PHYSICS OF BIO-EFFECTS

Diagnostic ultrasound exerts both thermal and mechanical forces on tissue, which could in theory cause tissue or organ injury.

Diagnostic ultrasound machines in general are preset at acceptable power levels (dependent on preset used) for safe application in the diagnostic scan of choice. However, the user can manipulate the preset, and modes resulting in higher intensity tissue exposures. This has definite local mechanical and thermal effects, which we need to be aware of.

Guidelines for exposure levels and exposure time limitations are available from all governing bodies, these should be abided by. In particular for POCUS we should be aware of these factors in any obstetric scanning, and most importantly in early pregnancy.

<u>THERMAL EFFECTS</u>

As ultrasound travels through tissue it undergoes attenuation, part of which is loss of energy due to absorption by tissues resulting in tissue heating. The degree of heating depends on a number of factors:

- Higher intensity (power per unit area) beam results in greater heating
- Higher frequency results in more rapid attenuation/absorption, and therefore heating
- Higher attenuating tissues (fibrous tissue) will absorb more energy and be exposed to greater thermal exposure compared to lower attenuating tissue (fluid containing)

IMAGING MODE AND THERMAL EFFECT

Stationary scanning modes (PW/CW Doppler, M mode) will cause a concentrated energy exposure within a smaller volume compared non-stationary modes (grey-scale and colour Doppler).

- PW Doppler is of particular concern

- Single line of sight
- Stationary
- High power/high amplitude pulse transmits

- CW Doppler has relatively less thermal effects to that of PW:

- Low amplitude continuous transmission
- Relative larger volume of exposure/less intense
- Lower transmit power

TISSUE NATURE AND THERMAL EFFECTS

As mentioned highly attenuating tissues will absorb more energy and undergo significant thermal effects. Other properties of tissue and their interfaces will affect the nature of the thermal increase.

- Highly vascular structures undergo less heating due to high blood flow

- Reflective interfaces (soft tissue/bone) suffer greater heating:

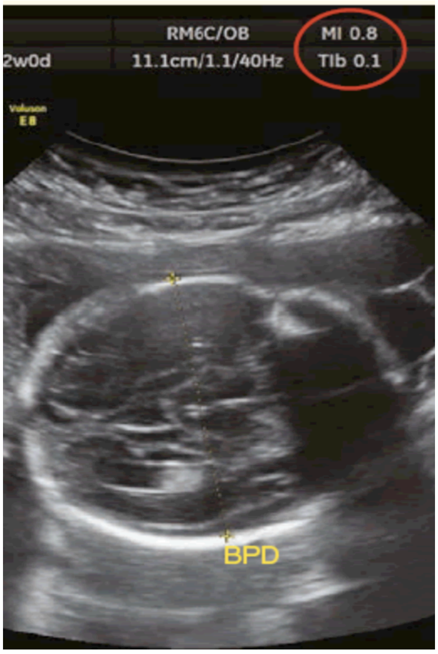
- High reflection of energy back into soft tissue
- Absorption of any transmitted energy within the bone results in conversion to thermal energy

Fetal and developmental embryo tissue is at particular risk from thermal injury.

THERMAL INDEX (TI)

The TI is calculated by the ultrasound machine based on machine settings (transmit power, frequency, depth, and mode), and clinical preset used. A number of assumptions about tissue exposure are used to produce a thermal index (TI).

