IAN DONALD & SALVATOR LEVI

PRESENT AND FUTURE OF DIAGNOSTIC ULTRASOUND

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Edited by

IAN DONALD &
SALVATOR LEVI

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FOREWORD

A series of annual symposiums was inaugurated in 1973 by the "Fondation pour la Recherche en Endocrinologie Sexuelle et l'Etude de la Reproduction Humaine" (F.R.E.S.E.R.H.).

The first symposium dealt with the endocrinology of reproduction, followed in 1974 by a symposium on senology.

The subject of the Third International Symposium of the F.R.E.S.E.R.H. was diagnostic ultrasound.

These annual publications of the F.R.E.S.E.R.H. demonstrate the diverse activities and disciplines that our collaborators at the "Clinique Obstétricale et Gynécologique de l'Hôpital Universitaire Brugmann" have shown to their respective fields.

Ultrasonics have become an integral part of the research arsenal, the data presented in this book are of interest to the clinician as well as to the ultrasonic specialist as one cannot ignore the ever increasing interest given to this field.

The contributors to this book bring to the field of diagnostic ultrasound unique expertise and the results should provide the reader with a timely picture of the application of ultrasonography.

R. Vokaer

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Held at Brussels, Belgium,
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Under the patronage of Her Royal Highness the Grand Duchess Josephine Charlotte

PREFACE

A spate of books is inevitable in a subject which, in the last few years, has more or less erupted on to the medical scene. As one American or European or even World Congress follows another a bewildered and largely uniformed medical public is likely to feel more and more "cast out in outer darkness with weeping and gnashing of teeth," because its rapidly advancing technology now far exceeds its rate of adoption into practice.

A few of us have been swimming with this tide for a number of years and often have given too little thought to bemused bystanders.

The work of the contributors to this volume is already well known to colleagues in this field but a balanced stocktaking account is needed above all by the clinical practitioner on whom the ultimate responsibility for applying this new science depends. He must be provided with an overall view of what can and cannot be expected of it, both now and in the immediate future, remembering always the competing demands of other sophisticated methods in the practice of medicine which grows daily more expensive.

An appreciation of cost-effectiveness and the possibility of side effects are also very much his concern.

It was natural that the major breakthrough should come first via the medium of gynaecology and even more so in obstetrics because of the immediacy of confirmation by other means, namely laparotomy or accouchement respectively. But this is only a narrow band in the diagnostic spectrum of sonar (as I prefer to call diagnostic ultrasound).

The intention of this book is to provide the reader with a broader view than the purely technical, to educate rather than to instruct, to interest rather than to overwhelm. The uncommitted reader can best judge for himself, how far these objectives have been achieved.

Ian Donald

The speakers invited by the F.R.E.S.E.R.H. (Foundation for Research in Sexual Endocrinology and the Study of Human Reproduction) to present a progress report on ultrasound diagnosis for the participants in the 3rd international symposium held by the foundation, have agreed to produce a study entitled: "Present and future of diagnostic ultrasound".

This subject is extremely topical as can be seen from the publication of numerous articles each month, although only a third of a century has elapsed since Dussik found that he could use ultrasound in neurological diagnosis.

Used for the direct or indirect detection of abnormal structures, ultrasound, because of great advances in technique, become a method of investigation which is particularly suitable for morphological studies of the human body.

Its extension to most medical disciplines and its use, not only in all university hospitals but also in a large number of other public and private institutions, is explained by several factors. Whatever may be its objective, ultrasonic examination provides much information of frequently proven value, be it anatomical, functional, quantitative or qualitative. As it is not uncomfortable for the patient and has no side-effects, the examination can be repeated as often as the practitioner finds necessary.

Our thanks are due to the authors of this study, each of whom has contributed a chapter on his own speciality, showing the present state of ultrasonic diagnosis and the outlook for the future. The study deals not only with their own experiences but also contains information provided by other workers in this field.

Readers interested in ultrasonic diagnosis will recognize, among the authors, many pioneers of ultrasonic techniques, many of whom are known throughout the world for their brilliant work and the encouragement they have given to the spread of this technique.

This work will be of great interest to all researchers in one of several of these fields and it will be invaluable for newcomers because it will save them much effort and many errors by enabling them to draw on the experience of others.

Salvator Levi

CONTENTS

TECHNICAL PROCEDURES AND IMAGING

GEORGE KOSSOFF

The ability to provide accurate cross-sectional views of soft tissue is the distinguishing feature of diagnostic ultrasound.

