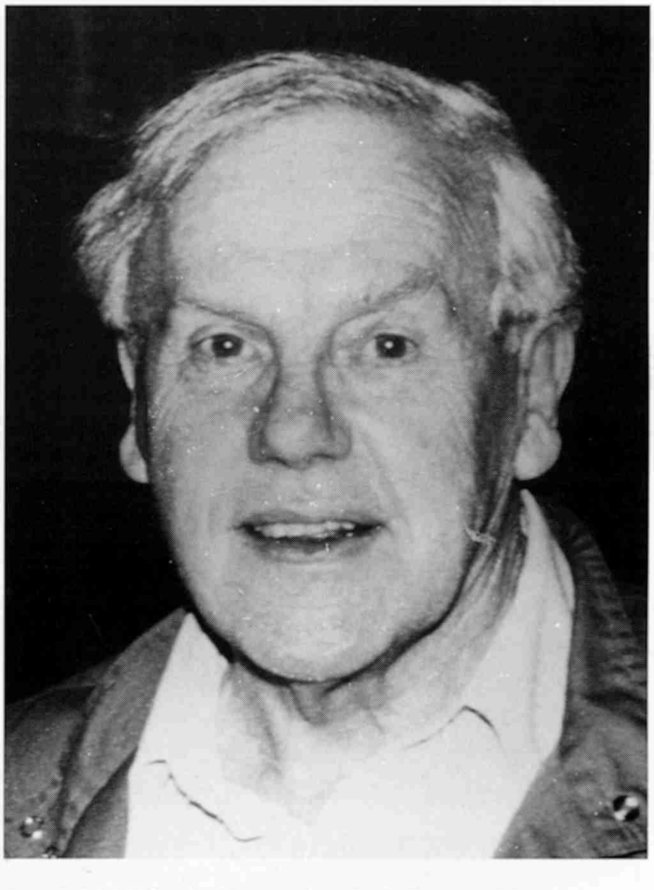

Fig. 1.3 J.J. Wild at the History of Medical Ultrasound Symposium, Washington, 1988. Dr Wild began his ultrasound experiments in 1949.

* As part of the work in the WUHM Ian Donald's first experiments were re-enacted on 19 July 1996. A KH Mk4 flaw detector as used in Babcock and Wilcox in the 1950s was borrowed from Axiom (NDT) Ltd; with only a few minor repairs this still worked after more than 40 years and the difference between 'cysts and tumours' could be distinguished. To avoid ethical problems these were simulated by using animal material: water-filled bladders and samples of muscle tissue (see Fig. 1.19). These were provided by Professor Jack Boyd in whose Department of Veterinary Anatomy, University of Glasgow, the re-enactment was carried out. As many people as possible who had been around at the time of the original experiments were invited [38]. Video recordings were made of the flaw detector traces and of the whole 3 h of activity. Extracts of this were used in a video [39].

the A-scan instrument from Mayneord had, as was common at that time, been designed to use a transducer with separate transmit and receive elements. Unfortunately, it had been inexpertly modified to use a single transducer resulting in paralysis for hundreds of microseconds after the transmit pulse. Donald's solution was to use a large water stand-off device, both clumsy and inconvenient. Brown overcame this by making another phone call, this time to Alec Rankine (interview with I.H. Spencer, 1996, BMUS Collection and Archive). In Brown's words 'Alec never respected formalities' and within days a brand new KH Mark 4 flaw detector (Fig. 1.5) worth £600 in 1956 was on its way from the factory in London to Glasgow.

The echo patterns from cysts, solid masses and normal bowel could be distinguished but Tom Brown realized the limitations of the A-scan as a means of presenting the enormous amount of echo information which was returning from inside the abdomen. He concluded that 'we needed some sort of automatic plotting device' but 'I found it difficult to fire Ian Donald or John MacVicar [Donald's Registrar at the time and later Professor of Obstetrics and Gynaecology in Leicester] with my "dream"; or even make them understand it' (T.G. Brown, 1988, personal communication). Was Donald blinkered by Wild's efforts to use ultrasound to differentiate between tissues? Just at this juncture it was suggested to Donald by physicians at the WIG that he try his apparatus on a woman '. . . supposedly dying with massive ascites due to portal obstruction from a radiologically demonstrated carcinoma of the stomach'. The A-scan showed well-separated echoes and MacVicar observed 'that it seems like a large cyst' [7]. It turned out that the physicians were uncertain of their diagnosis. After transfer to Donald's care, the lady was operated on and made a rapid recovery. This was just what was needed to secure financial support and enabled the KH deputy chairman, Bill Slater, to conjure up £500, later described by Tom Brown as 'a rather elastic sum'. This allowed him to build his 'dream'—the first contact scanner (Fig. 1.6).

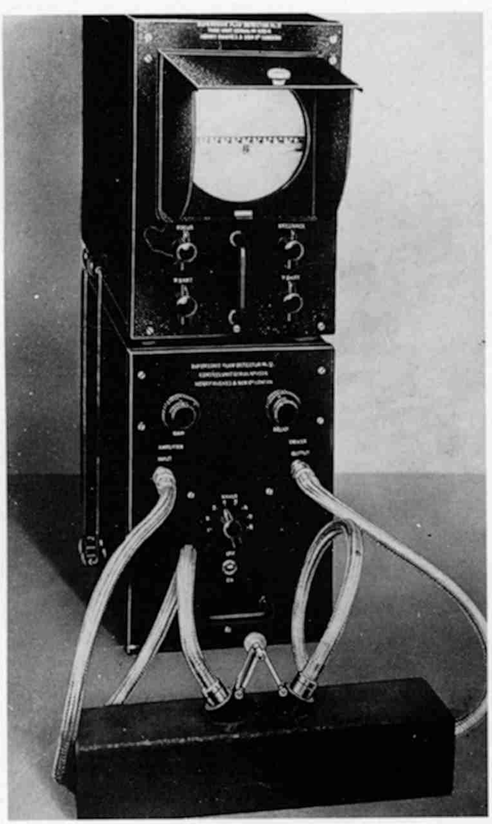

Fig. 1.4 Kelvin Hughes Mk2 flaw detector. This was based on an airborne radar set and was the type of instrument used by Professor Mayneord at the Royal Marsden Hospital, London, and then by Professor Ian Donald in his first experiments. An example of this unit is in the collection of the Science Museum, London.

