Looking at the unborn

Christie, DA; Tansey, EM

Wellcome Witnesses
to Twentieth Century Medicine

LOOKING AT THE UNBORN:

HISTORICAL ASPECTS OF OBSTETRIC ULTRASOUND

Volume 5 – January 2000

A Witness Seminar held at the
Wellcome Institute for the History of Medicine,
London, on 10 March 1998

**Witness Seminar Transcript edited
by E M Tansey and D A Christie**

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Key

Front cover photographs, L to R from the top:

Dr Tony Whittingham
Mr Usama Abdulla, Mr Thomas Brown, Mr Demetrios Economides
Professor Charles Whitfield, Dr Margaret McNay
Dr James Willocks, Mrs Lois Reynolds
Dr Marcolm Nicolson, Professor Norman McDicken
Mr John Fleming, Dr Angus Hall (chair)
Mr Thomas Brown, Dr Tony Whittingham
Mr Usama Abdulla, Professor Peter Wells

Back cover photographs, L to R from the top:

Mr Thomas Brown
Audience
Dr Malcolm Nicolson, Dr Angus Hall (chair)
:Professor Norman McDicken, Mrs Alix Donald
Dr Norman Slark
Professor John MacVicar
Dr Angus Hall (chair)

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INTRODUCTION

During the twentieth century the human body has become increasingly transparent. Since the announcement of X-rays in 1896, ever more sophisticated techniques have been developed to allow non-invasive examinations of the human body, including NMR, PET and CAT scanning.[1] It is now possible, with the benefit of ultrasound imaging, to see a body within a body, that is a developing fetus within its mother's womb. The ability to image the fetus and its associated structures has revolutionized the clinical management of pregnancy. The obstetric ultrasound scanner had its major origins in a programme of research undertaken in Glasgow in the 1950s and 1960s, under the leadership of the obstetrician, Professor Ian Donald. Donald's work was characterized by a remarkable series of collaborations between engineers and clinicians, many of whom have come together to take part in this Witness Seminar to consider the early history of ultrasound imaging, its technical development and clinical applications.

Roughly divided into two halves, the first session of the meeting discussed the early technical and engineering developments of the scanner. An important figure was William Slater of the Kelvin engineering firm (it went through several name changes and mergers during the period examined here) who believed in the medical and commercial possibilities of the new ultrasound technology, and who provided financial support for research and development work, often in opposition to his Board colleagues. It was the encouragement of Slater that allowed the young engineer Tom Brown the time and a modest budget to collaborate with Ian Donald in the development of a two-dimensional, direct contact scanner, first built in 1956. Brown also met Dugald Cameron, then a young art student interested in industrial design, whose early sketches of an improved ergonomic machine, made on the largest piece of tracing paper he could afford, were the source of his first paid commission. We are grateful to Professor Cameron for his permission to reproduce some of those early drawings here.

Convincing sceptical doctors that this new approach was useful was a story that emerged during the second part of the meeting. Many of the clinicians at the meeting recall the pre-eminence at the time of 'clinical judgement' and resistance of doctors who had spent years in 'training their hands to see', to a machine that they considered redundant. It was the practical demonstrations of the capabilities of the early scanners, the publications that arose from their use, and the increasing streamlining of the machines and their control consoles, that made them what one witness refers to as 'doctor-proof' as possible, that gradually convinced the majority of obstetricians to invest time and training in this new technology.

These are just a few of the memories and issues that are discussed here by our witnesses, to whom we are grateful for the time they gave us not only in planning and holding this meeting, but also during the lengthy editorial process, which is described below.

[1] Nuclear magnetic resonance and imaging were the subjects of a previous Witness Seminar, published as Tansey E M, Christie D A. (eds) (1998) Making the Human Body Transparent: The impact of nuclear magnetic resonance and magnetic resonance imaging. In *Wellcome Witnesses to Twentieth Century Medicine,* vol 2. London: The Wellcome Trust, 1–74.

WITNESS SEMINARS: MEETINGS AND PUBLICATIONS[2]

In 1990 the Wellcome Trust created the History of Twentieth Century Medicine Group to bring together clinicians, scientists, historians and others interested in contemporary medical history. Amongst a number of other initiatives, the format of Witness Seminars – used by the Institute of Contemporary British History to address issues of recent political history – was adopted, to promote interaction between these different groups, to emphasize the potentials of working jointly, and to encourage the creation and deposit of archival sources for present and future use.

The Witness Seminar is a particularly specialized form of oral history where several people associated with a particular set of circumstances or events are invited to meet together to discuss, debate, and agree or disagree about their memories. To date, the History of Twentieth Century Medicine Group has held over 20 such meetings, most of which have been published, as listed in the Table below.

Subjects for such meetings are usually proposed by, or through, members of the Steering Committee of the Group, and once an appropriate topic has been agreed, suitable participants are identified and invited. These inevitably lead to further contacts, and more suggestions of people to invite. As the organization of the meeting progresses, a flexible outline plan for the meeting is devised, usually with assistance from the meeting's chairman, and some participants are invited to 'set the ball rolling' on particular themes, by speaking for a short period of time to initiate and stimulate further discussion.

Each meeting is fully recorded, the tapes are transcribed and the unedited transcript is immediately sent to every participant. Each is asked to check their own contributions and to provide brief biographical details. The editors turn the transcript into readable text, and participants' minor corrections and comments are incorporated into that text, while biographical and bibliographical details are added as footnotes, as are more substantial comments and additional material provided by participants. The final scripts are then sent to every contributor, accompanied by copyright assignment forms. As with all our meetings, we hope that even if the precise details of some of the technical sections are not clear to the non-specialist, the sense and significance of the events are understandable. Our aim is for the volumes that emerge from these meetings to inform those with a general interest in the history of modern medicine and medical science, to provide for historians new insights, fresh material for study, and prompt fresh themes for research, and to emphasize to the participants that events of the recent past, of their own working lives, are of proper and necessary concern to historians.

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[2] Much of the following text is also published in the 'Introduction' to vol. 6 of *Wellcome Witnesses to Twentieth Century Medicine*. London: The Wellcome Trust, 2000.

ACKNOWLEDGEMENTS

'Obstetric Ultrasound' was suggested as a suitable topic for a Witness Seminar by Dr Malcolm Nicolson of the Wellcome Unit for the History of Medicine, University of Glasgow, and his colleague Mr John Fleming. They are currently engaged on a major historical study of medical ultrasound, and provided the names of many of the individuals to be invited, as well as assisting us in planning the meeting and deciding the topics to be discussed. They both contributed throughout the meeting and we are grateful to them for their input. We are equally grateful to Dr Angus Hall who also helped in planning the meeting itself, and for his excellent chairing of the occasion. Given the very visual nature of the subject, many of the participants brought slides that they showed during the meeting. It has not been possible to reproduce all of this material, but we do thank all those participants who have allowed us to reproduce some of their illustrations, and also Mr Tom Brown for providing a detailed key to Figure 7. Tom Brown and John Fleming have also assisted us at every stage of the editorial process, and been patient and generous in answering our questions.

As with all our meetings, we depend a great deal on our colleagues at the Wellcome Trust to ensure their smooth running: the Audiovisual Department, the Medical Photographic Library, and the Publishing Department, especially Julie Wood who has supervised the design and production of this volume. Mrs Jaqui Carter is our transcriber, and Mrs Wendy Kutner and Mrs Lois Reynolds assist us in running the meetings. Finally we thank the Wellcome Trust for supporting this programme.

Tilli Tansey
Wellcome Institute for the History of Medicine

1993 **Monoclonal antibodies**[3]
Organizers: Dr E M Tansey and Dr Peter Catterall

1994 **The early history of renal transplantation**
Organizer: Dr Stephen Lock

Pneumoconiosis of coal workers[4]
Organizer: Dr E M Tansey

1995 **Self and non-self: a history of autoimmunity**[3]
Organizers: Sir Christopher Booth and Dr E M Tansey

Ashes to ashes: the history of smoking and health[5]
Organizers: Dr Stephen Lock and Dr E M Tansey

Oral contraceptives
Organizers: Dr Lara Marks and Dr E M Tansey

Endogenous opiates[3]
Organizer: Dr E M Tansey

1996 **Committee on Safety of Drugs**[3]
Organizers: Dr Stephen Lock and Dr E M Tansey

Making the body more transparent: the impact of nuclear magnetic resonance and magnetic resonance imaging[6]
Organizer: Sir Christopher Booth

1997 **Research in General Practice**[6]
Organizers: Dr Ian Tait and Dr E M Tansey

Drugs in psychiatric practice[6]
Organizers: Dr E M Tansey and Dr David Healy

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[3] Published in Tansey E M, Catterall P P, Christie D A, Willhoft S V, Reynolds L A. (eds) (1997) *Wellcome Witnesses to Twentieth Century Medicine,* vol. 1. London: The Wellcome Trust, 135pp.

[4] P D'Arcy Hart, edited and annotated by E M Tansey. (1998) Chronic pulmonary disease in South Wales coalmines: An eye-witness account of the MRC surveys (1937–1942). *Social History of Medicine* 11: 459–468.

[5] Lock S P, Reynolds L A, Tansey E M. (eds) (1998) *Ashes to Ashes: The history of smoking and health*. London: The Wellcome Trust, 228pp.

[6] Published in Tansey E M, Christie D A, Reynolds L A. (eds) (1998) *Wellcome Witnesses to Twentieth Century Medicine*, vol. 2. London: The Wellcome Trust, 282 pp.

The MRC Common Cold Unit[6]
Organizers: Dr David Tyrrell and Dr E M Tansey

The first heart transplant in the UK[7]
Organizer: Professor Tom Treasure

1998 **Haemophilia: recent history of clinical management**[8]
Organizers: Dr E M Tansey and Professor Christine Lee

Obstetric ultrasound: historical perspectives[9]
Organizers: Dr Malcolm Nicolson, Mr John Fleming and Dr E M Tansey

Post penicillin antibiotics[10]
Organizers: Dr Robert Bud and Dr E M Tansey

Clinical research in Britain, 1950–1980
Organizers: Dr David Gordon and Dr E M Tansey

1999 **Intestinal absorption**
Organizers: Sir Christopher Booth and Dr E M Tansey

The MRC Epidemiology Unit (South Wales)
Organizers: Dr Andy Ness and Dr E M Tansey

Neonatal intensive care
Organizers: Professor Osmund Reynolds, Dr David Gordon and Dr E M Tansey

British contribution to medicine in Africa after the Second World War
Organizers: Dr Mary Dobson, Dr Maureen Malowany, Dr Gordon Cook and Dr E M Tansey

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[7] Tansey E M, Reynolds L A. (eds) (1999) Early heart transplant surgery in the UK. *Wellcome Witnesses to Twentieth Century Medicine*, vol. 3. London: The Wellcome Trust, 72pp.

[8] Tansey E M, Christie D A. (eds) (1999) Haemophilia: Recent history of clinical management. *Wellcome Witnesses to Twentieth Century Medicine*, vol. 4. London: The Wellcome Trust, 90pp.

[9] Tansey E M, Christie D A. (eds) (2000) Looking at the unborn: Historical aspects of obstetric ultrasound. *Wellcome Witnesses to Twentieth Century Medicine*, this volume, 80pp.

[10] Tansey E M, Reynolds, L A. (eds) (2000) Post penicillin antibiotics: From acceptance to resistance? *Wellcome Witnesses to Twentieth Century Medicine*, vol. 6. London: The Wellcome Trust, 72pp.

LOOKING AT THE UNBORN:

HISTORICAL ASPECTS OF OBSTETRIC ULTRASOUND

The transcript of a Witness Seminar held at the Wellcome Institute for the History of Medicine, London, on 10 March 1998

Edited by D A Christie and E M Tansey

PARTICIPANTS

Mr Usama Abdulla
Dr Wallace Barr
Mr Thomas Brown
Professor Dugald Cameron
Professor Stuart Campbell
Mrs Alix Donald
Mr Demetrios Economides
Mr John Fleming
Mr Hans Gassert
Dr Angus Hall (Chair)
Professor John MacVicar
Professor Norman McDicken
Dr Margaret McNay
Dr Malcolm Nicolson
Professor Jean Robinson
Dr Norman Slark
Dr Ian Spencer
Dr Tilli Tansey
Professor Peter Wells
Professor Charles Whitfield
Dr Tony Whittingham
Dr James Willocks

Others present at the meeting included:
Sir Christopher Booth, Dr Robert Chivers, Dr Rosalinda Snijders, Dr Saffron Whitehead

Apologies:
Professor M G Elder, Mr Gordon Higson, Dr Patricia Morley

Dr Tilli Tansey:[1] The subject of today's meeting, medical ultrasound, has arisen from a project that Dr Malcolm Nicolson is spearheading in the Wellcome Unit at the University of Glasgow, aided and abetted by Mr John Fleming. Malcolm, John and I have organized this meeting, Malcolm and John having done most of the hard work. A lot of that hard work is finding a suitable chairman and we are delighted that Angus Hall has agreed to do this. Angus started his engineering career at Kelvin & Hughes[2] in Glasgow and spent many years working in the Department of Midwifery at The Queen Mother's Hospital in Glasgow. He told me at lunchtime, he then decided that he would like to take life more easily. I don't know whether he was successful in that, but he moved to become Head of the Department of Medical Physics at St James's University Hospital in Leeds. He is a former Secretary and President of the British Medical Ultrasound Society[3] so we are very grateful that we have his expertise and historical knowledge to call on today in his role as Chairman of this meeting.

Dr Angus Hall:[4] Thank you very much. I would like to welcome you all to this meeting, in particular, Mrs Donald.[5] The reason we are here today is to debate the

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[1] Dr Tilli Tansey is Convenor of the History of Twentieth Century Medicine Group and Historian of Modern Medical Science at the Wellcome Institute for the History of Medicine.

[2] The rapidity of the development of medical ultrasound in Glasgow was due in substantial part to the active support of the Glasgow branch of Kelvin & Hughes Ltd, and its resident director, Mr W T Slater (see biographical note 38). Over the decade that it was involved, the trading name of the Glasgow operation (which was by then owned by S Smith & Sons England Ltd) changed with minor variations – first to Smiths Industrial Division, and then for a year or so before its closure in 1966 to The Kelvin Electronic Company. The Glasgow branch of the company had strong associations with one of the giants of nineteenth century science, William Thomson, later Lord Kelvin (1824–1907), who formulated the first and second laws of thermodynamics, and gave his name to the Absolute Scale of Temperature. While Professor of Natural Philosophy at Glasgow University (1846–1899), Kelvin took an interest in a business originally formed by his instrument maker, James White, renaming it Kelvin & James White Ltd. This then became Kelvin Bottomley & Baird Ltd in 1913 and became world famous for the manufacture of ships' compasses and other marine navigational equipment. After amalgamation with Henry Hughes and Sons of Barkingside in the late 1940s, the company's name changed again to Kelvin & Hughes Ltd. It was this traditional but highly innovative business which supported the ultrasound work during the critical formative years. Information provided by Mr Tom Brown, 24 May 1999.

[3] The British Medical Ultrasound Society (BMUS) was formed in 1977 out of the British Medical Ultrasound Group, which was an informal discussion group set up around 1969 as a joint initiative by those working in the field either as users or developers, the (then) Hospital Physicists Association, and The British Institute of Radiology. That Group, in turn, had its origins in a series of annual meetings organized by the journal *Ultrasonics*. These meetings covered various ultrasound topics, including the emergent medical interest, and a number of semi-private medically oriented meetings arranged by Dr Douglas Gordon (see also note 30 below). Information provided by Mr Tom Brown and Mr John Fleming, 24 May 1999.

[4] Dr Angus J Hall CEng FIEE FIPEM (b. 1939) initially trained as a Merchant Navy Radio Officer but after a short time at sea joined Kelvin & Hughes Ltd (see note 2 above) in 1957 as a trainee instrument maker and later worked as an electronics engineer on medical ultrasonic diagnostic equipment. He left the company in 1966 shortly before it closed, and, after a short spell with IBM, joined Professor Donald at the Department of Midwifery, University of Glasgow to carry out research and development in ultrasound. He was Secretary, for a number of years, and subsequently President (1981/82) of the British Medical Ultrasound Society (see note 3) which he, with others, was instrumental in setting up in the 1970s. Since 1982 he has been Head of Medical Physics at St James's University Hospital, Leeds, until his early retirement in February 1999.

[5] Mrs Alix Donald (b. 1918) married Ian Donald in London in 1937.

achievements, the failings, and the consequences and the impact of the work undertaken over the years. Today we are going to seek to answer two questions. What was it like at the time? And why did things happen the way they did? There are, I think, two strands to today's meeting and I have tried to compartmentalize it.

For the first half of the meeting, we will talk about the science and technology, starting with the events that led up to the introduction of contact B-scanning and the governmental and other implications that went with that; then after a break for tea, we will talk about clinical matters. So could I now call on Malcolm Nicolson to give a very quick refresher for some of us whose memories may be fading slightly. Malcolm is the senior research fellow at the Wellcome Unit in Glasgow and, as has already been said, has been working with John Fleming and others on the historical development of ultrasound.[6]

Dr Malcolm Nicolson:[7] I thought it would be appropriate to commence proceedings with a portrait of Ian Donald,[8] Regius Professor of Midwifery at Glasgow from 1954 to 1976 (Figure 1). I think it's fair to say that, without Donald's leadership and energy, medical ultrasound would not have developed as early or as quickly as it did. It's also very likely that without Donald's influence, medical ultrasound would not have taken on the vital clinically directed orientation that so strongly characterized the pioneering work in Glasgow. It was not immodest of Donald to say, as he did in 1969, that he had launched a new diagnostic science[9] with the emphasis very much on the word 'diagnostic'. So we are indeed honoured, as Angus has said, to have Mrs Alix Donald with us here today.

As most of you will know, the first ultrasound machine used by Donald was an industrial flaw detector (Figure 2), as employed in the non-destructive testing of metals.[10] A similar machine was in use in this industrial setting at Babcock and Wilcox[11] at Renfrew (Figure 3), where Donald did his very earliest investigations on biological materials. Here's the sort of image that these early machines produced. This is what is called an A-scan. We can see the large non-reflective space between two

[6] See, for example, Fleming J E E, Spencer I H, Nicolson M A. (1997) Forty years of ultrasound. In Cockburn F. (ed.), *Advances in Perinatal Medicine*, Proceedings of the XVth European Congress of Perinatal Medicine, Glasgow, September 1996. New York, London: The Parthenon Publishing Group, 92–99.

[7] Dr Malcolm Nicolson (b. 1952) is Senior Lecturer at the Wellcome Unit for the History of Medicine, University of Glasgow. He is working with John Fleming (see biographical note 20 below) and Ian Spencer (see biographical note 209 below) on a study, funded by the Wellcome Trust, on the development of ultrasound in Glasgow.

[8] Professor Ian Donald CBE FRCOG FRCP (1910–1987) trained in obstetrics and gynaecology in London. He was appointed Reader at St Thomas' Hospital, London, and then at the Hammersmith Hospital, London, where his main research interest was respiratory problems of the newborn. In 1954 he was appointed to the Regius Chair of Midwifery at the University of Glasgow. His initial work on ultrasound was at the Royal Maternity Hospital and the Western Infirmary in Glasgow; he moved to the new Queen Mother's Hospital at Yorkhill in 1964. He received many honours, including the Blair gold medal, the Eardley Holland gold medal, the Victor Bonney prize and the Maternity prize of the European Association of Perinatal Medicine.

[9] Donald I. (1969) On launching a new diagnostic science. *American Journal of Obstetrics and Gynecology* 103: 609–628.

[10] op. cit. note 33 below.

[11] Babcock and Wilcox Ltd of Renfrew manufactured boilers and other large welded pressure vessels for industrial and nuclear purposes, and used ultrasonic instruments extensively for weld-testing. Information provided by Mr Tom Brown and Mr John Fleming, 24 May 1999.

echoes which marks the presence of a large simple ovarian cyst (Figure 4). This image dates from about 1956. Donald began his investigations with A-scan ultrasound in 1955.[12] Ian Donald and his colleagues achieved some very impressive diagnostic coups with this equipment but it is significant, or at least it seems so to me as a historian, that Donald did not publish any account of his clinical investigations with the A-scan. For his first paper on ultrasound we had to wait until 1958 and until after the two-dimensional B-scanner had been invented. Perhaps this is a question that the meeting might consider later in the afternoon: why no A-scan publications?

The first two-dimensional, direct-contact[13] B-scan machine was built by Tom Brown[14] in 1956. Here is the sort of quality of image that the machine was capable of producing by the end of 1957 (Figure 5). Again, it is an image of a large simple ovarian cyst. Today I am speaking from my perspective as a historian, and I think the transition from A-scan to B-scan was by far the most significant single step in the development of the new technology. B-scan incorporated the ultrasonic image into the received framework of normal and pathological structure in a way that A-scan never could. I am not saying, of course, that this incorporation into the received image of anatomical structure was an unproblematic process, but B-scan made possible the production of images that were in principle at least recognizable as parts of human bodies.

We are accordingly very fortunate in having Mr Tom Brown, the architect of contact B-scanning, here with us today. I will embarrass him, of course, by showing a picture

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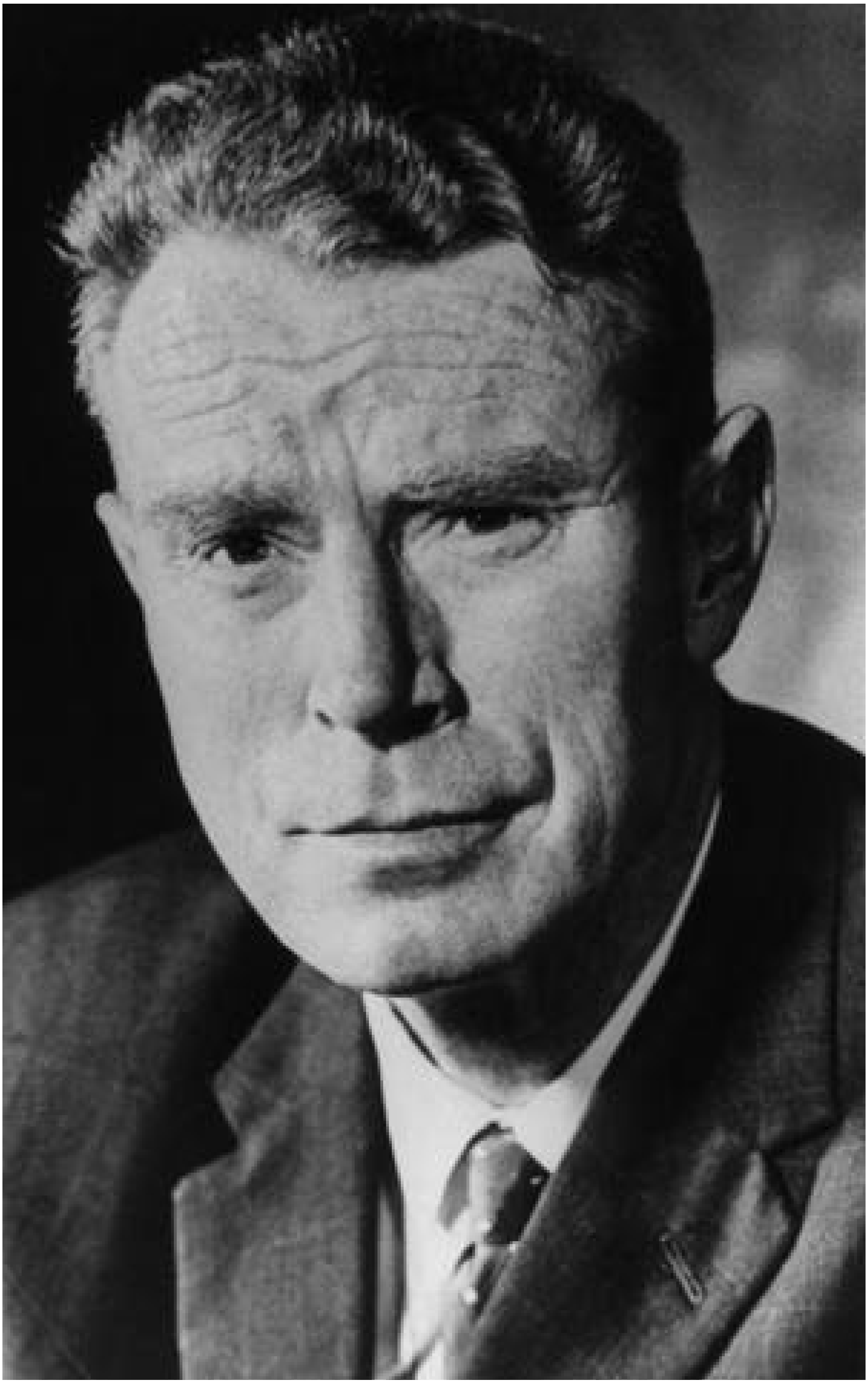
[12] Mr John Fleming prepared a draft chronology of medical ultrasound which was distributed at this meeting. For a history on the development of ultrasound see, for example, Blume S S. (1992) *Insight and Industry: On the dynamics of technological change in medicine*. Cambridge, MA: MIT Press, ch. 3, The constitution of diagnostic ultrasound, 74–118. McNay M B, Fleming J E E. (1999) Forty years of obstetric ultrasound 1957–1997: from A-scope to three dimensions. *Ultrasound in Medicine and Biology* 25: 3–56. See also O'Dowd M J, Philipp E E. (1994) *The History of Obstetrics and Gynaecology*. London: The Parthenon Publishing Group.

[13] Mr Tom Brown wrote: 'The prototype "bed table" two-dimensional scanner went into use late in 1956 [referred to as a "bed table" because a hospital bed table was used to support the scanning mechanism]. It was the first ultrasound scanner which produced a "compound" cross-sectional scan, combining translational and angular movements *with the ultrasonic probe in direct contact with the patient's skin*. All previous attempts had been based on much simpler scanning patterns or involved some sort of water-bath "stand-off" between the probe and the surface of the patient.' Letter to Dr Daphne Christie, 20 July 1998.

[14] Thomas Graham (Tom) Brown CEng MIEE (b. 1933) joined Kelvin & Hughes Ltd (see note 2 above) in Glasgow in 1951 as a trainee engineer. After some work on industrial ultrasonic equipment he began collaborating with Professor Ian Donald (see biographical note 8 above) in 1956 and continued this until leaving the company in early 1965, by which time he was in charge of all the industrial and medical ultrasound research and development work. After two years working on cardiological equipment he returned to medical ultrasound in 1967 when Nuclear Enterprises Ltd acquired the company's medical ultrasound business, and was joined shortly after by Brian Fraser (see biographical note 18 below). In 1970 Brown was a Research Fellow at Edinburgh University, where he investigated three-dimensional ultrasound imaging techniques. These would allow him to circumvent his basic patents on two-dimensional scanning (op. cit. note 89 below) which, apart from the restricted licence enjoyed by Nuclear Enterprises, effectively precluded any further UK participation in two-dimensional ultrasound developments. In 1973 he set up a small operation near Edinburgh on behalf of Sonicaid Ltd, to develop and manufacture a radically new form of ultrasound contact scanner that could produce three-dimensional stereoscopic virtual images of the body tissues. This was called the Multiplanar Scanner and was brought to market by 1976. It sold modestly to UK and overseas hospitals, but the project did not succeed commercially and was closed in 1979. Being unable to find further employment in the medical instrumentation industry, Brown moved into the offshore oil and gas business, where he remained until 1998. Tom Brown and Ian Donald were elected as the first Honorary Life Members of the British Medical Ultrasound Society in 1982.



Photographs and captions for Figures 1–6 and 8 provided by Mr John Fleming, coordinator of the British Medical Ultrasound Society (BMUS) historical collection. © BMUS historical collection, 1999.

Figure 1. Ian Donald, Regius Professor of Midwifery at Glasgow University, from 1954 to 1976.