B-MODE TECHNIQUE

The vast majority of ultrasonic examinations are currently performed by using the echo ranging or B-mode technique first described by Wild & Reid (1) and Howry & Bliss (2) in 1952. Short pulses of ultrasonic energy are emitted by the transducer and are reflected at discontinuities in acoustic impedance. The energy that is reflected to the transducer is converted back into an electrical impulse and is displayed as an increase in the brightness of a trace of an oscilloscope; the direction of the trace represents the direction of propagation of the energy. A cross-sectional view or echogram is obtained by scanning the direction of propagation of energy in the plane of the section and making the trace follow the same movement. As shown in Fig. 1, the view of the echogram is at right angles to the plane of the scan at a resolution determined by the axial and lateral resolution of the transducer; the latter also determines the thickness of the echogram. The three-dimensional composition is obtained by taking a number of echograms at different levels and/or different planes.

Emphasis was originally given to the display of echoes originating from the boundaries of major structures. These reflect the energy in a mirror-like or specular fashion and, when inclined to the beam, reflect the energy away from the transducer. The size of the echo is therefore critically dependent on the inclination; an amplitude decrease by a factor of one

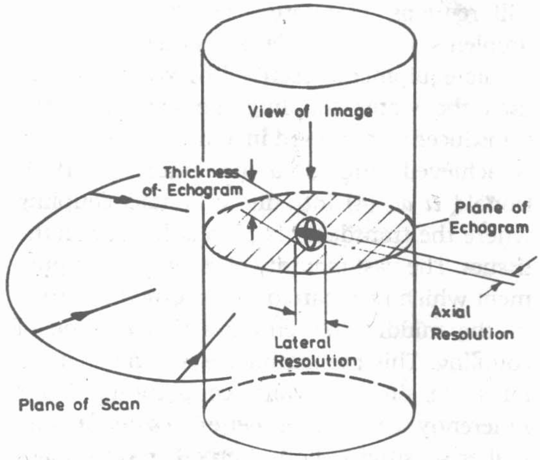

Fig. 1—1. Relationship between plane of scan, view of image and resolution in B-mode technique.

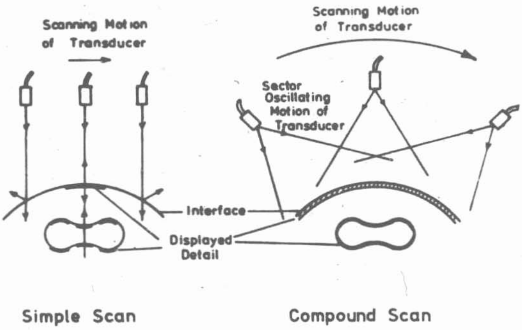

Fig. 1–2. Comparison of simple and compound scan.

hundred at an inclination of ten degrees is not uncommon. Thus, as illustrated in Fig. 2, in simple scanning where there is no superposition of lines of sight, the inclined outlines are not displayed and only a partial representation is obtained. To overcome this difficulty, Howry developed compound scanning in 1955 (3). In this method of scanning, the tissues are examined from many different directions with a large number of superposition of lines of sight in an attempt to ensure that all interfaces are at normal incidence to the examining beam at some time during the scanning period. Compound scanning does not compensate for inclinations away from the plane of the scan. This still remains, therefore, one of the unsolved problems of the B-mode technique.

The equipment described by Wild & Howry used the water coupling method where the transducer is immersed in a tank and coupling is achieved through a membrane. In 1958, Donald *et al.* (4) introduced contact coupling where the transducer is placed directly on the tissues. The vast majority of commercial equipment which first started to come on the market in the middle 60's employs this method of coupling. This predominance is somewhat unfortunate, since the water coupling method is inherently capable of better resolution and higher sensitivity; both methods have a place in the provision of a full range of clinical examinations.

Transducer

The transducer is the "eye" of the echoscope and its performance determines the axial and lateral resolution of the echogram. Because the echoes are displayed as dots of light, it is customary to consider the resolution in terms of the size of this dot of light (5). With most transducers, the axial resolution is of the same order as the size of the dot and is compatible with the other resolution-determining parameters of the echoscope such as mechanical stability of the scanner, linearity of monitoring, generation of position, and direction of trace, etc.

The lateral resolution of flat transducers is several times worse. Weak focusing by means of a lens or by using a curved transducer may be used to improve the resolution, but it only partially solves the problem, since the beam can be narrowed only by a factor of two to three over the whole depth of penetration into the tissues (6). As the degree of focusing is increased, a further reduction in the width of the beam is obtained. This improvement, however, is obtained over only a short focal distance, whilst a wide beam is obtained elsewhere. For this reason, strong focusing is not generally employed in B-mode equipment and the relatively poor lateral resolution of weak focusing transducers is the major source of image degradation of current echoscopes.

