Electromechanical Tissue Reconstruction: An Electrochemical Method to Reshape Cartilage

Jeremy Kallick, Jessica Kissel, Bryan M. Hunter, and Michael G. Hill*

Occidental College, Los Angeles, CA USA
Department of Chemistry

Functional and aesthetic defects in the head, neck, and airway that result from cancer surgery, trauma, or congenital malformations have led to the development of surgical techniques to reshape cartilage in order to restore or recreate damaged or absent structures. Conventional surgical techniques involve cutting, carving, or even morselizing cartilage tissue—each of which requires classic open operations, with all the attendant medical risks and costs. Recently, electromechanical reshaping (EMR) has been reported as a novel tissue-reshaping technique that combines mechanical deformation with the application of electric fields. In a typical embodiment of EMR, a cartilage sample is held in mechanical deformation by a jig, needle electrodes are inserted into the tissue, and a constant voltage is applied for 2-3 minutes. When the electrodes and jigs are removed, the cartilage assumes a new shape that approximates the geometry of the jig (for example, a 90° bend).

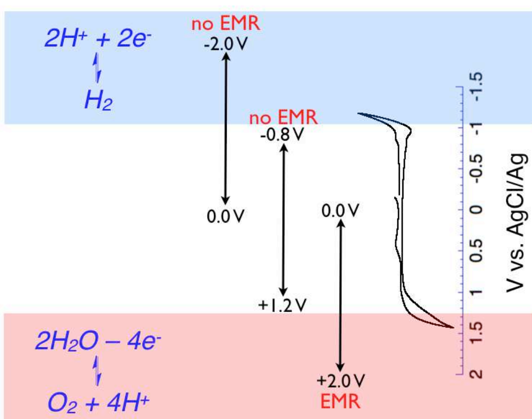

Figure 1. Summary of **EMR** shape-change dependence on applied electrochemical potential, using rabbit septal cartilage. In each set of experiments, a constant two-volt potential difference was maintained between the two working electrodes of a bipotentiostat, while the potentials themselves were poised at successively more positive values *vs.* a AgCl/Ag reference. Only when one or both electrodes were held positive of the water oxidation limit did shape change occur. The CV shows the *i-V* trace for PBS buffer at a platinum-needle electrode: potentials negative of ~ -1 V (shaded in purple) correspond to water reduction, while potentials positive of ~ 1.4 V correspond to water oxidation.

Although several possible mechanisms may play a role (*e.g.*, non-Faradaic protein and/or ion migration through the tissue caused by applied voltage gradients) our work suggests that the dominant pathway involves water electrolysis (and acidification) at the tissue/solution interface: (1) no EMR occurs unless at least one electrode in contact with the cartilage is held at a potential positive of the water-oxidation limit; (2) EMR does not require a voltage gradient across the tissue; and (3) the magnitude of EMR correlates directly with total anodic charge transferred (as opposed to electrolysis time, applied potential, voltage gradient, *etc.* (see Figures 1 and 2)).

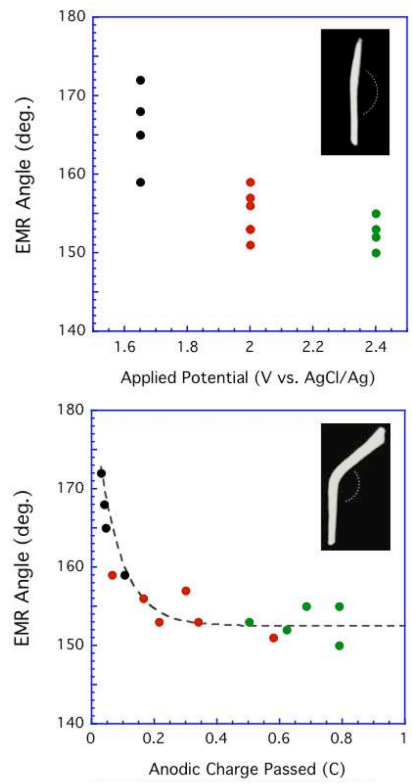

Figure 2. **EMR** "bend angle" data for rabbit septal cartilage. The top graph shows the bend angle as a function of applied electrochemical potential; the bottom graph shows those same data plotted instead *vs.* the anodic charge passed. Insets: (TOP) bend angle following 0.05 C passed; (BOTTOM) bend angle following 0.8 C passed at 2-V applied potential.

These observations suggest that EMR relies on diffusion into the tissue of key analytes generated during anodic electrolysis. We hypothesize that acidification at the anode and subsequent diffusion of protons into the tissue is the dominant process responsible for the shape change. Protonation of immobilized anions within the proteoglycan cartilage matrix disrupts the ionic-bonding network that provides structural integrity to the tissue. This, in turn, relieves the strain imposed by mechanical deformation. Subsequent re-equilibration to physiological pH restores the immobilized negative charges after molecules have locally "shifted" and reestablishes the ionic-bonding matrix, resulting in sustained shape change of the tissue. Herein, we present studies that map electrochemically generated pH gradients through mechanically strained cartilage tissue, and identify any reactive-oxygen species associated with the electrolysis process. Taken together, the results of these studies provide a roadmap for optimizing the conditions for effective shape change while minimizing tissue morbidity and mortality.