ULTRASONOGRAPHY IN OBSTETRICS AND GYNECOLOGY

Edited by

ROGER C. SANDERS, M.A., B.M., B.Ch., M.R.C.P., D.M.R.D., F.R.C.R.

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INTRODUCTION

In recent years biomedical engineering principles have been successfully applied to health care delivery. This has resulted in increased ability to obtain useful clinical morphologic and physiologic information in a nondestructive manner. With the development of gray scale ultrasound, the ability to obtain excellent representation of anatomic structures and to make dynamic functional measurements without delivering significant patient biologic burden has created new applications and offers great future potential for sonographic procedures. Although ultrasonic techniques have been successfully utilized in industry and other nonmedical areas, the application of B-scan ultrasound in the field of health care delivery had its initial acceptance and is still most widely used in the field of obstetrics and gynecology.

The circumstance whereby a number of anatomic structures of soft tissue density are suspended in a natural anatomic "water bath" was most fortunate for the development of the field of clinical obstetric and gynecologic ultrasound. Furthermore, the discipline of ultrasonography was advanced in large measure by the rapidity with which an ultrasonic impression could be proved or disproved following delivery. Thus, a large part of the advances made and the interest created in ultrasonography can be related to its association with the specialty of obstetrics and gynecology.

Additionally, considerations of the hazard to the developing fetus when other diagnostic methods are used for the evaluation of antenatal problems has given impetus to many attempts to define the potential biologic burden of ultrasound. Although one cannot pronounce with finality the completely innocuous nature of ultrasound, one can offer substantial data to support the concept that, at the levels clinically employed, very little significant risk of damage to the fetus exists. This fortunate finding has encouraged clinical use of obstetric sonography.

Much has been written about obstetric and gynecologic ultrasound. A new publication on the subject must have, if not a justification, a precise motive to explain the opportuneness of a new contribution. Although several texts exist that address themselves to obstetric and gynecologic ultrasound, these have so far taken the form of atlases. In this text we hope to describe in some depth not only the physical principles employed in ultrasonography but their relation to any biologic hazard. We wish also to explore the correlation between diagnostic images and embryologic development and consider in detail what morphologic structures are being visualized. Additionally, we hope to place the sonogram in its proper clinical perspective, not only in relation to other imaging modalities, but also to other diagnostic studies. We hope to detail a rather complete differential diagnosis for particular combinations of clinical presentations or ultrasonic appearances. It is believed that by so doing, the reader will gain a much greater understanding of the images and measurements made through ultrasonography as well as a more appropriate application of this modality to clinical medicine.

Several major technical advances have occurred in ultrasound in the last few years. Improved fabrication of transducers and development of better acquisition and processing techniques has markedly increased our ability to achieve increased information from ultrasound studies. The development of gray scale imaging compared to the bi-stable presentation has resulted in a significant improvement in our ability to portray minor, but clinically important, internal alterations in organs and structures. The development of sequenced multi-transducer arrays allows real-time imaging in obstetrics and thus (without additional biologic burden) observation of dynamic physiologic processes. Improved data acquisition and analysis afford an opportunity for quantitative measurements and reconstruction of images. These developments make feasible the type of computerized tomography seen in radiography; and tissue signature or characterization is now possible. Improvements that have been shown to be initially clinically useful have been discussed in this text and techniques with obvious future promise have been presented in an introductory fashion. This is not only new information but it is also clinically important. It has and will result in improved health care delivery in obstetrics and gynecology.

We are quite aware that information which was current at the time of publication can become dated in a field or discipline that is undergoing such significant changes as ultrasound. However, we believe that the new information and the different treatment of present information in this text should render it a clinically useful one at present and a foundation for future understanding of obstetric and gynecologic ultrasound.

This text, if it is successful, is a reflection of the expertise of our contributors to whom we are extremely grateful. They gave willingly of their great experience and special knowledge, endured our editing, and responded to our requests. Many persons contributed by providing editorial assistance and aid in manuscript preparation such as Drs. Mel Conrad, Jim Millis and David Krause, and Mrs. Carol Martin and Mrs. Yolanda Eldred. Additionally we would express our appreciation to Dr. Theodore M. King and Dr. Martin W. Donner who encouraged the collaboration of Radiology and Obstetrics and Gynecology in this effort. The patience, stimulation and cooperation of Appleton-Century-Crofts, especially Doreen Berne, is especially acknowledged. Finally, to our families who sacrificed the most, we express our deep appreciation.