Howry pointed out that the lateral resolution may be improved by combining compound scanning with an integrating display. The principle is illustrated in Fig. 3, which shows a point target scanned from different directions. When the target is scanned from one direction, it is displayed as a line: the thickness of the line is equal to the axial resolution; the length, to the lateral resolution. As the compound scan progresses and the target is scanned from different directions, the lines cross to form a star. With an integrating display such as a film, the intensity at the centre is built up whilst that of the sides remains unaltered, thus improving the lateral resolution.

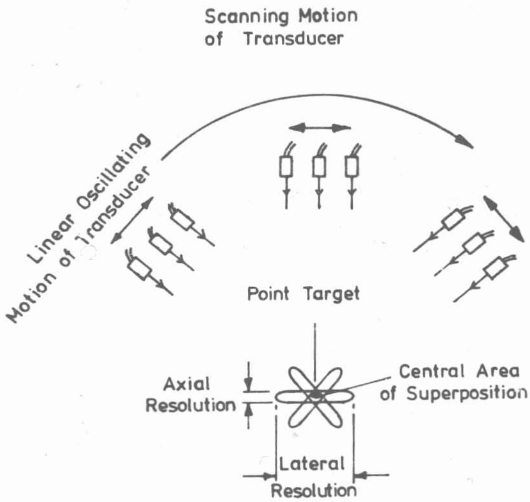

Fig. 1–3. Enhancement of central intensity resulting from a combination of compound scan and integrating display.

A focused transducer is also a more efficient collector of energy; it is, therefore, less critically dependent of inclination. Thus, more of the inclined structures may be displayed and the most detailed representation is obtained by examining the tissues with a focused transducer, using compound scanning and forming the image on an integrating display.

Computer control and processing of ultrasonic data

A number of investigators have described digital techniques to control the acquisition and processing of echoes so as to enhance the information content of the echogram (7, 8, 9, 10).

In the simplest process, the computer is used to control the scanning motions of the transducer, set the gain, give an automatic display of patient number, position of transducer, etc., and to correlate the ultrasonic data with other parameters such as heart beat and respiration.

At the next level of complexity, the memory of the computer is used to store the echogram with an amplitude range much greater than that obtained on oscilloscope displays. The echogram is then read out at selected receiver gain characteristic either in black and white or in colour. With echograms stored in memory, it is also possible to manipulate a set of echograms to obtain a display representing a section through any desired angle in the set or to combine a set to obtain multiple representation (11).

The most rewarding potential application of computers is in the processing of the data. The applications described so far include frequency analysis of echo waveforms (12), averaging and band pass filtering to enhance the signal to noise ratio, and inverse filtering to sharpen the axial and lateral resolution (13). With more powerful computers, other techniques such as cross-correlation of information obtained with multiple transducers become practical. These techniques may then be used to remove artifacts and to measure other acoustic parameters. Computers will undoubtedly play an ever increasing role in diagnostic ultrasound.

Real time displays

Present echoscopes take between ten to twenty seconds to form a compound scanned echogram. If real time viewing could be obtained without sacrifices in the quality of the echogram, it would have obvious advantages.

Currently, several instruments offer real time displays of simple scanned echograms. The Siemens Vidoson echoscope is the earliest of these instruments. It achieves a fast linear scan by utilising a rotating transducer situated at the focus of a paraboloid reflector which reflects the energy parallel to the axis and produces one linear scan for each rotation past the reflector. More recently, several versions of switched and phased array transducers have also been used to achieve a fast linear (14, 15) or sector scan (16). Unfortunately, most of these instruments form an image consisting of relatively few lines of sight and, up to now, the quality of the image is not as good as that obtained with the slower compound scanned echoscopes.

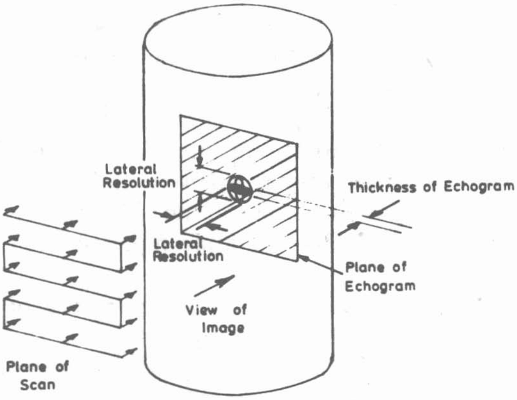

Fig. 1—4. Relationship between plane of scan, view of image and resolution in C-mode technique.

