Ultrasound in different environments and tissues

Ultrasound , generated using magneto-strictive, more often piezoelectric generators , propagates through the material medium as a wave of alternating thickening and thinning of molecules. In the soft tissues and fluids of the human body in the form of longitudinal waves , in bones also in the form of transverse waves .

The propagation speed of ultrasonic waves depends on the elasticity K and the density ρ of the medium according to the formula:[1]

$$v = \sqrt{\frac{K}{\rho}}$$

Although a higher density of a substance reduces the speed of sound propagation, at the same time, substances with a higher density usually have a higher elasticity. Therefore, ultrasound propagates fastest in solid substances (e.g. bones) and slowest in gases (air). In liquids and materials with a high water content (e.g. soft tissue) it travels at an average speed of 1540 m/s.

Acoustic impedance

Acoustic impedance , a quantity describing the relationship between ultrasound and the environment , depends on the density of the environment and the speed of ultrasound propagation. It is given by the relation:

$$Z = \frac{p_e f}{v_e f} = c.\rho$$

Where:

- Z = acoustic impedance
- p_{ef} = sound pressure;
- v_{ef} = acoustic velocity;
- ρ = density of medium;
- c = propagation velocity of ultrasound through the medium.

The environment offers a kind of resistance to ultrasonic waves and prevents the formation of zones of increased and reduced pressure (condensation and dilution of molecules). It can therefore be read from the formula that solid substances with a high density and speed of ultrasound propagation have a high impedance.

Acoustic impedance and ultrasound velocity values for selected tissues and environments

Tissue	Acoustic impedance Z [10^6 kg · m^{-2} · s^{-1}]	velocity [m · s^{-1}]
blood	1,62	1580
bone	3,75–7,38	3360
brain	1,55–1,66	1538
liver	1,64	1570
muscle	1,65–1,74	1568
water	1,5	1500
air	0,0004	340

[2]

Ultrasound at the tissue interface

As the ultrasound wave travels through the body , it encounters different tissue interfaces, with different tissues having different acoustic impedance and echogenicity – the ability to reflect ultrasound waves. At the tissue interface, a partial reflection of the wave (echo) occurs, a part passes on to the next tissue interface. The greater the difference in acoustic impedances and the echogenicity of neighboring tissues, the greater the wave reflection. The ratio between the intensity of the reflected wave and the intensity of the wave incident on the interface is given by:

$$R = \left(\frac{z_1 - z_2}{z_1 + z_2} \right)^2$$

Where:

- R = ratio of the intensities of the reflected wave to the incident wave;
- Z_1 = acoustic impedance of environment 1;
- Z_2 = acoustic impedance of environment 2.

If the acoustic impedance of the environment is 1 and 2:

1. $Z_1 = Z_2$, R = 0, there are no reflections at the medium interface. It is a homogeneous environment.
2. $Z_1 \neq Z_2$, partial reflection occurs.
   - $R \rightarrow 0$ – soft tissues with similar impedance;
   - $R \rightarrow 1$ – tissues with a higher impedance difference, e.g. soft tissue – bone, soft tissue – air.

The ratio of the intensities of the passing ultrasonic wave to the incident wave can also be calculated from this ratio:

$$T = 1 - R$$

The ultrasound examination method in medicine is based on this principle. However, during an ultrasound examination , it is undesirable for the waves to pass through the air layer between the ultrasound probe and the body surface (the difference between the impedance of air and soft tissue is considerable and large reflections would occur at this interface). Therefore, it is necessary to apply a gel to the surface of the body and thereby ensure impedance matching .

Part of the acoustic energy that is absorbed is converted into heat (ordered motion of molecules turns into disordered thermal motion).

Ultrasound in human tissues

Thermal effects

When ultrasound passes through living tissue , it heats the tissue due to energy absorption . This happens mainly at the tissue interface, but also when passing through homogeneous tissue. The rate of absorption is dependent on the ultrasound frequency . As the frequency increases, the absorption and dispersion in tissues increases and the penetration of ultrasound decreases . It is therefore necessary to use an ultrasound of a lower frequency (with a lower probability of wave deflection when passing through closer areas) with a lower resolution for the examination of deeper-seated tissues .

- *in an adult patient, a probe with a frequency of 5 MHz is suitable for examining superficial tissues, and a probe with a frequency of 3.5 MHz for deeper tissues.*

Absorption of ultrasound takes place in deeper tissues, which usually do not contain thermoreceptors. Therefore, there is no subjective perception of a local temperature rise.

Mechanical effects

As a result of the thickening and thinning of the environment, rapid pressure changes occur during the oscillation of molecules , which can lead to mechanical damage to structures due to cavitation , for example . During this physical phenomenon, vacuum cavities are formed in flowing liquids or in places of liquids with rapid pressure changes , which can damage cellular structures by their disappearance.

Physicochemical effects

The effect of ultrasound can, for example, lead to the excitation of molecules and acceleration of chemical reactions, tissue blood flow or metabolism.

Ultrasound is an excellent method for imaging soft tissues, but unsuitable for examining lungs and bones.

Links

External links

- https://vysetreni.vitalion.cz/ultrazvuk/
- http://ftplf2.agarek.com/fyzio/prvak/biofyzika/semin/tercaza_uz.php
- http://apfyz.upol.cz/ucebnice/details/ultrazvuk_terapie.pdf
- https://www.vutbr.cz/www_base/zav_prace_soubor_verejne.php?file_id=14149

References

- NAVRÁTIL, Leoš. *Biofyzika v medicíně.* 1. edition. 2003. ISBN 80-86571-03-3.

References

- Radiologická fyzika, Zvuk a ultrazvuk, Biofyzikální ústsav LF MU, 2014 (http://www.med.muni.cz/biofyz/files/radiologieBC/UZ2.pdf)

1. ROSINA, Josef, et al. *Biophysics for medical students.* 1st edition. Grada publishing, a.s., 2006. p. 86. ISBN 8024768682 .
2. NAVRÁTIL, Leoš. *Biophysics in Medicine.* 1st edition. Prague: Manus, 2003. ISBN 80-86571-03-3 .