Fig. 1.5 A KH Mk4 flaw detector, *c.* 1956 being using by Mr Jim Davis in the Babcock and Wilcocks factory to test steel plates. Soon after his first meeting with Professor Ian Donald, Tom Brown arranged the loan of an instrument of this type from KH to replace the Mk2 (Fig. 1.4). The Mk4 was used for most of the early A-scan experiments and then became part of the contact B-scan machine in Fig. 1.6.

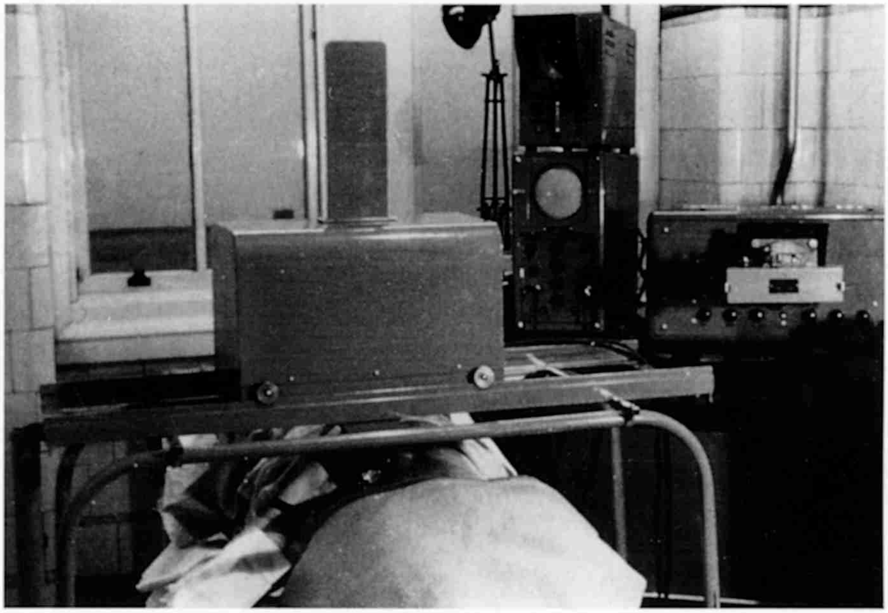

Fig. 1.6 The contact scanner in the Western Infirmary, Glasgow. This manually operated scanner was designed by T.G. Brown, at KH and used by Professor Ian Donald and Dr John MacVicar [22]. See text for more details.

This scanner had a transducer which could be moved freely in one plane while being kept in contact with the patient thus avoiding the use of a water bath, as was thought necessary by other experimenters of the time. To explain this different approach Brown wrote 'I was unaware at the time of Howry's beautiful neck pictures using a water bath. I was aware from my industrial experience, of the reverberation problems. But the most compelling reason was quite unrelated to technical considerations. The patients I was seeing in Donald's gynaecology wards were often elderly, and generally quite unwell, I could not see any technique being well received which involved disturbing these old ladies any more than necessary' (T.G. Brown, 1988, personal communication).

The first recorded image from this scanner was of a massive ovarian cystic carcinoma. At the 1988 Symposium Brown said 'I remember it being made and being rather disappointed by it' [21]. Images from this machine, such as Fig. 1.7, were published in the *Lancet* [22]. This paper was regarded by Ian Donald as his most important. Presumably the *Lancet* was chosen in order to reach a wide audience and promote the concept that pulsed ultrasound could be applied to more than obstetrics and gynaecology.

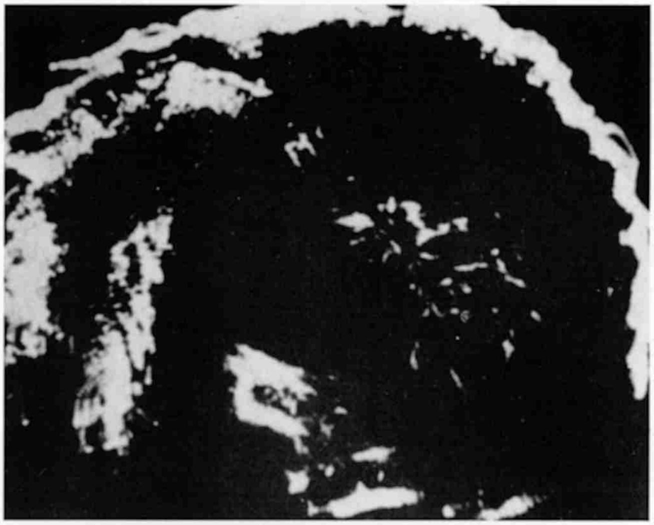

Fig. 1.7 Typical image, *c*. 1957, from contact scanner in Fig. 1.6. This transverse scan was recorded as being of a 'complex ovarian tumour (multilocular pseudomucinous cystadenoma)'. The somewhat irregular hand scanning is seen in the tracing of the almost semicircular abdominal surface.

Brown, however, could see that the prototype was difficult to use and that the pictures were probably influenced by the way in which the operator handled the probe. Howry [23] (Figs 1.8, 1.9) had quite separately expressed similar reservations. However, it was difficult in the prevailing Victorian atmosphere of the 1950s for Brown, an engineer without medical qualification, to take direct control of the scanning. He therefore did so indirectly by designing and building an automatic scanner largely funded by a grant from the National Research and Development Corporation. This monster of a machine (Fig. 1.10) produced thousands of images which are clearly recognizable in publications from Glasgow by the consistent scanning pattern (Fig. 1.11). This sort of devel-

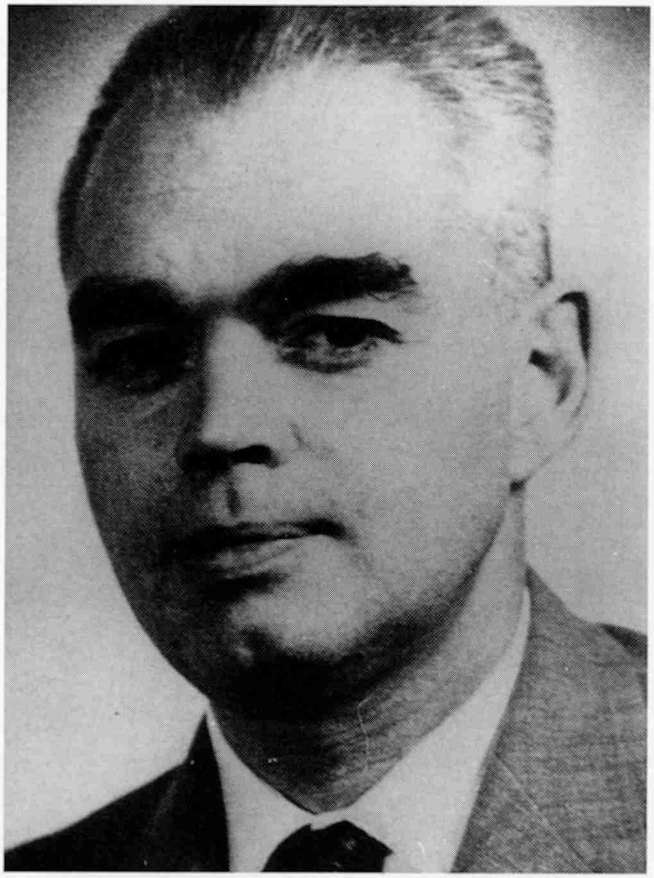

Fig. 1.8 Douglas H. Howry, *c.* 1960. (Courtesy of AIUM Archives.)

