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Review

Medical diagnostic applications and sources

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Abstract

The ways in which ultrasound is used in medical diagnosis are reviewed, with particular emphasis on the ultrasound source (probe) and implications for acoustic exposure. A brief discussion of the choice of optimum frequency for various target depths is followed by a description of the general features of diagnostic ultrasound probes, including endo-probes. The different modes of diagnostic scanning are then discussed in turn: A-mode, M-mode, B-mode, three-dimensional (3D) and 4D scanning, continuous wave (CW) Doppler, pulse-wave spectral Doppler and Doppler imaging. Under the general heading of B-mode imaging, there are individual descriptions of the principles of chirps and binary codes, B-flow, tissue harmonic imaging and ultrasound contrast agent-specific techniques. Techniques for improving image quality within the constraints of real-time operation are discussed, including write zoom, parallel beam forming, spatial compounding and multiple zone transmission focusing, along with methods for reducing slice thickness. At the end of each section there is a summarising comment on the basic features of the acoustic output and its consequences for patient safety.

Keywords: Diagnostic ultrasound; Beam-forming; Slice thickness; Coded excitation; B-flow; Tissue harmonic imaging; Ultrasound contrast agent; Doppler; Acoustic output

Contents

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1. Introduction

This paper reviews the ways in which ultrasound is used in medical diagnosis, with particular emphasis on the ultrasound source (probe) and implications for acoustic exposure. Applications can be divided into pulse-echo/imaging techniques and Doppler techniques for studying blood flow or tissue movement. The former generally use wideband pulses for good axial resolution whilst the latter generally use narrow bandwidth pulses in order to improve signal to noise ratio (SNR).

2. Choice of ultrasound frequency

In order to achieve good lateral resolution, which is the ability to resolve targets lying close together, side by side at the same range, a narrow beam is required. Good axial resolution, which is the ability to resolve targets close together, one behind the other on the beam axis, requires a wide pulse bandwidth. Both are improved by using higher frequencies. Unfortunately, penetration decreases as frequency increases due to increases in both absorption and scattering. The optimum choice of frequency is therefore a compromise, being the highest that will give a useful signal from the maximum depth associated with a particular application. In practical terms this means that around 3 MHz is typical of abdominal applications in adults, around 5 MHz in children, increasing to around 10 MHz in superficial regions such as the neck or breast, around 30 MHz for the anterior chamber of the eye or intra-vascular scanning, or even 100 MHz in very superficial applications such as imaging the cornea.

3. General transducer description

Nearly all medical diagnostic transducers (Fig. 1) use a thin piezoelectric disc or rectangular slab to convert electrical drive waveforms into ultrasound pulses and, conversely, ultrasound echoes into electrical echo signals. The thickness of the piezoelectric is chosen to equal half the wavelength at the required pulse centre frequency in order to achieve high sensitivity. The ceramic lead zirconate titanate (PZT) is normally used as the piezoelectric material due to its high electro-mechanical conversion efficiency.

However, PZT has a high characteristic acoustic impedance compared to tissue and so, in order to avoid poor transmission across the PZT/tissue interface, a matching layer is provided. This can give 100% transmission across the interface if its thickness is one quarter of a wavelength and its characteristic impedance is the geometric mean of those of PZT and tissue. The thickness is chosen to satisfy the quarter wavelength requirement at the required centre frequency, but the transmission efficiency falls at frequencies to either side of this. In order to reduce this effect from limiting the transducer bandwidth too much, some manufacturers use two or three matching layers with progressively reducing impedances between the PZT and the tissue. This means that each interface has a smaller reflection coefficient and so frequency sensitive resonances within each layer are dampened, preserving bandwidth.

Another benefit of improving transmission at the transducer face is the reduction of "ringing" after the electrical drive signal has ended. Such reverberations within the slab would elongate the transmitted pulses