frontiers | Frontiers in Physics

TYPE Editorial
PUBLISHED 19 October 2022
DOI 10.3389/fphy.2022.1055508

OPEN ACCESS

EDITED AND REVIEWED BY
Ewald Moser,
Medical University of Vienna, Austria

*CORRESPONDENCE
Simon Chatelin,
schatelin@unistra.fr

SPECIALTY SECTION
This article was submitted to Medical Physics and Imaging,
a section of the journal
Frontiers in Physics

RECEIVED 27 September 2022
ACCEPTED 10 October 2022
PUBLISHED 19 October 2022

CITATION
Chatelin S, Brum J, Garteiser P, Guo J, Salameh N and Gennisson J-L (2022), Editorial: Innovative developments in multi-modality elastography.
Front. Phys. 10:1055508.
doi: 10.3389/fphy.2022.1055508

Editorial: Innovative developments in multi-modality elastography

Simon Chatelin[1]*, Javier Brum[2], Philippe Garteiser[3], Jing Guo[4], Najat Salameh[5] and Jean-Luc Gennisson[6]

[1]ICube, CNRS UMR 7357, University of Strasbourg, Strasbourg, France, [2]Laboratorio de Acústica Ultrasonora, Instituto de Física, Facultad de Ciencias, Universidad de la República, Montevideo, Uruguay, [3]Laboratory of Imaging Biomarkers, Center of Research on Inflammation, UMR 1149 Inserm, Université de Paris, Paris, France, [4]Department of Radiology, Charité−Universitätsmedizin Berlin, Berlin, Germany, [5]Center for Adaptable MRI Technology, Department of Biomedical Engineering, University of Basel, Allschwil, Switzerland, [6]Laboratoire d'Imagerie Biomédicale Multimodale (BioMaps), Université Paris-Saclay, CEA, CNRS, Inserm, Service Hospitalier Frédéric Joliot, Orsay, France

KEYWORDS

elasticity imaging, elastography, multiscale, multimodality imaging, biomechanics

Editorial on the Research Topic
Innovative developments in multi-modality elastography

At the crossroads between biomechanics, medical imaging and wave physics, elastography has been widely developed over the last 30 years. These innovations go hand in hand with the tremendous expansion of knowledge and technological leaps medical imaging has undergone in the past decades. Whatever the modality, elastography relies on three key steps: 1) biological soft tissue is stressed; 2) the resulting displacement, strain or strain rate fields are encoded on images; 3) mechanical property maps are reconstructed from the previously encoded fields. Since the initial proposal of static elastography [1], numerous static [2,3], strain [4–7] and dynamic shear wave [8] imaging methods have emerged. Today, the most widely deployed, dynamic methods include vibro-acoustography [9], Acoustic Radiation Force Impulse (ARFI) [10–12], Transient Elastography (TE) [13–15], Shear Wave Elasticity Imaging (SWEI) [8,16], MRI Elastography (MRE) [17,18] and Optical Coherence Elastography (OCE) [19,20]. Reference is made here to some of the main founding studies of these different approaches, many of which have been widely extended subsequently. Each of these methods has its own advantages and disadvantages with respect to the application to which they are dedicated, and it is important to emphasize their complementarity. For example, MRE methods, even if more complex to implement, allow to obtain measurements with a contrast and an attenuation independent of the penetrated tissues when using ultrasonic or optical methods which, for their part, provide a much more "real-time" information. These aspects have been widely compared in the past in comparative studies and literature reviews [21,22]. However, and as it appears later *via* the different articles presented in this topic, the overlapping of these different methods allows today to move towards complementary approaches tending to blur these differences by getting the best of each method according to the targeted clinical application. We can mention as an example the use of focused ultrasound for the generation of shear waves in MRE [23–26].

In addition to developments in imaging methods themselves, the most notable advances in recent years have focused on both *in vivo* soft tissue excitation methods and on methods for reconstructing mechanical maps. Even if they are not yet the most important developments, we can for example underline the emergence passive elastography [27–29] and Deep Learning [30,31] as excitation and reconstruction methods, respectively. Through *in vivo* mechanical characterizations across different scales and ranges of behavior of biological soft tissues, elastography enables today the exploration of a very wide spectrum of medical applications, ranging from diagnosis in clinical practice to the understanding and modeling of many healthy and pathological organs.

Current challenges and perspectives in elastography

From the early days, elastography methods have brought together physicists, engineers and physicians with diverse and complementary backgrounds, ranging from medical imaging to wave physics and mechanics. Recent developments have further broadened this spectrum of skills by including new fields of research and applications, such as data science, artificial intelligence, interventional radiology and organ modeling. The diversity in researcher profiles involved in elastography calls for the need of communication channels that facilitate exchanges and synergies between different scientific communities that traditionally do not speak to one another.

