Poro-piezo-electromechanical model demonstrates how voltage gated ion channels can be activated by mechanical loading intervertebral disc tissue

Philip Poillot[1], Syed A.m. Tofail[1], Christine Lemaitre[2], and Jacques Huyghe*[3,4]

[1]Bernal Institute, University of Limerick – Ireland
[2]University of Sheffield [Sheffield] – United Kingdom
[3]Bernal Institute, University of Limerick – Ireland
[4]Eindhoven University of Technology [Eindhoven] – Netherlands

Abstract

Strain-generated potentials (SGPs) are known to activate mechanosensitive ion gating (2). Measured strain generated potentials have been attributed to electrokinetic phenomena such as streaming potentials. However, streaming potentials are generated between the extracellular space and the external solution, while the voltage gated ion channels sense the intra-extracellular voltage differences. Hence, our research question is: what potential can possibly activate the voltage gated ion channels during loading of the intervertebral disc? Using piezo force microscopy (1,3), we provide experimental evidence to support the potential contribution of piezoelectricity (mechano-transduction of electricity) in a linear and reversible manner with charge accumulation measured within human intervertebral discs (IVD) of 43.2 μC/m2 which is comparable to the threshold value (44.5 μC/m2) reported for cell membrane depolarization. Based on this finding in dehydrated tissue, we present a poro-ptezo-electromechanical model to demonstrate the effect of piezoelectricity of a hydrated extracellular space on the voltage-gating of ion channels. The piezoelectric effect was computed to increase the voltage gradient within the double layer of the membrane by 1 million V/m, resulting in a voltage signal of around 1 mV across the cell membrane, while streaming potential was predicted to have the sole ability to generate a mV response between the tissue and blood vessels outside the disc tissue. The latter signal cannot possibly be captured by the ion gates of the cell, while the piezoelectric signal can.

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*Speaker