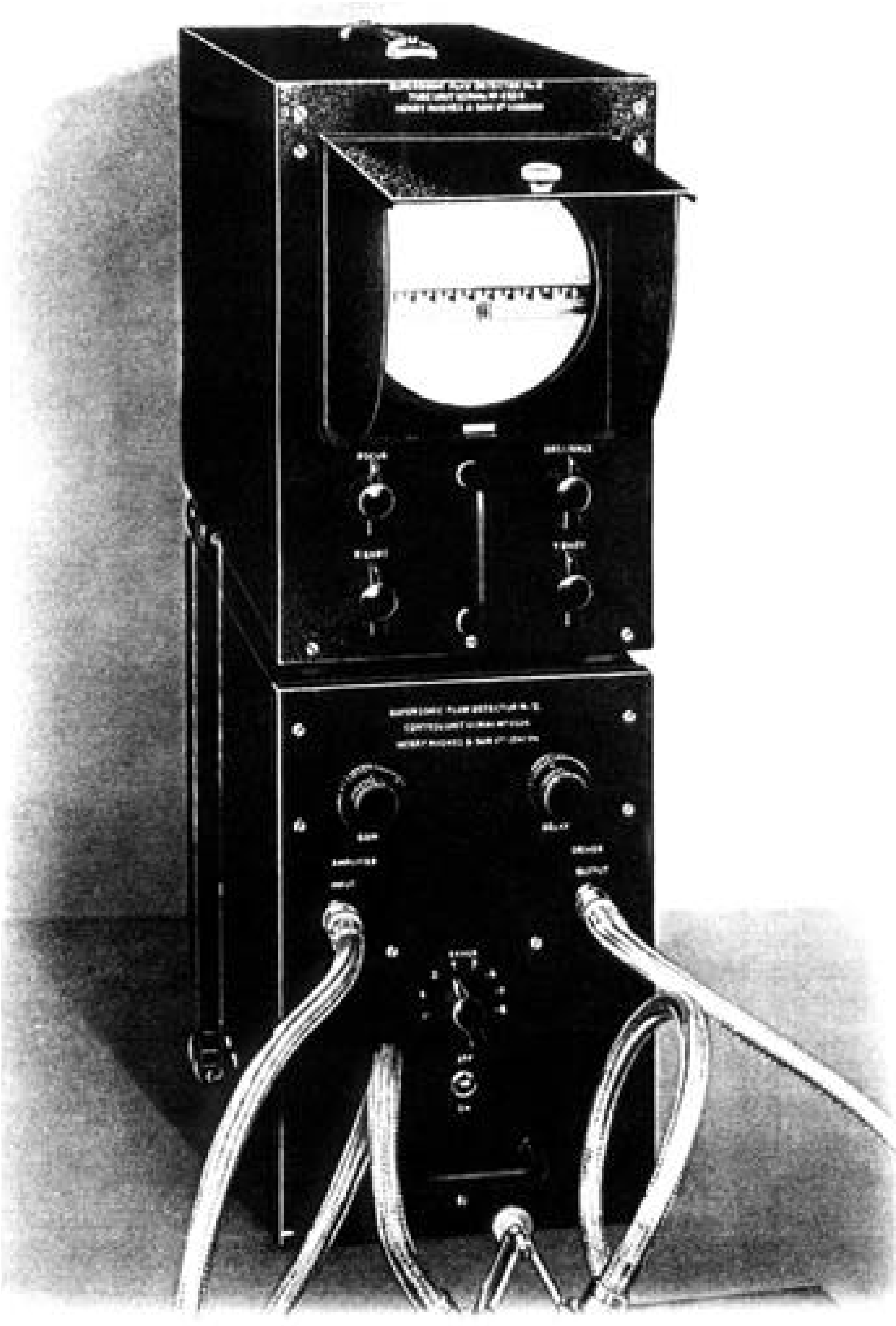


Figure 2. Henry Hughes 'Mark IIB' Supersonic Flaw Detector designed for the non-destructive testing of metals. Ian Donald's first experiments in the Western Infirmary, Glasgow, were with an instrument of this type.

Figure 3. A Kelvin & Hughes Mark IV flaw detector being used by the late Mr J Davis in the Babcock and Wilcox factory at Renfrew, where Ian Donald did his very earliest investigations on biological materials.

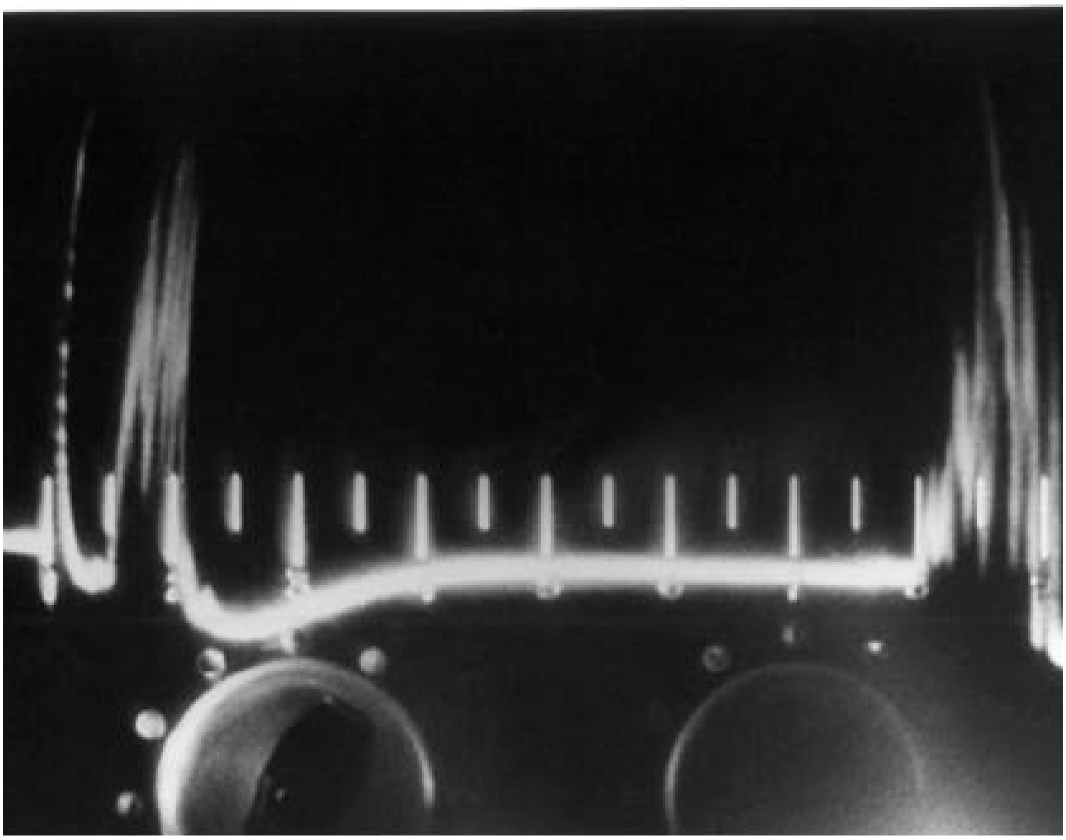


Figure 4. An A-scan from about 1956. Note the large non-reflective space between two echoes which marks the presence of a large simple ovarian cyst.

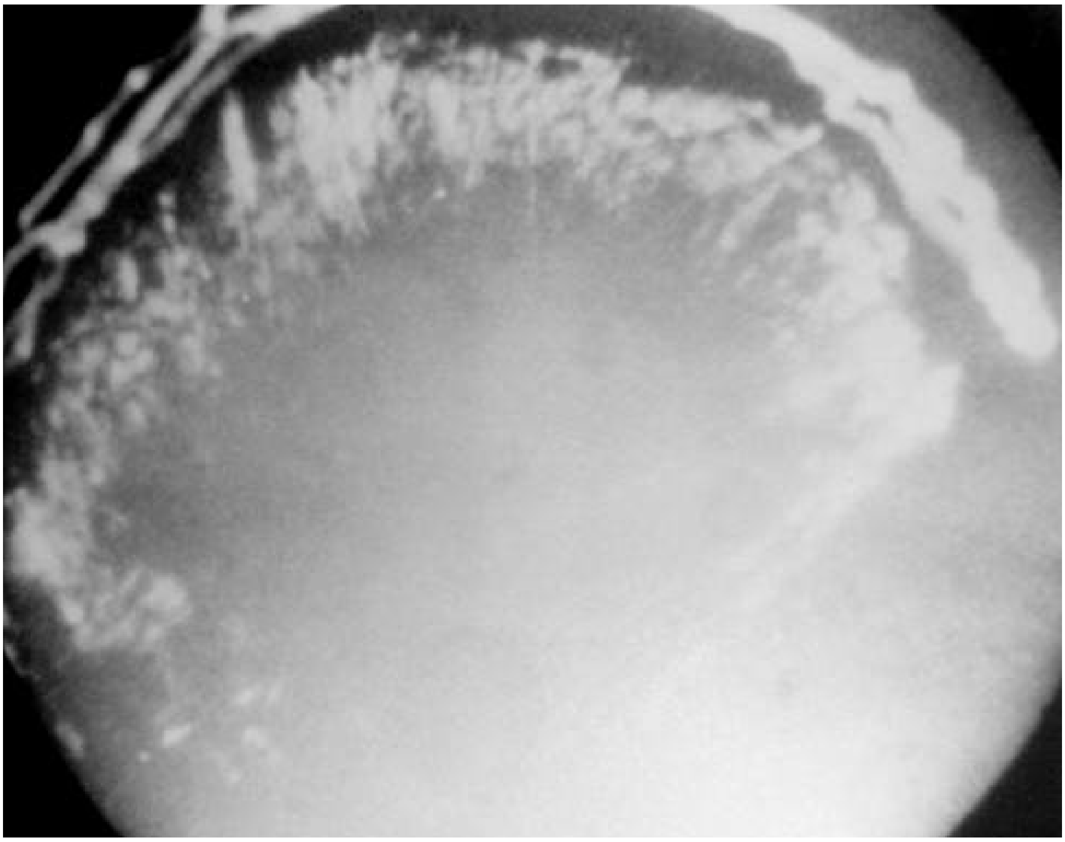


Figure 5. Image from the first contact B-scanner, dating from the end of 1957. The image is of a large simple ovarian cyst.

Figure 6. Tom Brown, standing in front of the newly built contact scanner, c. 1957.

of a rather younger Tom Brown, standing in front of the newly built contact scanner (Figure 6). Here's the same machine in clinical use in the Western Infirmary (Figure 7): you can see the screen behind the scanning box that sits above the patient. Mr Brown went on to build the first automatic scanner[15] and here are Ian Donald and John MacVicar employing it clinically (Figure 8). This process of technical development resulted in the Diasonograph, the first ultrasound scanner to be commercially produced and marketed. The sort of image that a Diasonograph was capable of producing from around 1964 was that of a polyhydramnios. The fact that this relatively rare[16] complication of pregnancy was successfully imaged at that date, which is after all fairly early on in the history of the technology's development, raises for me an interesting historical issue. It has been argued, notably by Ann Oakley,[17] that obstetric ultrasound, at least in the very beginning, was a 'toy for the boys', that is to say its early development was driven by technical rather than by clinical priorities. It would, I think, be foolhardy to deny that such considerations were not present in the early stages of the technology's history. Donald had always been fascinated since his boyhood by mechanical devices and therein certainly lay part of the attraction that the ultrasound scanner had for him. And he was certainly exemplarily well served by his engineering colleagues and co-workers, notably of course by Tom Brown, also by Brian Fraser[18] and

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[15] The automatic scanner was built to standardize the compound scanning process and to remove, as far as possible, operator bias from the results. It was a complex machine and probably the only one of its kind ever produced. Nevertheless, it worked successfully for about five years, during which time it allowed Donald and his colleagues to amass a large amount of clinical experience – from which any suggestion of operator bias had been substantially removed – and so helped establish the technique (see note 47 below). It was eventually replaced by the first of the hand-operated Diasonograph machines, but is preserved in the British Medical Ultrasound Society historical collection. Information provided by Mr Tom Brown, 24 May 1999.

[16] Mr Tom Brown wrote: 'I don't think polyhydramnios – or usually just "hydramnios" – is all that rare. It just means excess amniotic fluid in the womb, usually because the baby can't swallow for some reason. What *was* rare, and what could be dramatically demonstrated, was hydatidiform mole. This was said to be "very rare" but it's such a nasty condition and so difficult to diagnose otherwise, that we made a big impression by being able to *exclude* hydatidiform mole in a surprisingly large number of referred cases.' Letter to Dr Daphne Christie, 20 July 1998. Dr Malcolm Nicolson wrote: 'Mr Brown is right – the words "relatively rare" were not well chosen. What I was attempting to allude to was that hydramnios was a condition that was particularly well suited to identification using the early ultrasound equipment and that the ability to make a reliable diagnosis seems to have led to a more frequent recognition. But hydatidiform mole provides a better exemplification of the clinical usefulness of the technology at that stage in its development.' Letter to Dr Daphne Christie, 1 April 1999. See, for example, Robinson D E, Garrett W J, Kossoff G. (1968) The diagnosis of hydatidiform mole by ultrasound. *Australian and New Zealand Journal of Obstetrics and Gynaecology* 8: 74–78.

[17] Professor Ann Oakley has been Director of Social Science Research Unit, Institute of Education, University of London, London, since 1990. Her many publications include Oakley A. (1984) *The Captured Womb. A History of the Medical Care of Pregnant Women*. Oxford: Basil Blackwell Publisher Ltd. *idem* (1986) The history of ultrasonography in obstetrics. *Birth* 13: 8–13.

[18] Brian Fraser was a senior development engineer within Kelvin & Hughes Ltd (see note 2 above) and joined Tom Brown in about 1959 to assist with the development of the hand-operated scanning machine which had been ordered by Dr Bertil Sundén at Lund. Following the departure of Tom Brown in 1965, Fraser became head of the ultrasound engineering group at Kelvin & Hughes until its closure in 1966. He later joined Tom Brown at Nuclear Enterprises Ltd, Edinburgh. When the latter left to go to Edinburgh University, Brian Fraser led a team which brought about the development of the NE4102 and NE4200 series of Diasonograph instruments. These proved to be extremely successful products and became the *de facto* standard ultrasound scanners in the UK and elsewhere during the 1970s. Following the closure of Nuclear Enterprises, Fraser devoted his energies largely to veterinary applications of ultrasonic imaging. Information provided by Mr Tom Brown and Mr John Fleming, 24 May 1999.

later by John Fleming.[19] Certainly the technical story of ultrasound is a fascinating one by itself, but to my mind (contrary to Ann Oakley) what is really impressive about the early history of ultrasound is how closely the technical development process was linked to a clinical agenda and indeed how soon a clinical payoff came, and how very considerable that clinical payoff was.

Despite the fact that we are showing you these pictures, I would argue that Donald was not primarily interested in making pictures; he was interested primarily in making diagnoses. A simple example established the point and that is the case of placenta praevia. Reliable visualization of the placenta was achieved from about 1960 onwards. Not long after that innovation, and consequent upon it, came a wholesale transformation of the clinical management of suspected placenta praevia which was undoubtedly of enormous clinical and also, of course, social benefit to many expectant mothers who were thereby saved months of hospitalization. I hope that I am not trespassing upon the prerogative of the Chair by expressing the hope that perhaps later in the course of the afternoon we might devote some attention to gathering ideas from the members of our distinguished audience, as to which of the early clinical applications were most significant and most profound in their impact upon patients' care. Having posed one question about the history of the technology and one about its clinical aspects, I shall hand the meeting back to our Chair.

Hall: Thank you very much, Malcolm. I am sure that those pictures brought back a few memories to some of us. I would now like to start the proceedings. We have a slide projector here which people are very welcome to use – but the intention, I am told, of this meeting today is to get a written record. So please use slides if you must, but dare I say it, no lectures. Could I now ask John Fleming from Glasgow to say a few words about Tom Brown please.

Mr John Fleming:[20] When I was thinking what I might say today, a memory came back of something that Tom Brown had written and I thought that might be quite an interesting way to introduce him and to say a little about my involvement in ultrasound too.

Tom had been thinking about ultrasound, the scanning problem, and had been sent to Bill Halliday, the Chief Scientist of Smiths,[21] his employers, for an opinion on the building of such a machine. Thinking that the somewhat deaf Halliday had not quite understood, he started to explain again, and Halliday stopped him and said, 'Brown, I now appreciate the full enormity of what you are proposing'. I thought perhaps that's quite a way to sum up what in fact has happened, and that was in 1956.

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[19] See biographical note 20 below.

[20] John Fleming (b. 1934) worked in electronics at EMI and Ferranti for 11 years, and in 1962 moved to Smiths Industries Ltd, Glasgow, as a development engineer on medical ultrasound projects, principally the Diasonograph. Following Smiths' closure in 1967, he, together with Angus Hall (see biographical note 4 above), joined Professor Ian Donald at The Queen Mother's Hospital where he worked until his retirement in December 1997. He is Coordinator of the British Medical Ultrasound Society (BMUS) historical collection and Honorary Assistant Keeper of ultrasonic equipment to the Hunterian Museum, University of Glasgow, and an Honorary Life Member of BMUS (1994).

[21] See note 2 above.

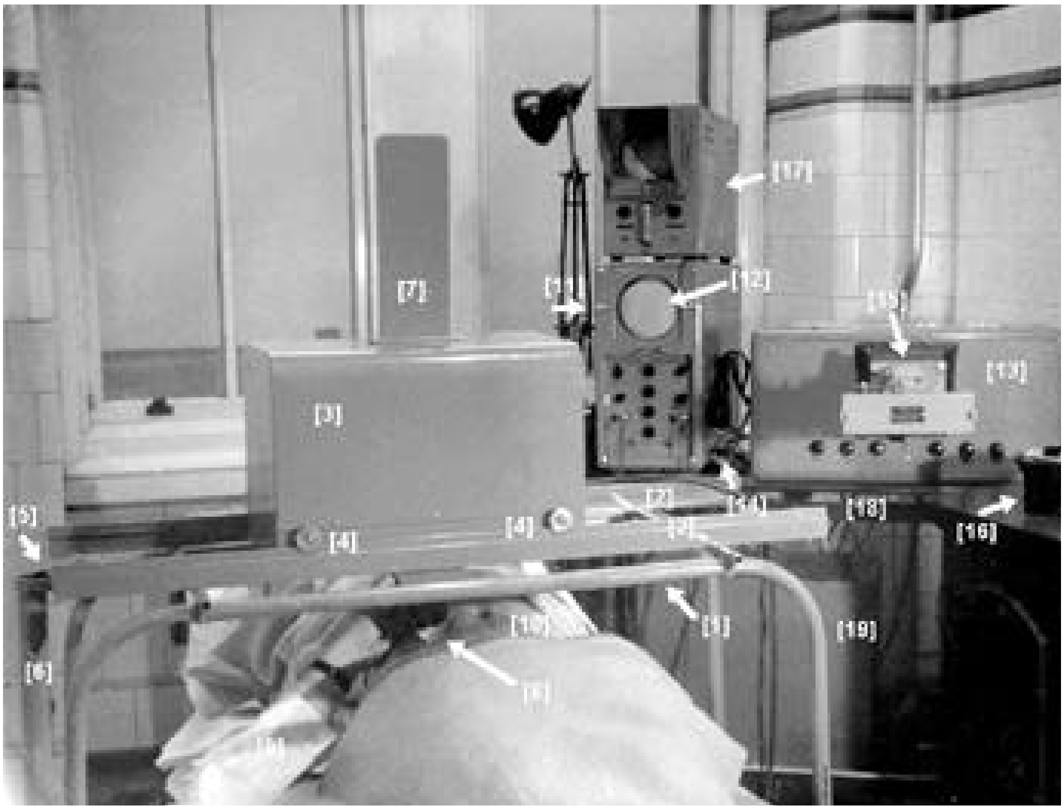

Figure 7. The first contact scanner in clinical use in the Western Infirmary, Glasgow.

Figure 8. The first automatic scanner, designed by Tom Brown, being operated by Ian Donald and John MacVicar in the Western Infirmary, Glasgow, c. 1960.

Key to Figure 7

Mr Tom Brown wrote:'This figure shows the prototype "bed-table" scanner made for Professor Ian Donald in 1956,with which the results reported in the *Lancet* were obtained (see notes 13, 25, 48 and 126).This apparatus forms the centre piece of the British Medical Ultrasound Society historical collection.

Mechanical System

The borrowed hospital bed table [1] with its original wooden top removed (and carefully stored for future restoration).The two rails [2], cut from proprietary cabinet-construction extruded aluminium alloy section, are fixed to cross-members clamped onto the bed table frame.

The scanner box [3], sometimes known as the "bread tin"because of its appearance, formed from a U-shaped heavy aluminium base, with a light steel cover. Two "kinematically-correct" vee-rollers [4] running on one rail,with a plain cylindrical roller (hidden) running on the far rail, providing five constraints, and permitting longitudinal movement only along the rails. The longitudinal movement was measured by an ex-Government 4" diameter wire-wound potentiometer fitted with a large "Meccano"* sprocket wheel. The sprocket wheel was driven by a length of Meccano chain running the length of the rails.The chain can just be seen [5] where it passes over another sprocket at the left hand end of the rails and disappears down a tube [6], within which it is attached to a counterweight.

The vertical "blade" [7] supports the probe spindle. This blade could move in a vertical direction only, being constrained by two vee-rollers on one edge and one spring-loaded vee-roller on the opposite edge. The vertical movement was measured by a second ex-Government 4"wire-wound potentiometer, operated by an internal system of glass-fibre cords and pulleys. The weight of the blade and probe assembly was counterbalanced by the Meccano chain passing down over two small sprockets and round an idler sprocket on the probe spindle. In this way the tension in the chain created by the counterweight in the tube [6] balanced the weight of the blade and probe assembly.

The double-transducer "probe" [8] was mounted on a spindle at the bottom of the blade between parallel plates,in such a way that it was free to rotate only in the plane of the horizontal and vertical motions. Rotation of the probe spindle was transferred via a system of glass fibre cords and pulleys to operate a sine/cosine potentiometer within the scanner box.

John MacVicar's hand and arm [9] can be seen reaching up from his crouching position to operate the probe on Tom Brown's abdomen [10], illustrating that ergonomic excellence had not taken a very high priority in this "feasibility study"design.

Electronic System

The electronic system was based on a converted Kelvin & Hughes Mark IV Flaw Detector [11].This provided the basic double-transducer transmitter/receiver functions, and an A-scope display screen [12].

The special circuitry for the contact compound scanning computational and display system was housed in the main cabinet [13]. Also in this cabinet was a second cathode ray tube (crt) to display the B-scan image. The necessary high-voltage power supplies were taken via a special connector [14] which can be seen low down on the side of the Mark IV unit.

The B-scan image was recorded by a Cossor 35mm oscilloscope camera [15] mounted in front of the second crt.The camera back contained two cassettes capable of handling thirty-foot rolls of film.One of the chores which fell on Brown or MacVicar after each scanning session was to open the camera back and remove the take-up cassette, and then in a "portable darkroom"glove system (not shown) remove the exposed film and seal it into the developing tank [16] for processing, all without letting any light in to destroy the day's work.

A further compound scanning display unit, fitted with a long-persistence crt [17], was initially placed on top of the Mark IV. The intention was to allow the operator to view the structures being scanned.Unfortunately, this led to the operators dwelling too long on structures which interested them,and so negating the compound scanning process and overexposing the "interesting" parts of the photographic image. Accordingly, the secondary display unit "disappeared" and the operators were then forced to scan "blind",with only the A-scope display to reassure them they were actually in contact and receiving echoes.

The entire electronic system was mounted on a hospital "apparatus trolley" [18]. Just visible on the bottom shelf of the trolley is a large box [19]. This is a mains voltage stabilizer, to ensure that the sensitivity of the scanning equipment was not affected by fluctuations in the electricity supply, not altogether unknown in Glasgow in the 1950s.' E-mail to Dr Daphne Christie, 25 November 1999.

* Meccano – a mechanical model construction set popular in the 1930s through to the 1950s.
Photograph and caption provided by Mr Tom Brown.

I joined Smiths as a development engineer in 1962, so things had moved on quite a long way from then. I just wanted to escape from an increasing involvement in military electronics. My main task was to redesign the circuits of the prototype machines, so that they could be put into production, something that Malcolm has already referred to. I worked with Ian Donald and John MacVicar and it was really quite a strange experience for me; I had never even met a professor before, let alone Ian Donald. After five years at Smiths they closed, and that's perhaps an aspect that may come up in this afternoon's meeting; the sort of commercial problems that companies face are really quite an interesting aspect and influential aspect of the whole history.[22] I was fortunate enough to be able to move into the unit that Professor Donald set up in The Queen Mother's Hospital and induced Angus Hall to return from an involvement with computers – relatively boring things compared with ultrasound. He came back from IBM and we set up a small unit and carried on work improving the Diasonograph and making it a much more stable machine (although it still had lots of problems), and getting involved in fetal measurements to a great degree. I had a particular working relationship with Hugh Robinson.[23] We established the measurement of crown-to-rump length which I am very happy to see in use in virtually the same way.[24] Then in 1980 Tom Brown gave me the contact scanner that he had built for Ian Donald, to take care of.[25]

[22] Similar problems are discussed in the NMR story, see Christie D A, Tansey E M. (eds) (1998) Making the Human Body Transparent: The impact of nuclear magnetic resonance and magnetic resonance imaging. In *Wellcome Witnesses to Twentieth Century Medicine*, vol. 2. London: The Wellcome Trust, 1–74.

[23] Hugh Robinson (b. 1943) worked in The Queen Mother's Hospital, Glasgow as a Research Registrar from 1971 to 1976, then as Lecturer, University of Glasgow, from 1976 to 1978. In 1976 the Head of Department, Professor Ian Donald, was succeeded by Professor Charles Whitfield. In 1978 Robinson moved to the Department of Obstetrics & Gynaecology, University of Melbourne, Australia. Since 1981 he has been Senior Specialist in Ultrasound at the Royal Women's Hospital, Melbourne. He is author or co-author of over 80 publications on ultrasound in obstetrics and gynaecology, which include his early work on fetal heart movement and pregnancy failure in the first trimester (op. cit. note 172 below). Towards the end of his time in Glasgow he was involved in the study of follicular development (op. cit. notes 175 and 176 below). Information provided by Mr John Fleming, 24 May 1999.

[24] Mr John Fleming wrote: 'This data was obtained using a Diasonograph (a static scanner) but did not need revising for use with real-time scanners.' E-mail to Dr Daphne Christie, 26 October 1999. The measurement of 'crown-to-rump length' remains the method of choice for estimation of gestational age in the first trimester. See Robinson H P. (1973) Sonar measurement of fetal crown–rump length as means of assessing maturity in first trimester of pregnancy. *British Medical Journal* iv: 28–31. Robinson H P, Fleming J E E. (1975) A critical evaluation of sonar crown–rump length measurements. *British Journal of Obstetrics and Gynaecology* 82: 702–710. See also British Medical Ultrasound Society. (1990) *Clinical Applications of Ultrasonic Fetal Measurements*. London: British Institute of Radiology.

[25] Mr Tom Brown wrote: 'There is a good yarn about how the prototype came to be preserved, involving one of the most colourful figures in the business, the late Dr Norman Smyth. Dr Smyth had both engineering and medical qualifications, and worked at University College Hospital as a clinician, and at the Northampton Polytechnic in the evenings developing the Sokolov ultrasonic image converter tube – a kind of specialized television camera aimed at converting ultrasound images directly into TV ones. Although he successfully supplied these tubes to the nuclear industry for examining fuel cells, there were many difficulties encountered when attempting to use them for medical purposes. In the early 1960s after the automatic scanner had been used routinely by Professor Donald, Dr Smyth borrowed the original "bed table" prototype scanner together with circuit diagrams of the electronics, to carry out direct comparisons between the two approaches to imaging. The prototype scanner was lost sight of until the late 1960s, when Dr Smyth contacted me to say that he was having to leave his laboratories at University College Hospital and did I want the prototype back? The following Sunday he turned up in his car at my home with the scanner in the boot. It then lay in my junk room for several further years, until an exhibition, arranged to mark Ian Donald's retirement, when it was passed into the safe keeping of John Fleming, and it now forms the centrepiece of the BMUS historical collection. An example of Dr Smyth's Sokolov tube is held by the Science Museum in London.' Note on draft version of transcript, 24 May 1999.

I unsuccessfully tried to offload this onto the Hunterian Museum in Glasgow, thinking, 'I am not a historian or a museum collector or anything.' But then a bit later on, the President of BMUS [the British Medical Ultrasound Society], Pat Morley,[26] who unfortunately is not able to be with us today, asked me to build up a historical collection for the Society, and I thought, 'That will be an interesting thing to do.' So I visited museums and I started work on this project of collecting things and built up quite a large collection of material. But long term is something that you have to think about in a museum and I am particularly grateful to Tony Whittingham for his support in persuading the Hunterian Museum, in the long term, to look after this collection, which has now become very substantial. When I visited Washington last year with Margaret McNay we saw the collection there[27] and I think we can say that the BMUS collection is larger and somewhat better organized than even the American collection! We have quite a substantial body of material; that's partly what induced Malcolm Nicolson to get involved with it four years ago and then to persuade the Wellcome Trust to provide a grant and employ Ian Spencer[28] and the whole thing has taken off and here we are today. So in a way perhaps I can paraphrase Bill Halliday and say, 'Brown, I now appreciate the enormity of the proposal that I should look after that scanner.' Tom, it's very good to see you here today and everybody else of course. I am very pleased that this meeting is taking place.

Hall: Well, Tom, without any further ado, could I ask you to tell it how it was, starting with the first bed-table contact scanner and how that came about.

Mr Tom Brown:[29] I haven't prepared anything very formal at all, but thinking about this meeting it occurred to me that in that brief period from 1956, through 1957 to 1958, a great deal was accomplished in a relatively short space of time.

Since that time, it has fallen to me to manage other people's research and development work, and were I faced with putting a timescale on what was actually done in Glasgow at that time, it would have been extended a good deal more.

