

## Elastography - Safety Aspects (up-date 2022)

### Basic Terminology

**ARFI** - acoustic radiation force impulse imaging. An elastographic technique that uses a short pulse of ultrasound to produce local displacements in tissue.

**Elastogram** - A map of tissue elasticity.

**Elastography** - A technique that images the stiffness of tissues, using manual or ultrasonic palpation techniques.

**MI** - Mechanical Index - a unitless parameter that is calculated online to give a rough estimation of the mechanical risk of the emitted beam associated with the actual settings of the device.

**Push pulse** - the impulse imparted to the skin surface to provide the tissue displacements needed to do elastography.

**Radiation force** - Force produced by the momentum transferred to tissue when an ultrasonic beam is absorbed or reflected.

**SE** - Strain elastography (see text).

**SWE** - Shear wave elastography (see text).

**TE** - Transient elastography (see text).

**THE** - Time harmonic elastography (see text).

**TI - Thermal Index** - a unitless parameter that is calculated online to give a rough estimate of the thermal risk of the emitted beam associated with the actual settings of the device.

### Introduction

The manual palpation that has been used by doctors for centuries to detect solid masses can now be augmented by ultrasound imaging methods. This is known as “elastography”. When the skin surface is “pushed”, the tissue structures below the surface move, the amount of displacement depending on the local stiffness. Ultrasound image correlation techniques can be used to show these displacements, and hence the different regions of stiffness. The “push” may be produced by mechanical or acoustic means, and may be (quasi-) static, harmonic, or pulsatile.

Elastography is used, amongst other

things, for the diagnosis of soft tissue lesions, atherosclerosis, thrombosis, kidney fibrosis, and benign and malignant tumours such as those of the breast and liver. With its increasing availability as a standard technique on diagnostic systems, and the expanding range of applications, it is important to understand the principles, and the implications for patient safety arising from its use.

### Basic Science

Elastographic techniques are used to map tissue stiffness, providing an “elastogram”. The premise is that some pathologies have a different stiffness from their surrounding tissues. If a push pulse is transmitted through the skin, the underlying structures will be displaced, the amount of movement depending on the local stiffness. There are a number of different types of elastography available:

1. **Strain Elastography SE** (or *strain rate elastography*): In this original method, the B-mode image taken before a quasistatic (slowly varying) push pulse is subtracted from that taken while the push is active. The push pulse is produced by an external mechanical impact, often using manual pressure applied to the ultrasound transducer itself. The change in the position of the echoes reflects the local displacement induced. If the gradient of the displacement with respect to distance from the surface (the strain) is mapped, an elastogram is produced. The “push” can also be produced by internal physiological motion. Here the axial gradient of the tissue velocity gives the strain rate, hence the name, strain rate imaging.

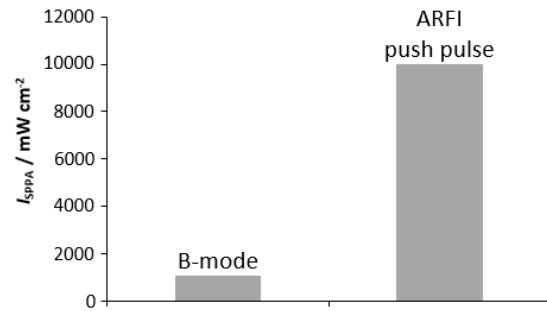
2. **ARFI**: The push pulse may also be produced using the radiation force produced by the transfer of momentum from the wave to the tissue through which it passes when it is absorbed or reflected. Short acoustic pulses (30 – 300  $\mu\text{s}$  long), which lead to displacements of 1-10  $\mu\text{m}$ , are

used. This is known as acoustic radiation force impulse (ARFI) imaging. Here, ultrasound image correlation methods are used to display the displacements directly to produce the elastogram.

**3. Transient Elastography TE:** A brief local mechanical impact on the skin surface from the ultrasound transducer gives rise to shear waves within the tissue, in particular from the transducer edges. The shear wave velocity which depends on the local stiffness can be calculated using speckle tracking techniques, and a map of shear wave velocity produced. Postprocessing allows the shear elasticity of the tissue to be imaged. An acoustical impact locally applied from ARFI can also be used to produce the shear waves for TE (then referred to as point shear wave elastography - pSWE [1]).