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CONTENTS

Ultrasound in Historical Perspective

LOUIS M. HELLMAN

The principles of ultrasonics have been known for many years. The first practical use of this imaging technique began with depth determination and submarine detection during World War I. Ultrasonic energy was also used to produce localized heat and at times to destroy tissue. It was not until after World War II, however, when improvement in transducers and miniaturization of electronic equipment made possible the detection of flaws in metal, that medical scientists began to test the visualization of human soft tissues for the purpose of diagnosis. These tissues were never well visualized by x-ray procedures. It followed naturally that experimenters hoped to visualize tumors of soft tissue either in the central nervous system, the breast, or the extremities. The names of the pioneers of this early work, such as Dussik [4] (1942), Denier [1] (1946), and Wild and Reid [15] (1952), are well known. Their instrumentation was crude and the resultant pictures were of questionable value. The late Douglas Howry [10] made a significant breakthrough in 1952 when he employed a compound scanning technique with the patient immersed in water. Unfortunately, he employed a "see-through" technique rather than the reflected one in current use. Nevertheless, the pictures of the neck that he and his colleagues obtained were good and lent impetus to the further investigations of this promising modality.

It was not until the late 1950s and the first half of the 1960s that the real potential of ultrasonic diagnosis began to be appreciated. The major contributions in design of equipment and in some of the diagnostic potentials were those of Professor Ian Donald [2, 3] of Glasgow and Dr. Joseph Holmes [9] of Denver. It is of little value to try to cite credit for first discovery between these two pioneers. Their approach to the instrumentation was different, but the machines they developed were equally satisfactory. They developed a means of coupling the transducer to the individual through an oil film. Both used compound sector scanning to give two-dimensional rather than unidimensional representation. The recording of the image by Polaroid camera made it possible to view a large number of scans with a minimum expenditure of time and effort. In retrospect the employment of compound sector scanning and the use of the oil film and camera seem to be simple ideas which should have been readily apparent. Nevertheless, as so often happens, it was these simple discoveries or applications that made possible the greatest advances.

Both Donald and Holmes initially followed the pioneers of this field in thinking that the greatest potential of sonography lay in the diagnosis of abdominal and breast tumors. In the early 1960s Donald took the natural step of investigating the possibilities of ultrasonic diagnosis in obstetrics. On hindsight, it is difficult to understand why this step was so long in developing. The abdomen of the pregnant woman presents an ideal contour for application of the transducer. The amniotic fluid offers an acoustic impedence difference to contrast the uterine wall and the solid tissues of the fetus within it. No other human tissues with the exception of the eye are so ideally adapted to ultrasonic diagnosis. Certain measurements of the fetus and uterus can be easily performed and, most important, repeated examinations not desirable by radiography, can be made.

Almost by accident Donald discovered that the unidimensional A-scan could be used in the measurement of the fetal biparietal diameter. This discovery led to the first paper by Donald and his colleagues in 1958 correlating fetal head size with the duration of pregnancy.

The development of compound sector scanning added great impetus to the investigations of pregnancy. A most fortuitous finding in 1963 by Donald demonstrated that the full bladder pushes the uterus slightly out of the pelvis, providing an excellent medium for transmission of the ultrasonic waves. This full bladder technique clarified the definition not only of the uterine wall, but of the fetal head and small parts as well. Further, it made possible the demonstration, first, of the anterior placenta and, later, of the posterior placenta. Donald's great enthusiasm for the use of ultrasonic techniques in obstetrics was transmitted to Holmes and his group, who almost immediately decided to follow the lead of the Glasgow group into this intriguing field.

The first paper dealing with this area was read by Dr. E. Stewart Taylor,[14] professor of obstetrics and gynecology at the University of Colorado, before the American Gynecological Society in the spring of 1964. Although his scan pictures were incredibly crude by comparison with today's photographs the potentialities were apparent. A personal visit by Donald to my laboratory at the State University of New York in 1964 stimulated me to investigate the potential of ultrasonic diagnosis in pregnancy. At that time Donald showed an early pregnancy in the uterus exemplified by a gestational sac.