There were several of influences at work. One of them was that we were living in the aftermath of World War II. There was an enormous collection of technology that had

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[26] Mr John Fleming wrote: 'Patricia Morley (b. 1929) began her work in ultrasound in 1968 as an Assistant in Radiology at the Western Infirmary, Glasgow. In 1980 she was awarded the FRCR and in 1982 was appointed "Consultant Radiologist with a major interest in Ultrasound" in the same department, retiring in 1994. Throughout her working life she was involved mainly with abdominal ultrasound but she had an interest in all specialities and was a major influence in the development of clinical diagnostic ultrasound. Pat's publications include many papers and chapters in textbooks and, in addition, she lectured extensively. A major work was the publication of *Clinical Diagnostic Ultrasound*, co-edited with Ellis Barnett (op. cit. note 187 below), her long-time colleague at the Western Infirmary (see also Fleming J E E, Spencer I H, Nicolson M. (1999) Medical ultrasound: germination and growth. In Baxter G M, Allan P L P, Morley P. (eds) *Clinical Diagnostic Ultrasound*, 2nd edition. Oxford: Blackwell Science). From 1978, she was a member of BMUS Council and, after four years, was elected Vice-President, serving as President from 1982 to 1984. During this time she suggested the establishment of a BMUS historical collection.' E-mail to Dr Daphne Christie, 31 May 1999.

[27] This refers to the collection held by the American Institute of Ultrasound in Medicine near Washington, DC, USA.

[28] Dr Ian Spencer contributes later in the meeting, see biographical note 209 below.

[29] See biographical note 14 above.

been developed and beautifully documented, particularly in the MIT [Massachusetts Institute of Technology] handbooks, so that if one had a technical problem – and a lot of the problems were electronic, not mechanical – there was a ready resource available for sifting through.

The other thing was that I didn't come into the medical ultrasound business 'cold'. Although I was still a young man, aged only 23, I had already spent a couple years directly involved under the late Alex Rankin,[30] in the development of new ultrasound techniques for non-destructive testing. There was a great deal of technical commonality between that and what we had to do with the scanning machine.

I now (mis-)quote the phrase, 'Shame is the spur'. When I had finished with the industrial ultrasound project I got the proverbial pat on the head and was told, 'Right lad, you've got to go to University, and we'll pay.' I spent an abortive year at what is now Strathclyde University attempting to learn applied physics, but I spent too much time playing snooker and generally enjoying the student lifestyle. However, I had really bitten off far more than my intellectual equipment could chew, so that, at the end of that year, I had to go back to Kelvin & Hughes,[31] feeling very sore, and ask for my old job back.

I was not popular; I was in disgrace and knew it. I was stuck in a corner and given a miserable little project to look after. So that, when the opportunity arose, and I heard, by chance, of Donald's use of an A-scope machine on people – and by the way Malcolm it wasn't *that* A-scope that he used,[32] it was another one – I could hardly contain myself.

I went home, looked up Professor Donald in the phone book and phoned him up, on Western 5050, that night. Had he been the least bit stuffy, none of this might have happened, but in fact he was delightful, and it wasn't long before I was invited to go

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[30] Alexander [Alex] Bryce Calder Rankin (1924–1963) trained as a metallurgist and was a pioneer in the application of ultrasound to non-destructive testing of metals. He was Head of Applications Engineering for this activity within Kelvin & Hughes (see note 2 above). Prior to 1956, Alex Rankin had been actively involved in supporting some of the pioneering work by Leksell and others in Sweden, and also workers elsewhere, including Dr Douglas Gordon (see note 3), in the use of ultrasound for detecting mid-line shifts in the brain. It was Alex Rankin who kick-started the relationship between Tom Brown and Ian Donald in 1956 by arranging the (semi-official) loan of a new Mark IV Flaw Detector for Donald's use. Alex died a tragic and untimely death in 1963. Information provided by Mr Tom Brown and Mr John Fleming, 24 May 1999. Mr Tom Brown wrote: 'Dr Douglas Gordon (1909–1997) contributed to the development of several electromedical technologies, including electroencephalography, electroconvulsive therapy and medical photography, before becoming one of the earliest in the UK to be interested in medical ultrasound. Probably his best-known and most successful innovation was his "comparator". This was used for obtaining substantially simultaneous A-scope traces from a pair of transducers placed on opposite sides of the head to detect asymmetry in the mid-line structures of the brain. Later in life he devoted much energy to the development of a mechanical pantograph-type two-dimensional scanning machine, but this venture was probably over-ambitious for the limited resources he had available, and was never fully completed. He was a colourful figure who travelled and lectured widely; he organized some of the earliest peer group meetings on medical ultrasound.' E-mail to Dr Daphne Christie, 9 November 1999.

[31] See note 2 above.

[32] See page 4.

and see what he was doing, and see the old black-crackle painted, Mark IIB 'Supersonic Flaw Detector' which he had managed to scrounge from the Royal Marsden Hospital in London.[33]

It became clear, even with that rather comical demonstration, with the 'water stand-off'[34] and all the rest of it, that it looked as if there was data coming back from within the body. I managed to scrounge a rather better machine through the good offices of Alex Rankin,[35] who contributed a lot indirectly to this subject.

Although this was a huge improvement, it seemed to me that the nature of the A-scope presentation was fundamentally incompatible with the nature of the problem, and particularly with the perceptual faculties of the user. In the years to come I was always wrestling with the problems of matching the apparatus to the perceptual faculties of the human user, all the way through into stereoscopy and three-dimensional imaging.[36]

So, with the background knowledge of Kelvin & Hughes' radar technology, it seemed to me that there was a reasonable chance of making a machine which would match the perceptual faculties and the echo information somewhat better. The fact that it turned out to be a two-dimensional 'slice' scanner was really due to the limitations of the technology of the day, because even then it was recognized that the problem was essentially a three-dimensional one.

But it was a case of one step at a time. I was quite impotent on my own, so I had to seek resources from the company and it was that which led to that wonderful interview with Halliday[37] – a quite delightful man.

The extent of the original undertaking on the part of Kelvin & Hughes was in a memo

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[33] Professor Mayneord at the Royal Cancer Hospital, now the Royal Marsden, in London had been using a Henry Hughes Mark IIB Supersonic Flaw Detector to examine the brain through the intact skull, though without much success. White D N. (1988) Neurosonology pioneers. *Ultrasound in Medicine and Biology* 14: 541–561. This apparatus was later loaned to Donald and was the machine in use when Tom Brown first met him in 1956.

[34] During the modification of the machine (Mark IIb) before Donald received it, the transmitter pulse generator had been connected directly to the input of the sensitive receiver amplifier, in an attempt to make the same transducer act as both transmitter and receiver. This was instead, as was normal at that time, of having separate transducers for transmitting and receiving purposes. The effect of this was to overload the sensitive amplifier and cause it to go into 'paralysis' for a time, thus incapable of detecting echoes from within the first few inches of the patient's tissues. Donald's pragmatic solution to this problem was to place the end of an open-ended glass cylinder about 250 mm long by 75 mm in diameter onto the patient's skin, using Vaseline as a seal, fill the cylinder up with water from a jug, and then dip the transducer (or 'probe') into the water. By the time the ultrasonic pulse had reached the patient's skin, the amplifier had had time to recover from its paralysis, and echo signals from within the patient could be seen at the extreme right hand end of the A-scope trace. The practical problem which followed was somehow to get the water back into the jug without soaking the patient or the professor. This is what is meant in this instance by a 'water stand-off'. The description is used differently elsewhere in the text: to mean any means of interposing water between the probe and the patient, for example, as Douglass Howry did, by placing the patient in a water tank (op. cit. note 39 below) or as Kossoff did (op. cit. note 78 below). Information provided by Mr Tom Brown, 24 May 1999.

[35] See biographical note 30 above.

[36] See note 14 above.

[37] The interview described by John Fleming on page 11.

from Bill Slater[38] who was the Deputy Managing Director and resident in Glasgow, which stated that Mr Brown had permission to spend half a day a week working with Professor Donald and had a budget of £500 with which to do the work.

It was on that understanding that the first contact scanner actually came into being. It was a very elastic sum of money and it owed a great deal to the scrounging capabilities of the young Brown and the tolerance of other people, because everyone really was on the side of the angels. There was a general desire to help.

One of the things that is often asked is this. Were we aware at that time, or was I aware at that time, of the work done by Douglass Howry?[39] The answer is, curiously, 'no'. Perhaps we should have been. Certainly I know that the Managing Director of Kelvin & Hughes[40] did have copies of Howry's paper, including his early neck pictures, which he did make available to us later.

However, I think that had we been aware of what Howry was doing, and had set out our stall to improve on Howry's work, we would have been stuck with immersion scanning.

Contact scanning came about for two reasons. One was that we didn't know any better; I didn't know what Howry had been up to.[41] Secondly, the practicalities of examining the patients in Donald's wards were such that there was absolutely no question of putting these people in tubs of water.

We did attempt, briefly, to have a 'water stand-off' in the form of a water-filled condom between the probe and the patient. However, I knew enough about the problems of water immersion testing for industrial purposes to know how difficult

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[38] William T Slater (Bill) (1903–1977) joined Kelvin Bottomley & Baird in 1923 (see note 2 above), and went on to hold many senior positions through the various amalgamations and reorganizations which followed. He oversaw many technological and commercial developments in the company's marine, industrial, aviation and medical businesses. He saw the medical and commercial potential of the medical ultrasound technology, and provided it with such active encouragement and financial support as he could manage, sometimes almost in defiance of the rest of the Board. Without Slater's enthusiasm and backing, and despite the contributions of all the others involved, it is very unlikely that the project would have succeeded, though sadly he retired before being able to see any commercial returns. Nonetheless, he played a most vital and far-seeing, if little known, role in the ultrasound story. Information provided by Mr Tom Brown, 24 May 1999.

[39] Douglass H Howry (1920–1969) became interested in the study of ultrasound for anatomical imaging during his internship in radiology at the Denver University Hospital in 1948. He published many papers on ultrasound, including Howry D H, Bliss W R. (1952) Ultrasonic visualization of soft-tissue structures of the body. *Journal of Laboratory and Clinical Medicine* 40: 579–592. Howry D H. (1957) Techniques used in ultrasonic visualization of soft tissues. In Kelly E. (ed.) *Ultrasound in Biology and Medicine*, Symposium, June 20–22, 1955, Illinois. Washington: American Institute of Biological Science, 49–65. Tom Brown and Douglass Howry became firm friends before the latter's untimely death. Information provided by Mr Tom Brown and Mr John Fleming, 24 May 1999.

[40] Mr G B G Potter, Managing Director of Kelvin & Hughes during the critical period, was somewhat unsympathetic to the medical ultrasound project, which put Mr Slater in a difficult position from time to time. Information provided by Mr Tom Brown, 24 May 1999.

[41] It must also be remembered that this was not a traditional scholarly academic project, where one might expect a thorough literature search before embarking on further work. The initiative to develop the imaging system came from within Kelvin & Hughes, and this was to all intents an initial, inexpensive feasibility study for a new product, in which time was of the essence. (Tom Brown was shortly due to go off to do his National Service for two years, though that never actually happened.) In the normal course of events this feasibility study would be followed by a patent search, in which any prior art would emerge, as in reality it did. Information provided by Mr Tom Brown, 24 May 1999.

that would be, and it was very quickly abandoned, and we went directly to the direct contact scanning system.

Hall: Can I just ask you something there, Tom? You had got to the stage where you'd got this B-scanner working. If we look at the images now, and I am being provocative, I could say that it was the eye of faith, that there was the 'famous' incident recorded of the patient, linked with Professor MacVicar. She had a large cyst which was actually non-malignant, but she had been left to quietly die.

Brown: [Looking at MacVicar for confirmation] No, it wasn't. I think that was done with an A-scope.

Hall: But I was under the impression that that's what brought the clinical interest forward diagnostically.

Professor John MacVicar:[42] Yes, it certainly was. The Professor of Medicine had made a diagnosis of malignant ascites in an elderly lady which seemed to be confirmed by radiography. Then from another unit a young upstart came with a machine to her bedside (it was with the A-scope we did it) and said, 'This isn't a malignancy, this is an ovarian cyst!'[43] I remember Professor Donald kicking me under the bed-screen and saying, 'Not at all, it is a malignancy, the Professor of Medicine says so.' So I kept quiet after that.

Hall: Would you say that that was a watershed?

MacVicar: It certainly was the first thing that made staff in the hospital recognize that this was a possible tool for the future.

Hall: I think Ian Donald himself said on a number of occasions that he thought that that was the watershed. In his own inimitable manner, he said, 'From that point on there could be no turning back' and he viewed it as being a stroke of luck, after some less fortunate events. Of course, the end of the story was that the patient was taken upstairs [to the gynaecological department] and had this great big cyst removed and lived, so far as we know, happily ever after.

MacVicar: What annoyed me was that Ian Donald got a cake from that woman every Christmas afterwards, and I never got any!

Hall: I think saving lives carries its own disappointments.

Brown: But we were told that the cake was totally inedible!

Hall: Could I ask either Dr Willocks or Professor MacVicar, in those early days, how

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[42] Professor John MacVicar FRCSGlas FRCOG (b. 1927) was appointed Registrar in the Department of Obstetrics and Gynaecology at the Western Infirmary and Royal Maternity Hospital in Glasgow in 1956 and was later Lecturer and Senior Lecturer in the Department of Obstetrics and Gynaecology, University of Glasgow. In 1974 he became Foundation Professor of Obstetrics and Gynaecology at the University of Leicester and retired from that post in 1992, now Emeritus.

[43] Mr Tom Brown wrote: 'If the Professor of Medicine said you had a malignancy, that was that, and it was not normally open to question. Our intervention was quite dramatic, and it was the fact that we had the temerity to question the Professor of Medicine's diagnosis on the basis of this upstart technique which gave the incident its high profile.' Letter to Dr Daphne Christie, 20 July 1998.

much value in fact did the simple B-scanner (the over-the-bed scanner) have in clinical practice as opposed to maybe being a vehicle for generating papers, if I could be slightly naughty in suggesting that?

Brown: Can I answer that? As a layman one of the things which impressed me about the medical people with whom I was dealing, was the courage with which they had to make life or death decisions on a patient's behalf, on the basis of guesswork. The impact of ultrasound on obstetrics, to me, was to remove a great deal of the guesswork which had hitherto applied. I came to the conclusion that in medicine there is no disgrace in not knowing that something is going on, if there is no diagnostic tool available with which to deduce it. In obstetrics in those days there was a lot of talk about 'clinical judgement' and 'my hands' and all this sort of thing, but at the end of the day you didn't know what was going on inside the uterus until it manifested itself externally, and sometimes tragically.

I don't think that case [of mistaken diagnosis of ovarian cyst] was a 'watershed'. I don't think it was a road-to-Damascus experience on Donald's part, although it's nice to simplify and dramatize things that way. I think there was, instead, a gradual process, which went on over a period of years, of demonstrating common clinical conditions which could be diagnosed, or of which a prospective diagnosis could be made ultrasonically and then tested against the clinical outcome.

One of the factors which is rarely talked about was the library of case notes which we built up. This occupied many drawers of our filing cabinet with every case, complete with notes and photographs and settings of the machine at the time.[44] One of the things that I think that Donald and John MacVicar and others did was to be religious about reviewing the outcome of these early investigations.

Hall: Could I take you on a bit, Tom. Sorry to put all the questions to you, but you were the key link in the early days, certainly scientifically and technically. What brought about the automatic scanner? With hindsight I could suggest it was a red herring in the development, certainly of contact B-scanning.

Brown: Well, there was great variability in the results. That variability could be due to the apparatus, or it could be due to the process of scanning, or could be due to differences between the patients themselves. The automatic scanner was, to some extent, an attempt to standardize the apparatus side of the equation.[45] The electronic side of it was already reasonably well standardized with the transmitter attenuators and the power-supply stabilization and the calibration system and so on – but the scanning process was not.

With the prototype B-scanner, the process of scanning was ergonomically horrific. The number of times I have seen John [MacVicar] here, crouching at the bedside, reaching up under this infernal machine, trying to carry out a regular compound scan over the patient, while getting olive oil running up his arms, and bumping his head on the underside of the frame. Generally it was an ergonomic catastrophe.[46]

[44] See note 47 below.

[45] See note 15 above.

[46] Mr Tom Brown wrote: 'But it *was* all done – after all – on a £500 budget!' Letter to Dr Daphne Christie, 20 July 1998.

The other side of it was that we were working in quite a Victorian environment. I was itching to get my hands on the equipment and determine what it could do, but there was absolutely no way in which a young male layman was going to lay a hand on a female abdomen in the obstetrics and gynaecology wards of the Western Infirmary in the 1950s.

So, I took control of the scanning process, through the automatic scanner. Whether that was a valid reason for building one or not, I don't know, but the payoff at the end of the day was that for the period from about 1960 through until 1965, when it was replaced by the first of the Diasonographs, the automatic scanner scanned I don't know how many thousand patients – but quite a few thousand patients[47] – and did so in a reproducible, standardized way.

The results of all those scans were logged in the database (a punch-card database, but it was a database nonetheless). That period in the early 1960s was a period of consolidation which, I think, really put the technique on the map.

Hall: You have forgotten, Tom, about one machine, the Sundén machine,[48] and that was a very interesting development. I would like to ask Professor Dugald Cameron to tell us about his involvement, which, of course, was with the aesthetics of the machine, and he also bears subsequent responsibility for the Diasonograph series of equipment. So, Dugald, would you like to give us the, dare I say, artist's viewpoint of the development at this time?

Professor Dugald Cameron:[49] I feel as if I am an impostor in this distinguished gathering, because I was a final-year art student at the Glasgow School of Art and like a number of my colleagues, we all fell in love with Tom Brown's sister-in-law, Elsa, who was a first-year art student at the Glasgow School of Art. She had told me that her brother-in-law was developing this new machine at Kelvin & Hughes and that, in fact, he didn't think much of industrial designers. That gave me the spark, because I was a very cheeky so-and-so then, probably as now, and I was determined that I would meet this chap and we would talk about it. We met in your flat, Tom, in Mount Florida and I've got some slides here that show this (Figures 9–14).[50] I have actually kept the records

[47] Mr John Fleming wrote: 'Over 3000.' Letter to Dr Daphne Christie, 28 July 1998. Mr John Fleming later added: 'The number is uncertain but, during the five or six years that I assisted Ian Donald and John MacVicar at the one or two scanning sessions per week, each with at least five patients, we must have scanned more than 2000. And there were many drawers full of record cards carrying sets of Polaroid prints before I joined the group. A few hundred still exist in the BMUS historical collection.' Note on draft version of transcript, 24 May 1999.

[48] In 1958, Dr Bertil Sundén, a young Resident in the Obstetrics and Gynaecology Department of the University Hospital in Lund, Sweden, convinced the authorities there to purchase an instrument like Donald's prototype bed-table scanner. The placing of a commercial order for such a machine (at £2500) was a breakthrough and an enormous morale boost for those involved at Kelvin & Hughes. It led to the conceptualization of a 'production' hand-operated machine. This instrument is referred to in this meeting as either the 'Lund' or 'Sundén' machine. This was the very first direct-contact scanning machine to be sold commercially anywhere in the world. For his published thesis see Sundén B. (1964) On the diagnostic value of ultrasound in obstetrics and gynecology. *Acta Obstetrica et Gynecologica Scandinavica* 43: 1–191.

[49] Professor Dugald Cameron OBE FCSD FRSA (b. 1939) was an Industrial Design student at Glasgow School of Art when he first came into contact with Tom Brown in about 1960, and went on to become Head of Industrial Design at the Glasgow School of Art in 1970, and Director in 1991.

[50] Only some of the slides are illustrated here. Copies of the slides will be deposited with the records of this meeting in the Contemporary Medical Archives Centre of the Wellcome Library.

of it all, including my first order for drawing, probably the first artist's drawing of an ultrasonic machine. That's how I got involved in it and got fascinated by it.

I knew nothing whatever about the whole business, but had a desire to make the thing ergonomically better so that the approach to the patient was better and that the doctors would find it easier to use. Indeed, Tom's view was to make it 'doctor-proof' and we tried to do this. These, in fact, were the first sketches done on your [to Tom] dining room floor in Mount Florida of how we thought this Sundén machine should be (Figures 9 and 10). This is the automatic contact scanner that we were talking about. And that was the proposal that Tom had – to make the Lund machine (Figure 11).[51] I remember saying that I thought it looked like a gun turret and that it was thoroughly inappropriate for pregnant ladies. This was the design drawing: Tom and I were arguing over how to make it so that it could be used by a seated or a standing doctor, but we determined, in fact, that you couldn't. It was useless for both, and therefore on that ergonomic basis this was not the right configuration for the machine. That was my attempt to give a three-dimensional view of what that machine was going to look like. On the left are the two sketches where what we thought we ought to do was to separate out the patient, the doctor, and the machine and try and put these three things in a better ergonomic relationship with one another, so that the doctor would actually be on a level with the patient and seated. That was the first drawing which I had been commissioned to do, and for which I received an order for £21. I had completed my studies and won a travel scholarship to Scandinavia, so this £21 helped that along quite a bit. But you will notice that there's one thing in the history of engineering drawings, there are very few that have been drawn to a scale of one-sixth. This one was because it was the biggest bit of tracing paper that I had and I couldn't afford any others. That showed the basic relationship of a desk for the doctor in which he could keep the various bits and pieces, including the olive oil when needed. The machine could be rotated in different ways so that it was very handy and the doctor could speak to the patient very easily. We had a lot of discussions about how to make it, but in fact it was made from a proprietary system called Widney Dorlec,[52] which was then adapted a bit and I had a lot of arguments about that. In fact, in retrospect, it was the right way to do it, because you didn't want to waste time on a lot of other things in concentrating on seeing if the thing would work. And we were very proud of that. I remember on one occasion though, going in and we had to saw a bit off the column because it wouldn't go through the door. I was very privileged to be involved with this group of engineers at the time, as I then became a postgraduate art student and I learnt an enormous amount from it. Tom and his colleagues were enormously patient with me, but I certainly learnt a very great deal. That was the first layout – not drawn by me – of the Diasonograph. This was to be the production version of the Sundén machine, and you see we were intending to make a bed for the patient as an integral part of that machine. The mechanics and the electronics of the thing were all separate. Indeed it was a

[51] Also referred to as the Sundén machine in this meeting. See note 48 above.

[52] Mr John Fleming wrote: 'Widney Dorlec Ltd, England, manufactured a set of components for the construction of cases suitable for electronic and electromechanical equipment.' E-mail to Dr Daphne Christie, 26 October 1999.

modular construction which you can see in a moment or two. That was the first Diasonograph built at Kelvin & Hughes at Hillington. Standing beside it, to add scale to the photograph, is Arthur Johnson[53] (Figure 12).

Hall: Dugald, can I stop you there and ask you a key question? You developed one machine – the Sundén machine – which, for the record, takes its name from Dr Bertil Sundén,[54] who ordered it. It was supplied to the University of Lund near Malmö [in Sweden]. You developed this Sundén machine at much expense and time. Why was it not pursued as the production machine?

Brown: It became clear that the automatic scanner was a one-off. The results obtained with the automatic scanner, although they were more consistent, were not different in kind from those which you could obtain with a manual machine, a hand-operated machine.[55]

Hall: Could that have been, Tom, because, in fact, the electronics hadn't improved? Basically the old bed scanner and the automatic machine used the same electronics?

Brown: Yes, they did. But I think what it demonstrated was that with a bit of assistance, a manual scanning process could achieve adequate clinical results without the complication and expense of the automatic machine, which was undoubtedly a very complicated bit of kit. The Sundén machine, in its own way, was also a prototype, because it was an attempt to make a hand-operated machine which would be functional but would not be oppressive to the patient.

If you cast your mind back to the image of the Sundén machine, it was on a heavy base, counter-balancing, and supporting a 'tree trunk', which couldn't possibly fall over onto the patient. Visually, the scanning frame was supported off that tree trunk like a branch, and the shape of the structure was such that we felt that a patient – and a very vulnerable patient with a pregnant abdomen – would not feel threatened by it. The display console that hung on the other side, over the base, added to that feeling of security.

However, the mechanical complexity involved in the 'elbow-shoulder and wrist-joint' mechanism in the Sundén machine was difficult to make. So when we came to think about a production machine, following the Sundén machine, the measuring frame which is a white box with a probe sticking out at the bottom was the same, however the mechanism for supporting it was simplified, and became a couple of bars that ran backwards and forwards inside a strong cabinet. So this was an attempt to make a cheaper Sundén machine. As it happened,[56] it turned out to be far more slab-sided and

[53] Arthur Johnson was one of the draughtsmen at Kelvin & Hughes.

[54] See note 48 above.

[55] Note that the Sundén machine was operated by hand. Mr John Fleming and Dr Angus Hall wrote: 'This machine is sometimes incorrectly referred to as "the Diasonograph".' Note on proofs, 23 December 1999.

[56] Mr Tom Brown wrote: 'The mechanical engineer involved, Mr David McNair, was working very competently in relative isolation at a time when everyone else was heavily involved in sorting out a commercially and technically difficult situation on industrial ultrasound. The emphasis was on ensuring that the mechanical design of the new Diasonograph was physically safe for the patient, and straightforward to manufacture, and this resulted in a design which was both of these things, though perhaps less pleasing aesthetically than the Sundén machine.' Note on draft version of transcript, 24 May 1999.

Figures 9–14.Early industrial design.

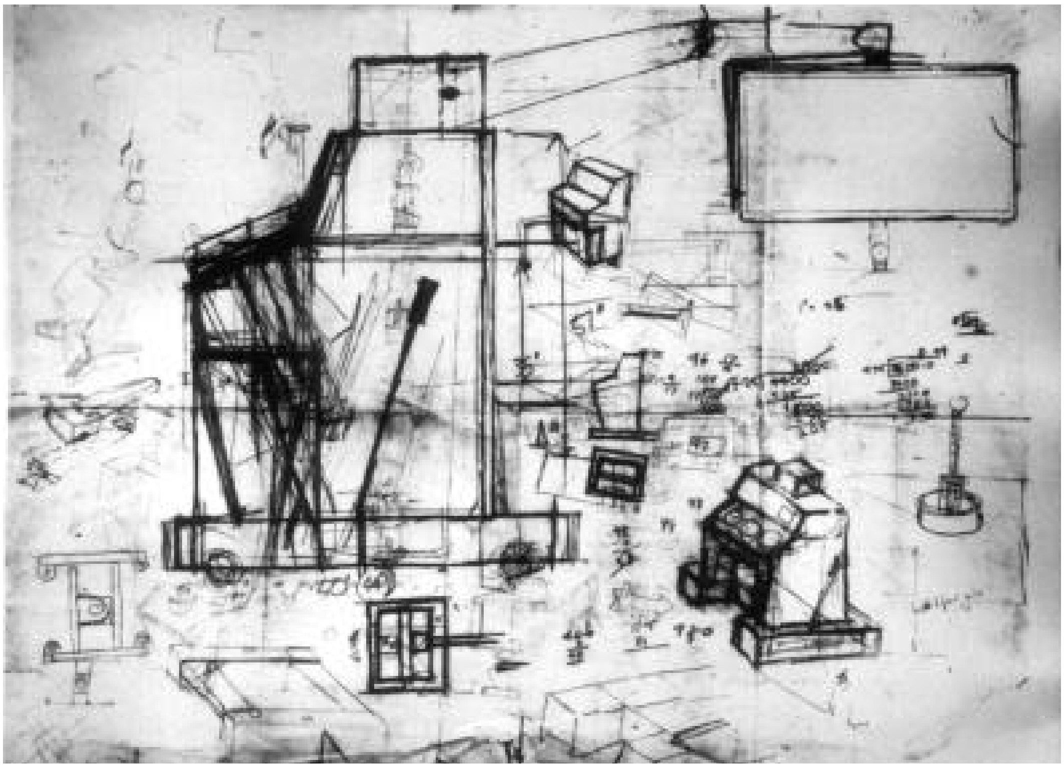

Figure 9. Dugald Cameron's sketch ideas on an original proposal for the Lund machine.

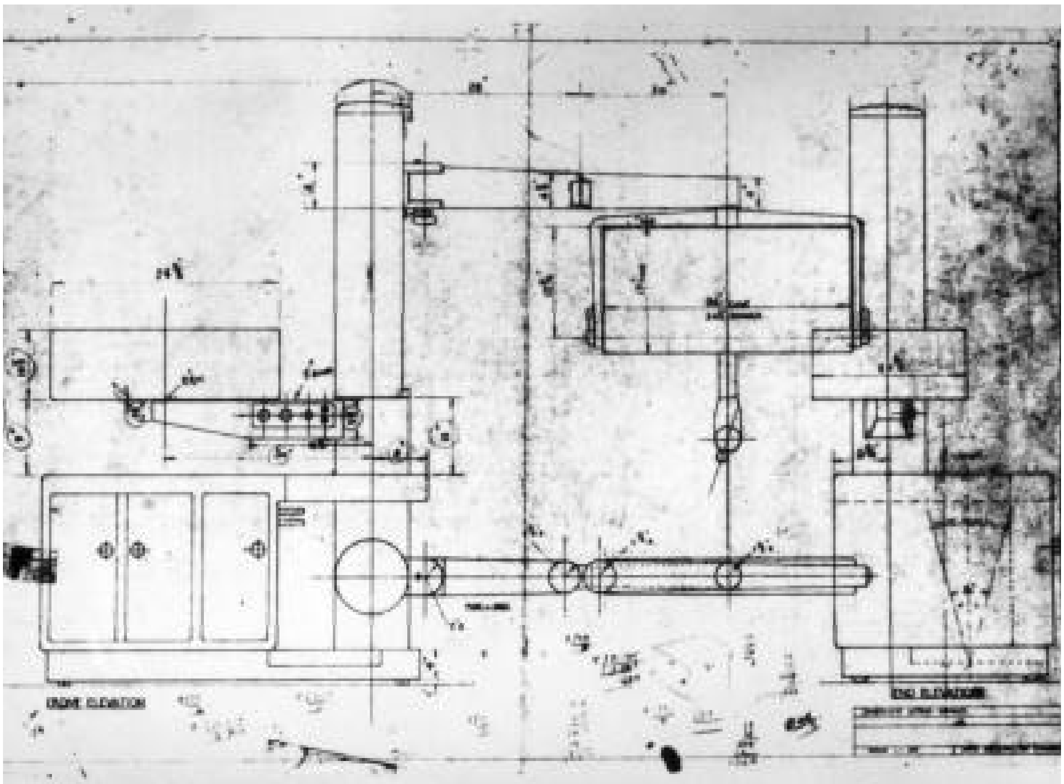

Figure 10. General arrangement: the re-designed Lund machine as it was actually built and delivered. Drawing by Dugald Cameron.