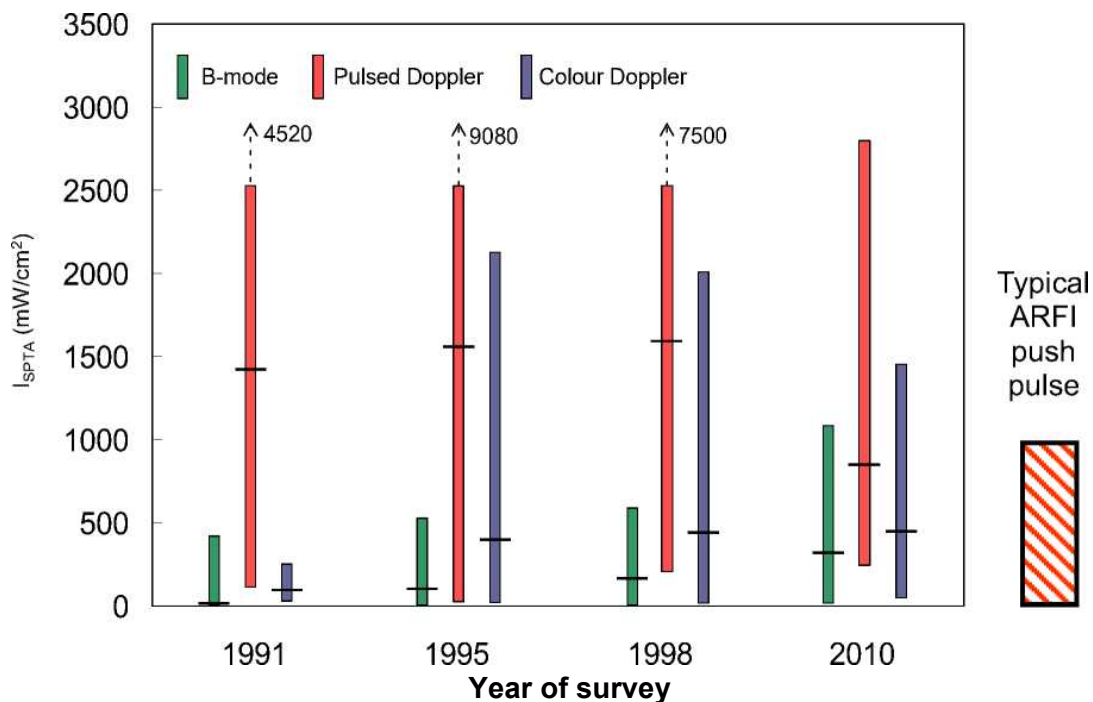
**4. Shear Wave Elastography SWE:** The acoustic radiation force impulse may be applied over a volume to provide 3D images of the shear velocity. In the depth direction, information may be obtained by placing the ARFI focus at different discrete depths into the tissue, or by sweeping the focus down the axis at a speed faster than

the shear wave velocity ( $1 - 10 \text{ ms}^{-1}$ ). More details of these techniques can be found in [1].



**Fig. 2** Spatial peak pulse average intensity for B-mode imaging, and for an ARFI push pulse [5].

**5. Time Harmonic Elastography THE:** The organ/tissue is stimulated by an external vibration source (shaker or loudspeaker) driven with multiple harmonic frequencies in the range between 30 and 100 Hz. The resulting tissue displacement is determined from the rf data acquired by B-mode scans with high frame rates and compound maps of the shear wave speed are reconstructed [3]



**Fig. 1** Manufacturer declared values of spatial peak temporal average intensity ( $I_{SPTA}$ ) in (2010) compared to 3 previous surveys in B-mode, pulsed Doppler and colour Doppler mode [2].

## Safety Implications

### Elastography using Mechanical displacement techniques: SE and THE

Since no additional ultrasound is used for SE, there is no increased concern about the safety of this technique over that of standard B-mode ultrasound [4]. A slight increase of  $I_{SPTA}$  for THE is possible, due to the higher frame rate.

### Elastography using Acoustic displacement techniques: ARFI & SWE

Safety concerns for acoustic radiation force impulse imaging arise from the use of the acoustic push pulses. Figures 1 and 2 compare the spatial peak temporal average intensities and spatial peak pulse average intensities used for ARFI with those used for B-mode imaging. Fahey et al. [5] have calculated that for the worst case condition of low acoustic absorption near the transducer, and high at the beam's focus, a temperature rise of 1.2 K might be expected with an "aggressive" ARFI imaging sequence ( $I_{SPPA} = 820 \text{ mW/cm}^2$ ). Herman & Harris [6] calculated that, for transient pushed that stayed within the FDA guidelines ( $\leq 720 \text{ mW/cm}^2$ ), temperature rises in soft tissue may be of the order of  $\approx 0.35 \text{ K}$ , but at bone  $\approx 8 \text{ K}$ . They pointed out that for standard B-mode imaging, the temperature is highest nearest the transducer, but that for these ARFI pulses the temperature is greatest at the focus.

The Thermal Index (TI) displayed may therefore not be appropriate, and they suggest that new models may be needed to describe these circumstances. Hsu et al. [7] measured the transducer front face temperature during ARFI acquisitions - they found peak temperature rises of 0.5 K. Concerns about heating might be expected to be greater for SWE where discrete ARFI foci are used than for when the fast swept focus technique is applied. The Mechanical Index (MI) as displayed for B-mode ultrasound assumes that single cycle pulses are used. For ARFI, the pulse trains are longer, and as the threshold for inertial cavitation

decreases with increasing pulse length, it seems prudent to assume that the MI displayed may be an underestimate [8].

## Conclusions and recommendations

When the impulse used to produce the tissue displacement is mechanical in origin, there is no reason for more concern about the safety of elastography than for B-mode imaging

- When acoustic radiation force impulses are used, significant temperature rises may occur, especially if bone lies in the beam.
- Transducer self-heating increases with high number of pulse sequences and scanning duration.
- When using ARFI, the temperature has its maximum at the focus, whereas in B-mode the maximum is close to the transducer.
- The displayed indices (MI & TI) may be an underestimate during ARFI imaging.

The ALARA principle should be applied when setting the output for acoustically induced elastography methods and the scanning time should be kept short.

Shear wave imaging uses long pulse sequences for which there is as yet limited experience, and thus caution, especially when exposing vulnerable tissues (such as, for example, plaques), is advised.

## References

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