opment cost a great deal of money so that the arrival of an obstetrician, Bertil Sunden, with a grant to buy an ultrasound machine must have appeared as a godsend. Following an introduction to A-scan by a neurologist, Lars Leksell, who also worked in Lund, Sweden, Sunden heard of Donald's work in Glasgow. In 1962 a machine was delivered to Sunden (Fig. 1.12). This was based on the original manual contact scanner; experience with the autoscanner having shown that the operator did not unduly affect the images. Sunden's subsequent MD thesis [24] provided independent confirmation of Donald's findings.

Having sold one machine KH, by then known as S. Smith & Sons, saw the prospect of a return on its investment. A development engineer (JEEF) was employed to work on the design of a scanner to go into production. This was in turn based on the Sunden machine and became the first scanner to be built in quantity. Twelve of these 1-ton Diasonographs (Fig. 1.13) were delivered to hospitals in the UK, USA and Iraq. In spite of this success and the large potential market (evident with hindsight) Smith's decided to close the Glasgow factory. Fortunately in 1967, the medical ultrasound interest was purchased by Nuclear Enterprises, Edinburgh, who went on to produce more to the Smith's design. They then took the bold and successful step of redesigning the system, the gantry was improved and the circuits redesigned using semiconductor devices to replace the by then outdated thermionic valves. Over 200 machines of the new design, in various versions—NE4102, NE4200, etc.—were sold before problems arose from the involvement of the parent company, EMI, in the computed tomography market. After complex manoeuvrings three small highly active Scottish companies* have continued in the ultrasound business.

Although there were unique aspects to the Glasgow story, events elsewhere in place and time were broadly similar. Particularly interesting was the earlier development of echocardiography initiated by Inge Edler in a search for a means to detect mitral regurgitation. Co-operation with Hellmuth Hertz and the loan of equipment from Siemens led, in 1953, to the first routine clinical application of diagnostic ultrasound (Fig. 1.14). The details of this development are described both, fully [1] and clearly and concisely [11].

Even as late as 1964 a similar story unfolded in Austria where Alfred Kratochwil was looking for an alternative to radionuclides for placental localization [25]. Hearing of the interest of a neurologist in the use of ultrasound led Kratochwil to borrow an A-scan from Kretztechnic, (Fig. 1.15). The move to two dimensions took place when Kratochwil became aware of the work of Donald *et al.* and persuaded Kretztechnic to build a B-scanner.

Notably different was the work at the Commonwealth Acoustics Laboratory in Australia. At this laboratory an ultrasonics institute was established and George Kossof, a physicist, started work on medical ultrasound (Fig. 1.16). Here to quote his colleague, obstetrician Bill Garrett, 'The difference between the Australian activities and those in North America and continental Europe was, we were physics advised by medicine, whereas almost all the others were medicine advised by physics. And this meant quite a lot in the outcome. For instance when we first started in 1959 we were not aware of Donald's work, . . . [Our] first pictures came out in 1962, clinical pictures, but the important thing was that we had superb images, better than those from people who used modified flaw detectors' [26]. Even though the work was initiated by a physicist it has to be noted that Garrett stated that their prime objective had been placental localization as the

* BCF Technology, 8 Brewster Square, Brucefield Industrial Park, Livingston, W. Lothian EH54 9BJ, UK. Diagnostic Sonar Ltd, Kirkton Campus, Livingston, W. Lothian EH54 7BX, UK. Dynamic Imaging Ltd, 9 Cochrane Square, Brucefield Industrial Park, Livingston, W. Lothian EH54 9DR, UK.