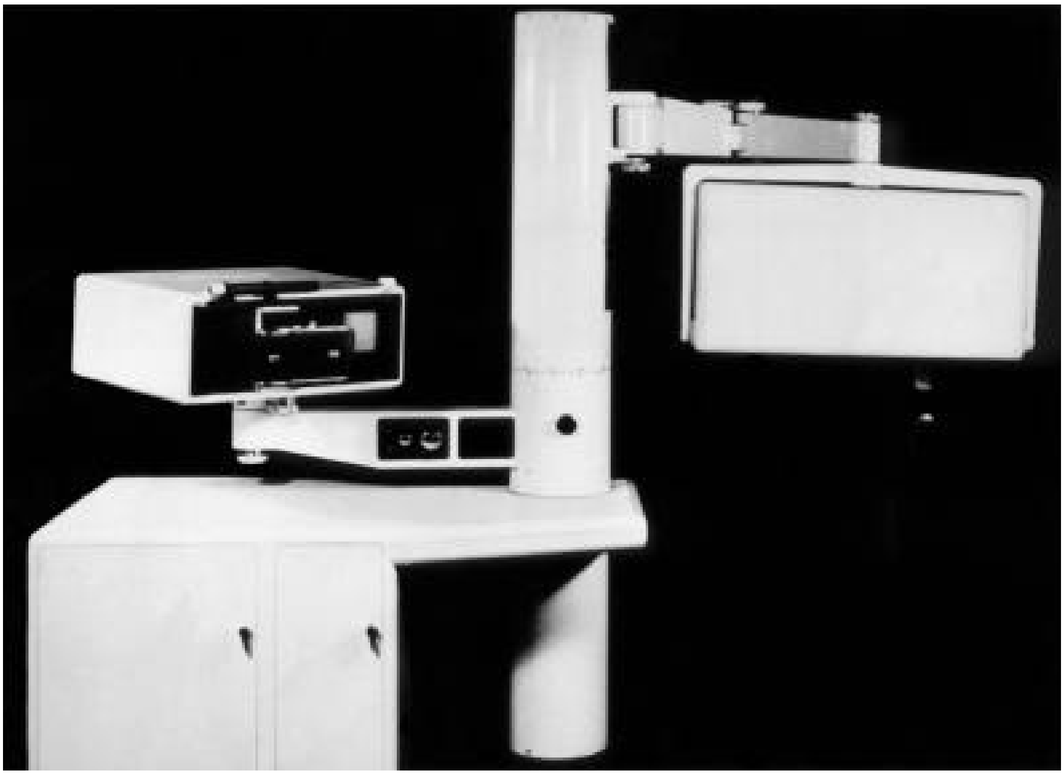

Figure 11. The Lund machine.

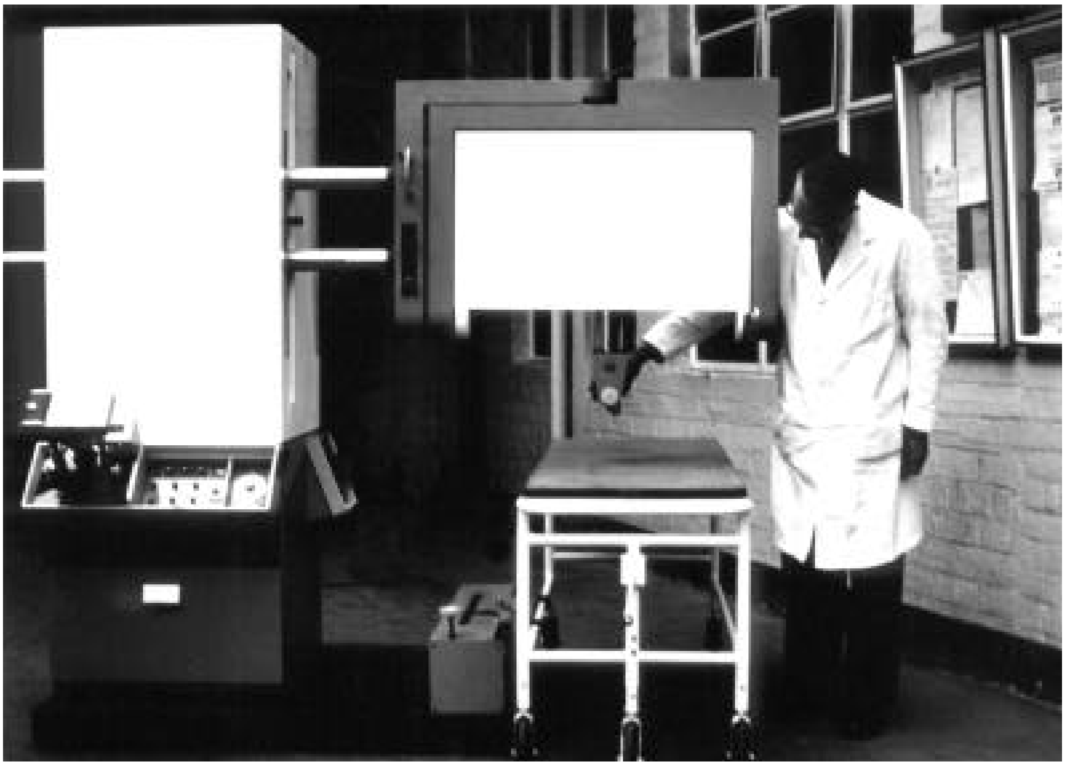

Figure 12. A newly assembled Diasonograph shown at Smiths (Kelvin & Hughes Ltd) Hillington works, Glasgow. Pictured next to the machine, to give an indication of its dimensions, is Arthur Johnson, one of the draughtsmen involved in the project.

Figure 13. The Diasonograph was modular in design and construction. Shown here, on the left of the photograph, is the electronics console which formed the lower half of the machine. The mechanical assembly on the right is the automatic scanner. This was originally used with the electronics assembly designed for the 'bed-table scanner'; at a later date this was replaced by a Diasonograph electronics console as seen here. This photograph was taken in the factory at Hillington, Glasgow, c. 1966.

Figure 14. Control panel of the Diasonograph – industrial design by Dugald Cameron. The most frequently used controls are in the extreme right-hand section: from the top – frequency selector, power switch and transmitter attenuator. The large dial in the centre section was used to set the mode of operation: B-scan, A-scan and inverted A-scan (for echo-encephalography), or M-mode. The other controls in this area are related to these modes of operation. At the left is a camera fitted with a Polaroid™ film back and an information projector to allow recording of patient data together with frequency and sensitivity settings, directly onto the film. A set of controls for occasional adjustment by an engineer are behind the hinged panel below the main control panel. This could be opened by the handle at the bottom of the picture.

heavy looking than I wanted, or than Dugald wanted. However, by that time we had all sorts of other problems within Kelvin & Hughes and at least a machine was produced.

Hall: And this is, in fact, what we are looking at, a Diasonograph (Figure 12). One of the things that always struck me – and I had only ever seen this once before in a Charlie Chaplin movie – a convict with arrows on his suit: low-and-behold, on the back of the Diasonograph on the maker's plate, was a government arrow. That was there, Dr Slark, for a very good reason, which I would like you to tell us about, from the point of view of governmental support of the ultrasound industry at that time.

Dr Norman Slark:[57] As I didn't come on the scene of ultrasound until about the back end of 1970, I feel very much a new boy in this environment. My recollection is that when I joined the Scientific and Technical Branch of the Supply Division of the Department of Health, which was at the beginning of December 1970, there was already at that time a perception of a need to evaluate some of this new equipment. There was, in fact, an evaluation programme just getting going which, as far as I can remember, involved a Diasonograph and also a Picker B-scanner, that looked like an oscilloscope with an arm on it.

Hall: The Picker B-scanner was, in fact, built around a Tektronix Storage Scope.

Slark: I can remember those two systems and we had a programme running with the Atomic Weapons Research Establishment (AWRE). The history was that there had been a cutback on AWRE nuclear weapons work. AWRE was told by the Government that it had to get a certain amount of its income from activity funded from external sources outside the nuclear weapons industry. So AWRE was looking for work. The Department of Health actually placed the technical evaluation of this equipment with AWRE, which was not, I may say, very successful. We intended to do a comparative reporting series. In fact, the delays on the production of reports were such that we decided that we were not going to get satisfactory comparative reports and it was far better to do things serially. That was a lesson we learned the hard way. Subsequent to that, the evaluation of ultrasound equipment was eventually taken over by the Scottish Common Services Agency, where Eric Leask[58] was involved at that time. Coming back to your starting point about broad arrows: there was a broad arrow on it. Perhaps this had some connection with the defence industry or was an original throwback to the early days of ultrasound, but Tom will know why it's got a broad arrow on it.

Brown: I think it may have meant 'This way up'.

Cameron: You may want to know that the configuration was split into the mechanics,

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[57] Dr Norman Slark (b. 1934) worked at the English Electric Valve Company on military and civil imaging systems for 11 years. In 1970 he joined the Scientific and Technical Branch of the Department of Health and was responsible for physics-based medical equipment research and development, later taking responsibility for radiology equipment services and evaluation. He retired from the Department of Health in 1994 but continued his imaging interests on a part-time basis at the Imperial College of Science, Technology and Medicine.

[58] Eric Leask was a senior civil servant in the Scottish Common Services Agency, and actively supportive throughout the period medical ultrasound was being developed in Glasgow and later in Edinburgh. Information provided by Mr Tom Brown, 24 May 1999.

which are the white bits, and the electronics, which were the grey bits. It was envisaged that the electronics, in fact, would be used on their own, so quite apart from sorting out the design of the machine ergonomically, in terms of patient and doctor, it was also sorted out in terms of mechanics and electronics. I would maintain to this day that the original design of this machine would stand up now in terms of its basic configuration, which was carried through and extended, in terms of the design of the Diasonograph.

Just to finish off the design story, this (Figure 13) was the automatic scanner fitted with a new electronics unit, which was the base of the Diasonograph, which in fact was sold on its own.[59] So it did stand up on its own.

The details of it: this was the control panel (Figure 14). It actually took quite a lot of thinking about, because part of Tom's requirement to make it 'doctor-proof' was to make it very easy to use. However, there were naturally a lot of knobs and switches associated with it, which determined three levels of control. For a really experienced experimenter like Donald, you had a whole series of controls in the panel that you brought forward below the control panel, so that was the tertiary bit. The secondary controls were the middle panel on the right of the camera and the primary controls were on the far right and you had a little blind to draw across, so in fact it could be operated by about three knobs.

We were due to get a Design Award, one of the very first ones, for the Diasonograph. Unfortunately, when the evaluation team came up to see it the actual machine was covered in notes and whatnot and I think Professor Donald was showing the full range of its activities and it frightened the life out of them. In fact, had it been a nurse or someone using it, we perhaps would have got the Design Award. There was a lot of early ergonomic thinking that went into the design, particularly for the design of the Sundén machine, which preceded the Diasonograph.

Finally, there was the Diasonoscope (a small portable device), which is basically a tarted up Mark VII flaw detector. We put it on its side in a decent box. I had an awful job with Kelvin & Hughes over the 'hammered-finish' paint. It was the flaw detector which basically produced the Diasonoscope. During the 1980s I renewed my interest with Tom and his three-dimensional scanning developments.

It was a great excitement for me, and Kelvin & Hughes had a rather special spirit about them which I saw from the outside, and even experienced in a way, which was wonderful. Peter Turner (who died a few years ago), the chief engineer at that time went to work for Honeywell[60] after it all folded up very sadly. He didn't like it very much and renewed his flying instructor's licence and then taught me to fly! So I have a lot to thank Tom for, and to thank Elsa Stevens[61] as she was then, for introducing me to the whole thing. It's a curious business to find that the first concept

[59] Mr John Fleming wrote: 'One was sold to Dr (now Professor) Wells and one to a Government department.' Letter to Dr Daphne Christie, 28 July 1998.

[60] Honeywell Controls Ltd, Newhouse, near Glasgow.

[61] Tom Brown's sister-in-law.

drawings were actually done in the basement of Charles Rennie Mackintosh's Glasgow School of Art.

Hall: Thank you. Could I turn to Dr Willocks and Professor MacVicar and ask if they could comment on how the images improved, if at all, from the automatic scanner towards the early Diasonograph?

MacVicar: I believe that Tom always thought I could cheat, because by using the manual controls he insisted I could make the picture look like the diagnosis I wanted. Now that was not really true but it was the stimulus for Tom to find something to remove operator bias, which was why he was so keen to develop the automatic scanner – to stop me cheating! But there were drawbacks to the automatic scanner.

Hall: Usama, you were involved in the early days and if my memory serves me right, one of the areas that you looked at was in fact placenta praevia and its diagnosis by ultrasound.

Mr Usama Abdulla:[62] Yes, indeed. I think Professor Donald was very keen to publicize our results and show the relevance of diagnosing placenta praevia. The placenta could not be seen initially but could be recognized by its fetal surface. For some time we knew that the space was that of the placenta, but placenta praevia was the difficult one to diagnose. Obviously a number of mistakes were made in the early days, but I think eventually the full bladder has helped[63] as we could see the lower edge of the placenta and the segment much more easily than before, and that was a big help. Obviously the use of olive oil on the patient's abdomen made it even easier to visualize.

Hall: Professor Stuart Campbell, would you like to add your bit?

Professor Stuart Campbell:[64] I think it was a great disappointment to Donald that he wasn't the first to publish on placenta praevia, because clearly Usama and Ian Donald

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[62] Mr Usama Abdulla FRCOG (b. 1937) worked with Professor Donald from 1965 to 1969 and together they published many papers on the early uses of diagnostic ultrasound, including placentography (op. cit. note 65 below). His research into the safety of ultrasound continued when he moved to Queen Charlotte and Chelsea Hospitals in London. With his appointments as Lecturer and then Senior Lecturer at Oxford and Liverpool Universities, respectively, he helped to establish the first ultrasound department in each of these cities. He has been Consultant Obstetrician and Gynaecologist at Fazakerley Hospital, Liverpool since September 1986.

[63] A full bladder has the effect of displacing the bowel and therefore allows a clear view of the pelvic organs, including the uterus. Diagnoses of small pelvic tumours and of early normal and abnormal pregnancy were then possible under these conditions. See, for example, MacVicar J, Donald I. (1963) Sonar in the diagnosis of early pregnancy and its complications. *Journal of Obstetrics and Gynaecology of the British Commonwealth* 70: 387–395. Donald I. (1966) The interpretation of abdominal ultrasonograms. In Grossman C, Joyner C, Holmes J M, Purnell E W. (eds) *Diagnostic Ultrasound.* New York: Plenum Press, 316–332.

[64] Professor Stuart Campbell DSc FRCPEd FRCOG FACOG (b. 1936) graduated from the Faculty of Medicine, University of Glasgow in 1961 and in 1965 worked as a research registrar under Professor Ian Donald at the Queen Mother's Hospital, Glasgow. In 1968 he took up a lectureship in obstetrics and gynaecology at the Queen Charlotte's Maternity Hospital in London, working under Professor Sir John Dewhurst, and became Senior Lecturer in 1973 and Professor of Clinical Obstetrics and Gynaecology in 1976. He was Professor of Obstetrics and Gynaecology at King's College Hospital, London from 1976 to 1996 and has been Professor and Chair at the Department of Obstetrics and Gynaecology and the Fetal Medicine Unit at St George's Hospital Medical School, London since 1996. He was President of the International Society of Ultrasound in Obstetrics and Gynecology from 1990 to 1998 and is an Honorary Fellow of the American Institute of Ultrasound in Medicine and Honorary Life Member of the British Medical Ultrasound Society.

were the first actually to show the placenta and I think Ian was very disappointed.[65] I think in fact his paper was held by the *American Journal of Obstetrics and Gynecology* for many, many months and I think he felt that it may have been a little bit deliberate. Ken Gottesfeld brought out the first paper.[66] But if you look at Ken Gottesfeld's paper there are no real images of the placenta, there is a space where you assume the placenta to be, and the displacement of the head forward, as Usama said. The first paper where there was real visualization of the placenta was by Ian Donald and Usama.[67] Ernest Kohorn and I slipped in a smaller paper,[68] in the same issue on the same subject, because I had moved down to London by that time, but clearly he and Usama were the pioneers of placentography.

Dr James Willocks:[69] I would like to say something about the question of manual scanning. As obstetricians we use our hands and Tom [Brown] has made reference to that already. Abdominal palpation is an important part of almost every examination at the antenatal clinic.[70] The eye of faith can certainly be misleading sometimes, and you mustn't allow it to influence you too much, but the long training that we had in abdominal palpation did certainly help when it came to using manual scanning techniques. This, I believe, gave us an advantage over radiographers and others and partly explains why diagnosis by ultrasound has flourished in the hands of obstetricians and gynaecologists.

Hall: I would like just now to digress slightly. There is a technical explanation in hindsight, which is a remarkably predictive factor as we all know. In fact, the early machines suffered from lack of sensitivity and I would like to ask John Fleming and Professor Peter Wells to give some comments on that, because certainly the early Diasonograph series of equipment suffered from inherent instability and other such problems that meant that one couldn't use all the gain that was available there to image the internal body structures.

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[65] Donald I, Abdulla U. (1968) Placentography by sonar. *Journal of Obstetrics and Gynaecology of the British Commonwealth* 75: 993–1006.

[66] Taylor E S, Holmes J H, Thompson H E, Gottesfeld K R. (1966) Ultrasonic placentography – a new method for placental localization. *American Journal of Obstetrics and Gynecology* 96: 538–547.

[67] op. cit. note 65 above.

[68] Campbell S, Kohorn E I. (1968) Placental localization by ultrasonic compound scanning. *Journal of Obstetrics and Gynaecology of the British Commonwealth* 75: 1007–1013. See also Kohorn E I, Secker-Walker R H, Morrison J, Campbell S. (1969) Placental localization: A comparison between ultrasonic compound B-scanning and radioisotope scanning. *American Journal of Obstetrics and Gynecology* 103: 868–877. Morrison J, Kohorn E I, Ashford C, Tredgod C, Walker R H, Blackwell R J. (1969) Ultrasonic scanning in obstetrics. 2. The diagnosis of placenta praevia. *Australian and New Zealand Journal of Obstetrics and Gynaecology* 9: 206–208.

[69] Dr James Willocks FRCOG FRCP (b. 1928) has been Honorary Clinical Lecturer in the University of Glasgow since 1964. He joined Professor Donald in 1958 when first training as an obstetrician and gynaecologist. He began scanning at the Western Infirmary and later moved to the Royal Maternity Hospital where he used the A-scope. His main interest in ultrasound was in establishing fetal cephalometry for clinical purposes. He was Consultant Obstetrician and Gynaecologist at The Queen Mother's Hospital and Western Infirmary from 1966 to 1990. He is the author of various articles on the life and work of Ian Donald, including Willocks J. (1993) Ian Donald and the birth of obstetric ultrasound. In Neilson J P, Chambers S E. (eds) *Obstetric Ultrasound 1*. Oxford: Oxford University Press, 1–18. *idem* (1996) Medical ultrasound. A Glasgow development which swept the world. *Avenue* (University of Glasgow Magazine) 19: 5–7.

[70] Dr James Willocks wrote: 'We were trained to form an "image", as it were, of the fetus by using our hands in gentle abdominal palpation.' Letter to Dr Tilli Tansey, 2 September 1998.

Professor Peter Wells:[71] That's certainly true and I'd like to explain that we used in Bristol the base of the Diasonograph. We were perhaps one of the first groups who actually acquired one of those and at the same time built our own scanning arms, very much like the Physionic scanner, although perhaps a little bit more cumbersome. Our scanner was described in 1964[72] at about the same time that the Physionic scanner came onto the market. Of course we had lots and lots of trouble with the stability of the Diasonograph electronics and it was only because of our firm friendship with Tom Brown, Angus Hall and John Fleming, that we were able to keep this going. I remember making pilgrimages to Glasgow and people from Glasgow came down to help us as well. The thermionic valve and other devices continuously drifted and stories were told of the 'third level of control'. There were other controls hidden inside the machine, which we became more and more familiar with. So we did learn a lot about how to use the Diasonograph as the basis for our scanner.

Can I also put in a word about the American scene? I wanted to try and put that into perspective. I think what we have heard about so far today has been British – particularly Scottish – and that's quite right, but I think it's worth remembering D H Howry's work in Denver in 1947 and that he made his first two-dimensional pictures in 1951 or 1952.[73] Also in the United States, Wild and Reid described their two-dimensional scanner in 1952.[74] At about the same time, developing from Dussik's work in Austria (I think it was with transmission ultrasound),[75] Heuter and Bolt wrote a report for the US Government on the future of ultrasound diagnosis – Heuter and Bolt were tremendous opinion formers in the acoustics world – which concluded that pulse-echo ultrasound wouldn't work, and that the future lay in transmission ultrasound.[76] A year or so later a man called Güttner, I think it was, a neurosurgeon, published a paper demonstrating that even with empty skulls you could get pictures

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[71] Professor Peter Wells FIPEM FInstP FIEE FREng (b. 1936) began work on medical ultrasound in 1960 and, from 1963, was concerned with developments in diagnostic methods. Working with his clinical colleagues Dr (later Professor) Ken Evans and Dr Frank Ross, he constructed an articulated arm scanner that was used with the Diasonograph electronics (see note 59 above) to provide a routine obstetric service in Bristol. He is presently Head of the Department of Medical Physics and Bioengineering of the United Bristol Healthcare NHS Trust, Honorary Director of the Centre for Physics and Engineering Research in Medicine in the University of Bristol, and an Honorary Professor in the University. He is also Editor-in-Chief of *Ultrasound in Medicine and Biology* and was conferred the Ian Donald Medal for Technical Merit by the International Society of Ultrasound in Obstetrics and Gynecology in 1998.

[72] Wells P N T. (1964) Developments in medical ultrasonics. *World Medical Electron*ics 4: 272–277.

[73] op. cit. note 39 above.

[74] Wild J J, Reid J M. (1952) Application of echo-ranging techniques to the determination of structure of biological tissues. *Science* 115: 226–230.

[75] Karl Dussik (b. 1908) began his study in ultrasonography during the late 1930s and was one of the first physicians to use ultrasound for diagnostic purposes, in particular applying ultrasound to brain structures. See Dussik K T. (1942) On the possibility of using ultrasound waves as a diagnostic aid. *Neurology and Psychiatry* 174: 153–168. See also Shampo M A, Kyle R A. (1995) Karl Theodore Dussik – pioneer in ultrasound. *Mayo Clinic Proceedings* 70: 1136.

[76] Heuter T F, Bolt R H. (1951) An ultrasonic method for outlining the cerebral ventricles. *Journal of the Acoustical Society of America* 23: 160–167.

which looked like pictures of the brain,[77] and that put transmission ultrasound into disrepute. I ask whether it set our American colleagues back because of those influential people going along a blind alley, and that gave the British the opportunity to race ahead thanks to Professor Donald's inspirational leadership?

Hall: John, is there anything you would like to add to that?

Fleming: Yes. You have raised the question of sensitivity, Angus. I was talking to Tom [Brown] last night about this and we were recalling that initially there seemed to be the objective of outlining organs in the body, not looking at their texture at all, just the outline.

But this is a very messy, complex sort of issue, because I remember Tom saying that it seemed to be that it was Kossoff[78] in Australia who had shown that greyscale was of value, but Tom was trying to get the full greyscale range of echo amplitudes recorded in the images, right from the beginning.

When I came and did some work on it, I had the impression that all we would ever do was to record the outline of structures and that seemed to be reluctantly accepted. The American machines went along that line quite a lot. When they eventually came into production they were based on this idea – most blatantly, with bi-stable tubes with just simple, black-and-white outlines and no internal structure of the organs. But then as the sensitivity improved, it became possible to record a much wider range of echo amplitudes; as Tom pointed out to me last night, you wouldn't have real time unless you could record a very wide range of echo amplitudes.

Hall: That touches on some work that we did at The Queen Mother's Hospital, which obviously coincided with the failure of Kelvin & Hughes (formerly Smiths Industries).[79] Kelvin & Hughes only ever built, if my memory serves me right, 12 Diasonographs. There was, just for the record, a political crisis in Scotland because yet another Glasgow company was failing. I forget if there was an election or something, but the Scottish office, I suspect, persuaded the Pringles, who owned Nuclear Enterprises,[80] to bail them out by taking over the business.[81] They bought the ultrasound business, and please

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[77] Güttner W, Fiedler G, Pätzold J. (1952) Über Ultraschallabbildungen am Menschlichen Schädel. *Acustica* 2: 148–156.

[78] See, for example, Kossoff G, Garrett W J, Radovanovich G. (1973) Grey scale echography in obstetrics and gynaecology. *Australasian Radiology* 18: 62–111.

[79] See note 2 above.

[80] Nuclear Enterprises (GB) Ltd, Edinburgh.

[81] Mr Tom Brown wrote: 'This is a considerable over-simplification. In reality the Supply Division of the Department of Health at Russell Square, London (Mr Sam Davies, Under-Secretary), played the leading role in finding a new home for what was considered to be a British – not just Scottish – development. Although I was working for Honeywell by then and technically out of that business, I visited Sam Davies and during a memorable interview, in which he agreed to listen but say nothing, gave him a good deal of background information about the situation. He in turn sent me to see various senior people in quite a number of UK companies who might be interested. Towards the end there was in fact quite a bit of competition, but latterly Nuclear Enterprises "came from behind" as it were and took the business virtually out of the mouth of Barr and Stroud of Glasgow, who were confidently expecting to get it. Unfortunately, Nuclear Enterprises did not buy the patent rights, and were content with a "paid-up" royalty-free licence. They paid £25 000 for the business, and for that acquired something like £65 000 of stock and work-in-progress, and recouped their investment many times over. The main patent rights then went to America, which is why I had to make the Sonicaid machine a 3-D one, to get round my own previous patents!' Note on draft version of transcript, 24 May 1999.

correct me if I am wrong, Hans [Gassert], they bought it thinking that they would make a quick buck by selling off the stock for what they could get and then recoup their investment and get the political masters out of a hole. That certainly wasn't the case, because we went on to see the Nuclear Enterprises series of Diasonographs.[82] Maybe Hans Gassert could fill us in on the viewpoint of Nuclear Enterprises' side of the story.

Mr Hans Gassert:[83] Everything that was said already sparks off memories and I don't know if I have been incredibly lucky all my life, because I came to Scotland and stumbled into Nuclear Enterprises because of Mercedes cars. I came upon Tom and Brian Fraser[84] by accident, at a coffee machine, and being the sort of guy I am, I think I said something like, 'What's that old rubbish in the corner?' and they started explaining.

Hall: Just for the record Tom Brown and Brian Fraser, who had both worked for Kelvin & Hughes, had with the equipment joined Nuclear Enterprises in Edinburgh.

Gassert: All I was going to say is that as far as I was concerned at this time I was selling nuclear equipment in Scotland. All of a sudden Tom Brown and Brian Fraser appeared, together with what I thought was a load of old junk – equipment full of valves, which by that time were really old hat. Being technically useless, especially at that time, knowing nothing about ultrasound, I made negative comments about this redundant equipment, and I wasn't surprised that I had to be educated about things like this. So they persuaded me – and I think I have got Tom probably to blame for getting infected by the ultrasound thing – after quite some persuasion, to take a piece of equipment, a simple A-scan unit, to a hospital and to show it to a doctor, because I couldn't see any point in trying to sell this stuff. I remember introducing it to people at the Western General Hospital in Edinburgh along the lines of, 'I am sorry to waste your time, and this is old junk and these people won't leave me alone, they forced me to show this to somebody,' and they said, 'Oh, I read something about this and let's have a look.' And they got a volunteer and looked at the volunteer's head and they got quite excited about it. Then they said, 'By the way, what does this control on the front panel mean?'[85] And this control said, 'Pig alive' and 'Pig dead.' I hadn't noticed that they had given me a 'pig grader' version (sold to pork producers!) of the old Diasonoscope. Anyway, I certainly remember that.

There were stories like this almost every time I tried hard to put people off buying this equipment, and virtually every time they bought it. I was a very slow learner;

[82] Mr John Fleming wrote: 'These were designated NE4101 (which was virtually identical to the Smiths "Diasonograph"), NE4102, NE4200, etc.' Letter to Dr Daphne Christie, 28 July 1998.