I believe that the diagnosis of fetal well-being in utero, particularly the indicators of adequate placenta function such as growth, and the diagnosis of malformations constitute some of the major problems in obstetrics. It was to these problems that our ultrasound experiments were directed. My colleagues were Mitsu Kobayashi from Japan and Miss Ellen Cromb. Dr. Kobayashi was particularly expert at manipulating the transducer to obtain sonograms of precision and excellent definition. I believe that it is still not presently possible to substitute mechanical movement of the transducer for expert coordination between hand, foot, and eye movement in obtaining fine sonograms. In this volume, the technical details are discussed in Chapter 2 by Ziskin, and a promising of real-time imaging is presented in Chapter 30. After 1965 most of our work was devoted to testing the accuracy of ultrasonic diagnosis. Thus, we investigated sources of error in fetal head measurements [5] in all diameters and in particular the association of fetal head measurements and fetal weight with the duration of pregnancy. Unfortunately, as so often happens, a single measurement does not give the precision one might wish. Thus, the measurement of the fetal head, although it is a good index of fetal growth, can be in error in instances of diabetes and chronic maternal hypertension, just where growth retardation and acceleration are most important. Further, although there is a correlation between fetal head measurement and the duration of pregnancy it is not as precise as one would wish. We also investigated the accuracy of placental localization [11] to prove, as Donald had predicted, that the ultrasonogram is by far the most precise diagnostic procedure. A comparison of the various techniques is offered in the chapter by Cohen and his colleagues. In addition, we were able to support the proposition that the ultrasonogram should replace hormonal and other methods for the diagnosis of hydatidiform mole. The characteristic ultrasound appearance is given in Chapter 22 of this text.

I shall never forget my excitement on seeing a small signet ring body within the cavity of the uterus in a patient who was just a little more than a week beyond her menstrual period. This gestational sac looked so much the way it should have looked from the demonstrations of early implantation by Arthur Hertig that there was no question in my mind as to what we were seeing (Figs. 1 and 2). The finding of these early pregnancies led directly to the discovery

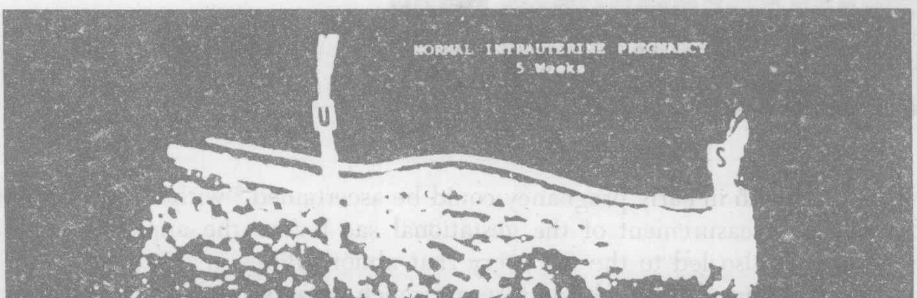

FIG. 1. Normal Intrauterine Pregnancy, 5 weeks. U, Umbilicus; S, Symphysis; Ut, Uterus; GS, Gestational Sac; Bl, Bladder. (From Hellman: Williams Obstetrics, 14th ed. Appleton-Century-Crofts)

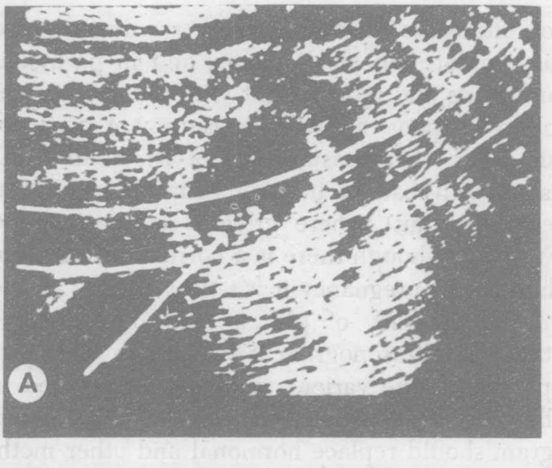

FIG. 2A, Magnified gestational sac showing inner cell mass (arrow). (About 2–3 weeks menstrual age). (Courtesy of Prof. Ian Donald)

