E21. Overview of the clinical applications of the new ultrasound technology

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Introduction

Medical ultrasound has been under development for more than 50 years. The early attempts at clinical ultrasound were performed with one-dimensional A-mode scanning (amplitude modulation). In the late 1950s and early 1960s two-dimensional images became available, but the technology allowed only bi-stable black and white images with limited soft tissue characterisation. The introduction of greyscale technology (B-mode scanning) in 1968 resulted in much wider clinical use and acceptance of ultrasound as a diagnostic method improved significantly. Images in the 1960s and early 1970s were static with either mechanical single- or multi-transducer water-path or contact scans. These were followed by single element sector or multielement linear transducers for contact scanning. In the 1980s, fast real-time-transducers for contact scans with improved beam formation were introduced with sector, linear or convex probes and electronic multi-elements providing further improvements. These were fundamental steps forward for the development of modern beam formation. Each step produced an improved image quality and diagnostic power resulting in the rapidly increased clinical use of ultrasound. With grey-scale imaging came diagnostic criteria based on sono-morphology. However, the poor spatial resolution of this ultrasound technology meant that its use was limited to the assessment of palpable lesions. Only after the development of high-resolution ultrasound in the 1980s did it become possible to detect non-palpable lesions in real-time.

The detection of blood flow using ultrasound (Doppler imaging) was also a major field of research. In the 1980s, only continuous-wave Doppler (CW) was available with a high enough sensitivity, but this did not allow for the combination of flow detection and imaging [1]. Pulsed Doppler and early colour Doppler instruments in the early 1990s allowed for accurate flow measurements in large vessels, but were insufficient for the assessment of tumour vascularity. Recently, the sensitivity of ultrasound equipment for low flow detection has dramatically increased and detailed flow studies of malignant lesions are now a reality [2].

'State of the art' equipment

Over the last ten years, high resolution scanners with fully digital beam-formers have been developed with high transducer frequencies, multi-channel focus and broadband transducer technology for high resolution and optimised tissue contrast. Doppler techniques have also improved and allow for flow detection in the feeding vessels of malignant lesions. These developments have influenced clinical research all over the world and led to a major expansion of the role of ultrasound in breast diagnosis including differential diagnoses, staging, detection of multifocal lesions, guided interventions and improved early detection in women with mammographically-dense breasts [3–5].

What is new?

Matrix array transducers: Linear-array transducers allow for good focusing in the two-dimensional (2-D) scanning plane, but beam formation in the perpendicular plane (slice thickness resolution) is limited. Matrix arrays contain not only one alignment of elements along the long axis of the transducer, but also several alignments of piezoelectric crystals perpendicular to the long transducer axis. This allows for electronic beam formation not only in the scanning plane, but also perpendicular to it. This improves slice thickness resolution. Transducers of this type require more than 1000 active channels to be processed in real-time. The advantage of this technique is better detection of small targets, improved tissue contrast and reduction of artefacts at different penetration depths.

Sono CT real-time compound imaging: Electronic beam steering allows for visualisation of an image simultaneously from different scan directions. In conventional real-time scanning, sound is only transmitted in one direction. Targets perpendicular to the sound direction are accurately displayed, while targets with oblique sound inclination angles are poorly displayed or even not visible. A real-time-compound-scan overcomes this limitation of ultrasonic imaging as the target image is assimilated from several different directions at the same time. This improves the display of tissue details, tissue contrast and sound penetration and also reduces artifacts.

Siescape, Panoramic scanning: This technology allows for the display of a large anatomical area by moving the transducer in a longitudinal direction along its scanning plane. Consecutive images are continuously stored in the memory. After the scan procedure is completed, the whole sequence is reconstructed and large

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cross-sectional slices can be displayed according to their original anatomical order. This enables a more realistic documentation compared with the small field of view of normal real-time images.

3-D, 4-D (Real-time 3D): With the transducer movement perpendicular to the scanning plane, a block of tissue volume can be stored in the memory. Dedicated 3-D transducers have an automatic mechanical device (a 2-D transducer in a special housing is driven by an electronic motor). This allows accurate positioning and reconstruction of the different scanning planes. Standard transducers can be used for 3-D imaging if they are connected with a special device. A transmitter is mounted on the transducer. A separate receiver (electromagnetic coil) positioned near to the patient transmits the position data to the memory for accurate 3-D reconstruction of the different planes. A third way of 3-D data recording is possible with newly developed software which allows for the recognition of consecutive scanning planes which are recorded by moving the transducer free-hand perpendicular to its scanning plane. The scanning must be performed within a given time interval. 3-D data are stored and displayed when the data acquisition is finished. Reconstructions of the 3-D data can be made in different ways. Most commonly, the 3 perpendicular planes are displayed simultaneously on the screen.

In breast diagnosis, this method does not facilitate or accelerate breast scanning or lesion detection. Like panoramic scanning, it is a method that improves documentation and the display of complex structures [4]. As 3-D data can be stored and reconstructed independently, reporting can be performed at any time and independent of the scanning procedure. The third plane of the reconstructed volume data is the horizontal c-plane, which is not visible on conventional scanning. This scanning plane opens new perspectives as the so-called retraction and compression sign is visible, an additional diagnostic criterion which may improve a benign–malignant differentiation. If ultrasound-guided punctures (fine-needle aspiration or core biopsy) are performed, the needle position can be controlled more accurately compared with 2-D imaging. In particular, the newly available real-time 3-D imaging (4-D) may offer more accurate ultrasound-guided interventions.

Tissue Harmonic Imaging (THI): When sound interacts with tissue structures, the frequency of the reflected waves is equal (fundamental frequency). In addition, higher frequencies are reflected which are called harmonics. However, these signals are very weak. In conventional B-mode scanning, the received frequency is equal to the transmitted frequency. With modern broadband transducers and extended signal processing, harmonic signals can be recorded which reduces artifacts and improves sound penetration and image quality.

Contrast harmonic imaging: Harmonic signals are also created from microbubbles when contrast agents are injected intravenously (i.v.). When harmonic signals are recorded separately from the fundamental signal, flow can be recorded by B-mode imaging with a high resolution. Separation of fundamental and harmonic frequencies requires narrow frequency-ranges. In order to use the full bandwidth of broadband transducers, contrast harmonic imaging is used in combination with pulse inversion technology. Each line is created by two signals with inversed or shifted pulses, therefore the fundamental signal is deleted and only harmonic signals are received and can be enhanced. This enables excellent visualization of small tumour vessels when suitable ultrasound contrast agents are injected.

Colour and power Doppler: The sensitivity for low vascular flow has been significantly improved by reducing the pixel size and improved signal processing. However, the Doppler signal (frequency shift) is angle-dependent, an important factor that limits the detection of vessels. In order to improve the display of lesions almost independent of the sound inclination angle, power Doppler was introduced some years ago. Instead of a frequency shift, the amplitude of the backscattered signal is colour-coded. Contrast agents have been introduced to improve the signal-to-noise ratio in colour and power Doppler techniques [6].

Conclusions

The technological innovations in high frequency ultrasound over the last decade are having an enormous influence on its diagnostic clinical applications. In the early decades of ultrasound development, its role in the diagnosis of breast cancer was rather limited. Now, the detection of small lesions and the ability to make differential diagnoses is greatly improved.

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