[83] Mr Hans Gassert (b. 1944) was in Marketing and Sales at Nuclear Enterprises Ltd from 1962 to 1975 and founded Diagnostic Sonar Ltd at the beginning of 1976.

[84] See notes 14 and 18 above.

[85] Mr Tom Brown wrote: 'This is a good anecdotal after-dinner story, but, in fact, it relates to a very basic and inexpensive instrument produced by Kelvin & Hughes to measure back-fat thickness on pigs. Because sales for this purpose were somewhat disappointing, an enterprising Kelvin & Hughes sales manager, Charlie Oliver, suggested that we might sell it to beauty salons or health farms to convince the clients that they were actually receiving some benefit for their money. The story is, that because of the instrument's origins, one of the controls was (somewhat inappropriately for this application), marked "Live – Killed – Cured" since the velocity of sound in pig fat depends on the status of the pig.' Letter to Dr Daphne Christie, 20 July 1998.

it took me months and months and months before I thought this was rather strange and, then I think it was Tom who was to blame or Brian, they finished me off by taking me to Glasgow where I met Ian Donald. That was a bit like somebody who's slightly religious meeting Martin Luther King, and after that I was totally convinced about ultrasound. Then I met so many wonderful people and had many, many confrontations telling people about ultrasound in hospitals. Usually the response was, 'What is it?' Smart as I am, I used to explain that it was sound that you couldn't hear, and they used then to go on and say, 'Why do I want to buy sound that I can't hear?' Then the arguments went on to what I heard earlier, 'I have had five years of training using my hands to see'[86] and I used to somehow have to explain, 'Well, it's not good enough and you need this machine to see.' It got quite tricky sometimes.

But back to Nuclear Enterprises, and yes, they thought they were making a killing buying the ultrasound business. They didn't know what to do with it to begin with, and I think nobody paid any attention to making any equipment until, I think with a little help from me, we ran out of the first few machines and we had to put together the next few. It was starting to get busy again and it took quite a while before we put together the first B-Scanner. I think they only sold one or so NE4101 Diasonographs[87] – that was really before my time – but then Brian [Fraser] and his colleagues (notably Mr Alan Cole) got busy designing the NE4102, and that was a different game altogether.

Hall: There was an interesting development there if I could comment, because, correct me if I am wrong, Tom, the old Diasonograph was built to be operated by two people, the classic doctor and assistant team. I believe it was planned that, in fact, the doctor would stand on the far side of the machine scanning the patient and somebody else would be operating the controls. Was that the case, Tom?

Brown: The object was to enable the machine to be used by one person. The original design which Dugald [Cameron] produced had an examination couch which was operated from the control panel side of the console. That design was not put into production. What was put into production was a machine that *had* to be used by two people, to my disgust and regret, but I was out of the scene by that time. The original design envisaged a situation where two people might well want to use it – one scanning and the other operating the controls – but it had to be possible in my view, and in our view, to operate the machine singlehandedly.

While I have the microphone, can I outline what actually happened commercially during that period, because it explains a lot of what happened subsequently.

Kelvin & Hughes were in the industrial ultrasound flaw detection business, and had been involved in a long-running law suit with the Sperry Products Division of Automation Industries in the States over fairly fundamental patents on industrial

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[86] This refers to the obstetrician's training in abdominal palpation, described by Dr Willocks on page 30.

[87] See note 82 above.

ultrasound. They were known as the 'Firestone patents'.[88] Kelvin & Hughes had built up quite a respectable set (or 'portfolio') of patents themselves on ultrasound, to which I contributed some, including a very fundamental one on contact B-scanning.[89]

It is astonishing that the ultrasound project survived at all, since after starting in 1956 and being left to run more or less unencumbered until 1959 or 1960, it was suddenly the case that the focus of all ultrasound work in Glasgow had to shift to industrial ultrasound, because of commercial difficulties the company got into over industrial automatic ultrasonic testing equipment.[90] So medical ultrasound had to take a very severe back seat from 1960 onwards. It was during that period that the development of the Diasonograph from the Sundén machine proceeded, but proceeded very much in the background – and very slowly.

It was for that reason that the Diasonograph never went into production until about I think 1965 or 1966, by which time I had left the company, and had been away at Honeywell for a couple of years.

In about 1966 the lawsuit between Kelvin & Hughes and Sperry[91] was finally decided in the US Supreme Court in favour of Sperry, and as part of the settlement thereafter,

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[88] Mr Tom Brown wrote: 'These were mainly to do with high-speed testing of railway track, using the Sperry wheel probe. This was a special ultrasonic probe arrangement with transducers fixed inside two hollow, water-filled rubber tyres which ran, one on each rail, and could detect cracks in them even when travelling at substantial speed. The crucial thing was that there was *something* – i.e. in this case the water and the tyre wall – between the transducer and the thing being tested. This was patented, and the crux of the patent battle was that any arrangement, with *anything* between the transducer and the testpiece, was said to come within the patent claims. The arguments went on for years, but the case was finally lost by Smiths in the US Supreme Court. It was this decision which was effectively the deathknell for all UK involvement in ultrasonic testing, including indirectly, medical ultrasound. *Never, ever,* underestimate the importance of patents!' Note on draft version of transcript, 24 May 1999.

[89] The operating principle of the contact compound scanner was the subject of patents in which Tom Brown is named as inventor (British Patent 863,874 *Improvements in and Relating to the Examination by Ultrasonics of Bodies having a Non-Planar Surface (1958)*) and corresponding foreign patents, including US Patent 3,086,390, the main claims of which are generally accepted as covering all subsequent 2-D contact scanning systems. There was also a little-known patent in which Tom Brown and Roy Haslett are co-inventors: British Patent 941,573 (1959), which anticipated the development of dynamically focused annular array transducers. These and other ultrasonic patents were subsequently acquired by Automation Industries Inc, in America, in about 1967, following the Smiths/Sperry patent lawsuit, and the closure of the Kelvin & Hughes ultrasound business. Information provided by Mr Tom Brown and Mr John Fleming, 24 May 1999.

[90] Mr Tom Brown wrote: 'The work I had done with Alex Rankin [see biographical note 30 above] around 1953/54 had resulted in a patented system for semi-automatic testing of metal parts, with various novel facilities such as stabilization of the test sensitivity, and recording of defect signals from selected regions of the test piece. This was particularly directed at testing of welded structures such as pressure vessels. Unfortunately, the performance of the prototype system made in Glasgow was never equalled by the "production" version, but in the interim the company had accepted a number of orders based on the performance of the prototype. This was to result in a number of disputes between the company and its customers, and in 1961 the entire industrial ultrasonic activity was transferred from the Essex factory to Glasgow to be sorted out. It was this task that occupied the attention of the team which had been originally built up to service the medical ultrasound project, although it was then augmented to support the industrial work. This redirection of resources resulted in the slowing down of development of the Diasonograph medical scanning machine. With hindsight, and from the point of view of overall medical acceptance, it was possibly not an altogether bad thing, because it provided a breathing space in which Donald, and later Sundén, could consolidate the medical usefulness of the techniques.' Note on draft version of transcript, 24 May 1999.

[91] Sperry Products Division of Automation Industries Inc., see note 88 above.

Kelvin & Hughes had to give an undertaking to come out of the ultrasound business completely. This was part of the reason that the Glasgow factory was closed down, and it was the reason that they had to divest themselves of the ultrasound business altogether.

It was for that reason that Nuclear Enterprises came into the picture. They were not the only suitors – there were a number of companies interested at that time[92] – but Nuclear Enterprises finally got it, and they got with it a paid-up licence to make these 2-D ultrasound machines. They didn't have any other licence rights, but they had the right to continue to manufacture 2-D machines to the basic patent. It was for that reason it appeared at the time to be impossible to persuade any other UK company to invest in the medical ultrasound market, making two-dimensional contact scanners.[93] That was the reason, when I went to Sonicaid, that we made a three-dimensional scanner, because it was the only way I could find of getting round my own basic patent on the two-dimensional scanning principles.

Cameron: That's the actual drawing of the Diasonograph [this slide is not illustrated here], which shows the bed that we put in, and which actually moved, and which was an integral part of the machine. That was how it was intended to be.

I hadn't realized, Tom, what had happened, because as a proud Glaswegian very much working in the city, I've watched the decline of industries along Clydeside – not only the shipbuilding but things like Kelvin & Hughes, a very proud name. It's a very sad business to see how many things were in fact developed, even invented, in Glasgow and the West of Scotland, which we now import. When we look at the unemployment, and so on, there's a social dimension and an economic dimension to the whole business, quite apart from the other fundamental parts of this, and it's a very sad story that we have. The ultrasound story is something that we should have been able to do. I hadn't realized in fact that Sperry had put the spanner in the works.

Hall: We now have the situation where we have got contact B-scanning: a new generation of equipment – the NE4102 series of equipment – was (dare I suggest it) more ergonomically designed so that the operators could scan, and also the controls faced them. This was probably, with hindsight, a forward step but a reverse step at the same time. That was, unfortunately, because the only means of recording images easily was to use what engineers called 'bi-stable storage tubes'. They, of course, reinforced the outline approach to imaging, where you didn't see the entire contents of the abdomen. If we now look at modern images, they are full of greyscale

[92] A survey commissioned by the National Science Foundation in the 1970s suggested there were five firms selling on the US market by 1969 (including one Japanese firm, Toshiba) and twelve by 1973. (By the end of the 1970s there were around 37 firms offering equipment worldwide.) See Colton R M. (ed.) (1982) *Analysis of the Five National Science Foundation Experiments to Stimulate Increased Technological Innovation in the Private Sector*. Section V (medical instrumentation). Washington DC: National Science Foundation.

[93] Mr Tom Brown wrote: 'Automation Industries, having acquired the basic medical scanning patents, went on to try to enforce them and claim royalties from all the manufacturers then in the field, but this was resisted, and, it is said, that it was the threat of an anti-trust action which dissuaded them, and cleared the way for future competitive development of ultrasound scanners. Nevertheless, the demand for a substantial initial fee plus punitive royalty demands thereafter existed for some years and inhibited commercial development of other 2-D scanners.' Note on draft version of transcript, 24 May 1999.

information; they give all the visual clues to diagnosis. If we could jump ahead a bit, possibly to think about the introduction of scan conversion, I wonder, John Fleming, if you might give us some input to what was a very significant development in modern imaging.

Fleming: Yes, it suddenly allowed you to store images with significant greyscale. The first scan converters were introduced for television systems conversion,[94] but they were applied to ultrasound, which was a different format of scan conversion and you got a bright, clear image. The first ones were analogue and pretty unstable. You needed to be a bit of artist to keep them adjusted correctly, but it was a very significant step.

Hall: The problems that the early scanners had focused on the fact that they used Polaroid™ film, which has poor characteristics anyway in terms of greyscale.[95] What you were asking the operator to do was to scan a variable-size abdomen, requiring certain sensitivity of controls, at speeds such that you managed to expose the picture properly on this Polaroid™ film; very difficult to do. Scan conversion removed that; it has what we would call a 'peak memory', which simply remembered the peak value of echo stored in any one location. You could scan over an area and it would simply record the maximum value. It simplified the scanning process. We could photograph the result after we'd looked at the image. Still not easy to do, but it became much more practical. At the same time we moved into the advent of real-time scanning[96] and there were two developments there. There was the linear-array real-time scanner with no moving parts, followed possibly by the rotating-wheel type of mechanical

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[94] They were first developed to convert from the original 405-line TV standard developed by EMI to the 625-line system. Information provided by Mr Tom Brown and Mr John Fleming, 24 May 1999.

[95] Tom Brown wrote: 'This touches on a very significant historical twist in the ultrasound story, which is central to an understanding of why things happened the way they did. It is misleading to suggest that the greyscale limitations "focused" or were otherwise due to the use of Polaroid™ film. The characteristics of Polaroid™ film were known, and could be accommodated in the design of the electronic system. Alternatively, as was done for a time, the "bottom bend" in the photographic characteristics could be compensated by slightly pre-exposing the film before use in the "light box", which was otherwise used to photograph the record card giving details of the scan. However, the most significant issue is that first Douglass Howry, and then independently myself, and later Kossoff who took the process even further, recognized the potential advantages of "compound scanning" and integration of the echo information on a photographic emulsion. This allowed the build-up of genuine echo information obtained during multiple "passes" of the scanning sound beam over the target structure, while spurious artifacts, due to reverberation or side lobes, faded into a background haze. It also had the subtle advantage of exchanging some redundancy in the scanning process for an enhancement of the otherwise poor lateral resolution of the transducer, by "looking" at the same target from several different directions. As Kossoff in particular demonstrated, this also led to quantitatively meaningful greyscale rendition. This process has much in common with signal averaging techniques used in other fields to extract genuine signals from a noisy background. However, these advantages only arise with a systematically executed compound scan, and in practice few manual operators carried out such a scan properly, and so the full advantages of photographic integration were seldom achieved. The significance of the use of a peak-reading scan converter was that it made it easier for a user to obtain a relatively indifferent if passable image, even with poor scanning technique, but it completely negated the advantages of compound scanning and signal integration (see Brown T G. (1967) Visualization of soft tissues in two and three dimensions – limitations and development. *Ultrasonics* 5: 118–124). There is a curious side-light on all this, in that CT scanning can be regarded as an extreme example of "viewing" the radiodensity of tissue cells from a multiplicity of positions, and using computational methods rather than photographic integration to make a diagnostically useful cross-sectional image.' Note on draft version of transcript, 24 May 1999.

[96] For a review see Winsberg G. (1979) Real-time scanners: a review. *Medical Ultrasound* 3: 99–106.

scanner.[97] Certainly that type of scanner was an adjunct to the Diasonograph series of equipment manufactured by Nuclear Enterprises. I would like to hear how that development came about.

Dr Tony Whittingham:[98] I came into ultrasound in 1970. At that time it was a world of contact scanners and water-bath scanners. Phased arrays had been invented by Jan Somer in Holland:[99] this was a way of electronically steering a beam from a fixed point against the skull. He was interested in imaging the brain. His system had side lobe problems and the beams were rather wide, so few people were getting really excited by this work.

There had also been some work done by Buschmann, developing an eye scanner based on 10 discrete transducers arranged around the arc of a circle,[100] but generally everything was either contact scanner - or water bath-based. Suddenly into this situation, in 1971, came a publication by Bom in Holland. He arranged 20 disk transducers in a block of plastic in a linear format so that each one looked straight ahead. By switching between these elements (transducers) in sequence, hecould produce a 20-line image of the moving heart, with frame rates of 190 frames per second.[101]

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[97] Largely developed by Professor McDicken's (see biographical note 109 below) group in the Department of Medical Physics at Edinburgh University, and incorporated into the Nuclear Enterprises Diasonograph products. Information provided by Mr Tom Brown and Mr John Fleming, 24 May 1999. Dr Angus Hall wrote: 'There are various ways of producing a real-time image by mechanical means, either by rocking a single transducer backwards and forwards or by using a rotating wheel. In either case the imaging format is a sector. In collaboration with the Department of Medical Physics, University of Edinburgh, Nuclear Enterprises produced a real-time scanning assembly based on a rotating wheel driven by a stepper motor. Within the wheel were four discrete transducers mounted radially at 90-degree intervals. The active face of each transducer was flush with the wheel rim. The wheel was coupled to the patient via an acoustic window. The transducer assembly could either be used with a stand-alone electronics unit or be plugged into the later series of Diasonograph instruments, in which case the operator had the option of either contact B-scanning or real-time sector imaging.' Letter to Dr Daphne Christie, 11 August 1999.

[98] Dr Tony Whittingham FIPEM FInstP (b. 1944) has been Head of the Ultrasonics Section at the Northern Regional Medical Physics Department at Newcastle General Hospital since 1972. He has been teaching ultrasound scanning since the 1970s in Aberdeen, and later Newcastle-upon-Tyne, and pioneered the development of linear-array scanners in the UK. He was President of the British Medical Ultrasound Society from 1988 to 1990.

[99] Somer J C. (1968) Electronic sector scanning for ultrasonic diagnosis. *Ultrasonics* 6: 153–159. Somer J C, Lengdeek J. (1971) Ultrasonic processing for medical diagnostics. *Proceedings of the British Acoustical Society*, Spring Meeting, April 1971. Mr Tom Brown wrote: 'Though Somer pioneered their use for medical purposes, phased-array beam-steering systems had been known for a very long time before that, having been developed and used extensively in submarine warfare, but the technology was all classified. Bill Halliday, Kelvin & Hughes' Chief Scientist to whom I was sent in 1956, was in the difficult position of knowing a good deal about this, but was inhibited from telling me because of the Official Secrets Act. Several parties, including Professor D G D Tucker's group at Birmingham University, had been attempting to have the work declassified by developing alternative means of doing the same things. It was Tucker's published work, coupled with that of Voglis, which prompted Haslett and me to file our application for patents in 1959 (see note 89) covering an annular array dynamically focused transducer system, intended for medical purposes (Tucker D G, Gazey B K. (1966) *Applied Underwater Acoustics*. Oxford: Pergamon Press Ltd).' Note on draft version of transcript, 24 May 1999.

[100] Buschmann W. (1964) Ein neues Gerät der Ultraschalldiagnostik. Proceedings of *Symposium Internationale de Diagnostica Ultrasonica in Ophthalmologia*. Berlin, 3–5 June, 1964. Augenklinik der Charité: Humboldt–Universität zu Berlin, 31–35. *idem* (1965) New equipment and transducers for ophthalmic diagnosis. *Ultrasonics* 3: 18–21.

[101] Bom N, Lancee C T, Honkoop J, Hugenholtz P G. (1971) Ultrasonic viewer for cross-sectional analysis of moving cardiac structures. *Biomedical Engineering* 6: 500–503, 508.

I think it was in 1971 that I was at a meeting of the British Medical Ultrasound Society in Glasgow. Bom was unable to attend to present his work, but he sent a film. I remember to this day the excitement when the film was shown of his 20-line image. The audience stood up and applauded the celluloid, because Bom wasn't there to receive the accolade himself. That, to me, showed that a hand-held, lightweight probe that could be moved around the patient was now possible. None of this cumbersome equipment, water-bath or otherwise, was there to hover over the patient, and it was the way forward. The problem was that 20 lines is nowhere near enough for an acceptable diagnostic image. As you know, if you look at a television screen there are 500 visible lines, and the line structure becomes evident once you get below about 200 lines. So the challenge that I saw was how to make the number of lines greater. I tried various ideas, but the one that worked was to make an array of very narrow rectangular elements and to use a group of these to form a square aperture. This group of elements defining a composite transducer would scan the line in front of itself. Then you drop one element off from one end, put another element on at the other end, in front of the group, and advance the active group along the array in this way. When I was doing this I was totally unaware that it would work. I hoped it would work, but I was worried that there would be cross-coupling from the end elements of the group into what should have been passive elements, so that you might not be able to get a well-defined active aperture. But it did work, and that proved to be the way forward, because you could make finer and finer elements and get more and more lines into the array.[102]

Tom Brown has said he was unaware of the work of Howry[103] when he was developing the contact scanner and the water-bath scanners. I subsequently found out that King in America was working on the same idea as me.[104] He had a group of three elements in the array, whereas I had four. Today the number of elements goes up to 128 or more. I think this has been a feature in the development of medical ultrasound. People have been very enthusiastic. They have had an idea but they have been perhaps less than perfectly diligent in doing the literature searches. We have found that time and again people have got excited, thinking that they have invented something, and they have, in fact, been one of a number of simultaneous inventors.

Hall: I wonder if I could ask Professor Campbell to comment on the introduction of real-time scanning in conjunction with NE4102? Because, to be provocative, it seems it was almost a rear-guard action – the static B-scanner, with the facility to do real-time scanning as an add-on. Did it really have a part to play, Stuart?

Campbell: If I can just go back a little, one of the seminal moments in my scanning career was when I first saw Kossoff's pictures from Australia where he used the

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[102] See Whittingham T A. (1979) *Theoretical and Experimental Studies of Real-Time Ultrasonic Imaging in Medicine.* PhD Thesis. Newcastle upon Tyne: University of Newcastle upon Tyne.

[103] op. cit. note 39 above.

[104] King D L. (1973) Real-time cross-sectional ultrasonic imaging of the heart using a linear array multi-element transducer. *Journal of Clinical Ultrasound* 1: 196–200.

Octoson.[105] I know he used a water-delay scanner, but he was the first, to me as a clinician, to introduce the concept of greyscale. Subsequently the scan converters came along very quickly and greyscale was introduced to the Diasonograph, to our B-scanner.

When I was at Queen Charlotte's Hospital (I had moved to London), I was asked to train some people in Singapore in ultrasound. I went with great alacrity – I had never been so far away before – and it was a Siemens Vidoson machine, with flickering real-time images. A rotating mirror produced the real-time image, but it was cumbersome and very difficult to use and no way was the resolution as good as the Diasonograph. So I really didn't think much of real-time at that time. Then I paid a visit to Montreal to give a lecture. Fred Winsberg, who invited me, said, 'Do you want to see the ADR[106] real-time scanner?' It was Marty Willcocks [founder of ADR] who was the one who really developed electronic real-time scanning in a commercial way. I went down and I was just so bowled over with this concept of placing a linear-array transducer on the patient, seeing the fetus and its movements, and with the ease of scanning that I picked up the phone and phoned the Chief Executive of my hospital straight away and said, 'You must buy this machine, it would cost £13 000.' So I ordered it straight away and took it back to London and to me it was one of the most staggering innovations in ultrasound I had experienced in my life. It, of course, made scanning immediately much easier. In fact I led a very nice life at the time with the Diasonograph because you needed years of practice to be able to use it, and once you reached that level, very few people could overtake you, for the Diasonograph was the best machine in the world.

Even before the scan converter, the Diasonograph had some levels of dynamic range[107] – I don't know if Tom [Brown] can talk about that – which was much greater than the Picker machine in America. So I could virtually go to America anytime and know nobody had got anywhere near the quality of the images or the techniques that we were using.

All of a sudden, with real-time, anybody could be trained to do ultrasound very quickly. It universalized ultrasound. It meant that ultrasound took off in virtually every district hospital very, very quickly. If we had stayed in the static era, it would still have been in the hands of an elite few who had trained and practised the craft of ultrasound. Now ultrasound became a universal technique, so real-time was the great breakthrough.

Hall: It's interesting to hear your comment about Kossoff's water-bath scanner,[108] because using that type of water-bath scanner obviously gave you much more control

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[105] op. cit. note 78 above.

[106] The Advanced Diagnostic Research Corporation (ADR) was founded in February 1972 in Tempe, Arizona, to research ultrasound technology for obstetrical and abdominal applications. ADR developed the first commercial linear-array real-time scanner; these were marketed in 1974. An improved machine, Model 2130, was announced in 1976. ADR was acquired by Advanced Technology Laboratories Inc in 1982, now one of the large ultrasound companies. Information provided by Mr Tom Brown and Mr John Fleming, 24 May 1999.

[107] op. cit. note 111 below.

[108] op. cit. notes 78 and 95 above.

over the scanning time and speed and therefore it was easier to fit the returning echoes into the exposure characteristics of the film, again a problem of contact B-scanning.

Professor Norman McDicken:[109] Just to complete the picture. You mentioned the spinning wheel real-time scanner. I think one of the things that we learned from the Australian work was the value of good transducers and the importance of very weak signals. Although we called it greyscale scanning, we had good transducers and we kept very weak signals in the picture. As better and better transducers were put onto the Diasonograph and we thought that, since the linear-array images and so on were still fairly crude, we could do better if we could get the transducers off the Diasonographs, put them on a wheel and spin them in an oil bath, with a small hand-held device.

So we developed that. We did that in Edinburgh, actually, and sold it to EMI (by that time, Nuclear Enterprises had become EMI).[110] So that's how that real-time scanner ended up on the Diasonograph and there was also a stand-alone unit. I think EMI sold about a thousand of them, so they came in with good-quality images. That sort of technology functioned well; we can still buy them, but it's something like 15 years into the lifetime of that type of real-time scanner. There was a very immediate debt in the subject to the Australian work when things started looking like anatomy. It was a very significant step forward.

Brown: The whole question of greyscale is shrouded in quite a bit of misunderstanding, I think. One of the things that one learned from radar technology is that the signals which come back from a target area are of two types. There is specular reflection, which is when the energy is reflected as though from a mirror, and the size of the signals which come back can be extremely high. Then there is scatter, which is from the substructure of the medium through which the energy is being transmitted. The fact of the matter is that in the early days of contact B-scanning the sensitivity, particularly of the quartz transducers which were available, was such that one could really only obtain specular glint echoes.

A lot of the early effort was devoted to increasing the dynamic range[111] of signals that could be captured and presented on the display. Although I had been unaware of

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[109] Professor Norman McDicken FIPSM (b. 1940) took up medical ultrasonics in 1967 when he moved to the Department of Clinical Physics and Bioengineering in Glasgow after completing his PhD in nuclear physics at the University of Glasgow. He ran probably the first teaching course in the world on medical ultrasound, set up by Dr John Lenihan, Director of the Physics Department. In 1974 he moved to the University of Edinburgh to continue work on ultrasound and became Professor of Medical Physics and Medical Engineering and Director in 1988.

[110] Electrical and Musical Instruments (EMI) (Middlesex) traditionally made records and home entertainment equipment, having pioneered electrical (in place of mechanical) recording in the 1920s and television in the 1930s. Later they were heavily involved in Radar and other defence projects. EMI, who had developed a phased-array system, model 4500, took over the ultrasound division of Nuclear Enterprises in 1977, recognizing the prospects that ultrasound was seen as having and hoping to consolidate their position in the medical field. EMI's role in computed tomography (CT) and nuclear magnetic resonance (NMR) is described in Christie D A, Tansey E M. (eds) (1998) op. cit. note 22 above. Mr John Fleming wrote: 'Would it be correct to say that EMI is better known for its involvement in CT than NMR? Perhaps it is just me as I worked with [Professor Sir Godfrey] Hounsfield before he got onto CT; hence I was very aware of that work although I had left EMI.' Note on draft version of transcript, 24 May 1999.

[111] Mr Tom Brown wrote: 'As time went on we could also see that there were smaller echoes present, but there was a practical problem in the electronics, complicated by the limited range of tones available in the film, of somehow "compressing" the very large and very small signals into the same image – this is what is called the "dynamic range".' Letter to Dr Daphne Christie, 20 July 1998.

Howry's work at the time we started in 1956,[112] I subsequently got to know Doug Howry very well indeed and we became quite close friends. I found a parallelism between his approach and my own, in terms of 'hunting for (weak) echoes' using a compound scanning process.[113]

One of the subtle advantages of the compound scanning process is that it enables you, with a fairly wide acoustic beam, to exchange a certain amount of redundancy in the scanning process for an enhancement in the azimuthal (lateral) resolution. The initial *raison d'être* of compound scanning was to find echoes from structures which did not lie parallel to the skin surface, but it had this additional bonus of enhancing the resolution by redundancy in the scanning process. That resolution enhancement is the same basic technique which was used in neurology for signal averaging of electroencephalogram signals coming back from the brain, hidden beneath a noise level. Curiously, it is the fundamental principle that underpins the CAT scanner.[114] The CAT scanner just does it on a grand scale.

So it was a sound principle, but because we were focused on this business of specular and non-specular echoes with a very large dynamic range, and all the difficulties this led to, I tended somewhat to discount the early real-time scanning attempts – particularly the 20-element array.

It was a bit like the occasion when Lord Kelvin was reputed to have said that heavier-than-air flying machines were a physical impossibility.[115] It was a mistake, and a mistake on a grand scale, and it didn't take me terribly long to realize it. The thing that real-time has that contact B-scanners don't have is the vital ability to display motion.

If you display a moving picture to someone, then that someone will see – or will believe they see – far more detail in the image than they will do if you freeze that image and present them with a still picture. The reasons behind it are to do with the ways the brain processes information. These are very subtle and I wouldn't even attempt to explain them, but you have only got to go to a cinema and see a moving picture and then stop it as a still frame to realize the immediate degradation in the quality of the image. It is that which to me is the real magic of real-time scanning.

Hall: I wonder if we could just go back and talk about the scientific and technical aspects of an area that Professor Stuart Campbell was very much instrumental in following on from the work of Dr Willocks and, I think, yourself, Professor MacVicar – namely fetal measurement, first of all biparietal diameter measurement, and then, of course, later on, area and circumference measurement. Dr Willocks, as I recall, you started off on fetal growth and fetal maturity simply using A-scan equipment. Would you like to tell us something very briefly about that?

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[112] See note 39 above.

[113] See notes 15 and 95 above.

[114] Mr John Fleming wrote: 'Originally the technique was referred to as computed axial tomography (CAT); later axial was dropped (CT).' E-mail to Dr Daphne Christie, 26 October 1999.

[115] Lord Kelvin was Professor of Natural Philosophy at Glasgow University, see note 2 above.