In this context, the present topic aims to capture the current elastography landscape, whatever the imaging modality, and highlight the transdisciplinary potential of the tools and methods developed by each of the communities. In order to fully understand these new developments as well as the issues and applications associated with them, this topic first proposes five literature reviews on:

- elastic waves generation: on the one hand for MRE specifically Gnanago et al., and on the other hand for passive elastography Brum et al.;
- the use of machine learning for model-free mechanical property mapping Hoerig et al.;
- multi-scale opportunities of ultrasonic and optical elastography methods Ormachea and Zvietcovich;
- specific clinical applications of MRE for the characterization of malignant tumors Pagé et al.

In addition, original research papers of this topic focus on methodological developments for multimodal elastography, with particular emphasis on reconstruction methods for poroelasticity Aichele and Catheline, Sowinski et al., Theodorou et al., scattering, strain Liu et al., Rippy et al. and multiscale mechanics Garczyńska et al., Garczyńska et al., as well as on the development of multimodal numerical models Torres et al. and experimental phantoms Chatelin et al., Yushchenko et al. Finally, it was shown in some clinical applications that multimodal elastography can be leveraged in order to take full advantage of the complementarities across modalities as illustrated in some clinical studies Goudot et al., Kreft et al., Pan et al., Li et al.

To conclude, this Research Topic successfully highlighted that despite using different approaches, strong interrelationships and transfers between different modalities appear most fundamental and beneficial for the future development of elastography.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Acknowledgments

Our deepest thanks go to all the authors and reviewers who have participated and greatly contributed to the creation and publication of this topic.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Ophir J, Céspedes I, Ponnekanti H, Yazdi Y, Li X. Elastography: A quantitative method for imaging the elasticity of biological tissues. *Ultrason Imaging* (1991) 13(2):111–34. doi:10.1016/0161-7346(91)90079-W

2. Garra BS, Cespedes EI, Ophir J, Spratt SR, Zuurbier RA, Magnant CM, et al. Elastography of breast lesions: Initial clinical results. *Radiology* (1997) 202(1): 79–86. doi:10.1148/radiology.202.1.8988195

3. Itoh A, Ueno E, Tohno E, Kamma H, Takahashi H, Shiina T, et al. Breast disease: Clinical application of US elastography for diagnosis. *Radiology* (2006) 239(2):341–50. doi:10.1148/radiol.2391041676

4. Shiina T, Doyley MM, Bamber JC. Strain imaging using combined RF and envelope autocorrelation processing. *IEEE Ultrason Symp Proc* (1996) 2:1331–6. doi:10.1109/ULTSYM.1996.584292

5. Varghese T, Ophir J. A theoretical framework for performance characterization of elastography: The strain filter. *IEEE Trans Ultrason Ferroelectr Freq Control* (1997) 44(1):164–72. doi:10.1109/58.585212

6. Barbone PE, Bamber JC. Quantitative elasticity imaging: What can and cannot be inferred from strain images. *Phys Med Biol* (2002) 47(12):310–2164. doi:10.1088/0031-9155/47/12/310

7. Hall TJ, Zhu Y, Spalding CS. *In vivo* real-time freehand palpation imaging. *Ultrasound Med Biol* (2003) 29(3):427–35. doi:10.1016/S0301-5629(02)00733-0

8. Sarvazyan AP, Rudenko OV, Swanson SD, Fowlkes J, Emelianov SY. Shear wave elasticity imaging: A new ultrasonic technology of medical diagnostics. *Ultrasound Med Biol* (1998) 24(9):1419–35. doi:10.1016/S0301-5629(98)00110-0

9. Fatemi M, Greenleaf JF. Ultrasound-stimulated vibro-acoustic spectrography. *Science* (1998) 280(5360):82–5. doi:10.1126/science.280.5360.82

10. Nightingale KR, Palmeri ML, Nightingale RW, Trahey GE. On the feasibility of remote palpation using acoustic radiation force. *The J Acoust Soc America* (2001) 110(1):625–34. doi:10.1121/1.1378344

11. Nightingale K, Bentley R, Trahey G. Observations of tissue response to acoustic radiation force: Opportunities for imaging. *Ultrason Imaging* (2002) 24(3): 129–38. doi:10.1177/016173460202400301

12. Palmeri ML, Wang M, Dahl J, Frinkley K, Nightingale K. Quantifying hepatic shear modulus *in vivo* using acoustic radiation force. *Ultrasound Med Biol* (2008) 34(4):546–58. doi:10.1016/j.ultrasmedbio.2007.10.009

13. Catheline S, Thomas JL, Wu F, Fink M. Diffraction field of a low frequency vibrator in soft tissues using transient elastography. *IEEE Trans Ultrason Ferroelectr Freq Control* (1999) 46(4):1013–9. doi:10.1109/58.775668