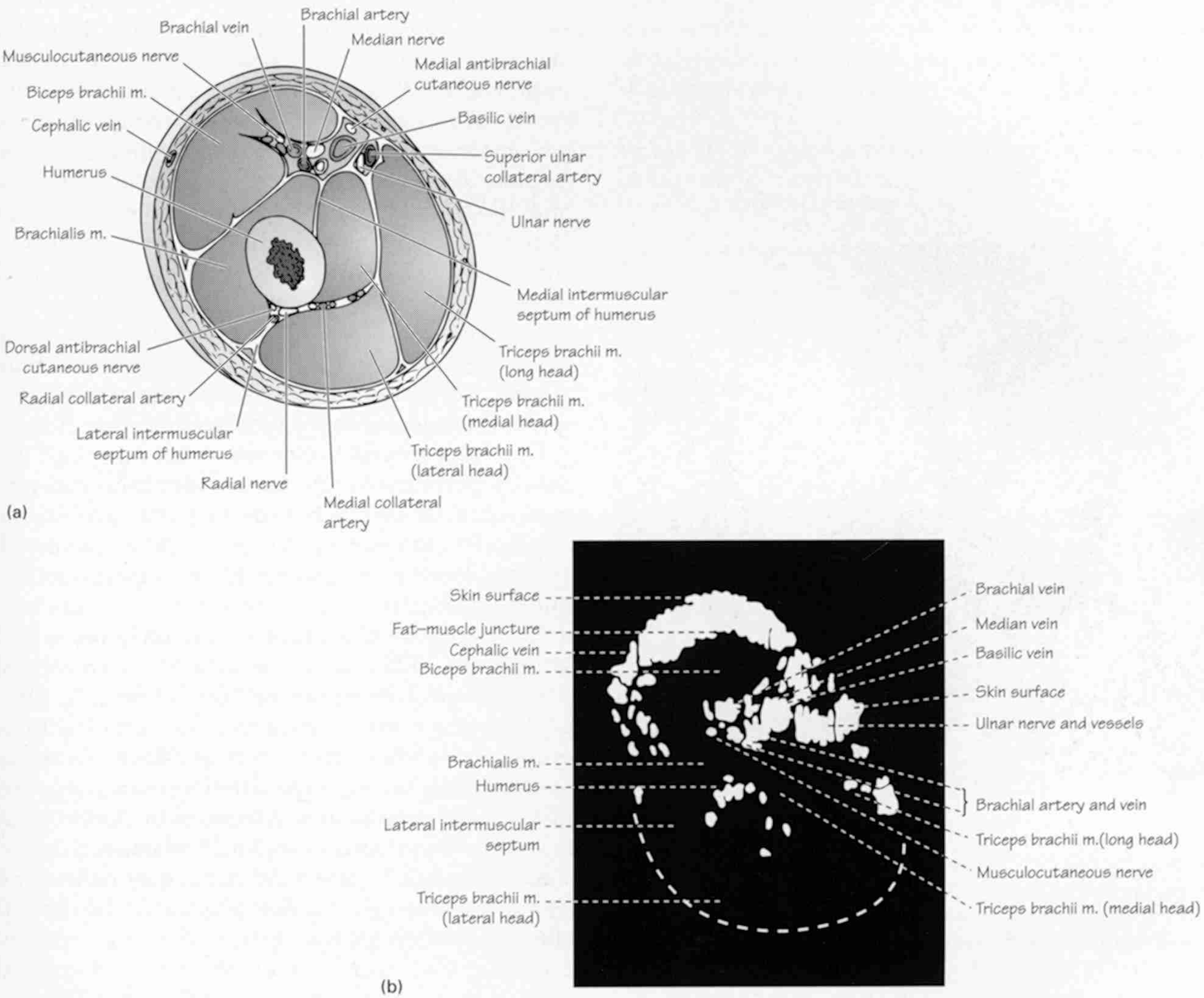

Fig. 1.9 An image from Howry's Somascope [40]. (a) Cross-section and (b) somagram through the mid-third of the right arm. (Courtesy of AIUM Archives.)

available methods of the time 'were very poor'. Their pictures particularly of fetal anatomy were truly remarkable (Fig. 1.17) and a clear demonstration of the importance of grey scale. This led to a rejection of storage tubes, both the bistable type, which showed only black and white, and the variable persistence ones which produced very few grey tones between black and white.

The combined momentum of the work in these various areas, geographical and clinical, was to change ultrasound from an 'eccentricity' as described by Donald [27] to something with possibilities. Then began the long haul to establish ultrasound as a routine diagnostic tool which could be widely applied. Even in Glasgow there was reluctance to accept this new-fangled ultrasound technique. When that reluctance subsided there was more reaction not against ultrasound *per se*, but just reaction towards the new. For example, even Ian Donald dismissed Doppler as not being of any real value. And real-time was seen as a step backwards; perhaps this is understandable because the first real-time scanners exhibited serious shortcomings; limited field of view, poor resolution, poor beam shape and gaps in the image [28]. Also, these scanners had been developed specifically to examine the heart and there was only a gradual realization that they could be of value on many parts of the body. Of course it is now clear that it had great advantages; they were easier to use and demonstrations were far easier hence sales improved (see Fig. 1.1), encouraging further development. The market enlarged, sales increased even more and the real price of machines fell dramatically in spite of greatly increased electronic complexity. Real-time had given an enormous impetus to ultrasound [29].

As can be seen from the brief chronology at the end of this chapter the development of Doppler ran almost in parallel with the development of 2D imaging. Doppler ultrasound had been in industrial use, then in 1957 Satomura [30] demonstrated its use to record heart valve motion. Four years later Kaneko *et al.* [31] were able to show that blood flow could be detected. From these observations tremendous development followed resulting in the simple but useful fetal heart detector to instruments for measuring blood velocity, the development of real-time spectral analysis and the combining of B scan and Doppler in duplex systems. Then an almost unnoticed paper by Namekawa *et al.* [32] working at Aloka laid the foundations for colour Doppler, rapid development and improvement followed leading to 2D images overlaid with colour to indicate blood or tissue velocity. More recently we have seen the development of power Doppler to give a display indicating tissue perfusion.

Three-dimensional ultrasound is now advancing rapidly; this too has a long and complex history. Its earliest manifestations were seen in the work of Howry and more significantly Brown who designed a 3D capability, albeit unused, into the autoscanner used by Ian Donald (T.G. Brown, 1988, personal communication). The problems of displaying 3D images inhibited its use. However, in 1972 at Sonicaid Ltd Brown designed the Multiplanar scanner (Fig. 1.18) the first commercial 3D machine [33]. This did not become a commercial success; one factor was the lack of a clinical problem requiring its capability. Now technology has advanced and some of the limitations forced upon Brown have disappeared. Additionally, clinical practice now has greater demands and expectations so that there is a growing desire to view in 3D. Among the indicators that its time has come was the first congress, in 1997, on 3D in obstetrics and gynaecology [34].

Fig. 1.10 The Kelvin Hughes automatic contact scanner designed by Tom Brown and used by Professor Ian Donald (left) and Dr John MacVicar to produce thousands of scans from 1959 to *c.* 1967. The electronic units on the trolley were previously used with the manually operated scanner (Fig. 1.6).

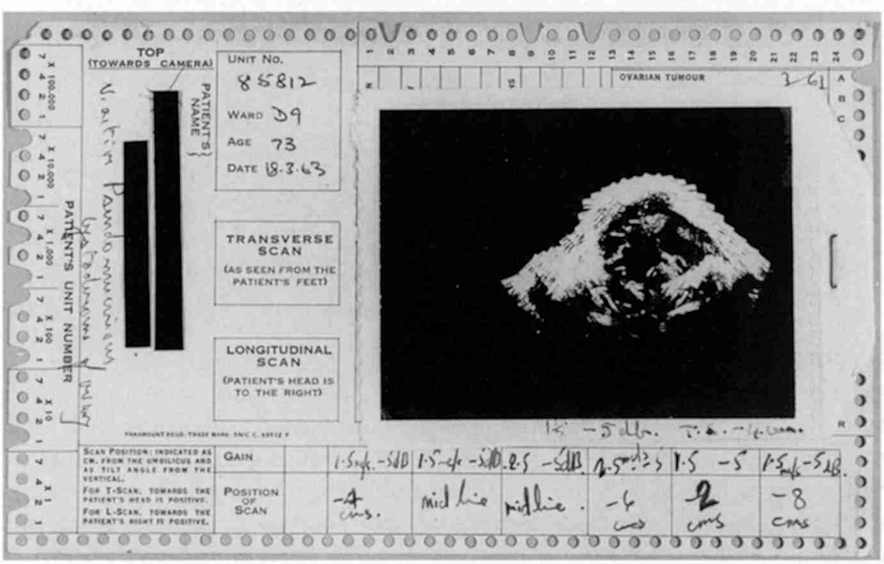

Fig. 1.11 Image and record card (partly annotated by JEEF) from autoscanner, March 1963. This transverse scan was interpreted as showing a 'cystadenocarcinoma of ovary' and found to be 'very active multilocular pseudomucinous carcinoma with almost solid portions, microscopically malignant'.

