Interaction between tissue and ultrasonic mechanical waves for diagnosis: challenges from modeling to patient application

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Abstract

Ulatrasonic-based elasticity quantification technologies will enable a new class of biomarkers that quantify the mechanical functionality of soft tissue, opening a new diagnostic technique to a broad range of pathologies. Towards this problem, we work on enabling new sensor technologies linked to soft tissue biomechanics, to endow a new class of biomarkers that quantify the mechanical functionality of the cervix, and indeed any soft tissue. Abnormalities in the structural architecture of soft tissues are intimately linked to a broad range of pathologies including tumors, atherosclerosis, liver fibrosis or osteoarticular syndromes. The unexplored nature and applicability span of mechanical biomarkers and torsional waves endows a foundational diagnostic technology.

Ultrasonic characterization and understanding of soft tissue has been developed as a clinical diagnostic tool over the last two decades [1] and evolved through different technologies: quasi-static, dynamic elastogra-phy, based acoustic radiation force: ARFI, vibroacous-tography or pSWE, or on direct excitation: sonoelasto-graphy and our emerging torsional wave principle [2].

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Existing ultrasonic techniques are restricted to map first order tissue stiffness. In contrast, our recent advances covering (a) torsional waves (shear elastic waves that propagate in quasifluids radially and in depth in a curled geometry), (b) sensors (based on a novel arrangement of concentric sandwiches of piezo- and electro-mechanical elements), (c) propagation models and (d) patient testing, are allowing to quantify the mechanical functionality through relevant parame-ters beyond linear: dispersive and nonlinear. These higher order mechanical parameters may become key discriminating biomarkers since: (1) the physics of wave propagation is explaining how dispersion is a compound expression of the rheological, poroelastic, and microstructural scattering phenomena governed by the complex fibrous multiscale microarchitecture of the stroma, which undergoes characteristic changes during pathologies [3]; and (2) the extreme hyperelasticity that soft tissue exhibits clearly manifests as quantifiable harmonic generation, hypothesized to strongly depend on the unfolding of its collagen fibres, which again controls the tissue’s mechanical functionality.

Current challenges span:

1. To understand how structural architecture of soft tissue is intimately linked and controls a broad range of pathologies, which underpins the foundation of a new diagnostic technology.
2. To develop new sensor technologies capable of effectively sensing tissue elasticity, and yield simple and robust diagnostic tests and instruments.
3. To ground a new generation of biomarkers of physical nature based on the mechanical micro-architecture and properties of the tissue.

References

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