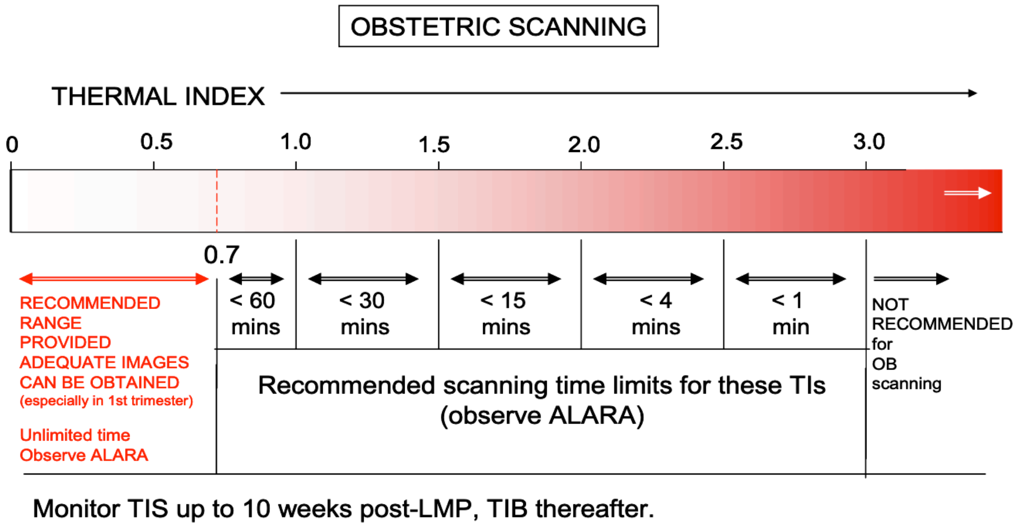
$$TI = \text{Transducer Power} / \text{Power required to cause a maximum temperature rise of } 1^{\circ}C \text{ anywhere within the beam}$$



Source: Wozniack et. al.- Imaging in Medicine (2012)

The TI is gives a reference for potential heating effects of an active scan. It is calculated dependent on the tissue type of exposure. For example, TIS for soft tissue, TIC for cranial, and TIB for bone. The safe TI is dependent on the tissue being exposed.

For general scanning a TI < 1.5 is considered safe (< 1.0 for ophthalmic ultrasound). In early pregnancy scanning (< 10/40) a TIS of < 0.7 is considered safe (BMUS), an increasing TI above this will mean scanning time must be limited (see image from BMUS).



Source: BMUS

- **In POCUS early pregnancy ultrasound, Doppler ultrasound should be avoided given potential thermal effects** and the lack of any added clinical value. Brief use of M mode can be utilised to measure fetal heart rate.