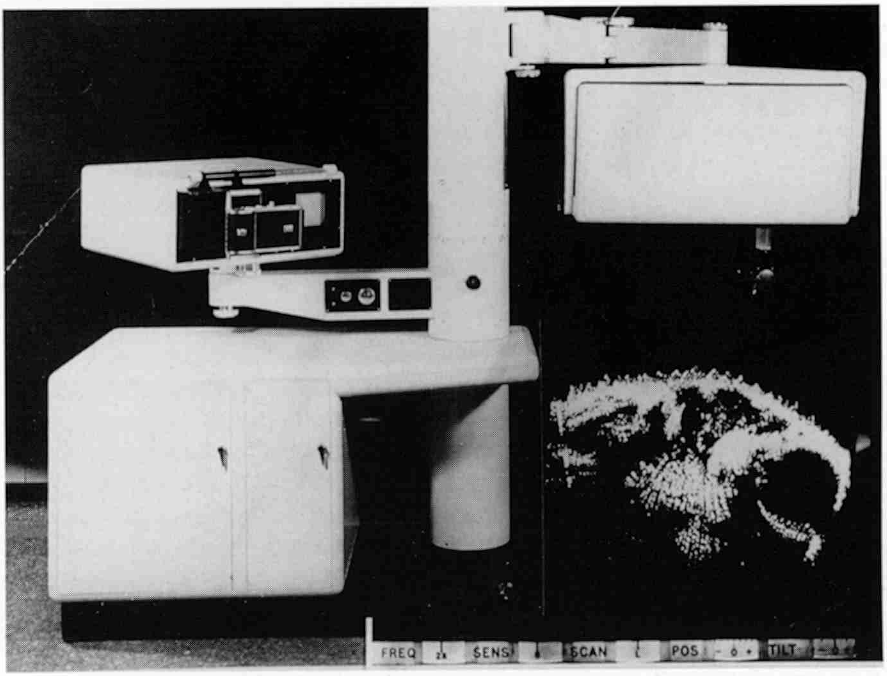

Fig. 1.12 The machine delivered to Dr Bertil Sunden, Lund, Sweden, in 1962. The images seen on the insert, have a characteristically 'spotty' appearance due to the very low pulse repetition rate of $25\,s^{-1}$. This low rate was used to ensure a low acoustic output and thus minimize exposure of the patient and required the operator to scan slowly and therefore more evenly across the patient. (Courtesy of the BMUS Historical Collection.)

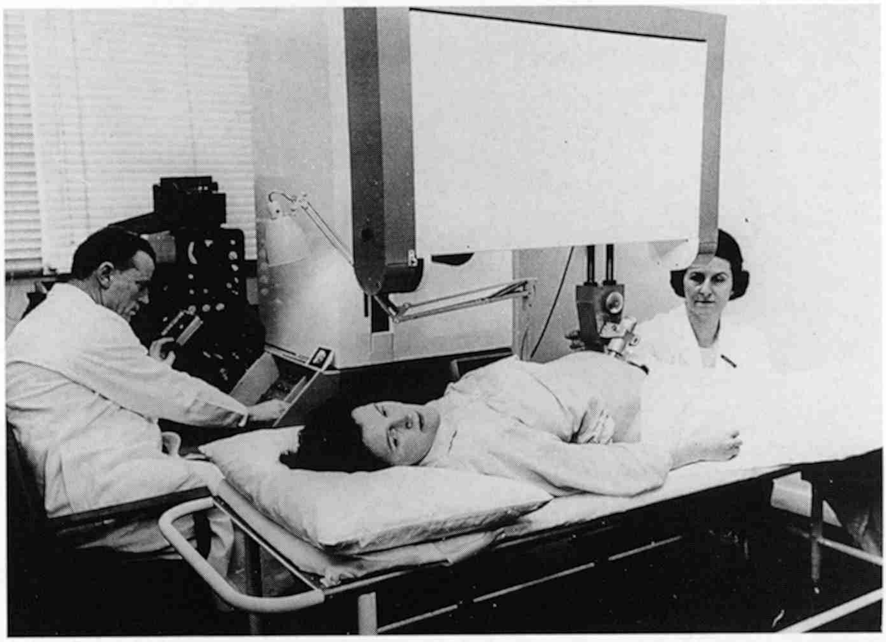

Fig. 1.13 Professor Ian Donald and Mrs Ida Miller posing with the KH diasonograph in the then recently opened Queen Mother's Hospital, Glasgow *c.* 1964. The scanning frame was supported by a substantial and very stable gantry to allow scans in virtually any plane. The electronics used thermionic valves in circuits derived from the Mk7 industrial flaw detector. At this time the Mk7 seen in the background was still used with an electronic caliper unit for fetal cephalometry.

Ultrasound is now so widely used that some radiologists claim it provides 40% of all medical imaging. Its use has spread to almost every medical speciality. This chapter has attempted to give some insight into the complex nature of the factors which allowed medical ultrasound to develop and grow. Perhaps if nothing more it will foster sympathy for today's new ideas—they may have a potential just as great as ultrasound had 50 years ago. An even broader view is possible as portrayed by Ellen Koch [35] when addressing the audience of ultrasound pioneers at the HMUS 'You should consider yourselves as pioneers in a much broader context than the