C-MODE TECHNIQUE

The C-mode or constant depth technique provides a view of the image that is at right angles to that obtained with B-mode technique. In this technique, the transducer is scanned in the plane of the image and only the echoes that are received from a constant depth are displayed (17). As illustrated in Fig. 4, the resolution of the C-mode echogram is determined by the lateral resolution of the transducer, whilst the thickness of the echogram is determined by the axial resolution.

The main advantage of the method is that it allows strongly focused transducers to be used in the examination, since only the echoes received from the focal depth need be displayed (18). Unfortunately, the technique has a number of serious disadvantages. The scanning time is considerably increased. It is difficult to implement compound scanning and, as the tissues in front of the displayed plane are not visualised, some confusion in the interpretation of the results is possible, especially if there are some excessive changes in attenuation in tissues in front of the displayed plane.

FOCUSED TRANSMISSION IMAGING

Focused transmission imaging provides another method of obtaining cross-sectional views

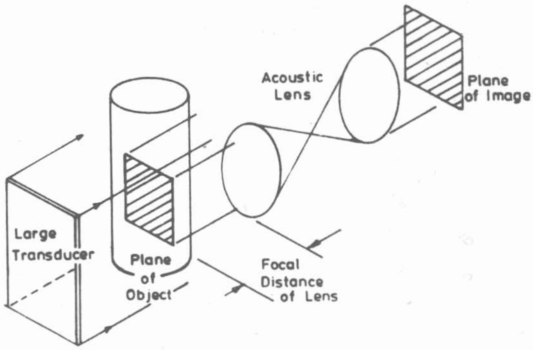

Fig. 1—5. Principle of focused transmission imaging.

(19, 20). The technique is a development of acoustical holography, which has proved to be disappointing in its application to the visualisation of soft tissue up to now. The principle of operation of focused transmission imaging is illustrated in Fig. 5. The object under examination is irradiated by a large diameter ultrasonic beam. The energy that is transmitted through the object is focused by an acoustic lens on to an imaging surface which converts the acoustic energy into either a mechanical deformation that may be examined by optical techniques or directly into electrical form.

The view of the image is in the focal plane of the lens and is similar to that obtained with the C-mode technique and the three-dimensional composition is obtained by moving the object through the focal distance of the lens. A major advantage of focused transmission imaging is that the wide ultrasonic beam replaces the scanning plane of the transducer, so that the scanning is effectively instantaneous while the large diameter gives a high lateral resolution. The technique is not readily adapted to short pulse operation; therefore, the thickness of the image is determined by geometrical depth of focus of the acoustic lens, which is relatively long.

The technique is presently used mainly in the laboratory where it has produced some excellent views of thin specimens. In the clinic, the application of the method is severely restricted by degradation in the quality of the image by structures out of the focal distance of the lens. The successful implementation of the technique in the clinic awaits the solution to this problem.

DOPPLER IMAGING

When the ultrasonic energy strikes a moving interface, the frequency of the reflected energy is altered proportional to the velocity of the interface which is the Doppler effect. By scanning the transducer in either the B-mode or C-mode manner and displaying only the energy whose frequency has been altered, it is possible to specifically image the moving interface. In particular, the erythrocytes in blood give rise to Doppler-shifted signal and Doppler imaging is a recently developed technique used to visualise flow in major, relatively superficial, blood vessels such as the carotid and femoral arteries.

With continuous Doppler equipment, which has no depth discrimination, the transducer is scanned as in the C-mode technique and is used to map out the lateral dimensions of the vessels (21). With pulsed Doppler equipment, which have depth discrimination, the transducer may be scanned in either the B or C-mode manner to give either cross-sectional or longitudinal views (22). Doppler imaging will undoubtedly become a major ultrasonic examination technique.

GREY SCALE ECHOGRAPHY

Until recently, the majority of abdominal echoscopes used a storage tube oscilloscope to display the echogram. It is a characteristic of the storage tube that the brightness of the stored dot is constant, irrespective of the size and number of echoes that it represents. Echograms formed on a storage tube oscilloscope, therefore, are not capable of displaying the information contained in the magnitude of the echoes and have a characteristic black and white contrast appearance. This is adequate in applications where the diagnosis may be made on the shape, position, and size of structures delineated by the echoes from the boundaries, but is not sufficient for study of the nature of tissues which are acoustically similar, where it is essential to display the amplitude and difference in amplitude of echoes of nearly equal strength.

The internal texture of soft tissue organs is not homogeneous, since these have certain stromal and glandular organisation and are traversed by blood vessels of varying size. The distinguishing feature of all these interfaces is that they are much smaller than the ultrasonic beam. They therefore give rise to diffuse reflections; i.e., the energy is reflected uniformly in all directions and is thus independent of inclination.