Willocks: There was a flaw detector available in the Royal Maternity Hospital in Glasgow. Now I must explain that Professor Donald had responsibility for two separate departments, obstetrics and gynaecology. Gynaecology was at the Western Infirmary, which he made his base and where all the ultrasound equipment was established. But the project of studying fetal biparietal cephalometry was conducted naturally enough where the pregnant women were, at the Royal Maternity Hospital at Rottenrow on the other side of the city centre.[116] There was nowhere to keep the equipment; it just stood in the corner under a sheet. There was no cupboard even in which to store it and we had to wheel it around the wards on a little trolley. There were a number of things that assisted us in getting reasonable results. One was that perfected by my colleague, Tom Duggan:[117] the technique of the electronic cursor, which produced the bright spot on the sharp echo that you obtained from either side of the biparietal diameter if you were examining correctly. We were then able to conduct a series of pathological studies at the same time to give some information about the speed of ultrasound in the various components of the fetal skull, scalp, bone, etc. So we were able to produce a reliable figure for converting time into distance and seeing what the biparietal diameter was. A-scan hung on, in this area, because it was the only equipment we had on site to do this, and it gave reasonable results.

You have referred to our use of serial measurements of the fetal head during pregnancy to indicate growth. This was the first study using ultrasound to measure fetal growth anywhere in the world. It proved to be of considerable importance.[118]

When The Queen Mother's Hospital opened in 1964 everything became unified and I think we should hand over to Professor Campbell at this point, because it was he who developed the technique further, using the B-scan presentation, and planned an outline of the fetal skull which provides more sophisticated results.

Campbell: I came to The Queen Mother's Hospital in 1964 and in 1965 was made a Hall Tutorial Fellow which is a position, I was told, where everybody subsequently succeeded, so there was a great onus on me to succeed. I was attached to the man with the machine – that is, James Willocks – because he used to go round the wards with

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116 Willocks J, Calder A A. (1985) The Glasgow Royal Maternity Hospital 1834–1984. 150 years of service in a changing obstetric world. *Scottish Medical Journal* 30: 247–254.

117 Tom Duggan (b. 1933) began working with Ian Donald in the Department of Midwifery, in March 1959, on neonatal respiratory problems. He transferred to the Department of Anaesthetics in March 1962, but continued to work with Donald, and that year developed the prototype 'fetal cephalometer' in collaboration with Dr James Willocks [see biographical note 69 above]. This, also known as an 'ultrasonic caliper', added bright dots to the A-scan trace. These dots could be set onto the echoes defining the biparietal diameter and their separation, in millimetres, could be read from a dial. Tom Duggan was employed by Kelvin & Hughes from February to November 1963 to assist with transducer development, and then went on to work for the University of Strathclyde from 1963 on tissue mechanics, and later at Mearnskirk Hospital on powered prostheses. In 1973, following the departure of Norman McDicken [see biographical note 109 above], he joined Dr Lenihan's department to take over running the courses on medical ultrasound. Information provided by Mr Tom Brown and Mr John Fleming, 24 May 1999.

118 See Willocks J. (1963) *Foetal Cephalometry by Ultrasound*. MD Thesis. Glasgow: University of Glasgow. Willocks J, Donald I, Duggan T C, Day N. (1964) Foetal cephalometry by ultrasound. *Journal of Obstetrics and Gynaecology of the British Commonwealth* 71: 11–20. Willocks J, Donald I, Campbell S, Dunsmore I R. (1967) Intrauterine growth assessed by ultrasonic foetal cephalometry. ibid. 74: 639–647.

the Diasonoscope, this metal flaw detector which displayed little blips from the sides of the fetal skull. James said that it gave reasonable results, but I also went round with a pair of calipers and measured the baby's head afterwards to see how they correlated, and they didn't always correlate very well.[119] That was understandable, because the right section of the head often wasn't always obtained. I then learned with Ian Donald how to scan with the Diasonograph. I started to scan the fetal head and I was able to work out the planes, to be able to cut the fetal head so that you could always see the midline echo, which we called the falx. I think it was the medial aspect of each cerebral hemisphere, so that if a true transverse section of the head was obtained, the midline echo was always in the middle of the skull. Then I switched to the A-scan for measurement, because in those days you could get a more precise measurement with the A-scan. Now we don't bother: we just put calipers on the B-mode image, but the technique is basically the same. You have to align the probe, but it's so much easier with real-time now to obtain the correct plane. In those days it took time to adjust the scanning gantry so that the midline echo was in the middle and aligned right down the middle of the brain. So I built up what I regarded were accurate charts of the growth of fetal skull throughout pregnancy. There was no such thing as research fellowships in those days. You did your research when you were a Registrar. So I had my clinic on Sunday mornings. I said to Ian Donald that cephalometry was the new religion. So all these Glasgow ladies who were very tolerant of me came up on Sunday mornings and I measured their babies' heads and drew graphs of the normal growth of the skull throughout gestation and then started to check gestational age by early measurements, and then when I went to London I got onto abdominal circumference and other measurements.

Hall: John, could you, just for the record, talk about the development of the incorporation of cephalometry into B-scanners, because that was not an overnight process.

Fleming: Yes. I'll go back a step. At Smiths[120] we built a Diasonoscope which was an A-scan instrument designed for echo-encephalometry. That had an add-on unit which matched it visually, which was a fetal cephalometer, unbelievably large in volume. That was sold for a while as a fetal cephalometry system, but then that quickly disappeared with Stuart's work and the cephalometer was added to the Diasonograph.

Hall: I have got to stop you. There was another stage before that. If my memory serves me right, Stuart actually scanned the patient, found the right location, and actually switched over to the cephalometer, which was quite separate.

Fleming: I never knew how that switch actually got there. I think Stuart must have put it there himself. He's an electronic engineer and he doesn't let on. Yes, there was a coaxial switch, rather a strange device, stuck on the bezel of the Diasonograph so he

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[119] Dr James Willocks wrote: 'The measurement made by ultrasound was checked after birth by measuring the baby's biparietal diameter with a caliper fitted with a Vernier scale. It was interesting that babies born in the normal way usually had a measurement less than that obtained antenatally by ultrasound. This was due to the moulding process during birth. Babies born by elective Caesarean section had measurements which correlated much more accurately with the antenatal measurements by ultrasound.' Letter to Dr Tilli Tansey, 2 September 1998.

[120] See note 2 above.

could scan, get an image, and then switch over and do his measurement on a Mark VII flaw detector and I, do have a picture of that. Yes, you are quite right.

Campbell: One of the frustrating things was the caliper dials – they wouldn't go below 5cm. Therefore all my charts started at 20 weeks initially and it was only when eventually John [Fleming] managed to get them to go right down that I extended them right down to about 14 weeks.

Hall: And then after that, John – if I can prompt you – the cephalometer was installed alongside the static B-scanner.

Fleming: Yes, but it was just an add-on unit. It was only when you came to the NE4102 that the caliper became part of the scanning machine.

Hall: And that really led to modern measurement techniques as we now know them?

Fleming: And then you [Hall] and I, if I can just jump ahead slightly, developed an area perimeter measuring unit, which again was an add-on to a Diasonograph.

Campbell: Just one trivial thing. One of the things that I did differently was that, while most people sat to scan, I stood to scan, because it meant that I could switch over to the A-scan machine much more easily, and also I could get through more patients much more quickly. So the huge gantry of the Diasonograph I managed to push around while I was standing, and I found that that speeded up the process. I remember Ernest Kohorn[121] coming from London and saying, 'Oh, that has opened a new vista; standing to scan has made a big difference.'

Hall: It was always said in the early days that an alcoholic tremor could be an asset, because these early operators actually indulged in a form of manual real-time scanning. Certainly looking at an early pregnancy, they would scan in a darkened room looking at the long persistent display on the Diasonograph, and you could see very clearly what Tom [Brown] was alluding to. You could see the moving fetus, yet when photographed on Polaroid™ film there appeared to be very little there. It was a very early demonstration of the persistence of vision and also what the eye can integrate and interpret. Malcolm, you wanted to say something.

Nicolson: If you indulge me just a bit, it goes back to my first comments and what Tom said about them. Tom kindly suggested that the slide of the Mark IV ultrasonic flaw detector wasn't the appropriate one. He's quite right, of course, that the first one that Donald used clinically was the Mark II and, I suppose, being defensive as we historians are, I should explain to you why I picked the slide of the Mark IV to show, rather than the slide of the Mark II. The reason I picked the Mark IV was that our researches in Babcock and Wilcox,[122] in reconstructing the experiments that Donald did at Babcock and Wilcox, have led us to the opinion that the very first machine that Donald had in his hands was actually a Mark IV, albeit only

[121] Ernest Kohorn was then at University College Hospital. He published work with Campbell on placental localization. op. cit note 68 above.

[122] See note 11 above.

for two days at Babcock and Wilcox. But the first clinical work done was with the Mark II.

Hall: I must thank our clinical colleagues for their forbearance in an arena which was somewhat technical at some stages, but brought back memories to quite a few of us. I would now like to deal with the clinical aspects of the development of obstetric ultrasound and could I suggest we just follow the same format, starting with the early days and working forwards and to that end I would like to invite James Willocks to open this session by giving us a very quick overview of the early days and then you will be followed by Professor MacVicar who will expand on that.

Willocks: Professor MacVicar and I have always had a certain crisis of identity. We are like Tweedle-dum and Tweedle-dee, we always seem to be one mistaken for the other. So it came as no surprise to find that we were both invited to do the same thing at this meeting. We have been through it all before. I was congratulated on my appointment to the Chair of Obstetrics and Gynaecology in Leicester[123] and John MacVicar was congratulated by an eminent Professor of Medicine on the birth of my third daughter! So we are quite familiar with this sort of scene.

The first thing to be said about the early days of ultrasound from the clinical point of view is that this was research in the clinical front line. It was work done on and with women who were facing major gynaecological surgery or childbirth, both of them significant crises in life, and it is against this background that you must think about what went on in these early days.

In modern times we would never have got away with it. The Ethical Committee would have refused it flat, but such was the prestige of a Scottish professorial medical unit in the 1950s that there was never a word, and I don't remember any woman refusing examination. The end result was a development from Glasgow which swept the world. Our ancient University, founded in 1451, has seen many developments in science, in medicine, and in engineering, but it is safe to say that in the 20th century one of the most significant of these has been the medical use of ultrasound. It, of course, would never have happened had it not been for Ian Donald.

I would like for the purposes of this meeting to turn the clock back to the time when a young, irreverent, red-haired professor from London came into the conservative atmosphere of Glasgow to turn everything upside down. As has been said, Professor Donald's wartime experience interested him in the possible medical use of Sonar,[124] which was not a particularly user-friendly technique until contact scanning was developed with Tom Brown at the helm on the technical side. Scanning was done pre-operatively in a side room adjacent to the gynaecological wards in the Western Infirmary and it was followed up in many cases by operative treatment which revealed whether the ultrasound diagnosis was correct or wrong, and rejoicing or mourning followed accordingly. The operative sessions could be quite fraught and I must say in

[123] This was MacVicar's appointment, not Willocks'.

[124] Sonar: Sound Navigation and Ranging.

all this Ian Donald was greatly sustained by the calm, good humour and supreme operative skill of Dr Wallace Barr,[125] who is here today. Some people, reading about Donald's work with ultrasound, might go away with the idea that he was some kind of a backroom boffin, but in fact he was a clinical chief of the old school, a full-blooded figure, larger than life to many people. John Fleming said that, when he joined us, he didn't know anything about professors and he certainly didn't know anything about a super professor like Ian Donald, who had all the characteristics in full measure.

The early results of the A-scan pictures weren't particularly good in 1956, but things improved with time. An interesting B-scan presentation was of John MacVicar's abdomen. I don't know whether the measurements are still the same or whether they are more or less as they were in those days, but this just shows that the investigators were quite willing to submit themselves to this technique. When I started it was gleefully said that my head contained no solid material!

All the early work came together with the most important paper ever published on medical ultrasound. It had rather an unpromising title, 'Investigation of abdominal masses by pulsed ultrasound',[126] and the tone of the paper, if you read it, was rather diffident. It introduced this technique and hinted gently at the end that it might be of great use in the future, but now Donald, MacVicar and Brown had really got things going. We have heard a bit from Brown, and we are now going to hear from MacVicar.

MacVicar: I consider that the success of the original work depended on three separate things: the people, the place and the time. And I would like to start with the time, because James has already referred to that. 1956 was a lot different from 1996 and I really don't think a Western Infirmary Ethical Committee would ever have allowed us to use an industrial flaw detector on patients.[127] Nor do I think that the patients would have submitted to examination if they had had to sign a form which said, 'I hereby agree to this examination by an experimental machine and I don't know all the consequences thereof.' Although we had a lot of discussion with the patients beforehand, it certainly would not have been accepted nowadays. We were lucky in 1956.

With regard to the people, it was fortunate that the three of us came together during 1956 in Glasgow, each of whom contributed in their own particular way to the development of ultrasound for diagnostic purposes. Ian Donald was a visionary, a man of ideas, with intensive drive. As head of the University Department, he had access to many different patients, and these patients worshipped the ground he walked on and therefore would allow any examination he wanted to be carried out. Tom Brown had the technical expertise which made him capable of acknowledging what was possible and was able to produce the machines which complemented the ideas the clinicians suggested. The generous support of Tom by Kelvin & Hughes should never be

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[125] Dr Wallace Barr contributes later in the meeting.

[126] Donald I, MacVicar J, Brown T G. (1958) Investigation of abdominal masses by pulsed ultrasound. *Lancet* i: 1188–1195.

[127] See also Professor Jean Robinson's comments on page 67.

forgotten. I was merely a young, aspiring Registrar who wanted to get some research work under my belt so that I might succeed in a specialist career. So these were the people at the start.

The place was a gynaecological ward, and gynaecological wards are full of patients with big masses and it was big masses initially which ultrasound was able to diagnose. Some people have referred today to the work that the Americans had done previously but having viewed that later, when I was doing my thesis,[128] I discovered that a lot of their work was done on very small breast lesions where they were trying to make a diagnosis which was very difficult histologically, far less ultrasonically.[129] So we were lucky that this flaw detector could now detect flaws in the human body – because they were big.

Acoustic coupling proved a problem initially and various materials were used to try to improve picture quality. Several Japanese groups and some in America had acquired a barrel-shaped water-bath where the probe went around the outside. Acoustic coupling between body and probe was effective and efficient because of the layer of water. But any of you who know Glasgow women will appreciate that it is not easy to get them into water for hygienic purposes, far less to get them into water for investigations. The idea that they would take to water for an ultrasound examination was a non-starter.

Then came the use of condoms and finger cots, because we thought that condoms and finger cots full of water would be efficient and more acceptable. If any of you have ever experienced a condom burst by a probe on a patient's abdomen which soaks the patient, soaks the bed and soaks you, you will realize that we had to find another method for acoustic coupling!

This was when olive oil became the substance of choice since it was well tolerated by patients, especially if it was suitably warmed. The bottle used to be balanced on the radiator in the room all afternoon while the scanning was in progress and the patient had to have a good wash afterwards. Although olive oil proved a very good acoustic coupling medium, it was messy. After a session, Tom and I had our hands, shirts, ties, handkerchiefs and trousers completely impregnated with olive oil and smelt accordingly. So also did the patient's records.

We started using different frequencies.[130] We would start with 2.5 MHz and go to 1.5 and then to 1 MHz.[131] In these very large abdominal masses, if you used a 1.5-MHz

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[128] MacVicar J. (1959) *Ultrasound as a Diagnostic Aid in Obstetrics and Gynaecology*. MD Thesis. Glasgow: University of Glasgow.

[129] Wild J J, Reid J M. (1952) Further pilot echographic studies on histologic structures of tumors of the living intact human breast. *American Journal of Pathology* 28: 839–861.

[130] The frequencies of the ultrasound probes used at that time were 1, 1.5 and 2.5 million cycles per second – MHz in present terminology. (Lower frequencies penetrate better but give poorer resolution.)

[131] Mr John Fleming wrote: 'I have no memory nor evidence of the 1 megacycle per second [1 MHz] probe.' Letter to Dr Daphne Christie, 28 July 1998. Mr Tom Brown wrote: 'A 1MHz frequency was provided, originally used industrially for testing coarse-grained materials like cast iron, but in practice it was rarely used medically.' Note on draft version of transcript, 24 May 1999.

probe, you could make a fibroid look like an ovarian cyst. Eventually it became obvious that the 2.5 MHz-probe was preferable.

To record the images obtained, we used a 35-mm camera fitted to the screen of the Mark IV flaw detector. Obstetrical training teaches you to identify objects in darkened cavities by touch and this was why I was chosen to use the so-called mobile darkroom which looked like a woman's muff. Into this I would put the 35-mm film, so that at the end of the afternoon when it was developed we had a pictorial record of all we had done. As I was manipulating the film within the 'darkroom', it occasionally slipped out and rolled along the floor – thus the records of the whole of the afternoon's work were lost. The advent of the Polaroid™ camera was a great boon and blessing. Although the team was overjoyed at detecting at least a difference in acoustic properties between ovarian cysts and fibroids, a further study of these tumours immediately after surgical removal, as James has mentioned, was undertaken using a plastic water-bath with a rubber diaphragm at one end on which to place the probe. It soon became apparent that the A-scan was not good enough, because as you rotated the tumour within the water-bath you got completely different pictures. Also it became obvious that tumours outside the body had different acoustic properties to tumours *in situ*. Blood coursing through them in the patient was almost certainly the reason for the different properties.

Somebody mentioned how nothing was published on the A-scan work.[132] This was due to the fact that it was only used for a matter of a year to 18 months before being superseded by the B-scan. The main clinical value of A-scan was to assist in prioritizing patients. Gynaecological waiting lists extended for a year to 18 months. If a woman had a fibroid which was not giving her any trouble you could wait and operate at her convenience. If she had an ovarian cyst, it necessitated operation as soon as possible in case of malignancy.

Similarly, when we started using B-scan we compared the appearance of malignant with non-malignant ascites which proved of help as far as the diagnosis of the underlying cause was concerned and the urgency of treatment. The initial work was not met with great enthusiasm by anyone, especially some of my colleagues. I remember one saying that the new technique was only of value to a gynaecologist who was blind and had lost the use of both hands – but he has denied that since!

It soon became apparent that we had to go on from A- to B-scanning. Tom Brown, as I said earlier, was very concerned that with manual scanning we could cheat and make the pictures look anything we liked to agree with our clinical diagnosis. Tom wanted to get rid of operator bias.[133]

The development of the automatic scanner was one solution, although I did not particularly approve of it. I felt that patients accepted the doctor using the probe across their abdomen and not just standing at the side and operating it automatically.

[132] See Dr Malcolm Nicolson's contribution on page 5 above.

[133] See note 15 above.

I remember a disastrous day when we had a very stout patient. We put the automatic scanner on her and it suddenly started to dig in because the soft flabby fat stopped progress across the abdomen and the probe oscillated on one spot burrowing deeper into the six or eight inches of fat. We had to stop rather hurriedly.

The new display (B-scan) coupled with immediate Polaroid™ pictures reduced the time necessary for scanning and a diagnosis was reached far more quickly. When we started on pregnancies, one of the drawbacks to progress was the length of time before the scanning of early pregnancies with the patient having a full bladder was considered.

Hall: Can I stop you there, John, and ask you a question about that? To what extent was it fortuitous that The Queen Mother's Hospital opened and the patients moved to that side of the city and gave you access readily to obstetric patients? Because in the Western Infirmary there were gynaecological patients. You could say that you were going to open them up anyway, so the result of the ultrasound examination did not matter.

MacVicar: No. In the Western Infirmary we had often patients with early pregnancy complications, either incomplete, threatened or missed abortions. With these we wanted to establish a diagnosis early but scanning before 12 weeks was difficult.[134] Having used my own full bladder as an ovarian cyst[135] it was strange that it passed us all by that looking through the bladder was a very reasonable way to examine the pelvic organs in early pregnancy.

Brown: May I interrupt you, John. One of the early applications of ultrasound, if you recall, was measuring residual urine after Manchester repairs[136] and you became expert in assessing the amount of urine in the bladder using the A-scope. You had a curious formula for doing it, I seem to remember, but I think it was *that* experience that led to the recognition that a full bladder was a window into the pelvic organs.[137]

MacVicar: It might have been because it was a very sensitive area to me. The amount of urine in the bladder after repairs, especially my repairs, was easy to assess since my patients had more urine in the bladder than anybody else's. But why did we not think of using the full bladder to see early pregnancies long before we did?

The hours of work and the tiredness of those taking part are difficult to appreciate after all this time. Patients were meticulously examined and when we ran out of patients we just used ourselves and I mentioned my tummy earlier and I've got Tom's

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[134] Professor John MacVicar wrote: 'Before 12 weeks of pregnancy the uterus lies within the pelvis as does the empty bladder. When the woman lies on her back loops of small bowel, containing air, lie just underneath the abdominal wall which reflect the ultrasound waves so that they cannot penetrate down into the pelvis. After 12 weeks of pregnancy the uterus rises up into the abdomen and pushes the bowel upwards away from the anterior abdominal wall. Similarly, as the bladder fills it also rises up into the abdomen and thus a "window", which can look down into the pelvis, is formed through which the ultrasound can penetrate.' Letter to Dr Daphne Christie, 30 March 1999.

[135] op. cit. note 63 above.

[136] Using ultrasound, the amount of residual urine could be roughly estimated without resorting to catheterization. Mr Tom Brown wrote: 'A Manchester repair was an operation used to correct a gynaecological prolapse (prolapsed uterus).' Note on draft version of transcript, 24 May 1999.

[137] op. cit. note 63 above.

neck and his leg in my own collection. Nevertheless, had it not been for the enthusiasm of Ian Donald, the many hours of work might well have achieved nothing worthwhile. But irrespective of how tired or depressed Tom and I were, Ian Donald always maintained that there was a big future for this diagnostic science and said, 'You are going to do the following tomorrow.' That was what kept us coming back the next day. I think each of us contributed a little and there was the tremendous driving force behind us. You must bear in mind that this was done over and above a normal day's work. Tom and I particularly used to work until eight and nine at night and then go home exhausted, sometimes without even a film of the day's work!

Hall: As an addition to that, I can remember as a much younger man than I am now attending the British Congress of Obstetrics and Gynaecology in Glasgow in 1967. Ian Donald was speaking – that was the only reason I was there – and I remember getting quite distressed when a comment that has been echoed here already was made in front of me, when this chap turned to somebody and said, 'This really is nonsense' and I saw my career vanishing down the tubes. I am glad to say that was not the case.

But then, Professor MacVicar, you along with Donald and others moved to The Queen Mother's Hospital where there was more space available. Usama [Abdulla], I can't remember, but were you involved before Stuart Campbell or at about the same time? Would you like to take up the tale of the early days of that development?

Abdulla: I arrived in Glasgow in July 1965. I remember there was the British Congress which I attended just before I became involved. The year before that Professor Donald was visiting Iraq, and said, 'Would you like to come and learn something about a new technique which I have developed called ultrasound?' I leapt at the idea and within a year I was in Glasgow using the Diasonograph. In those days, as mentioned before, we used lots of the olive oil and I don't know how we still have our wrists intact, as the repetitive movement especially over the pregnant abdomens was so continuous. At one time I could recognize whether the scan was done by Professor Donald, by Stuart Campbell, or by other colleagues, just from the shape of the movement over the abdomen; that in turn was printed on the Polaroid™ prints and slides.

Professor Donald was a very persuasive person. He enthused everybody and always wanted to see further progress. That is how I am sure we were so keen to discover and see more and more with ultrasound.

Hall: At that stage of the development, how do you think the asset of having ultrasound really affected clinical diagnosis and practice?

Abdulla: I think it did. Initially there were some doubts and some of these have been mentioned. For example, we thought that the placenta was low-lying, or that there could be twin pregnancy, when this was not the case. Obviously the images were not as good as one sees now and therefore the accuracy wasn't as good and so there was some doubt about the value of ultrasound. But under that sort of pressure we all continued and carried on until the results became better and better and with better results the implications for clinical diagnosis were greater.

Willocks: Professor Donald's tireless ability to publicize this technique, his great persistence and courage in facing all criticism and his always hopeful attitude, were very essential things. Had ultrasound not been driven by such a strong personality I doubt whether it would have got off the ground even with all the good clinical results that were obtained. It might have languished as some other developments in medicine have in the past.

I have been asked to speak about the early days of fetal measurement.[138] I started on these investigations round about 1960. The principle of the ultrasound cephalometry done by A-scan is where you see clear echoes obtained only when the beam passes through the biparietal diameter. That is the principle it works on and we built the technique up, as I said, with some experimental work, including pathological work. There was the apparatus in use in the maternity hospital and pretty primitive it looks now (Figure 15). A barium titanate[139] probe was used at that time, and that was the basis on which we were able to go forward and devise not only an idea of the size of the infant based on the size of the head, but also of the growth of the child by serial measurement over many weeks of the later part of pregnancy. A side-shoot of this was an attempt to develop echo-encephalography in the newborn, and those of you who have had or have newborn babies will know that they are rather mobile objects and are not very easy to examine. The only way to do it was to put the probe on the one side of the head and then on the other.

What we were trying to discover was any shift in the midline of the brain and the presence of possible intracranial haemorrhage. Many premature babies died from intraventricular haemorrhage. We were, for example, trying to pick up blood clots inside

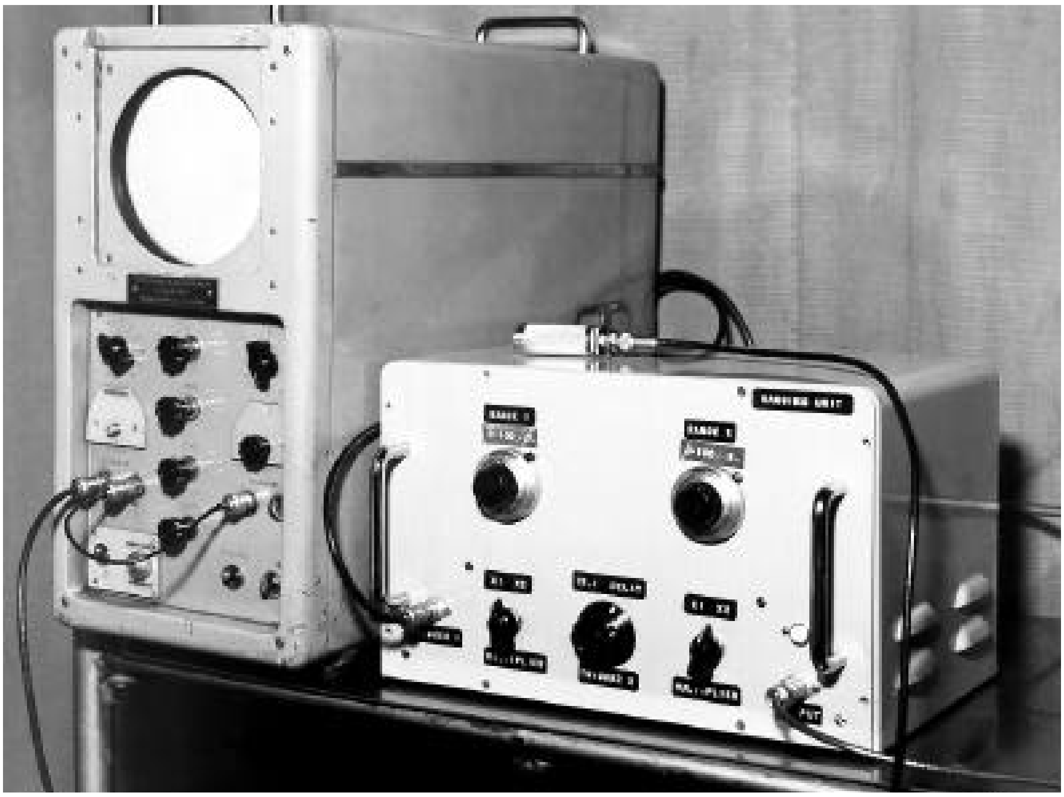

Figure 15. The apparatus in use for fetal cephalometry (head measurements) by ultrasound.

the brain. It didn't progress perhaps as well as it should, but as Professor Campbell has told you the work on fetal cephalometry went on and is still used after many years.

Professor Donald, in the early 1960s, was facing a personal crisis with heart disease. He had the first of his several operations for mitral stenosis while this work was all going on. There was a memorable meeting at the Royal Society of Medicine on the 12th of January 1962. Ian Donald was still technically an inpatient in the Western Infirmary in Glasgow recovering from his valvotomy, which in these days was a pretty hazardous and major operation. We had prepared a film on the various applications of ultrasound which we thought was pretty good, and we weren't worried about the meeting. John MacVicar and I were more worried about the state of health of our chief who emerged on a dark, foggy night to go to London looking blue and breathless. However, we got to the meeting and the Professor began his presentation, 'A new diagnostic echo-sounding technique in obstetrics and gynaecology.'[140] The film that we had broke in several pieces and had to be hastily repaired. The Professor collapsed with acute dyspnoea and every sign of a medical crisis in the early stages of the meeting but rapidly recovered. John MacVicar and I continued with our presentation and we all breathed a great sigh of relief at the end of the day. That was in 1962 and it was the first time that many people in our specialty had heard of diagnosis by ultrasound.[141]

Hall: I wonder if we could now move on and hear from that great exponent of fetal cephalometry and the development of other relevant methods of measurement, Professor Stuart Campbell.