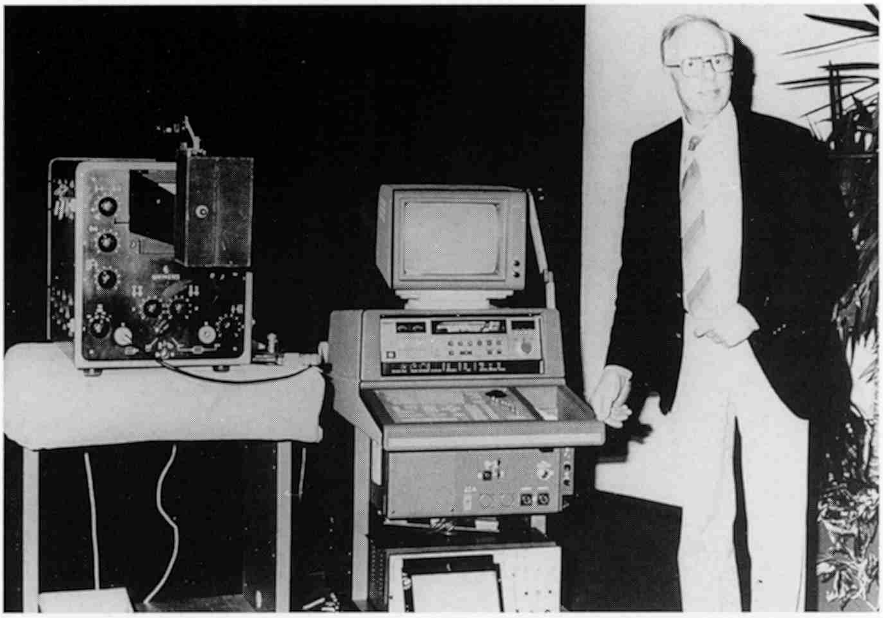

Fig. 1.14 The late Professor Hertz pictured here with, on the left, the Siemens Ultraschall-Impulsgerat which he modified for cardiology. Inge Edler and Hellmuth Hertz used this apparatus to produce the first echocardiograms in 1953. This picture taken in 1982 also shows in the centre a Siemens Sonoline CD echocardiography scanner.

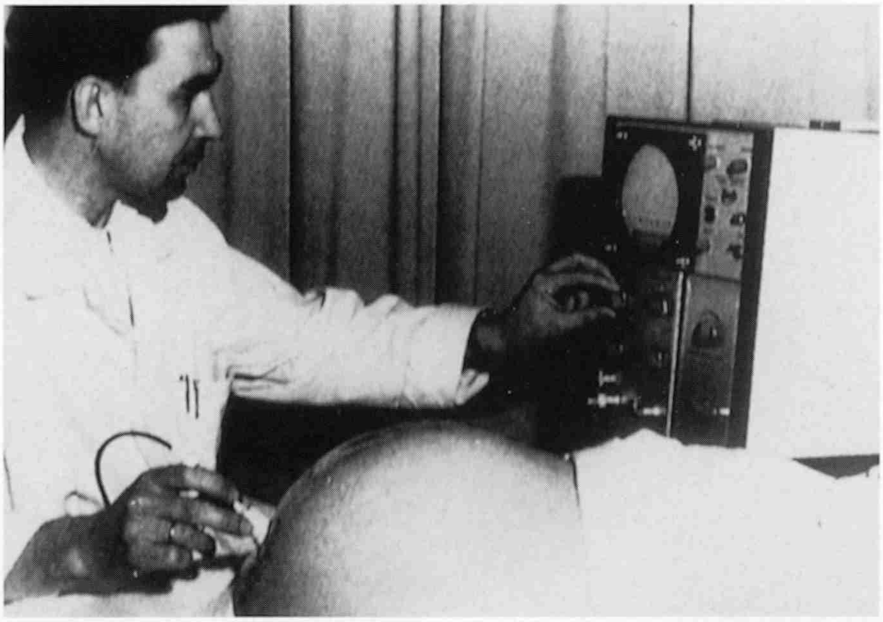

Fig. 1.15 Dr Alfred Kratochwil using a Kretz A-scan instrument in 1965.

research and practice of ultrasonography. As you work together in the next two days framing the history of ultrasound you are in a unique position to put aside the questions of priority or the nitty-gritty detail of technical developments and consider instead how the emerging interest in ultrasonics continued or diverged from existing research traditions in each country. How non-scientific factors played a role in shaping scientific and medical practice, and how the interactions of individual researchers and practitioners served to carve out a fruitful new style of clinical research incorporating the skills of the physicist, the engineer and physician alike'.

Acknowledgements

We would like to acknowledge the support of the Wellcome Trust, the British Medical Ultrasound Society and the Department of Obstetrics and Gynaecology, University of Glasgow.

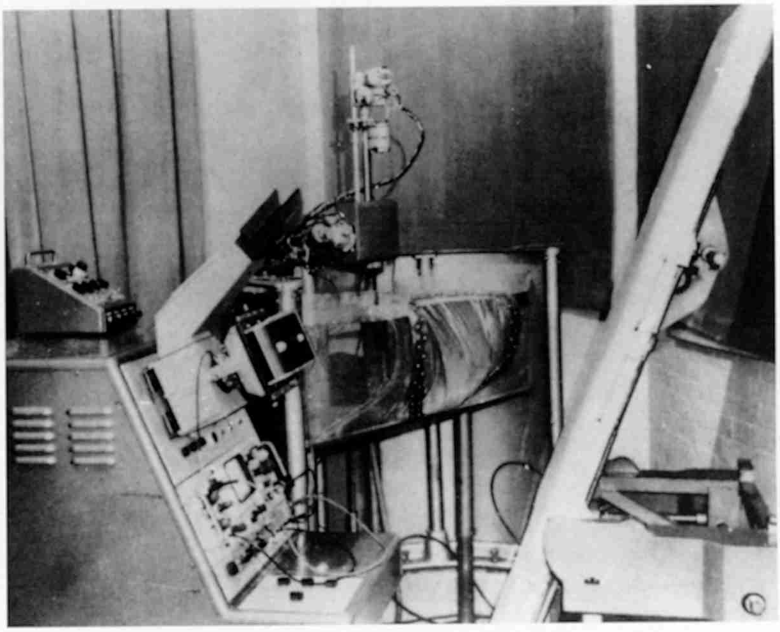

Fig. 1.16 The CAL Echoscope designed by Dr George Kossof [41]. The transducer in the water-filled coupling tank (centre of picture) scanned the patient who was positioned with the abdomen against the membrane while supported by the tilting stretcher on the right.