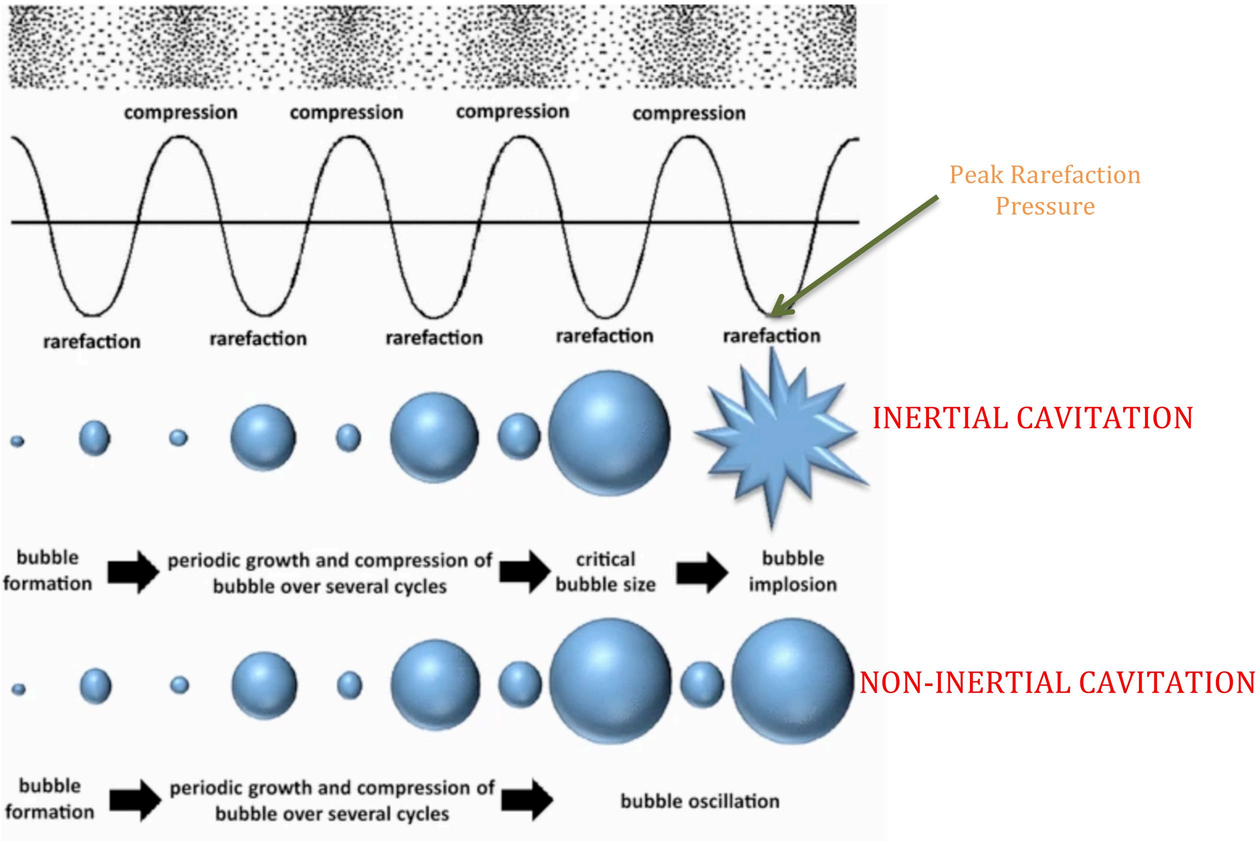
MECHANICAL EFFECTS

The most important mechanical effect of diagnostic ultrasound is the potential for cavitation. This occurs within exposed tissues containing micro-bubbles, such as lung and intestine.

Other mechanical effects within tissue also exist. Radiation forces is the force an object is exposed to from energy reflecting or being absorption. In general diagnostic ultrasound these forces are relatively minimal, but at non-diagnostic exposure levels significant tissue damage may occur.

CAVITATION AND MECHANICAL INDEX (MI)

Within tissues containing gas bubbles the changes in pressure from ultrasound exposure will cause cavitation forces. This results in expansion and contraction of the gas bubbles in response to the pressure changes over time.



Source: Zhara et. al. Ultrasound Cavitation- Journal of Medical and Biologic Engineering (2019)

- This may result in stable non-inertial cavitation, or the inertial cavitation collapse of micro-bubbles. **Inertial cavitation results in significant energy exposure to tissue, which may be damaging.**

The mechanical index (MI) is a measure of indicated risk for cavitation to occur:

$$MI = \frac{\text{Peak Rarefactional Pressure}}{\sqrt{\text{Operating Frequency}}}$$

- MI used as a surrogate measure of all potential non-thermal bio-effects (including radiation forces)
- Generally acceptable MI is < 1.9 (< 0.23 for ophthalmic ultrasound)

KEY POINTS

- Ultrasound has potential thermal and mechanical bio-effects

Thermal Bio-effects

- Greatest with stationary scan modes in particular PW Doppler using high power transmits

- Risk of heating greater in highly attenuating tissue and with higher frequency (increased attenuation)

- The TI is a measure of potential thermal heating

- High risk tissues for thermal effects include fetal and eye and have a lower acceptable safe exposure:

- General scanning TI < 1.5
- Fetal scanning TI < 0.7
- Eye scanning TI < 1.0

Mechanical Bio-effects

- Mechanical force of greatest concern is cavitation effects on micro-bubbles, in particular inertial cavitation that can cause high-energy tissue exposure.

- The MI is a measure of the risk for the occurrence of cavitation. MI is used as a surrogate measure for all other potential non-thermal bio-effect mechanisms.

- Generally a MI < 1.9 is considered safe

- Eye scanning MI < 0.23

Time of Exposure

- The MI and TI do not take into account time of exposure
- The ALARA principle should be always considered

REFERENCES

British Medical Ultrasound Society. Safety Guidelines

Australasian Society of Ultrasound Medicine. Standards and Practice

The Physics and technology of Diagnostic Ultrasound: A Practitioner's Guide. By Dr Robert Gill.