14. Sandrin L, Tanter M, Gennisson JL, Catheline S, Fink M. Shear elasticity probe for soft tissues with 1-D transient elastography. *IEEE Trans Ultrason Ferroelectrics, Frequency Control* (2002) 4(4):436. doi:10.1109/58.996561

15. Bercoff J, Chaffai S, Tanter M, Sandrin L, Catheline S, Fink M, et al. *In vivo* breast tumor detection using transient elastography. *Ultrasound Med Biol* (2003) 29(10):1387–96. doi:10.1016/S0301-5629(03)00978-5

16. Bercoff J, Tanter M, Fink M. Supersonic shear imaging: A new technique for soft tissue elasticity mapping. *IEEE Trans Ultrason Ferroelectr Freq Control* (2004) 51(4):396–409. doi:10.1109/TUFFC.2004.1295425

17. Lewa CJ. Magnetic resonance imaging in the presence of mechanical waves. *Spectrosc Lett* (1991) 24(1):55–67. doi:10.1080/00387019108018124

18. Muthupillai R, Lomas DJ, Rossman PJ, Greenleaf JF, Manduca A, Ehman RL. Magnetic resonance elastography by direct visualization of propagating acoustic strain waves. *Science* (1995) 269(5232):1854–7. doi:10.1126/science.7569924

19. Schmitt JM. OCT elastography: Imaging microscopic deformation and strain of tissue. *Opt Express* (1998) 3(6):199–211. doi:10.1364/OE.3.000199

20. Chan RC, Chau A, Karl W, Nadkarni S, Khalil A, Iftimia N, et al. OCT-Based arterial elastography: Robust estimation exploiting tissue biomechanics. *Opt Express* (2004) 12(19):4558–72. doi:10.1364/OPEX.12.004558

21. Vappou J. Magnetic resonance- and ultrasound imaging-based elasticity imaging methods: A review. *Crit Rev Biomed Eng* (2012) 40(2):121–34. doi:10.1615/CritRevBiomedEng.v40.i2.30

22. Ormachea J, Parker KJ. Elastography imaging: The 30 year perspective. *Phys Med Biol* (2020) 65(24). doi:10.1088/1361-6560/abca00

23. Souchon R, Salomir R, Beuf O, Milot L, Grenier D, Lyonnet D, et al. Transient MR elastography (t-MRE) using ultrasound radiation force: Theory, safety, and initial experiments *in vitro*. *Magn Reson Med* (2008) 60(4):871–81. doi:10.1002/mrm.21718

24. Liu Y, Fite BZ, Mahakian LM, Johnson SM, Larrat B, Dumont E, et al. Concurrent visualization of acoustic radiation force displacement and shear wave propagation with 7T MRI. *PLOS ONE* (2015) 10(10):e0139667. doi:10.1371/journal.pone.0139667

25. Bour P, Marquet F, Ozenne V, Toupin S, Dumont E, Aubry JF, et al. Real-time monitoring of tissue displacement and temperature changes during MR-guided high intensity focused ultrasound. *Magn Reson Med* (2017) 78(5):1911–21. doi:10.1002/mrm.26588

26. Vappou J, Bour P, Marquet F, Ozenne V, Quesson B. MR-ARFI-based method for the quantitative measurement of tissue elasticity: Application for monitoring HIFU therapy. *Phys Med Biol* (2018) 63(9):095018. doi:10.1088/1361-6560/aabd0d

27. Sabra KG, Conti S, Roux P, Kuperman WA. Passive *in vivo* elastography from skeletal muscle noise. *Appl Phys Lett* (2007) 90(19):194101. doi:10.1063/1.2737358

28. Sabra KG, Archer A. Tomographic elastography of contracting skeletal muscles from their natural vibrations. *Appl Phys Lett* (2009) 95(20):203701. doi:10.1063/1.3254834

29. Gallot T, Catheline S, Roux P, Brum J, Benech N, Negreira C. Passive elastography: Shear-wave tomography from physiological-noise correlation in soft tissues. *IEEE Trans Ultrason Ferroelectr Freq Control* (2011) 58(6):1122–6. doi:10.1109/TUFFC.2011.1920

30. Murphy MC, Manduca A, Trzasko JD, Glaser KJ, Huston J, Ehman RL. Artificial neural networks for stiffness estimation in magnetic resonance elastography. *Magn Reson Med* (2018) 80(1):351–60. doi:10.1002/mrm.27019

31. Solamen L, Shi Y, Amoh J. *Dual objective approach using A convolutional neural network for magnetic resonance elastography* (2018). Available from: http://arxiv.org/abs/1812.00441. (Accessed December 2 2018).