Storage tube oscilloscopes are obviously unsuitable for the display of the internal echoes, since all soft tissue organs would be displayed as areas of solid echoes and some method which is capable of displaying the magnitude of echoes must be employed.

The magnitude of echoes may be displayed by using the grey scale of a photographic film, the echogram being obtained by exposing the film throughout the scanning period (23, 24). With a standard film such as the Polaroid type 107, it is possible to portray at least ten shades of grey and, by suitable design of the receiver, allocate these shades to the magnitudes of greatest interest. Since the magnitude of echoes from boundaries is highly dependent on inclination, it is more useful to allocate a large portion of the grey scale of the film to the display of internal echoes.

The size, pattern, and distribution of the internal echoes is dependent on the structural organisation and architecture of the examined tissues. Thus, many organs are portrayed with a distinct characteristic appearance. This allows the investigation of tissues in acoustically similar surroundings such as are encountered in soft tissue differentiation studies to give a new dimension to the range of investigations that can be undertaken by ultrasonic examinations.

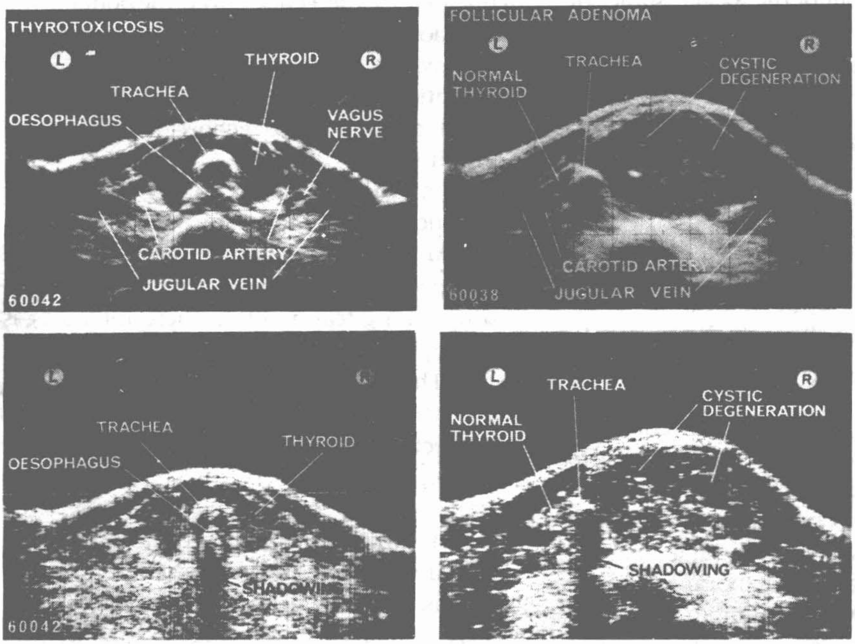

Fig. 1–6. Compound and simple scans of patients with thyrotoxicosis and follicular adenoma illustrating the solid-liquid and soft tissue differentiation capability of grey scale echography.

Liquid-filled structures, being internally homogeneous, do not return internal echoes and are readily recognised on the echogram by their dark echo-free internal appearance and the direct reliable identification of even the smallest liquid-filled areas forms a major feature of grey scale echography.

Grey scale echography gives a new role to simple scanning, since it is possible to study tissues by their internal appearance even when the outline echoes are not received on grey scale echograms. In fact, simple scanning gives "the clearest single line of sight" representation of tissue texture, i.e., because there is no superposition of lines of sight from different directions, the resolution of the echogram is not degraded by the movement of tissues during the scan or from lack of alignment of equipment or due to variations in velocity in the traversed tissues. Compound scanning still gives the most detailed representation and, because the internal echoes do show some small magnitude variation with angle, gives a different "integrated-multiple line of sight" tissue texture information. Shadowing or enhancement behind local changes in attenuation is not as evident on compound scan echograms due to superposition of lines of sight that do not traverse these areas and these changes are more apparent on simple scanned echograms.

Both methods are regularly employed in our department; first, compound scanning to get detailed anatomical representation and then simple scanning in areas of interest indicated by the compound scan echograms for its extra texture and least-blurred representation.

The various features of grey scale echography are illustrated in Fig. 6, which shows a compound and simple scan echogram of the thyroid in cases of throtoxicosis and follicular adenoma (25). The echograms were obtained at 2 MHz using a medium focused transducer and each major graticule on the echogram corresponds to 1.3 cm in the patient. All four echograms clearly show the liquid filled areas such as the carotid artery, jugular vein, and the cystic degeneration in the adenoma. A uniform internal texture which is much finer than the texture