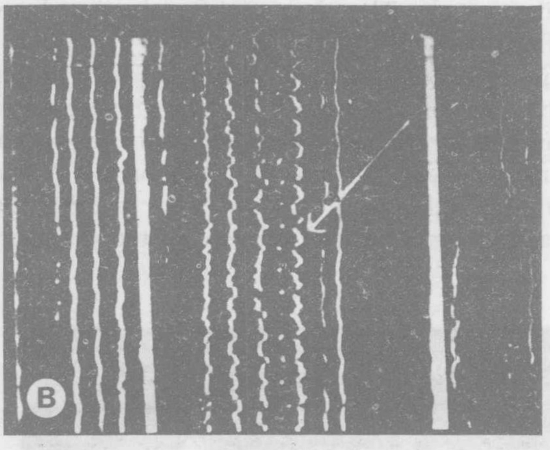

FIG. 2B. Fetal heartbeat (arrow) obtained from the inner cell mass of the gestational sac above by focusing ultrasonogram beam through gestational sac. (Courtesy of Prof. Ian Donald)

that fetal growth in early pregnancy could be ascertained [6] with a high degree of accuracy by measurement of the gestational sac before the appearance of the fetal head. It also led to the discovery that abnormalities of the gestational sac were as A. Hertig and J. Rock had forecast, much more frequent than had hitherto been realized. It is interesting that the paper that we published on this subject agreed so precisely with the findings of Donald and his co-workers. Chapter 10 elaborates on the ultrasound findings of the first trimester.

Because of the imprecision of the correlation between fetal head growth and fetal weight and the duration of pregnancy it seemed to us that the determination of the volume of the placenta [7] should be not only possible with ultrasonic techniques but extremely useful. We developed the mathematical formulas to make these measurements and proved at least to our own satisfaction, by examining placentas before and then directly after delivery, that our calculations gave a reasonably correct estimation of placental volume. Unfortunately, this work attracted little attention and as far as I know has not been repeated by others.

Another aspect of ultrasonography is the biologic burden imposed on the fetus. Safety has been, and is, uppermost in the minds of most people who deal with ultrasonography.[18] It is particularly pertinent when ultrasound is used for the diagnosis of early pregnancies. The fetus might be especially sensitive even to the very low levels of imposed energy. As early as 1966 Smyth [13] examined the effect of diagnostic ultrasound on embryos of various animals. In 1970 I. Donald, B. Sunden, and I pooled our clinical experience with ultrasound in early pregnancy but were unable to show any resultant abnormalities. Similarly, during the same year Woodward [16] was unable to detect any significant damage, while MacIntosh [12] in Cape Town reported possible chromosome damage in a preliminary communication. This work was not confirmed by Donald or other centers in Edinburgh, Cardiff, and London.

All evidence so far shows that the clinical usage of sonar at the energy levels now employed clinically appears to be safe. According to Donald, however, "The possibility must be faced that there may be safety threshold limits, possibly different for different tissues, but these have yet to be determined. We have therefore to insure that future development of more powerful and more sophisticated apparatus does not introduce new and as yet unforeseen hazards." [2] Techniques should be developed for measuring the energy produced by ultrasonic machines, and these machines should be standardized. I realize the technical difficulties that such an endeavor entails; nevertheless, I do not believe that it is beyond the range of possibility to develop a measuring device for energies of this small magnitude.

I have reviewed one facet of the use of ultrasound, namely, in the practice of obstetrics. This technique has opened the possibilities of prenatal diagnosis and the analysis of fetal and embryonic growth in a manner hitherto undreamed of. It is altogether probable that Donald's prophecy, that there will be only a rare major department of obstetrics and gynecology in the world without access to ultrasound, will indeed come true. To a large extent this prophecy has been fulfilled in the United States, and now departments of radiology make routine use of ultrasonic diagnosis.

In the future, we should see vastly improved techniques both in image definition and in tissue penetration. We should see improvement in the images through the use of the gray scale. Further, it is possible that we will expand two-dimensional imaging to three-dimensional visualization. Real-time and transmission techniques offer exciting new areas for advancement. For man who has gone to the moon and explored the minute particles of matter, the technical development of improved ultrasonographic electronics should be but a minor achievement.

This volume presents some of the modern developments that I did not dream possible even five years ago. In closing I would like to pay deep homage to those who have pioneered this field. In particular, I would like to pay my respects to Ian Donald, who pioneered many of the discoveries and who, in spite of a severe protracted illness, has continued to make valued contributions and to inspire new and young investigators in this ever-developing field of endeavor.

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