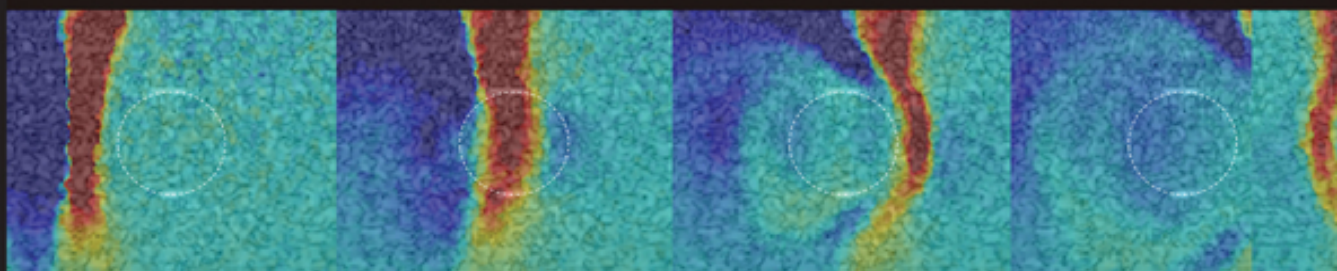


Wiley Series in Acoustics, Noise and Vibration

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# ULTRASOUND ELASTOGRAPHY FOR BIOMEDICAL APPLICATIONS AND MEDICINE



Edited by  
Ivan Nenadic  
Matthew Urban  
James Greenleaf  
Jean-Luc Gennisson  
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## **Ultrasound Elastography for Biomedical Applications and Medicine**



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## Section I

### Introduction



## 1

## Editors' Introduction

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Medical imaging has become an integrated part of modern medicine. Images are made on the basis of exploiting physical processes as contrast mechanisms. For example, X-Ray imaging takes advantage of the differences in mass density of different tissues. Magnetic resonance imaging uses proton densities and magnetic relaxation times to create exquisite images of different soft tissues. Ultrasound imaging takes advantage of acoustic impedance differences related to the compressibility of tissue.

Palpation has been practiced by physicians for centuries because pathological tissue “feels” harder or stiffer than normal tissues, as in the examples of breast tumors. Palpation has some disadvantages – such as being subjective, dependent on the proficiency of the examiner, insensitive to deep or small lesions, and difficult to compare assessments at different time points. For the last 25 years scientists have been working on methods to create images based on the material stiffness differences of tissues in the body. This imaging modality has come to be known as elasticity imaging or elastography. The advantages of such a modality are that it would be objective, quantitative, independent of the examiner, and have high spatial and temporal resolution.

Within the field of elasticity there is a very large parameter space of different material properties – such as the Young’s modulus, shear modulus, Poisson’s ratio, viscoelasticity, anisotropy, nonlinearity, and density [1]. These different properties vary in different tissue types, some over narrow ranges and some over large ranges – such as the shear modulus which can range over six orders of magnitude [2, 3].

There is a wide range of pathological processes that change the material properties of tissue such as the liver, breast, thyroid, skeletal muscle, pancreas, spleen, kidney, myocardium, vasculature, brain, bladder, prostate, etc. Different conditions, such as inflammation, fibrosis, edema, and cancer, all contribute to changing the material properties of organs because the constituents of the organs are altered on the microscopic scale and that translates into changes observed at the macroscopic scale (micrometers to centimeters).

Elastographic measurements require some form of mechanical stimulation or excitation to cause deformation. Then a measurement system is needed to measure the resulting deformation. The deformation can be caused by an external applied source, such as mechanical vibration, an internal source, such as acoustic radiation force, or an endogenous process, such as the pumping of the heart. Based on the particular form of excitation and its temporal and spatial

characteristics, different material properties can be evaluated. The measurement system could be magnetic resonance imaging, ultrasound, optical, or acoustic (hydrophone or accelerometer). For the purposes of this book, we focus only on ultrasound-based measurement of deformations.

This book is comprised of chapters written by pioneers and innovators in the field of ultrasound-based elastography. The book is broken up into eight primary sections.

The first section provides an overview of ultrasound physics and imaging theory, a primer on mechanical stimulation of tissue and its response, and ultrasound-based methods for motion estimation. In Chapter 2, Drs. Roberto Lavarello and Michael Oelze provide a systematic review of ultrasound physics and imaging formation relevant for the field of ultrasound-based elastography. Dr. Kevin Parker gives an overview of the continuum of excitation used in this field in Chapter 3. Chapter 4, by Drs. Jingfeng Jiang and Bo Peng, provides a thorough treatment of the ultrasonic and signal-processing methods to measure tissue motion, which is one of the main components of any elastographic measurement.