Campbell: I arrived in Glasgow in 1964/5 as a senior house officer, so I really came at the same time as Usama [Abdulla]. I thought he came a little before me, but we started about the same time. As a Hall Fellow I immediately became involved in ultrasound, following the white coat tails of James Willocks, the man with the machine, and then basically introducing myself to Ian [Donald] who was really quite an intimidating senior doctor to a young Registrar because he was totally brilliant – he always asked quick, unexpected questions and expected you to know the answer. He did have a quick temper. I learned the technique of just being quiet while he calmed down a little bit, and then he was fine, the essence in the ultrasound department. If a patient's bladder was overfull, Ian would be pretty angry, not with the patient, but with whoever it was that allowed the bladder to be overfull. So you just learned to be quiet and he soon calmed down, because he was an extraordinarily generous man I have to say – quite the most ethical and generous senior doctor I have ever really met. I worked with Ian and

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[138] The measurement of crown-to-rump length and fetal cephalometry. Dr James Willocks' recollections about the early days of fetal measurement at that time are written in a letter to Dr D Christie on 2 September 1998, and will be deposited with the records of this meeting in the Contemporary Medical Archives Centre of the Wellcome Library. See also page 43.

[139] Barium titanate is a synthetic ceramic which has greatly superior properties as a transducer to the natural quartz ones used earlier.

[140] Donald I, MacVicar J, Willocks J. (1962) Sonar: a new diagnostic echo-sounding technique. Illustrative example of ultrasonic echograms. The use of ultrasonic cephalometry. *Proceedings of the Royal Society of Medicine* 55: 637–640.

[141] MacVicar J, Donald I. (1963) op. cit. note 63 above.

developed this A- plus B-scan technique of measuring the head and developed growth charts. My obsession while I was still at The Queen Mother's Hospital was to predict gestational age accurately, and to predict the date, the time, of delivery.

I started to measure the fetal head in women with uncertain dates and then to predict when they would deliver and compare it with the vague dates that they usually gave. I published that work after I came to London,[142] but it was all based on the Glasgow data. Few people believed it in those days, and it's only over the years that people have accepted it as the way of dating the pregnancy, and the earlier you do it the better. I was limited initially by the five-centimetre problem with the calipers,[143] but that was solved. Usama worked on placentography – that was his thing – and eventually they published the seminal paper on placentography which was slightly after the Americans did.[144] However, because the Americans were using the Picker machine their placentography paper wasn't very convincing whereas Ian Donald's and Usama's was totally convincing.

After I left for London, Hugh Robinson came to Glasgow and he developed the crown-to-rump length measurement. The machine [NE4102] was modified in such a way that you got much higher resolution, with expanded images. Hugh was able to enlarge the image so that you saw the early embryo and the crown-to-rump length much better. He actually developed charts of the growth of the embryo in the first trimester which I still use today.[145] His work with John Fleming was classical, seminal work. I moved to London and I introduced routine screening of the whole population in Queen Charlotte's. When I got to Queen Charlotte's they didn't have a Diasonograph and I used to take my ladies over to University College Hospital where Ernest Kohorn was.[146] I used to drive them over in my little red MGB with the patient in a red blanket and I used to park in the car park about 500 yards away from the hospital. We used to walk through the streets of London to the hospital and I would diagnose placenta praevia or whatever it was and then take them back to Queen Charlotte's Hospital.

Eventually the Department of Health gave us a machine for trial and I was able to get going with some work and I introduced screening for all women for dating. In my 1969 paper[147] I recommended that all women should be dated, not just women with suspect dates, and so I put it into practice there. Then I began to see anomalies such as anencephaly.[148] Alphafetoprotein was being measured at this

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[142] Campbell S. (1968) An improved method of fetal cephalometry by ultrasound. *Journal of Obstetrics and Gynaecology of the British Commonwealth* 75: 568–576. *idem* (1969) The prediction of fetal maturity by ultrasonic measurement of the biparietal diameter. ibid. 76: 603–609.

[143] This refers to the caliper dials not going below 5 cm.

[144] op. cit. note 65 above.

[145] op. cit. note 24 above.

[146] See note 121 above.

[147] Campbell S. (1969) op. cit. note 142 above.

[148] Professor Stuart Campbell showed several slides of fetal anomalies which are not illustrated here. See, for example, Campbell S, Johnstone F D, Holt E M, May P. (1972) Anencephaly: early diagnosis and active management. *Lancet* ii: 1226–1227. Chervenak F, Isaacson G, Campbell S. (eds) (1992) *Textbook of Ultrasound in Obstetrics and Gynecology*. New York: Little Brown.

time.[149] Some women came with high alphafetoprotein, but some anomalies we picked up just because of this routine scanning that we were doing at around 20 weeks. I am not sure whether this came from high alphafetoprotein or whether from a routine scan: I would have to look up the paper.

Real-time scanning produced an even better image of an anencephalic fetus. This would be in the mid-1970s when this would be diagnosed. So real-time made a huge improvement. Even in those early days, certainly in the second trimester, you could see that large U-shaped abnormality in the fetus, and I realised that you could diagnose spina bifida. So I started to look very hard. I started to look at the skull. I could see the ventricles of the brain. I concentrated on spina bifida, hydrocephalus and other anomalies at that time.

There were other groups beginning to do this work also, Hansmann[150] in Germany and John Hobbins[151] in America, but the diagnosis of anencephaly, spina bifida and hydrocephalus or ventriculomegaly were the first early diagnoses made of fetal abnormalities.

Having said so, they weren't *the* first diagnoses to be made, because Sundén, I think, probably has to be given the credit of recording the first anencephalic, but he diagnosed it in the third trimester and he did that way back in the early 1960s.[152] I think James Willocks or John MacVicar will probably confirm that. The diagnoses I made were before 20 weeks and so, of course, this actually influenced the decision-making process as to whether to offer termination or not. To me the great seminal changes were the introduction of greyscale in the early 1970s, then in the mid-1970s the linear-array real-time scanning, which totally transformed the way we practised; in the 1980s it was then transvaginal ultrasound.

Although most of the credit will go to people like Timor-Tritsch[153] and a lot of Israeli groups, transvaginal sonography actually began with Kratochwil[154] in Vienna in the late 1960s, early 1970s, but he was not using real-time scanning and therefore it was very difficult and it never took off. Really transvaginal sonography took off from *in vitro* fertilization (IVF). I set up the first IVF unit that was completely outpatient, based on a

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[149] See, for example, Brock D J, Sutcliffe R G. (1972) Alpha-fetoprotein in the antenatal diagnosis of anencephaly and spina bifida. *Lancet* ii: 197–199. Seller M J. (1972) Alpha-fetoprotein in anencephaly. ibid. 716–717.

[150] Hansmann M, Windemuth W, Bellmann O, Niesen M, Lang N. (1975) Prenatal diagnosis of fetal abnormalities in the second half of pregnancy. *Archiv fur Gynakologie* 219: 406–408. Hansmann M, Häckelöer B J, Staudach A. (1986) *Ultrasound Diagnosis in Obstetrics and Gynaecology*. Berlin: Springer Verlag.

[151] Hobbins J C, Winsberg F. (1978) *Ultrasonography in Obstetrics and Gynecology*. Baltimore: Williams and Wilkins.

[152] op. cit. note 48 above.

[153] Timor-Tritsch I E, Rottem S. (1987) Transvaginal ultrasonographic study of the fallopian tube. *Obstetrics and Gynecology* 70: 424–428. *idem* (1991) *Transvaginal Sonography*. Amsterdam: Elsevier.

[154] Alfred Kratochwil practised as an obstetrician and gynaecologist at the Second University Frauenklinik, Vienna, Austria, using A-mode ultrasound on his patients. He first published on diagnostic ultrasound in gynaecology and obstetrics in 1966. See, for example, Kratochwil A. (1966) Possibilities of ultrasound diagnosis in labor gynecology. *Wiener Klinische Wochenschrift* 78: 190–191. *idem* The diagnostic use of ultrasonics in obstetrics and gynecology. *Zentralblatt fur Gynakologie* 88: 1032–1042.

technique that was first described by Susan Lenz[155] from Copenhagen, where she actually put a needle through the maternal bladder into the ovary, into the follicle, and aspirated an egg. When I was at King's I said to John Parsons,[156] whom I had just appointed, 'That's the way you are going to get eggs, no more general anaesthetic, no more laparoscopy, we are just going to stick a needle through the woman's bladder and collect the eggs.' We did that, and had an outpatient IVF system before anybody else. Then people started to look for other methods. John Parsons started to pass the needle through the urethra – still doing abdominal scanning – and then the transvaginal method (I think it was a chap called Dellenbach back in France who developed a transvaginal method),[157] where he slid the needle along the transvaginal probe into the ovary, and that was the opening up of a huge improvement in imaging.

Hall: Could you put an approximate date on when the type of transvaginal scanning you have just described started in IVF? I don't mean Kratochwil's work, which was known about. Also, for reasons that maybe some of the clinicians could advance, can you say why transvaginal scanning never really took off in the early days?

Campbell: It would be about 1982 or thereabouts.

Wells: What about von Micsky?[158] I thought von Micsky in New York preceded that work.

Campbell: What work was this? [The transvaginal work.] He developed a transvaginal probe didn't he? I would have to check up the references.

Hall: Are you talking pre-Kratochwil?

Campbell: The first person to design a transvaginal probe was J J Wild.[159] There is a prototype there and I think he actually used it.

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155 Lenz S, Lauritsen J G, Kjellow M. (1981) Collection of human oocytes for *in vitro* fertilization by ultrasonically guided follicular puncture. *Lancet* i: 1163–1164.

156 Mr John Parsons FRCOG has been Honorary Consultant and Senior Lecturer in Gynaecology at King's College Hospital, London, since 1984 and was one of the first pioneers in the technique of outpatient *in vitro* fertilization. See, for example, Parsons J, Riddle A, Booker M, Sharma V, Goswamy R, Wilson L, Akkermans J, Whitehead M, Campbell S. (1985) Oocyte retrieval for *in-vitro* fertilisation by ultrasonically guided needle aspiration via the urethra. *Lancet* i: 1076–1077. Riddle A F, Sharma V, Mason B A, Ford N T, Pampiglione J S, Parsons J, Campbell S. (1987) Two years' experience of ultrasound-directed oocyte retrieval. *Fertility and Sterility* 48: 454–458.

157 Dellenbach P, Nisand I, Moreau L, Durand J L, Rouard M, Forrier A, Gerlinger P. (1988) The transvaginal method for oocyte retrieval. An update on our experience (1984–1987). *Annals of the New York Academy of Sciences* 541: 111–124.

158 Lajos I von Micsky (1918–1976) joined the obstetric and gynaecology staff of St Luke Hospital in New York in 1963, and became Chief of the Ultrasonic Division of the Radiology Department in 1969. Professor Peter Wells wrote: 'On page 9 of *Medical Diagnostic Ultrasound: a Retrospective on its 40th Anniversary*, [Goldberg B B, Kimmelman B A. (1988) Kodak Health Sciences, Eastman Kodak Company] there is a photograph with the caption "Dr Wild's rigid transvaginal probe, c.1960". Professor Campbell was correct, and I was wrong. The work of von Micsky is mentioned in the same publication, on pages 28 and 29; he developed a probe that was actually inserted transvaginally into the uterus.' Letter to Dr Daphne Christie, 29 March 1999. See also von Micsky L I. (1965) Ultrasonics in obstetrics and gynecology. *Obstetrics and Gynecology* 25: 420–421.

159 John Julian Wild (b. 1914) built the first handheld 'contact' scanner for clinical use in the basement of his home in Minnesota. Wild subsequently developed other types of ultrasonic imaging equipment including transrectal and transvaginal scanners and a scanning device for mass screening of patients for breast cancer. See Goldberg B B, Kimmelman B A. (1988) op. cit. note 158 above. See also Shampo M A, Kyle R A. (1997) John Julian Wild – pioneer in ultrasonography. *Mayo Clinic Proceedings* 72: 234.

Wells: That was the transrectal probe. I don't think he ventured into the vagina.

Dr Margaret McNay:[160] Could I just add that I think the Japanese too developed a transvaginal approach, if you refer back to the early papers in the 1950s. There was very little interchange of ideas between the Japanese and the West, but I think, Tom, am I not right, that many of their developments were along very similar lines to your own in the early days and they certainly described a transvaginal approach?[161]

Brown: There was a famous Japanese stool with an opening on which the patient was sat and which was a transrectal probe at that time. When this subject came up for discussion with Ian Donald he just sniffed at it, and said, 'Typical psychopathology of the Japanese' and the idea was dismissed. It was a long time coming and it should have come earlier.

Whittingham: Could I make a comment on the caliper side of things? It's just an interesting point about the choice of caliper velocity. I think it was the NE4102 that had the foresight to have a little panel with controls behind it, allowing you to set the caliper velocity, and in fact the system velocity, to anything you wanted. There was a period of a few years where this, and whatever the other manufacturers were doing, led to some confusion. A given patient could have a BPD [biparietal diameter] measurement in one hospital, where they'd decided to adopt, say, 1600 metres per second, as recommended by Professor Campbell in his paper,[162] and then up the road where the machine might be calibrated, at 1540 metres per second. The baby would apparently shrink in the course of the two measurements, just because it was a different assumed speed of sound. I wrote a letter to the *British Journal of Radiology* in 1971,[163] naively as a physicist, saying why don't we just stick to what the machine can measure – which is time – and quote the BPDs in microseconds. It's been done by the astronomers. They talk about light years. It didn't seem to be very well received. I can't think why! But nowadays, and I am not sure how it happened, everybody seems to have settled on 1540 metres per second. It isn't questioned anymore.

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[160] Dr Margaret McNay FRCOG (b. 1945) developed the clinical application of ultrasound from 1978 to 1996 in The Queen Mother's Hospital, Glasgow, where she was Consultant and Head of the Department of Obstetric Ultrasound. Her main interest was in the prenatal diagnosis of congenital abnormalities and fetal therapy.

[161] In 1958 M Ishihara and H Murooka presented a paper at the 19th meeting of the Japanese Society of Obstetrics and Gynaecology, describing the practice of the vaginal probe and A-mode presentation and demonstrating a relatively large series of a given anomaly. See also Wagai T, Yoshimoto S. (1959) Application of ultrasonic diagnostic methods in obstetrics and gynaecology. *Journal of the Japanese Obstetric and Gynaecological Society* 11: 169. Tanaka K, Wagai T, Kikuchi Y, Uchida R, Uematsu S. (1966) Ultrasonic diagnosis in Japan. In Grossman C, Joyner C, Holmes J H, Purnell E W. (eds) *Diagnostic Ultrasound*. New York: Plenum Press, 27–45.

[162] Mr John Fleming wrote: 'The value of 1600 metres per second was originally suggested by Dr James Willocks in his MD thesis (op. cit. note 118 above). His measurements on neonates and post mortem specimens gave an average of 1600 metres per second which was generally used in Glasgow including, of course, being used by Stuart Campbell.' E-mail to Dr Daphne Christie, 26 October 1999. See Campbell S, Newman G B. (1971) Growth of the fetal biparietal diameter during normal pregnancy. *Journal of Obstetrics and Gynaecology of the British Commonwealth* 78: 513–519.

[163] Whittingham T. (1971) The ultrasonic biparietal diameter, expressed in time units. *British Journal of Radiology* 44: 481–482.

Hall: If I could just make a comment as Chairman's privilege? What the early workers were trying to do was to make the ultrasound measurement agree with what they mechanically measured. If you actually think about it, if you are measuring growth, it doesn't matter if you use 1540 metres per second, provided you use that figure consistently and establish that diameter measurement to the maturity of the fetus. I think that's how the confusion came about.

Dr Wallace Barr:[164] My only contribution to the proceedings is the fact that I was there at the moment of conception of ultrasound. When Ian Donald came to Glasgow I was his fellow consultant in the Western Infirmary and it was our custom to have a session each day to discuss the proceedings over a glass of sherry. When he came to Glasgow he had invented or contrived some additions to a respirator.[165] This didn't really satisfy his inventive capacity and he was looking around for something else. One day he came in and said, 'I think I have found it' and he proceeded to produce an article about submarine detection.[166] He said, 'I think this ASDIC[167] technique could be applied to medicine' and the next thing was that he had to find some means by which a detector of this kind could be available. He learned that Babcock and Wilcox, a firm of boilermakers in the district,[168] had an ultrasonic flaw detector so he immediately contacted the Director of Research in Babcock and arranged a meeting. I went to that meeting and the next thing was to arrange to visit the factory to see the flaw detector in use. We did this and, of course, there was nothing which would be suitable for the detection of tumours. But Ian talked this over with them and they decided that he could come down again, this time bringing a selection of tumours; my motor car boot was filled with large ovarian cysts and fibroids and so on, which we took down to the factory. They had produced some kind of primitive transducer and a water-bath, because it was realized that air produced acoustic impedance. Anyway, this was taken and we took primitive pictures with an engrossed audience of the workers in the factory who thought it looked rather like an abattoir. We came back and he was still frustrated by the fact that there was something in this idea, and how could he develop it.

That same evening[169] a telephone call came from one Tom Brown, purely by chance, and that was the start of this providential partnership between Tom Brown and Ian Donald. I would like to emphasize the fact that if it hadn't been for Tom Brown's ability to provide the technical know-how, ultrasound might never have got off the

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[164] Dr Wallace Barr FRCSGlas FRCOG (b. 1919) has been Honorary Clinical Lecturer at the University of Glasgow since 1960. He was Consultant Obstetrician at The Queen Mother's Hospital in Glasgow from 1960 to 1985 and Consultant Gynaecologist at the Western Infirmary in Glasgow from 1955 to 1985.

[165] See Willocks J. (1993) op. cit. note 69 above.

[166] Langevin M P. (1928) Les ondes ultrasonores. *Revue Générale de l'Electricité* 23: 626–634. Biquard P. (1972) Paul Langevin. *Ultrasonics* 10: 213–214.

[167] ASDIC, the Allied Submarine Detection Investigation Committee.

[168] See note 11 above.

[169] Mr Tom Brown wrote: 'I do hope Dr Barr will forgive me, but there was in reality quite a gap between these two events. I've long believed in the intervention of Lady Serendipity in our affairs, but that would have been asking rather too much of her.' Note on draft version of transcript, 24 May 1999.

ground. Then, of course, he had the enthusiastic help of the junior staff, James Willocks and John MacVicar, who immediately added to the speed of the whole thing. I would like just to emphasize this coming together of the two factors; if it hadn't been for Tom Brown and Ian Donald, there might never have been ultrasound as we know it.

Hall: I would like to take the opportunity to pick up on one little aspect of Hugh Robinson's work.[170] The detection of early fetal life these days is routinely done by Doppler ultrasound,[171] but there was a period before that when Hugh Robinson was using measurements, calipers, and crown-to-rump length measurements, but he also used that as a technique for the detection of early fetal life.[172] John [Fleming], can you maybe talk on that for a minute or two?

Fleming: He used actually an A-scan technique. It was on the Diasonograph NE4102. He would search until he saw a fluttering movement on the A-scan and then switch to M-mode and record heart rate and produce graphs of heart rate against gestation. It was a very positive indication of fetal life.

Hall: I think the advantages often were that you no longer had the patient waiting for several days or more for a diagnosis of missed abortion. You could tell if there was still viable fetal life there and, I suspect, though I may be wrong, that it still can be done earlier than you might detect early fetal life by Doppler ultrasound. Can anybody comment on that?

Campbell: I think Doppler is the earliest now. You can see the fetal heart beating at six weeks.[173]

Hall: Which is about the same time that Hugh Robinson was detecting early fetal life, at six or seven weeks.

Campbell: I wanted to mention one other advance that was made in Glasgow after I left. A chap called Joachim Hackelöer came as a research fellow from Germany. Kratochwil had, with his transvaginal scanner, actually observed the follicle,[174] but nobody had paid much attention. Joachim Hackelöer tracked the development of the follicle in the follicular phase of the menstrual cycle and the development of the corpus luteum.[175] It really set a whole new application of ultrasound in motion, that is, the monitoring of ovulation, especially in the infertile woman. As I mentioned

[170] See notes 23 and 24 above.

[171] See, for example, De Vore G R, Brar H S, Platt L D. (1987) Doppler ultrasound in the fetus: a review of current applications. *Journal of Clinical Ultrasound* 15: 687–703. Maulik D. (1989) Basic principles of Doppler ultrasound as applied in obstetrics. *Clinical Obstetrics and Gynecology* 32: 628–644.

[172] Robinson H P. (1972) Detection of fetal heart movement in the first trimester using pulsed ultrasound. *British Medical Journal* iv: 466–468. *idem* (1975) The diagnosis of early pregnancy failure by sonar. *British Journal of Obstetrics and Gynaecology* 82: 849–857.

[173] op. cit. note 171 above.

[174] op. cit. note 154 above.

[175] Häckelöer B J. (1978) Ultrasonic demonstration of follicular development. *Lancet* i: 941. Häckelöer B J, Robinson H P. (1979) Ultrasonic demonstration of follicle and corpus luteum development in normal menstrual cycle and its relation to hormone profiles. *Archives of Gynecology* 228: 556–558.

before, it was not a big step to then place a needle in the follicle to collect eggs for IVF treatment. But the tracking of the ovarian follicle began in Glasgow with Hackelöer, and Hugh Robinson was on the paper.[176]

Hall: What I would like to do is to go forward to the more modern diagnostic techniques, looking at Professor Whitfield and Margaret McNay, and then finish off on the question of safety.

Gassert: Just two or three quick comments. I have experience of almost everything that has been mentioned, but often on the other side of the fence. For example, you mentioned vaginal scanning. I believe the single most significant thing that helped vaginal scanning to catch on was the experience of doctors in America. In America they are faced with very many large, really fat, patients in early pregnancy. It's very difficult to scan them abdominally and, in fact, the enthusiasm of these doctors that I met and talked to was instant when they realized that you didn't need to fill the bladder, you didn't have to rely on the patient's information being accurate, you could scan everybody and I think that it was the commercial drive that made the transvaginal scan common or standard.

A very quick thing on the subject of oil, which gets everywhere. I learnt the hard way a long time ago (which is why we started producing ultrasound gel in Scotland) to save my own shirts from having to get washed because of the oil. When I took the first samples of Diagnostic Sonar gel to Ian Donald he was not at all impressed; in fact he said, 'This stuff is rubbish, it needs to be fluid.' I went away somewhat upset and then one evening, because he constantly mentioned this word oil, oil, oil, it must be oil, arachis oil, olive oil, any kind of oil is fine, I thought blast, 'I wonder that if the word 'oil' is in someway something that can be used, does it describe a particular product or something?' So I looked it up in the dictionary and I discovered that it only really refers to viscosity, so I named the first gel that I succeeded in selling Ian Donald 'echo oil'. As soon as I brought the bottle and the label said 'oil' on it, he said, 'This is great.' But it was a thin gel, so that was another story.

To comment on Stuart's [Campbell] experiences. Much of the work he has done I have 'sold' abroad everywhere without Stuart realizing it. It's because I sold Stuart's work that people like Hackelöer came. I can remember Stuart upsetting me once in the early days when he didn't know me very well, when I brought two 'gurus' from Germany, Hansmann and Hackelöer, and I phoned him up from London saying these chaps had just arrived. I said something like, 'I believe they know you' and Stuart said, 'Of course they know me.' So they learnt about the early experiences in Glasgow and they had their Siemens machines in those early days. They couldn't do the early pregnancy examinations and accurate dating because the Siemens machine didn't have any calipers. People were using mechanical calipers to make very crude measurements; they were really Doubting Thomases who didn't believe until they came and people like Stuart showed. Then they went away and they bought these Diasonograph

[176] See Häckelöer B J, Fleming R, Robinson H P, Adam A H, Coutts J R. (1979) Correlation of ultrasonic and endocrinologic assessment of human follicular development. *American Journal of Obstetrics and Gynecology* 135: 122–128.

machines. But they never scrapped their real-time scanners and that's what convinced me that real-time scanning was going to take off. It's a great shame that the company I worked for, Nuclear Enterprises, didn't build a real-time machine.

The first commercial real-time scanner was the Siemens machine, but the first commercial linear-array real-time scanner was not ADR,[177] but Organon Teknika.[178] The second one was probably ADR, and the third one was definitely from a little company called Diagnostic Sonar.[179]

Whittingham: Just to make a comment on that last remark. There was in fact a British machine that pre-dated the Organon Teknika. That was a device sold by GEC Medical[180] by the name of RITA (real-time imaging transducer array) which was a little device which you could add to your static B-scanner and turn it into a real-time machine.[181] That was sold commercially in the UK.

Hall: I wonder if we could now jump forward and talk about the clinical aspects of ultrasound in the context of the modern equipment. I wonder if some of you clinicians can comment on what real-time scanning has brought to the clinical scene.

Professor Charles Whitfield:[182] I was asked to answer a question, 'What it was like at the time' and I am afraid I took that to mean at the very early clinical development of obstetric ultrasound. My experiences of scanning were simply with an old Vidoson that we used to navigate amniocentesis. This was in Belfast, where we did about 30 or 40 amniocenteses a week. This use has not been touched on. To us it was a huge advantage to be able to avoid the placenta, particularly in somebody who has relatively little amniotic fluid, and sometimes these are the mothers from whom we most often wanted a sample of amniotic fluid. Ultrasound helped you there. Of course the more modern indication is with intravascular fetal transfusion and all sorts of fetal surgical interventions. What I call the navigational side of ultrasound is of great assistance.

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[177] See note 106 above.

[178] Organon Teknika. Data on this company's products are in the BMUS historical collection.

[179] Dr Angus Hall wrote: 'Diagnostic Sonar Ltd, Livingston, West Lothian, Scotland. An early manufacturer of real-time scanners. The company is still trading.' Letter to Dr Daphne Christie, 30 October 1999.

[180] GEC Medical Equipment Ltd, Nuclear, Therapy and Ultrasound Division. Mr John Fleming wrote: 'I have, in the BMUS collection, a pamphlet showing the RITA instrument. The leaflet is not dated but is filed with a price quotation dated 20 December 1977. The price is given as £2500 plus a charge of £225 for interfacing to the customer's standard A- and B-scan equipment.' E-mail to Dr Daphne Christie, 17 November 1999.

[181] Mr Hans Gassert wrote: 'I am absolutely convinced Whittingham's comment about RITA predating Organon's scanner is incorrect. Whittingham himself earlier refers to the inventor of the linear array (Professor Nicolaas Bom) of the Cardiothoracic Centre in Rotterdam and Organon co-operated with Bom. I saw Organon scanners on the Continent long before RITA was ever heard of.' Fax to Dr Daphne Christie, 18 October 1999.

[182] Professor Charles Whitfield FRCPGlas FRCOG (b. 1927) was Senior Lecturer, Consultant Obstetrician and Gynaecologist at the Belfast Teaching Hospital from 1964 to 1974, Professor of Obstetrics and Gynaecology at University Hospital of South Manchester from 1974 to 1976 and Regius Professor of Midwifery at The Queen Mother's Hospital and Western Infirmary, Glasgow, from 1976 to 1992, succeeding Professor Ian Donald. He was Chairman of the Joint Ultrasound Group (to establish training requirements) of the Royal Colleges of Obstetricians and Gynaecologists and of Radiologists from 1986 to 1987 and of the Working Party on Obstetric Ultrasound in Scotland in 1988.

Regarding the specific question, 'What was it like at this time?' and then, 'Why did things happen the way they did?', I think that these have been dealt with or will be dealt with. From the viewpoint of obstetricians in general – what were our real concerns once it seemed clear that ultrasound was going to have a future? An honorary attachment with Professor Donald in Glasgow in 1964 had convinced me that obstetric ultrasound did have a future, but later in that year in America I was told it was just a dream of a mad, red-headed Scotsman, so I should forget it! I was told confidentially, nothing, no good will come of it, but of course that was wrong.

What were our main problems in the 1950s, 1960s, and into the 1970s? On the maternal side, maternal deaths, of course, but death is just the tip of the iceberg, below which is a lot of morbidity that is often due to the same causes, but not quite so severe. There were three big causes of mortality and morbidity in those days, two of which ultrasound can't help, namely abortion, and in those days mainly illegal abortion,[183] and hypertensive diseases. But haemorrhage was still one of the major killers and that was where we've already talked about placentography,[184] in which ultrasound was a huge advance. Up to then X-rays could be used, and similarly in the early days of ultrasound, you diagnosed or you thought you diagnosed where a placenta was, either because there seemed to be nothing else there, or by displacement of the fetal head. So ultrasound made a huge advance there. With the less dramatic bleeds after miscarriage or after delivery, the information that there were no longer bits of placenta in the uterus was a huge advantage, not only clinically, but also in the context of the savings of hospital beds, because the alternative was to keep the patient in. For example, in placenta praevia you might keep the poor lady in hospital for months.

But the fetus was, of course, the subject that was really exercising most of us, and of our two patients, it is the one that, generally speaking, is at most danger. And this was at a time when astronauts were beginning to go up in the sky and round the world and it seemed odd to a lot of us, who thought that we were experts on the fetus, that there had been no mortality among the astronauts but there was still much among our fetuses. Of course, one of the reasons was that the astronauts were highly selected, whereas the fetus is not selected; they would be well-trained and were all very fit, nothing like our fetuses. But the most important thing was that they were able to stick transducers on the astronauts so nobody ever had to ask them what they were doing, or how they were feeling, and they didn't even need to take pictures of them. In the meantime, here was the fetus and all we could do was listen to its heartbeat and try to feel its outline (palpation still comes in useful today). It was now that fetal phonocardiography and electrocardiography and ultrasound became the parents of real fetal medicine.

