Bioelectromechanical Imaging by Scanning Probe Microscopy: Repeating Galvani's Experiment on the Nanoscale

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Purpose:

Since the discovery in the late eighteenth century of electrically induced mechanical response in muscle tissue, coupling between electrical and mechanical phenomena has been shown to be a near-universal feature of biological systems. Functional properties of biological systems are determined by an intricate set of mechanical and electromechanical interactions on the length scales that span several orders of magnitude: from macro to nano. The main motivation of studying electromechanical properties in biosystems is to understand the relationship between physiologically generated electric fields and mechanical properties on the molecular, cellular and tissue levels.

Methods:

We use Vector Piezoresponse Force Microscopy, a variant of SPM, to image piezoelectric properties in calcified and connective tissues such as tooth enamel and dentin and cartilage. This technique is complemented by Acoustic and Ultrasonic Force microscopies to probe complementary information on local mechanical properties.

Results:

We demonstrate real space imaging of a spiral single collagen fibril in tooth enamel with ~5 nanometer resolution. In dentin and cartilage, the nanostructure of collagen network is visualized based on local electromechnical properties. We also illustrate an approach for imaging local molecular orientation from vector electromechnical data, the task inaccessible by other techniques. Imaging of elastic properties difference between enamel and dentin is also demonstrated.

Conclusions:

By measuring sub-Angstrom mechanical response of a biological system induced by an electric bias applied to a conductive SPM tip we visualize the spatial shape and molecular orientation of collagen molecules with ~5 nm resolution. This repeats the Galvani experiment on a nanometer scale - more than 200 hundred years later and with a million times higher resolution. The potential of this approach for further studies of electromechnical coupling in functional tissues on the cellular level is discussed.

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Bio:

Sergei Kalinin is currently a research staff member at the Oak Ridge National Laboratory. He completed his Ph.D. in Materials Science at the University of Pennsylvania in 2002 (with Dawn Bonnell). His previous undergraduate and graduate work in Materials Science was conducted at Moscow State University, Moscow, Russia. His research focuses on the development and quantitative interpretation of electromechanical and electrical scanning probe microscopy techniques, including nanoelectromechanics of ferroelectric materials, transport measurements in nanotubes, nanowires, and polycrystalline materials, and recently on atomic resolution imaging by STM and non-contact AFM. He has served as a member of NSF MRI panel, a symposium organizer for MRS meeting, an instructor for Lehigh Microscopy course (2005), and is currently a member of American Vacuum Society NSTD board. As a student, he earned multiple research awards including AVS Graduate Student Award and several MRS Graduate Student Awards. Sergei was recognized with the Ross Coffin Purdy Award of American Ceramics Society (2003) for the development of Scanning Impedance Microscopy, a novel SPM technique for the characterization of frequency-dependent transport on the nanoscale. He is also a recipient of Wigner Fellowship of Oak Ridge National Laboratory. He has authored more than 50 scientific papers, 6 book chapters and several patents.