The second section provides an in-depth theoretical background on continuum mechanics and wave propagation. Wave propagation in anisotropic, bounded, and viscoelastic media is covered in detail. Chapter 5 provides the basis for continuum mechanics and solutions to wave equations as a foundation for elastography. In Chapter 6, Dr. Jean-Luc Gennisson presents theory for shear wave (or transverse wave) propagation in anisotropic media. Chapter 7, by Dr. Javier Brum, describes wave propagation in bounded media, which has applications to thin structures such as vessels, myocardium, cornea, and tendons. Chapters 8 and 9 cover measurements of tissue viscoelasticity.

The third section is devoted to methods that have been developed based on quasi-static compression and endogenous excitations. Compression elastography, particularly as applied in nonlinear materials, is covered in Chapter 10. Dynamic strain and strain rate in cardiac applications are addressed in Chapter 11 by Dr. Jan D'hooge and colleagues. Dr. Marvin Doyley describes vascular and intravascular elastography methods in Chapter 12. Dr. Carolina Amador presents different approaches for measurement of viscoelasticity with creep-based methods in Chapter 13. Lastly, Dr. Elisa Konofagou writes about wave and strain imaging based on the intrinsic motion present in the cardiovascular system in Chapter 14.

The fourth section describes methods based on external vibration for generating propagating waves in the tissue. Two different approaches for performing dynamic elastography measurements with harmonic excitations are presented in Chapters 15 and 16. Methods that produce harmonic acoustic radiation forces including vibro-acoustography, harmonic motion imaging, and shearwave dispersion ultrasound vibrometry are presented by leaders in these methods in Chapters 17–19, respectively.

The fifth section details methods that use mechanical and acoustic radiation force to perturb the tissue within the organ itself with transient excitations. Transient elastography, described by Dr. Laurent Sandrin and colleagues in Chapter 20, is a mechanically based system used primarily for investigation of liver diseases. Dr. Stefan Catheline presents methods to use time reversal techniques for measuring wave propagation in the body in Chapter 21. Chapter 22, by Drs. Tomasz Czernuszcwicz and Caterina Gallippi, describes the acoustic radiation force impulse (ARFI) imaging method and its applications. The supersonic shear imaging method is presented by Drs. Jean-Luc Gennisson and Mickael Tanter in Chapter 23. Dr. Stephen McAleavey presents the benefits of applying single tracking location shear wave elastography in Chapter 24. Lastly, Chapter 25 describes the comb-push ultrasound shear elastography method developed by Drs. Pengfei Song and Shigao Chen, which uses multiple simultaneous acoustic radiation force push beams to generate shear waves for measurement of local shear wave velocity.

The sixth section provides insights into emerging areas that are being explored in the elastography field. Chapter 26, by Dr. Sara Aristizabal, provides an overview of different shear wave elastography approaches applied to characterizing elastic properties in anisotropic tissues. The use of guided waves for shear wave elastography and quantitative measurement of mechanical properties in thin tissues is addressed in Chapter 27 by Drs. Miguel Bernal and Ivan Nenadic and colleagues. Rheological model-free approaches for measuring viscoelasticity are described in Chapter 28. Lastly, methods that combine quasi-static compression elastography and dynamic shear wave elastography are presented to measure nonlinear elastic parameters in Chapter 29.

The seventh section reviews clinical application areas, including measurements made in abdominal organs, cardiovascular tissues, the musculoskeletal system, and breast and thyroid tissues. Chapter 30, by Dr. Matthew Urban, provides an overview of these clinical applications. Chapter 31 describes abdominal applications with shear wave elastography in liver, kidney, spleen, pancreas, intestines, bladder, prostate, and uterus. The group at Duke University led by Dr. Gregg Trahey describe the use of ARFI for cardiac applications in Chapter 32. Additional description of other cardiovascular applications of shear wave elastography are provided in Chapter 33. Dr. Jean-Luc Gennisson details the use of supersonic shear imaging for musculoskeletal applications using different levels of contraction of skeletal muscle and measurements in tendons in Chapter 34. Dr. Azra Alizad writes about the use of shear wave elastography in breast and thyroid applications in Chapters 35 and 36, respectively.

The final section provides a reflection on the growth of elastography from a literature-based perspective by Drs. Armen Sarvazyan and Matthew Urban. Different transitions in the field are described from a literature citation approach.

We believe that this book provides a review of the field after two decades of development, a snapshot of current clinical applications, and look to future areas of investigation. Elastographic methods are now installed on a plethora of clinical scanners and the inclusion of these methods is still being introduced in many clinical practices in hepatology, oncology, cardiology, obstetrics, nephrology, and radiology, among others. This past 25 years has been devoted to development of many efficacious methods and we believe that development will continue to evolve such that elastographic methods are available on all types of ultrasound scanners. This will enable another 25 years of clinical application to provide clinicians noninvasive tools for improving diagnosis and monitoring of treatment and other interventions, providing benefit to a multitude of patients worldwide.

## References

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