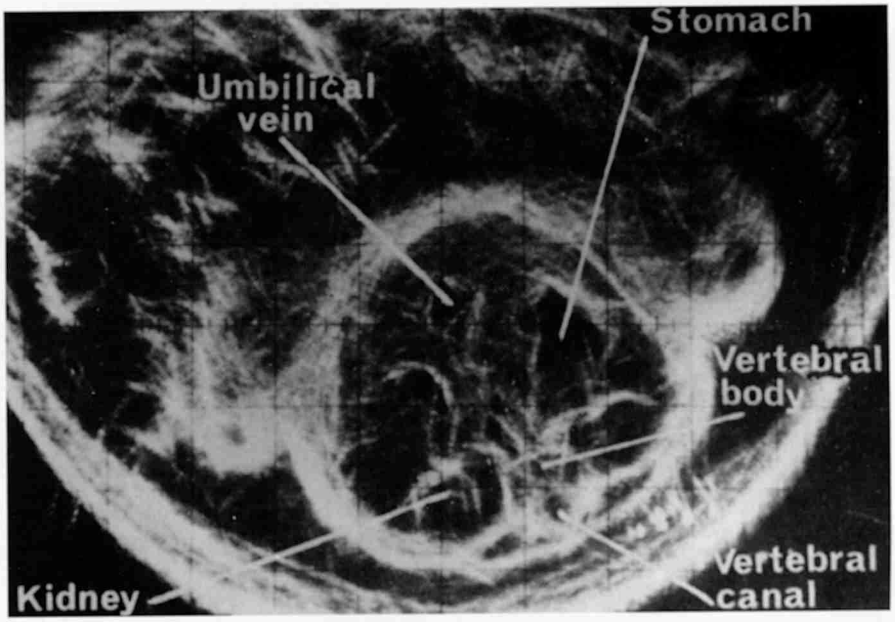

Fig. 1.17 An image from Kossoff and Garrett [42]; transverse scan showing fetal abdomen, vertebral column, kidneys, stomach and umbilical vein. This image is later than the Echoscope in Fig. 1.16 but displays the excellent grey scale and resolution seen in their earliest images.

Appendix 1: Diagnostic ultrasound—historical landmarks

This very brief, rather selective, set of 'landmarks' acknowledges only a few of the multitude of people who over the last hundred or more years have contributed to the development of diagnostic ultrasound.

1842 J.C. Doppler (Austria), paper on the Doppler effect.

1880 J. and P. Curie (France), discovered piezoelectric effect.

1917 P. Langevin (France), built first piezoelectric transducers, found lethal effects on fish.

1929–49 S. Sokolov (USSR), suggested use of ultrasound for imaging flaws in material, subsequent research led to at least two patents.

1937–50 K.T. Dussik (Austria), efforts to use through-transmission in neurology.

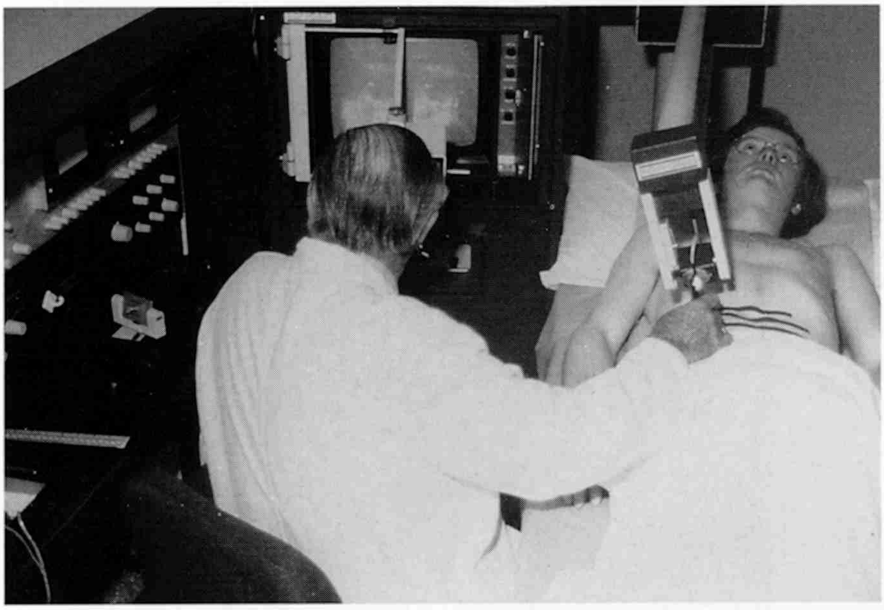

Fig. 1.18 Sonicaid 5000 Series multiplanar scanning system seen here in use by Dr G.B. Young, Edinburgh. The transducer is free to move in three dimensions. The image could be a conventional B-scan, by restraining the transducer to movement in one plane, or a series of parallel transverse scans could be viewed from an oblique viewpoint, these appeared one behind the other as in a perspective drawing. Longitudinal scans would appear to cut through the transverse scans. A realistic 'solid' 3D image could be presented by viewing a stereo pair of images [33].

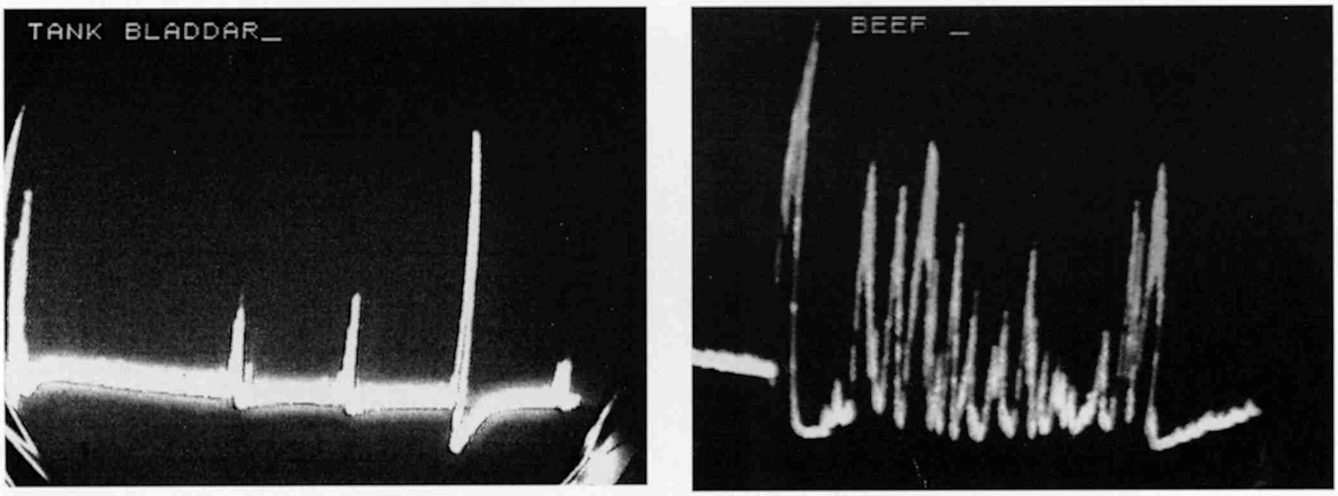

Fig. 1.19 A-scan traces made during the re-enactment of Professor Ian Donald's earliest ultrasound experiments (see footnote on p. 5). (a) Echoes from a water-filled animal bladder; (b) a sample of muscle tissue.

