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Editorial: Pushing the physical limits of wave propagation in soft tissues: an add-on to shear wave elastography

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Editorial on the Research Topic
Pushing the physical limits of wave propagation in soft tissues: an add-on to shear wave elastography

Shear wave elasticity imaging (SWEI) relies on the generation and tracking of low frequency (10^2–10^3 Hz) shear waves to image and quantify the tissue's shear modulus, which is representative of the stiffness in biological tissues. It is well known that tissue stiffness is related to certain pathologies, such as breast or prostate cancer and liver fibrosis [1]. Therefore, the shear modulus, also called the storage modulus, is an important biomarker that aids in the diagnosis of these diseases. Other mechanical parameters related to SWEI, such as viscosity and anisotropy factors, can also serve as useful biomarkers, although they have been less frequently investigated.

Several research groups are working to push the physical limits of SWEI, either by exploring new applications that necessitate the development of more comprehensive wave propagation models or by providing new approaches within the existing models to address the limitations of the current methods. Therefore, the aim of this Research Topic is to present the latest experimental, methodological and theoretical developments in wave physics related to soft tissue that contribute to extend the applicability of SWEI or the development of new biomarkers.

Undoubtedly, viscosity is an important biomarker in soft tissues. Numerous proposals exist to estimate the viscoelastic properties of soft tissues using SWEI. However, measurement noise, especially when employed *in vivo*, is a common challenge across all these methods. The work by Reem Mislati et al. addresses this problem by combining plane wave single-track location (pSTL) with the frequency-shit (FS) method. By doing so, they show that fitting the shear wave spectra to a gamma distribution produces better results in both phantoms and *in vivo* experiments. In addition, the pSTL-FS proposed method reduced artifacts from higher attenuation values closer to the push beam and lower attenuation values farther from it.

In addition to viscosity, the anisotropy of the tissue must often be considered when modelling wave propagation, particularly in skeletal muscle. However, the anisotropy of arteries has been little explored. The work by Sauvage et al. addresses this challenge. They use high frame rate 3D imaging to measure 3D pulse wave (PW) propagation in phantom vessels, both isotropic and exhibiting helical anisotropy. The PW was generated using a peristaltic pump, simulating natural waves in the body produced by the heart. The results show that anisotropy affects the PW propagation, causing the wavefront to form an angle with the vessel's axis. The authors conclude that anisotropy is crucial for interpreting experimental results related to arterial elasticity, with potential implications for diagnosing cardiovascular diseases.

Diastasis recti (DR) is a common condition in pregnancy, characterized by the separation of the rectus abdominis muscles, which may persist for months or even years *postpartum*, potentially affecting body posture. Although there is consensus that ultrasound imaging offers the best diagnostic method for DR, controversy remains regarding the diagnostic criteria. The work by Wang et al. proposes incorporating SWEI as an additional marker for diagnosing and assessing potential risk factors for DR. In a study involving 171 volunteers, they show that the Young's modulus in the rectus abdominis (Y_r) was significantly lower at 37 weeks of gestation than at 12 weeks, with average reduction of 49%. At 6 weeks *postpartum*, Y_r recovered to an average of 83% of its value but remained still significantly lower than during the first trimester of pregnancy.

Beyond ultrasound, there are other modalities of elastography, with magnetic resonance elastography (MRE) having a long research history. This method has the advantage of accessing regions of the body, such as the brain, where ultrasound is challenging due to the skull. Recent investigations show alterations in the brain's stiffness triggered by external stimuli. The work by Flé et al. proposes a simulation of a mouse head to image electromechanical properties of the brain with a synchronized MR-based methodology. They simulate the application of noninvasive brain stimulation (NIBS) by inducing electric field via direct electrodes placed on the scalp which allowing modulation of specific cerebral regions. The Lorentz forces induced by the electrical stimulation give rise to elastic waves, which are used to reconstruct local images of the complex shear modulus. This information, together with magnetic resonance electrical impedance tomography (MREIT) and transcranial alternating current stimulation (tACS), has the potential to map the electromechanical properties of the brain and provide biomarkers for assessing tissue health.

MRE is used extensively in the liver but less frequently in the kidney because of its complex internal structure and smaller size. Usually, pneumatic or piezoelectric drivers are employed to generate shear waves inside the body for MRE. However, this strategy often results in relatively low amplitude waves within the kidney, limiting detailed elasticity mapping of its internal structures. In the work by Marcos Wolf et al. the authors employed a rotating eccentric mass transducer, together with a gel pad placed on the posterior lateral wall to generate the internal waves. This transducer, used with a 3T whole-body MR system, allowed them to map the complex shear modulus in the kidneys of 10 healthy volunteers across all gross anatomical segments simultaneously during fasting and hydration. The transducer was driven at a frequency of 50 Hz. This frequency allowed for feasible breath-hold durations while minimizing drastic attenuation, thus preserving the penetration depth. The results demonstrate the capability of this setup to differentiate between anatomical regions in the kidney before and after hydration.

In recent years, research on elasticity estimation from surface wave measurements has increased, with applications in biomechanics or food industry. Like MRE, an external actuator generates low-frequency waves in contact with the body, and different methods can be used to track the surface waves in a free surface of the body. The goal of elastography by surface waves (ESW) is no to create an elasticity map but to estimate a mean elasticity value within a region of interest (ROI). Thus, without the machinery required for tissue imaging, the elasticity estimation in ESW can be delivered at a higher frame rate. In the work by Grinspan et al. the authors used a ESW setup to measure the shear wave speed in the biceps brachii and the brachioradialis of seven healthy volunteers during isometric torque ramps. While these ramps are standard in biomechanics research, the novelty in Grinspan et al. lies in varying ramp durations from 5 s to 20 s, with simultaneous measurements of both muscles. The results show that the maximum elastic value reached by each muscle behaved differently with varying ramp duration. While it increased for the *brachioradialis*, the opposite was true for the biceps.

All papers published in this Research Topic are exploratory. They provide proof-of-concept across diverse areas where the limits of shear elasticity imaging can be expanded beyond the current state-of-the-art to add new information with the potential to become new biomarkers for clinical use.

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