E20. Overview of the new technology in breast ultrasound

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Introduction

Technological advances have steadily improved the quality of ultrasonic breast images over a period of fifty years. Breast ultrasound has firmly established itself in the last decade as an essential adjunct to mammography, and in a number of clinical situations it is the imaging modality of choice. Ultrasound not only displays breast anatomy and pathology, but also provides information about tissue vascularity and tumour angiogenesis.

Early technology and its interpretation (1950s to the 1970s)

Water bath scanners: The first reports of ultrasound in the breast were published in the early 1950s with information on the acoustic properties of breast tumours and some two-dimensional images, and at that time, research was directed towards tissue characterisation rather than imaging. Ultrasonic systems specifically designed for breast imaging in the mid-1950s were water-bath machines capable of only displaying the major constituent tissue interfaces.

A number of ultrasonic imaging systems were developed during 1960s in different countries. The improvements in image quality resulting from large aperture transducers, better signal processing and a variety of scanning modes (simple, sector, compound) culminated with the introduction of "grey-scale echography" in 1969. By the middle of the 1970s, dedicated mechanical real-time scanners became available for breast examinations, and provided images of diagnostic value.

Spectral Doppler interrogation: The use of the Doppler effect in medical ultrasound was first demonstrated in 1957, and then twenty years later Doppler signals were shown to originate from breast malignancies. Hand-held continuous-wave Doppler transducers were used to detect blood flow, and the frequency-shifted ultrasonic information interpreted by either listening to the time-varying signals or displaying the frequency components of the signals in the form of a spectral display. In the years to follow, considerable research was undertaken using continuous-wave and pulsed-wave Doppler techniques to determine which characteristics of the Doppler signals provided the best discriminating ability. Examination protocols were slow as most of the breast volume had to be interrogated with hand-held probes, and the presence of abnormal flow patterns identified from the spectral display.

Interpretive criteria: Attempts to differentiate between benign and malignant lesions from the ultrasonic information began in the mid-1950s, but with improvements in equipment performance in the 1960s, diagnostic criteria were established from specific features present in the images. The implementation of "grey-scale echography" in the 1970s resulted in a significant improvement in image quality and clinical reports were issued describing breast anatomy and characteristic features found in a variety of solid lesions. Utilising both simple and compound scanning, multiclassification criteria were established, and benign and malignant solid lesions could be differentiated.

Recent and new developments in the technology and its interpretation (1980s, 1990s)

Real-time scanners: Improvements in linear-array transducer technology and equipment design resulted in the introduction of electronic real-time scanners in the 1980s. The lower resolution compared with the earlier mechanical scanners limited the clinical usefulness of the newer technology for breast imaging. Developments in broadband and high dynamic range multi-element array technology with the introduction of multichannel signal processing meant that real-time scanners with their high degree of manoeuverability replaced mechanical equipment for many examinations. In the breast, the best images were still obtained with large aperture annular array transducers in mechanical sector scanners.

During the 1990s, advances in beam-forming and array technology, together with digital signal processing resulted in significant image quality improvements. With better high frequency transducer materials, multidimensional arrays and multichannel processing, the spatial and contrast resolution of images approached the upper limit allowed by the existing technologies.

In addition, in the 1990s, panoramic imaging and real-time compounding were introduced. Panoramic imaging allowed an entire cross-section of the breast to be displayed in a single sweep, and this overcame one of the limitations of linear arrays which by design had a

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restricted field of view limited by the transducer geometry. The panoramic image was formed by the electronic addition of a number of separate images resulting in a single composite view. Real-time compounding was achieved by the superposition of a number of images acquired from different locations and directions, and this provided a composite image with improved signal-to-noise which better demonstrated lesion conspicuity and characterisation, margins, and internal echo definition. **Colour flow mapping:** The Doppler spectral display was a simple method to show blood flow, but the acquisition of the data and the interpretation of the signals was lengthy and difficult. In comparison, colour Doppler imaging (an extension of pulsed wave Doppler) introduced during the mid-1980s provided a faster method of displaying tissue vascularity, and localised flow. Flow information was superimposed on the "grey-scale image" of the anatomy and pathology, and assigned colours displayed an estimate of the blood flow. Two methods were used to generate colour information: one based on the mean Doppler shifted frequency from the blood, known as conventional colour Doppler; the other based on the power of the Doppler signal backscattered from the blood, known as power or intensity Doppler.

With malignant breast tumours, abnormal vascularity results from the newly developed vessels due to angiogenesis. The resultant low flow and slow flow requires colour Doppler equipment to be sensitive to these parameters. Diagnostic criteria have been difficult to establish due to the variability of the information, but features are based on the detection of flow in small vessels; the number of vessels present, and the tortuosity and branching configurations when compared with normal vessels.

The development of ultrasonic contrast agents has shown promise for improving the display of the small vessels. However, there is a lower limit in the sensitivity of the equipment to detect flow. Doppler signals from moving particles may not be detected even with the presence of contrast agents where the speed of flow in very small vessels is similar to the motion of the surrounding tissues.

Harmonic imaging can overcome the limitation as contrast agent microbubbles resonate at twice the frequency of the incident ultrasound beam, and provide harmonic echoes considerably stronger than the fundamental levels. Improvements have been reported in the signal-to-noise ratio; reduced reverberations; reduced side lobe artifacts; and improved resolution and sensitivity. More complex imaging methods based on non-linear propagation and pulse inversion imaging may prove effective for the delineation of lesion vascularity.

Interpretation: The advent of high resolution systems during the 1990's contributed significantly to the clinical acceptance of ultrasonic breast imaging. Diagnostic criteria were applied more rigidly, and accurate differentiation between benign and malignant solid lesions was possible. Breast ultrasound became the accepted imaging modality for problem-solving and also for guiding interventional procedures. Whilst ultrasound could in some instances demonstrate clinically-occult cancers, it was not accepted as a technique suitable for screening. There was considerable enthusiasm for assessing lesion blood flow, but the difficulty in establishing vascular diagnostic criteria and the lack of agreement on which parameters were important meant that the vascular features were of little clinical value.

Future developments and improved interpretation

Advances in technology resulting in better transducer materials and more sophisticated signal processing will make breast ultrasound an even more important imaging modality for the detection, diagnosis and management of patients with breast disease. A better understanding of angiogenesis and echo-enhancing agents will extend the role of ultrasound by providing data on tissue vascularity and lesion blood flow.

Broad clinical goals have been established in which current and new technologies have the potential to improve breast ultrasound, and provide clinical solutions. The areas include the detection of preclinical breast malignancies in women less than 40 years of age; the more accurate differentiation of benign and malignant lesions; the prediction of response to treatment and intervention; the facilitation of image-guided diagnosis; and the total removal of small lesions.

A number of technological advances have been identified which will lead to improved image quality and more accurate interpretation, and these include: larger fields of view; higher frequency transducers; overall reduction of noise; better image display methods; improved methods of comparing examinations performed over a period of time; better methods to distinguish fat lobules; increased contrast ratio of microcalicifications; improved methods of displaying vascular morphology and identifying areas of unusual vascular function; effective methods to compare ultrasonic and mammographic images; better methods for imaging mobility and stiffness; volumetric determination of tissue excision incorporating 3-dimensional (3D) imaging; and selective delivery to target areas of cytotoxic and therapeutic drugs activated by exposure to ultrasound.

References

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