1943 D.O. Sproule (Henry Hughes, UK), first demonstration of supersonic apparatus.

1945 F.A. Firestone (Sperry Inc., USA), supersonic reflectorscope (A-scan).

1946 C.H. Desch, D.O. Sproule, W.J. Dawson (UK), 'The detection of cracks in steel by means of ultrasound waves'.

1948 D. Howry (USA), started experimental work.

1949 G.D. Ludwig, F.W. Struthers (USA), detection of gallstones and foreign bodies.
J. Wild (USA), started experimental work.
J.R. Uchida (Japan), built an A-scan instrument.

1950 J.J. Wild, D. Neal (USA), first paper detecting changes of texture in living tissue.
L.A. French, J.J. Wild, D. Neal (USA), detection of cerebral tumours.

1953 I. Edler, H. Hertz (Sweden), first recording of an echocardiogram.

1954 K. Tanaka (Japan), started using contact scanning for neurology.
Ian Donald (UK), started experimental work.
I. Edler, H. Hertz (Sweden), first paper on echocardiology.
J.J. Wild, J.M. Reid (USA), visualization of breast lesions.

D. Howry, J. Holmes *et al.* (USA), papers on visualization of soft tissues.
H.P. Kalmus *et al.*, papers on acoustic flow meter systems.

1956 T.G. Brown joined ID (UK) and improved A-scan.
Denver group (USA), paper on 3D and stereo methods.
S. Satomura (Japan), studying heart with Doppler.
G. Baum/J.G. Henry *et al.* (USA), papers on ophthalmic ultrasound.
T. Cieszynski (Czechoslovakia), first intraluminal transducer.

1957 T.G. Brown (UK), built contact scanner for Ian Donald.
E.J. Baldes *et al.* (USA), 'Forum on ultrasonic measurement of blood velocity'.

1958 I. Donald, J. MacVicar, T. Brown (UK), first paper on diagnostic ultrasound from Glasgow.

1959 T.G. Brown (UK), started work on automatic contact scanner.
D.L. Franklin, D.W. Baker *et al.* (USA), pulsed Doppler flow meter.

1962 B. Sunden (Sweden), started using the first B scanner sold by Kelvin Hughes.
K. Kato showed that RBC were source of Doppler shift signals.

1963 Kelvin Hughes (later Smiths) (UK), first Diasonograph manual contact scanners sold.
Denver (USA), contact scanner in use.

1964 Denver (USA), group's first publication on obstetric use of contact scanner.
Physionic Inc. (USA), Porta-Arm scanner delivered to Denver group.

1965 W. Buschmann (GDR), showed 10 element array for the eye.
First International Congress, Pittsburgh, 33 papers from nine countries.
SKI Doptone (USA), fetal heart detector on market.

1966 K. Kato (Japan), described directional Doppler.
Postgraduate course on diagnostic ultrasound started in Denver (USA).

1967 W. Krause, R. Soldner (FRG), Siemens 'Vidoson' real-time scanner.
Cardiac scanning by Y. Kikuchi and K. Tanaka (Japan).

1968 J.C. Somer (Netherlands), electronic phased array sector scanner.
D.A. Lobdell (USA), annular array.

1969 P. Peronneau (France), flow profiles with multigate Doppler.
Kretztechnik AG (Austria), built vaginal transducer for A. Kratochwil

1970 Courses on diagnostic ultrasound started in Glasgow (UK).

1971 N. Bom (Netherlands), linear array 'for moving cardiac structures'.

1972 First commercial linear array scanner from ADR Inc. (USA).

1973 D.L. King (USA), first paper on use of linear array; referred only to cardiac use.

1974 F.E. Barber, D.W. Baker *et al.* (USA), duplex echo Doppler scanner.
B.A. Coglan *et al.* (UK), time compression spectrum analyser.

1977 T.G. Brown (Sonicaid, UK), multiplanar 3D scanner in production.

1982 K. Namekawa, C. Kasai *et al.* (Aloka, Japan), described colour Doppler at WFUMB-82.
Acuson (USA), delivered first 'computed sonography' system.

1983–96 The performance of ultrasound systems improved rapidly, Colour Doppler imaging, both giving velocity and 'power' displays has became commonplace and 3D arrived on the scene. It has been estimated that ultrasound now accounts for 40% of all medical imaging.

1997 First World Congress on 3D Ultrasound in Obstetrics and Gynaecology, Mainz, Austria.

Appendix 2: Ultrasound collections

American Institute of Ultrasound in Medicine

American Institute of Ultrasound In Medicine (AIUM), 14750 Sweitzer Lane, Laurel MD 20707-5906, USA. The large collection and archive is the result of the work of Professor Barry Goldberg who organized a symposium on the history of medical ultrasound in Washington in 1988; included are five large filing cabinets (a total of 25 drawers) of papers, audio- and videotapes, images and photographs, and a considerable number of pieces of hardware including Howry's early scanners.

German Society of Ultrasound in Medicine

In 1995 an ultrasound museum was established in Dresden by the German Society of Ultrasound in Medicine (DEGUM). The collection is housed in the Hygiene Museum, Dresden which underwent reconstruction during 1997. It is intended that the principal focus, will be on the development of ultrasound in the German-speaking countries of central Europe [36,37] (H. Lutz, 1997, personal communication).

British Medical Ultrasound Society

The British Medical Ultrasound Society (BMUS) Historical Collection was established in 1984. Currently it contains over 60 items of hardware, scanners and associated equipment, a wide range of manufacturer's literature and a substantial and increasing archive of unique documents. Many items of hardware are on display in the Department of Obstetrics and Gynaecology, University of Glasgow, Queen Mother's Hospital, Yorkhill, Glasgow G3 8SJ, UK. The archive material is also available for viewing and study. In the long term the collection will pass into the care of the Hunterian Museum, University of Glasgow. Glasgow G12 8QQ, UK.

Science Museum, London

A Kelvin Hughes Mk2 flaw detector (see Fig. 1.4) of the type used by Ian Donald in his early experiments is in the Science Museum, London. There are also a few other ultrasound items in store including the Smiths Diasonograph used by Professor Stuart Campbell when working at Queen Charlotte's Hospital.

Other collections

As industrial non-destructive test equipment supplied much of the equipment used by the early experimenters it is of interest that the British Institute of Non-Destructive Testing is establishing a collection. Also a few items of medical ultrasound equipment are in store at the Royal Scottish Museum, Edinburgh, UK.

Note added in proof

Since writing this chapter a further article in a series on the history of medical ultrasound has been published in *Ultrasound in Medicine and Biology* [43].

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