Preface.

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As that of many other scientific fields, the history of ultrasound clinical use for bone is made of booms and regressions. Clinical bone imaging technology is largely based on using X-rays. But since X-rays imaging does not provide all of the information that is needed by clinicians, particularly for bone strength assessment, in the second part of the twentieth century researchers turned to ultrasound. The first investigations using ultrasound for bone assessement reported in the late 1950s were designed to monitor fracture healing [1]. Despite the publication of interesting results, it took 25 years before diagnostic ultrasound succeeded in attracting clinicians in a completely different field, that of osteoporotic fracture risk prediction [2].

In parallel and approximately in the same period, efforts have been made to enhance fracture healing using physical methods such as ultrasound stimulation, which has become known as low-intensity pulsed ultrasound (LIPUS). The first clinical report that ultrasound stimulates fracture healing traces back to early 1950s [3]. But it was not until the 1980s that basic scientists and physicians get attracted by LIPUS [4]. Since then, scientific studies -- in vitro and animal studies to clinical trials and case series -- provided a growing body of evidence on the potential of LIPUS to enhance fracture healing. This has been nicely reviewed in the invited contribution by Padilla et al. [5].

The late 1990s and early 2000s have been the golden age of quantitative ultrasound (QUS) methods to assess bone, a field commonly referred to as “Bone QUS”. Those years, engineers, scientists and clinicians combined their efforts to invent and make available ultrasound technologies to benefit the patients in order to improve the prediction of fracture risk [6]. While various approaches have been developed to measure both cancellous or cortical bone sites, the most advanced technologies that were proven to be clinically useful were the devices measuring the calcaneus (a cancellous bone site) at the heel. However, diagnostic QUS-based methods have failed to emerge as an alternative to X-ray, they have more or less receded into the background. The LIPUS technology has been made commercially available to clinicians in those years, but is still not widely clinically used.

Despite the fact that ultrasound can be used clinically, both for diagnosis and therapy, the interaction of ultrasound waves with bone is by no means well understood, hampered by the structural complexity of bone. This probably partly explains that the clinical use of ultrasound for bone diagnosis and therapy is still not widespread. This is particularly the case for cancellous bone, a highly porous and heterogeneous complex medium in which single or multiple wave scattering phenomena and poroelastic propagation seem to be intricate. It is for this reason that ultrasonic propagation in bone has been under intensive investigation recently, with a particular emphasis on modeling and simulation. A step forward has been made in the past decade with the widespread availability and intensive use of modern numerical simulation tools such as finite difference time domain (FDTD) or finite element modeling (FEM) sofware packages. Modeling can be seen as a major need in order 1/ to relate QUS variables to relevant bone biomechanical properties and to quantify these properties; 2/ to gain deeper insight into mechanisms by which therapeutic effects on bone are mediated; 3/ to integrate multiscale knowledge; 4/ to optimize QUS measurements and LIPUS protocols and to drive future experiments. The field is vivid and continuously stimulates productive research. The original model proposed in the invited contribution by Meziere et al. to interpret propagation phenomena observed in cancellous bone is a good example of this vitatliy [7].

Diagnostic bone assessment has long been focused on cancellous bone which is known to be more metabolically active than cortical bone. Such a focus resulted in neglect of cortical bone. However, the role of cortical bone has recently been recognized as central to the occurrence

of fractures. This has led to a resurgence of research projects on elastic waves propagation in cortical bone, especially as the cortical bone is still poorly evaluated by X-ray imaging modalities.

Another quite vivid research route investigates multi-scale bone elastic properties with the aim to expand our current understanding of structure-functions relationships. To this end, the scalability of ultrasound is highly relevant and a study combining high resolution modalities such as Brillouin scattering and scanning acoustic microscopy is reported in the invited contribution by Matsukawa et al. [8].

Despite many efforts by several groups worldwide to investigate interaction mechanisms between bone and ultrasound and to develop ultrasound technologies into an effective clinical method, it must still be considered to be in the incubation stage. The goal in this special issue is to provide the reader with a timely compilation of the most recent accomplishments that have been made in the field of “Application of ultrasound to the diagnosis and treatment of bone diseases”.

Besides the three above mentioned invited contributions, thirteen papers report experimental and modeling works on ultrasound propagation in cortical bone and cancellous bone. Cortical bone is preferentially investigated with guided waves, which has required the introduction of original signal processing methods and simulation techniques. In three papers of the SI, guided waves are also proposed to monitor fracture healing. Speed of sound and ultrasound attenuation through trabecular bone is investigated in analytical models and intensive numerical computations in order to move beyond the predictions of Biot poroelastic model in infinite medium. Ultrasound provide a variety of methods which are adapted to the limited size of bone samples. Basic research on bone elasticity and anisotropy is investigated in two papers of the special issue, at the millimeter scale and at the microscale using Brillouin scattering.

References

1. M. Siegel, G. T. Anast, and T. Fiefld s, "The determination of fracture healing by measurement of sound velocity across the fracture site," *Surg Gynecol Obstet*, vol. 107, pp. 327-32, 1958.

2. C. M. Langton, S. B. Palmer, and S. W. Porter, "The measurement of broadband ultrasonic attenuation in cancellous bone," *Eng Med*, vol. 13, pp. 89-91, 1984.

3. C. Corradi, A. Cozzolino, "Ultrasound and bone callus formation during function," *Arch Ortop*, vol.66, pp. 77—98, 1953.

4. L. R. Duarte,” The stimulation of bone growth by ultrasound," *Archives of orthopaedic and trauma surgery*, vol.101, pp. 153-9, 1983.

5. F. Padilla, R. Puts, L Vico, and K Raum, “Stimulation of bone repair with ultrasound: a review of the possible mechanistic effects models”, *Ultrasonics*, this issue.

6. P. Laugier, “Instrumentation for in vivo ultrasonic characterization of bone strength”, IEEE Trans Ultrason Ferroelec Freq Contr, vol. 55, Pp. 1179-96, 2008.

7. F. Mézière, M. Muller, E. Bossy, A. Derode, “Measurements of ultrasound velocity and attenuation in numerical anisotropic porous media compared to Biot's and multiple scattering models”, *Ultrasonics*, this issue

8. M. Matsukawa, R. Tsubota, M. Kawabe, K. Fukui, ”Application of a micro-Brillouin scattering technique to characterize bone in the GHz range”, *Ultrasonics*, this issue

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