So what were the main things that we wanted to know about the fetus? We wanted to know if there was a fetus present in early pregnancy. Ultrasound's the answer; if so, how many? Multiple pregnancies have much bigger risks of lots of things, as the

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[183] The Abortion Act was passed in 1967.

[184] op. cit. notes 62, 65–66 and 68.

obstetricians know.[185] Is it alive (or are they alive)? That was important. How old is the fetus? That is very important. It may be hard for non-obstetricians to understand this simple point, because people have been dating pregnancies, quite often incorrectly, from the menstrual cycle for I don't know how many centuries. But it is terribly important because we were getting more and more interested in the fetus that was at risk, doing all sorts of tests, mostly biochemical, but largely forgetting that the normal values for a lot of these tests change as pregnancy proceeds. So unless you really know how old the fetus is, in terms of gestational age, no wonder some of these tests gave the wrong results. It is terribly important for the fetus that's at risk from simply snuffing out *in utero*, as you really need to know when it is safe to deliver or unsafe to go on waiting. This has changed very much recently with better paediatric care, giving you much more leeway. I used to think about the high-risk pregnancy in terms of two lines crossing on a screen, with the risks *in utero* increasing as the pregnancy proceeds, but also with the counter-risk of delivering too early and of neonatal death from respiratory immaturity decreasing. What you wanted was to pick out where those two lines crossed, showing when to deliver the patient. There were many tests, but it's only if you know the problem, the scale of the problems, and the gestational age, that you can interpret these.

We also want to know if the fetus is properly formed in most of these things and how much amniotic fluid there is – and only ultrasound gives us real help.

Hall: Dr McNay is a successor of, dare I say, the older gentlemen who are sitting here who used to work at The Queen Mother's Hospital. I think you, Margaret, may well be able to give us an insight into the period beyond the beginning when the equipment became up-to-date, and what implications it's had from your viewpoint.

McNay: I think it would be true to say, and I think the others would agree with me, that ultrasound has contributed more to changes in obstetric practice in the second half of this century than any other form of investigation. Much has already been said about ultrasound answering so many of the clinical questions and dilemmas, and Stuart [Campbell] has alluded to its role in prenatal diagnosis and in invasive procedures. Most of us are well aware of how it is now used so successfully. But I think the point that I would like to make is that I didn't come into ultrasound until 1978, by which time it was really established. I was a junior in Glasgow in the early 1970s and even at that time – and I think this is probably relevant for people to remember, despite all that has been said positively about the role of ultrasound – it still wasn't accepted by many of Ian Donald's clinical colleagues. Glasgow was in some ways a divided city and there was the new Queen Mother's Hospital and Rottenrow.[186] I was

[185] Professor Charles Whitfield wrote: 'The best highly ultrasound-relevant example is intrauterine growth restriction of one or both fetuses. Other examples, in which ultrasound is most helpful (and these days could fairly be called essential), include: hypertensive disorders, including pre-eclampsia, antepartum haemorrhage, both placenta praevia and placental abruption.' Letter to Dr Daphne Christie, 12 April 1999.

[186] Dr Malcolm Nicolson wrote: '...McNay is talking about there later being two maternity hospitals in Glasgow with two Professors of Obstetrics, with very different views on a number of matters – Professor Sir M C MacNaughton in the Glasgow Royal Maternity Hospital and Professor Ian Donald in The Queen Mother's Hospital.' Note on draft version of transcript, 16 November 1999. See also note 116 above.

brought up in Rottenrow. Ultrasound in those days was simply not believed and it's sad, looking back on it now, but I think it is important that people recognize that those who had the courage of their convictions to maintain their research and development in ultrasound really have to be congratulated. Without the vision of Ian Donald and his successors we wouldn't be in the position we are today, and even in those times when one might have thought that it would have been more generally accepted throughout the UK, it wasn't.

Hall: We've talked extensively about ultrasound in its obstetric context, but I would like to record at this meeting the contribution made in the Western Infirmary by Pat Morley and Ellis Barnett[187] who, using the Diasonograph series of equipment and the earlier equipment, carried out many examinations in other organs of the body that are now routinely examined, the kidneys and the liver. There were some remarkably good greyscale images in the early days of liver disease, and they pushed it forward in that area. It's unfortunate that for personal reasons neither of them can be here today, but I think it's well worth recording the contribution they made.

Campbell: Can I add two more things? They are both bees in my bonnet, so I may as well get them out. We haven't mentioned Doppler ultrasound (colour Doppler). To me colour Doppler has already made huge advances into obstetrics, and also in gynaecology. It began in the early 1980s and the quality of the colour Doppler equipment is so staggeringly good now, that in the uterus you can see virtually every spiral artery with the new Acuson Sequoia machine.[188] And with colour and pulsed Doppler we can now predict women who are at risk of pre-eclampsia and, as a result, we can prevent a lot of it happening. We can detect hypoxia in the fetus with Doppler and can trace the progression to acidaemia. We can predict when a fetal heart is going into failure by measuring venous flow to the heart. It is such a source of knowledge that we mustn't ignore this tremendous development. Although Tom was a pioneer of 3-D, the 3-D machines now give fairly fast reconstruction and are giving quite staggeringly beautiful images of things like the fetal face and extremities. I haven't the slightest doubt that when this process is speeded up with faster computing and electronic scanning that 3-D will make a big impact in the future. What I am really trying to say is that it hasn't stopped. Ultrasound is a technique which has continued to develop. All these clever engineers continue to develop new equipment and it is we clinicians who get the benefit and apply it in clinical situations. If there weren't new developments, of course, the development of new clinical applications would stop, and we would say we have done everything. But the engineers keep coming up with new things and it's still a very exciting field. There is now a journal *Ultrasound in*

[187] Drs Patricia Morley and Ellis Barnett were at the Radiodiagnostic Department of the Western Infirmary in Glasgow. Using a prototype version of the Nuclear Enterprises Diasonograph they studied over 250 patients with pelvic masses. See Morley P, Barnett E. (1970) The use of ultrasound in the diagnosis of pelvic masses. *British Journal of Radiology* 43: 602–616. See also note 26 above.

[188] Acuson was founded in 1979 and in 1983 introduced 'system 128' using 'Computed Sonography'. Further development and enhancement has led to the current model, 'Sequoia', with a wide range of Doppler facilities. Information provided by Mr John Fleming, 24 May 1999.

Obstetrics and Gynecology,[189] which is devoted to the whole science and now has a high impact rating: it's one of the top journals now in obstetrics and gynaecology.[190]

Mr Demetrios Economides:[191] I wanted to ask a question of all the people who were involved at the time. What were their thoughts regarding the safety of ultrasound in scanning pregnant women, especially in early pregnancy?

Hall: It's a subject that has waxed and waned over the years. Would anybody like to speak on that topic to close the meeting, the last bit of the session?

Whittingham: There has been an incredible increase in power levels and intensity levels from the machines of those early days to those that are around today.[192] A manufacturer from America said to me just in conversation a few weeks ago, 'Some of our machines are hot.' That was the American way of putting it. Our own measurement experiences indicate that whereas average intensities of a fraction of a milliwatt per square centimetre were fairly common in the early 1970s, they are now measured in watts per square centimetre. This is partly because the absolute powers have increased in the search for smaller and smaller signals and at higher and higher frequencies, and partly because the beams are getting narrower and narrower and that's putting up the intensities. So I think that in the early days they were quite right to say that ultrasound was safe; whether that's so certain today is only true if you exercise prudence.

Abdulla: I think all of us who worked with early ultrasound were very concerned that ultrasound may cause problems or damage, especially to the fetus. Ian Donald raised this subject on many occasions[193] and he was always wondering whenever there was a case of fetal abnormality whether it had anything to do with the ultrasound. One of the projects he undertook was that he linked with workers in Lund, Sweden and Professor Hellman of New York. They surveyed a vast number of maternity patients and looked at the incidence of abnormalities in babies born to patients who had ultrasound examinations, and found favourable results.[194] There were problems when in 1970 an article by MacIntosh and Davey from South Africa showed that there were

[189] *Ultrasound in Obstetrics and Gynecology*, the official journal of the International Society of Ultrasound in Obstetrics and Gynecology, was launched in 1990 by The Parthenon Publishing Group. Professor Stuart Campbell is Editor-in-Chief.

[190] All significant journals within a specialty are ranked by impact factors, which show the average citation rate per published item, which is measured by dividing the number of times the journal has been cited by the number of items it has published. See Garfield E. (1979) Citation analysis of scientific journals. In *Citation Indexing, its Theory and Application in Science, Technology and Humanities*. Toronto: John Wiley & Sons, 148–239.

[191] Mr Demetrios Economides FRCOG (b. 1956) has been Consultant Obstetrician and Gynaecologist, Senior Lecturer at the Royal Free Hospital School of Medicine, London, since 1992. His research interests include ultrasound in early diagnosis of fetal abnormalities.

[192] Whittingham T A. (2000) Acoustic outputs of diagnostic machines. In Ter Haar G, Duck F A. (eds) *Safety of Medical Diagnostic Ultrasound*. London: British Institute of Radiology, 16-31.

[193] See, for example, Donald I. (1974) The safety of using sonar. *Developmental Medicine and Child Neurology* 16: 90–92. *idem* Placental localization by sonar – a safe procedure. *British Journal of Radiology* 47: 72.

[194] Hellman L M, Duffus G M, Donald I, Sundén B. (1970) Safety of diagnostic ultrasound in obstetrics. *Lancet* i: 1133–1134.

chromosomal breakages or damage when they exposed human blood cultures to continuous ultrasound.[195] This worried a lot of people, so much so that when the news hit the local papers the number of ladies attending the ultrasound department virtually dropped to zero that week.

Hall: I can add a comment on the MacIntosh and Davey scenario which was very worrying at the time, because they were claiming chromosome abnormalities at the levels produced by a Doptone instrument[196] which, of course, is used for the routine detection of fetal life. Not so many people know of the subsequent refutal of that paper by one, if not both, of the authors.[197] Unfortunately, I can't recall the details off the top of my head, but it does exist. The work was subsequently refuted.

Abdulla: The work we did at Queen Charlotte's Hospital, when I moved from Glasgow and joined Stuart [Campbell], involved looking at ladies who were exposed to ultrasound just before they were delivered, so that the baby's blood was exposed to recent ultrasound while being monitored in labour. Also, we looked at blood cultures from patients and fetuses exposed to ultrasound just before termination of pregnancy. I remember having to take the blood sample from the Chelsea Hospital to the Genetics Laboratory at University College Hospital. These fetuses were exposed for quite a long time to ultrasound but we found no increase in the chromosomal damage or breakages.[198] I think that with the negative results from these papers one could manage to refute the implications of that worrying article from South Africa.[199]

MacVicar: I suppose it appears simplistic now, but we knew that there could be damage from ultrasound because of its use in therapeutics. We went to the Department of Anatomy in the University of Glasgow and were told that a very sensitive tissue was the demyelinated nerve fibres in the brains of new-born kittens. So we took the machine (A-scan) and we irradiated the brains of kittens, having removed the top of the skull, for over an hour.[200] The kittens were then killed and the

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[195] MacIntosh I J C, Davey D A. (1970) Chromosome aberrations induced by an ultrasonic fetal pulse detector. *British Medical Journal* iv: 92–93.

[196] This instrument was manufactured by Smith Kline Instrument Co., USA.

[197] MacIntosh I J C, Davey D A. (1972) Relationship between intensity of ultrasound and induction of chromosome aberrations. *British Journal of Radiology* 45: 320–322. See also MacIntosh I J C, Brown R C, Coakley W T. (1975) Ultrasound and '*in vitro*' chromosome aberrations. ibid. 48: 230–232.

[198] Boyd E, Abdulla U, Donald I, Fleming J E, Hall A J, Ferguson-Smith M A. (1971) Chromosome breakage and ultrasound. *British Medical Journal* ii: 501–502. Abdulla U, Dewhurst C J, Campbell S, Talbert D, Lucas M, Mullarkey M. (1971) Effect of diagnostic ultrasound on maternal and fetal chromosomes. *Lancet* ii: 829–831. Abdulla U, Talbert D, Lucas M, Mullarkey M. (1972) Effect of ultrasound on chromosomes of lymphocyte cultures. *British Medical Journal* iii: 797–799.

[199] op. cit. note 195 above.

[200] This work was carried out on anaesthetized animals in accordance with Home Office regulations under the Cruelty to Animals Act (1876). Professor John MacVicar wrote: 'The work was carried out within the Department of Anatomy, University of Glasgow. The animals were supplied to them and we merely put the transducer on the animals after they had been anaesthetized and the top of the skull removed by the Reader in Anatomy, Professor Bacshish, who held the appropriate licence to carry out such animal experiments. ...The experiments were legally covered and correctly carried out.' Letter to Dr Daphne Christie, 11 November 1999.

histology looked at by the anatomists. They found, to our relief, no detectable abnormality or tissue damage.[201] Later we went on to irradiate pregnant rats, and over three generations the anatomists didn't find any abnormalities in the offspring, but then we were not looking for genetic defects.

Brown: It's extremely difficult to prove a negative and it appears to me that crying wolf about the safety of medical ultrasound has almost become an industry. That paper from South Africa was extremely destructive and I believe that it was later found that the results were due to faulty experimental technique.

Hall: Yes, they were in fact found to be due to a faulty experimental technique.

Brown: Sterilizing agents in the vessels or something of the sort [Hall: That's correct]. It was a horrific incident and, of course, the press picked it up and made a meal of it. However, that does not mean that one should not exercise responsibility, and one of the things about which I feel some pride in the early medical ultrasound work in Glasgow was that we set out with a policy of reducing the energy transmitted into the patient to the absolute minimum, consistent with an adequate clinical result. Now, unfortunately, that policy was not followed in America. I don't think it is being followed there even now.

If you wish to control the sensitivity of an ultrasound machine, you can do it in two ways. You can modify the gain of the amplifiers which are receiving the signals or you can modify the amount of energy transmitted into the patient. Our philosophy was to have the amplifiers running full out, limited only by noise, and to control the sensitivity by reducing the amount of energy transmitted. I'd still commend that as a way to go.[202]

Professor Jean Robinson:[203] First, I would like to comment on the remark that 'modern-day ethics committees would not allow what had gone on in Glasgow.'[204] I came here hot-foot from a multi-centre research ethics committee which was discussing trials of completely new equipment which had not been used on live patients. It wasn't ultrasound stuff, but, of course, ethics committees do require you to say exactly what you are doing, exactly which questions you are trying to answer and, of course, to get consent. That is the thing that has changed. This question of safety does worry me. I do remember reading on a number of occasions that Ian Donald raised this.[205] Antenatal ultrasound is one of the technologies which has

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[201] The results of this work are reported in Ian Donald's 1958 *Lancet* article, op. cit. note 126 above.

[202] Dr Angus Hall wrote: 'The effectiveness of altering the power transmitted into the patient to control system sensitivity during scanning was investigated. It was found to reduce considerably the energy transmitted into the patient whilst still obtaining clinically acceptable images. See Hall A J. (1975) *An Investigation into Certain Aspects of the Safety of Diagnostic Ultrasound*. MSc Thesis. Glasgow: University of Glasgow.' Letter to Dr Daphne Christie, 30 October 1999.

[203] Professor Jean Robinson was Chair of the Patients Association from 1973 to 1975 and has been Honorary Research Officer, Association for Improvements in the Maternity Services since 1989 and visiting Professor, School of Health Sciences, University of Ulster since 1997.

[204] See Dr James Willocks' contributions on page 46.

[205] op. cit. notes 126, 193 and 194 above. See also Donald I. (1974) New problems in sonar diagnosis in obstetrics and gynecology. *American Journal of Obstetrics and Gynecology* 118: 299–309. *idem* (1979) *Practical Obstetric Problems*, 5th edn. London: Lloyd–Luke (Medical Books).

functioned within a background pattern of quite well-informed consumer criticism for a very long time and despite the very clever and brilliant work which people have done, why is it that consumers have been continually critical? First, the fact that it was translated into routine use without proof of necessity or benefit, and secondly that we wanted long-term follow-up of people on whom it was used, and controls to see what there should be. The long-term epidemiological studies are not entirely reassuring. The studies on monkeys are certainly not reassuring; what we learned as consumers from the ultrasound history was that we were going to demand that long-term follow-up should be built in on all technology and treatments on pregnant women,[206] and that one should look at the social costs and psychological costs and benefits as well as whether the technology itself worked. But we want a richer, wider, deeper, and longer term evaluation of what very clever, very well-meaning, very brilliant people are doing.

Hall: I think we have got to be careful to distinguish between what harm or damage is done by inexperience or clinical misdiagnosis and what Tony Whittingham was referring to as the increase in the power modern ultrasound machines used in certain imaging modalities, certainly with power Doppler, continuous high-power Doppler use.

Wells: I just wanted to make the point that the purpose of today, I think, is to review the history and what actually happened. We are not here to make points about what should happen in the future, we are here to review what's happened in the past and to hear people who actually remember events as they took place, telling us about it. And I think, although the safety issue is a very important problem and it's something which prudent people will be concerned about in current practice, from my point of view today I hope we won't spend a lot of time being anxious about the safety and the way in which it is being handled. I want to hear how it was handled, I don't really want to discuss in the light of what we know today whether what was done then was what we would have done today had we been in those circumstances.

Campbell: I promise these are my last words. I think the first thing is that the 1958 paper,[207] that classic paper which James Willocks alluded to, contained quite a big section on safety, so it was quite clear even in 1958 that Ian Donald was very concerned about safety issues and in fact it's an amazing paper. You know, the modern tendency is to string out your data into about five or six papers, but Ian Donald had basic techniques described in great detail, clinical examples, discussion and safety. It was a *magnum opus* in every sense of the word. Professor Robinson's comment that there was great consumer opposition to ultrasound, of course, is absolutely nonsense. There is no technique – *no* technique – which is so overwhelming demanded by women.

Hall: Sorry, Stuart, I have said already we are not here to discuss this – it's the history we are talking about.

Campbell: I think it's relevant to the history that this has always been a technique that

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[206] For an account of experimental animal work, see Hu J H, Ulrich W D. (1976) Effects of low-intensity ultrasound on the central nervous system of primates. *Aviation Space and Environmental Medicine* 47: 640–643.

[207] op. cit. note 126 above.

has been welcomed by women. We won't get into discussions on safety, because there is quite an extensive amount of follow-up now of babies in randomized studies, which is reassuring.[208] We won't get into that debate, but just to make one point very clear, this has always been a technique which has been very easy for the practitioners to use. It's always been a joy, because the ultrasound image should be a shared experience, and that's the exciting thing that those of us who work in ultrasound have always experienced no resistance to at all. Maybe we have oversold it, but whatever it is, women want it, because they can see their babies and bond with their babies.

Hall: I am sure that you and Professor Robinson will have a fascinating discussion after the end of the meeting.

Dr Ian Spencer:[209] One of the nice things about doing the job as the research assistant on this particular project – the history of obstetric ultrasound – is of course you get to read a lot of the early papers. One of the first MDs on diagnostic ultrasound was that written by Professor MacVicar.[210] One of the most interesting parts of Professor MacVicar's thesis is that there is an extensive review of the safety question in the period up to the beginning of that team's work on the question of obstetric ultrasound and, indeed, gynaecological ultrasound. Perhaps it's a story which is not part of our brief, but the interesting thing that Professor MacVicar reviewed in his MD thesis was that, of course, therapeutic ultrasound, with much higher power outputs, had actually been used in Britain since the 1930s. Quite apart from that, there was a number of other studies on attempts at diagnostic ultrasound. The interesting thing was that all of these Glasgow experiments used power outputs which were far lower than anything that had been reviewed previously. And, although in hindsight one can look at Professor Donald's experiments on cats' brains[211] or whatever else and say, 'Well, that's not a lot for a new technology, is it?', at the time, in relation to other techniques which were being introduced, it was actually seen as an extremely conservative approach. So there is also the whole history of therapeutic ultrasound.

The other thing that's interesting is that engineers working with ultrasound in industry had been using it for a number of years and curiously enough no-one thought to inquire, 'Is this injuring engineers at all?' And one of the other factors which I suspect was reassuring to Professor Donald and the rest of his coworkers, was the fact that engineers had been using the thing for years with obviously no ill-effects.

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[208] See, for example, Salvesen K A, Bakketeig L S, Eik-Nes S H, Undeheim J O, Okland O. (1992) Routine ultrasonograpy *in utero* and school performance at age 8–9 years. *Lancet* 339: 85–89. Salvesen K A, Vatten L J, Eik-Nes S H, Hugdahl K, Bakketeig L S. (1993) Routine ultrasonography *in utero* and subsequent handedness and neurological development. *British Medical Journal* 307: 159–164. For a review on the safety of obstetric ultrasound, see Economides D L, Braithwaite J M. (1996) Safety of ultrasound in obstetrics. *Contemporary Reviews in Obstetrics and Gynaecology* 8: 11–14.

[209] Dr Ian Spencer (b. 1961) was research assistant to Professor Iain Cameron and Dr Malcolm Nicolson at the Wellcome Unit for the History of Medicine, University of Glasgow, from 1995 to 1998. During that period he studied the development of medical ultrasound in Glasgow, 1954–1976.

[210] op. cit. note 128 above.

[211] See page 66.

Hall: Can I just make one comment on that? The ill-effects on the engineers actually would be that their thumbs dropped off, or in my case that my mental acuity would disappear, because I used to check the mid-line shift instruments on my head. Need I say any more on that possibility? I would like now to bring the meeting to a close, but I think it's fitting as I do so that, we've spoken scientifically and technically and clinically about our experiences, but I wonder if Mrs Donald might like to say something from a personal viewpoint?

Mrs Alix Donald:[212] There's not much I can say after this wonderful afternoon where there has been so much of great interest. I looked up some things early this morning as I needed to be reminded when things happened ultrasonically. I didn't find the paper that I really wanted, which was an account of the first 25 years of ultrasound.[213] It was perhaps just as well, as these steps forward have been discussed this afternoon by so many far better qualified to talk about them than I am. But two incidents came vividly to mind.

In Dallas, Texas, Ian was shown the first real-time scanning machine brought from Phoenix, Arizona, by some talented young men. Ian was, of course, wildly excited. They wanted to carry him off to Phoenix to show him more, but sadly Ian couldn't change his next commitments. However, it wasn't too long before he had one of his own.

I was also reminded of the date of Ian's meeting with the Pope in 1979. Ian was invited to speak in Milan. He showed a real-time film of an eight-to-nine-week fetus, perfectly formed, with all four limbs moving energetically, which infuriated a lot of Italian women in the audience who hoped for an abortion law in Italy. The film seemed to make it unthinkable. Ian was hurried out by the back door in case of trouble. The Pope was, of course, delighted and received Ian very kindly in Rome speaking excellent English. Ian was surprised to notice that a Cardinal in attendance on the Pope carried a small tray on which lay some of his reprints!

I could talk endlessly of such memories. Thank you for making it such a wonderful opportunity for me to see, and hear, so many old friends from Glasgow, and from all over the place.

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[212] See note 5 above.

[213] Donald I. (1980) Medical Sonar: the first 25 years. In Kurjak A. (ed.) *Recent Advances in Ultrasound Diagnosis 2*. Amsterdam: Excerpta Medica, 4–20.

GLOSSARY

Acidaemia
An abnormally low pH of whole blood.

Alphafetoprotein
The fetal equivalent of albumin. During pregnancy the detection of raised maternal serum alphafetoprotein might indicate the presence of a fetal abnormality, such as neural tube defects.

Amniocentesis
A procedure in which a needle is placed transabdominally into the amniotic cavity in order to remove fluid for analysis, inject solutions that will induce abortion, or infuse dyes for radiographic studies. Often used in the diagnosis of chromosomal abnormalities and genetic disorders.

Anencephaly
The absence of a major portion of the cerebral hemispheres in the fetus.

Ascites
The intraperitoneal accumulation of watery fluid in the nature of a transudate (like sweat). The abdomen may be greatly distended by the accumulation of many litres of fluid.

A-mode
A-mode display is one in which the presence of echoes is indicated by vertical 'blips' on a bright horizontal baseline. The higher the blip, the stronger the echo signal. The greater the distance of the blip from the left of the screen, the greater the distance of the reflecting structure from the ultrasonic transducer (see Figure 4).

B-mode
B-mode (or B-scan) is a generic term that is now used in medical ultrasound to describe all display systems which present a two-dimensional 'slice' picture of reflecting tissue interfaces in the flat plane being scanned. This applies to both static and real-time scanners. Usually the echoes are shown as bright spots or lines on a dark background, although a 'negative' image is technically possible and has sometimes been used. With the advent of three-dimensional ultrasound imaging, the use of 'B-mode' should probably be restricted to two-dimensional ultrasound imaging systems which scan and display only a single plane at any one time (see Figure 5).

Biparietal diameter (BPD)
The diameter across two parietal bones of fetal skull [see Willocks J, Donald I, Duggan T C, Day N. (1964) op. cit. note 118 above].

Bi-stable image
High-amplitude signals are represented as white dots and weaker echoes are represented as black, without any shades in between.

Caliper
The ultrasonic caliper is used to measure the separation between the echoes representing the separation of two surfaces. It is commonly used to measure BPD. It takes its name from a mechanical instrument with a pair of adjustable legs that can be set against opposing surfaces or at two specific points on a surface for the precise measurement of the distance between them. It is often used to measure the inside or outside diameter of an object.

Crown-to-rump length
The distance between the crown of the fetal head and the tip of the fetal rump in the normal curled-up fetal position.

Echo-encephalometry
A technique used for detecting mid-line shifts of the adult brain, due to injury or disease, through the intact skull.

Greyscale mode
Amplitudes of varying intensity are assigned shades from black to white, thereby greatly improving image quality.

Hydatidiform mole
A pre-cancerous condition in which the placental villi become oedematous, thus forming small watery cysts which are well described as having the appearance of a 'bunch of grapes'. See also note 16 above.

Hydrocephalus
Any condition in which there is an abnormally large volume of cerebrospinal fluid within the skull.

Hypoxia
An inadequate oxygen concentration in body tissues.

Laparoscopy
The endoscopic examination of the peritoneal cavity and surface of accessible abdominal organs (for example, the uterus) by means of a laparoscope. Commonly used for the diagnosis of endometriosis.

M-mode or motion ultrasound
See Time motion (TM)-mode.

Phased arrays
A technique for changing the effective direction of an ultrasonic beam, either during transmission or reception or both, by introducing controlled time delays between signals entering or leaving different parts of a subdivided transducer.

Placenta praevia
A placenta situated more or less centrally in the lower segment of the uterus, so blocking the os, or birth canal, and likely to result in severe haemorrhage during the birth process.

Polyhydramnios (or simply hydramnios)
The presence of an abnormally large amount of amniotic fluid for a particular stage of pregnancy, commonly associated with fetal abnormality, maternal illness or interference in normal fetal physiology by toxic or other substances.

Pre-eclampsia
An obstetric condition occurring in the second half of pregnancy, characterized by hypertension, proteinuria and usually oedema.

Real-time imaging
Allows the acquisition and display of images to occur so rapidly that their formation and display appear to be simultaneous. The first commercially available real-time ultrasound machine was the Siemens Vidoson (invented by Richard Soldner).

Scan conversion
A process carried out in an electronic device, usually with some form of intermediate storage mechanism, by means of which an image created in one format – for example, as a series of 'vectors' (lines) in arbitrary directions – can be converted to another format, such as a 'raster' image as used in television. In the process of conversion other aspects of the image may also be altered, such as the degree or characteristics of the 'greyscale' that is presented to the observer.

Spina bifida
Lower developmental defects characterized by the absence of the vertebral arch, usually in a number of contiguous vertebrae (i.e. a common defect affecting several otherwise joined up vertebrae).

Three-dimensional (3-D) ultrasound
Ultrasound scanning and imaging was extended into three dimensions at quite an early stage in the development of medical ultrasound, though it has only recently become commonplace. The object is to present a three-dimensional image of the tissue structures. This can be either a 'perspective view' of a tissue surface, such as a baby's face, or a 'volume' image showing the relationship of multiple tissue structures in three-dimensional space. In the latter case, stereoscopy is sometimes used to give the user a greater appreciation of the spatial relationships involved.

Time motion (TM)-mode
TM-mode is employed to examine the movement of tissue structures with time. The most common application is echocardiography, where it is used to display the motion of the heart valves and wall. However, it was also used, early in the development of obstetric ultrasound, to detect early fetal heart movements to confirm fetal life. TM-mode is rather like A-mode, but in TM-mode the baseline is brightness-modulated by echo signals, and the entire baseline is moved, relatively slowly, perpendicular to its length, so that movement of the echoes is traced out.

Trimester
A period of three months. First trimester, the first three months; second trimester, the middle three months; third trimester, the last three months, of a human pregnancy.

Ultrasound
Sound waves, or mechanical vibrations, beyond the range of human hearing. In the medical context, these are in the region of one to 20 million vibrations per second.

Ventriculomegaly
Abnormally large ventricles of the brain.

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