Statement of Research and Teaching Interests

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Research and teaching interests: auditory macro/micro/nano mechanics; mathematical biology; tensor calculus; continuum modeling of complex biological/mechanical systems; hybrid WKB/finte-element analysis; fluid-structure interactions; (bio)fluid mechanics; constitutive law for soft living tissues; analysis of biomedical images; finite-deformation elasticity; cardiac mechanics and heart growth; mechanical coupling of vascular diseases.

Current research and future plans:
An important physical aspect of hearing is the phenomenon of wave propagation on the cochlear partition. Sound stimuli are transmitted as waves that result from the interaction of the fluids and partition structures in the cochlea, a complex 3-D spiral fluid-organ-membrane coupled structure in the inner ear, which transforms sound-induced vibrations of the middle ear into electrical signals in the auditory nerve. Due to technical difficulties, both measuring and modeling of the motion of the cochlear partition and its surrounding fluid are extremely challenging. As a result, modeling the cochlea by full 3-D numerics is currently not practical when the real fluid-structure interactions and detailed cellular structures in the organ of Corti are involved. Therefore, I developed a hybrid analytical/numerics approach to modeling the fluid-structure interactions and vibrational patterns in the cochlea (Cai, Shoelson and Chadwick (2004), Proceedings of the National Academy of Sciences, 101:6243-6248; Cai and Chadwick (2003), SIAM J. Appl. Math., 63(4):1105-1120). In our new hybrid approach, we let the WKB perturbation method to deal with the axial propagation of waves and use finite-element method in the transverse planes with a physically realistic cross-section geometry of the hearing organ. We solve the fluid-solid interaction eigenvalue problem for the axial wavenumber, fluid pressure, and the vibratory relative motions of the cochlear partition. The details of the cochlear fluid flow and pressure fields are calculated, along with displacements of the elastic structures. I believe that the hybrid approach developed in this study is a very efficient and powerful tool for investigating complex biological/mechanical systems.

I'm also the first author on the paper, "Motion analysis in the hemicochlea," *Biophysical J.*, 85(3):1-8, 2003. In this paper, I developed and applied a new optical flow image processing technique, a fast, efficient and geometry-based approach, to recover motions of successive video images in the hemicochlea preparation. We take the incompressible nature of the motion into consideration and avoid the calculation of image spatiotemporal derivatives, which are often nearly singular in large regions of the images. Furthermore our method also avoids both the well-known "aperture problem" and the need for high contrast edges. This technique reveals, for the first time, the motion of the tectorial membrane, which has been difficult to track in the hemicochlea preparation.

We also published the following papers: Cai, H. and R.S. Chadwick, "Computation of modes and motion analysis in a transverse section of the cochlea," in: Gummer, A.W. (Ed.), *Biophysics of the Cochlea, from molecules to Models*, World Scientific, Singapore, 2003, pp. 400-408, and Chadwick R.S., Shoelson, B. and Cai, H., "Surface Green's functions for an incompressible, transversely isotropic elastic half-space," *SIAM J. Appl. Math.*, 2004, 64:1186-1197.

In spite of the tremendous efforts that have been made toward the understanding of hearing transduction, many basic issues remain unclear. Followings are some of my future research projects in auditory mechanics:

- Functional significance of coiling in mammalian cochlea
- Stimulation mechanism of the inner hair cell stereocilia
- Energy flow and active process in the cochlea

Graduate studies:
During my Ph.D. study in France, I first learned the perturbation method from my supervisor, Prof. Jacques Ohayon, and I successfully applied the method to model the effects of topological organization of myocardial fibers on cardiac mechanics. However, while my work was deemed sufficient to merit a Ph.D. thesis, I elected to extend my studies into tensor calculus and the theory of continuum mechanics. With these additional tools, I then developed a biomechanical model to simulate the growth of human fetal left ventricle. This model describes mathematically the constitutive relation of the myocardium, an active, living, anisotropic tissue with complex fiber orientation and residual stresses, which undergoes finite deformation during development.

My Master Degree of Engineering was devoted to the development of a CAD software package for the design of machine tool hydraulic equipments. Thereafter, I developed several CAD and CAPP software packages that were used in industry and earned governmental awards in China.

Teaching statement:
I have taught a variety of courses, including biomechanics, solid/fluid mechanics, FEM, and scientific English; and I received an "Excellence in Teaching" award by Dalian Jiaotong University in 1992. As the head of the Laboratory of Hydraulic Transmission and Control and the Computer Center of the department of mechanical engineering, I gained invaluable experience for guiding practical projects of both undergraduate and graduate students. I would like to have the responsibility of teaching courses in biomathematics, (bio)mechanics and (bio)fluid mechanics. Moreover, I welcome the opportunity to develop new courses for your curriculum. In particular, I have strong foundations in – and the ability to teach – scientific programming in biomedical engineering, continuum modeling in biomedical engineering, fluid-structure interactions in complex biological systems, tensor calculus with applications, and constitutive theory for soft living tissues. In my approach to teaching, I:

- Encourage students to learn how to learn and think
- Explain basic equations and laws in alternate ways
- Interact with students by asking appropriate questions
- Provide real-world examples from my research experience
- Use different materials such as multimedia, and computers