In the Professors' Own Words (annotated)

Charles W. McCutchen, Jan. 18, 2013

The dedications in "Basic Orthopaedic Biomechanics and Mechano-Biology," Third Edition, 2005 (editors Van C. Mow and Rik Huiskes, Lippincott Williams and Wilkins, Philadelphia) are as follows:

To my many brilliant and creative graduate students, and postdoctoral fellows, to whom I owe much of my academic success.

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To my wife, Barbara, for all her loving support over the years and for her unfailing encouragement throughout my long hours pursuit of excellence year after year.

---Van C. Mow, Columbia University

To my graduate students, who taught me more than I taught them.

----Rik Huiskes, Eindhoven University of Technology

The second paragaph on page 19 of the the book's historical introduction starts,

The major breakthrough in cartilage biomechanics research began with the publication of a paper by Mow and co-workers in 1980 (41) [Mow *et al.* 1980]. The hypothesis of this paper is based on the well-known fact that soft biological tissues such as articular cartilage contain large amounts of water, and that the frictional drag of flow through the interstices of the tissue is a dominant factor in controlling frictional dissipation within the tissue and thence its viscoelastic behaviors. This paper immediately won the ASME Melville Medal (1982) for best archival literature of that year and it rapidly became the most frequently quoted paper ever published in the *Journal of Biomechanical Engineering*. It has led to a paradigm shift not only for

cartilage research, but also for other biological tissues, both hard and soft. This theory, based on a continuum mechanics approach, allowed a theoretically sound and rational approach to ever-increasing sophistication in the modeling of articular cartilage deformational behaviors, e. g., incorporating the (sic) some of the details of cartilage collagen-proteoglycan microstructural information into the theory.

The above breakthrough was the rederiving of M. A. Biot's consolidation theory and calling it the KLM model. Using it, the Mow group calculated the flow of fluid when a free-draining indenter is slid against a layer of poroelastic (they called it biphasic) material, a situation unrelated to joints. Against a free-draining surface there is no pore pressure and therefore no fluid lubrication. But the predicted flow in this "self-generating mechanism" imitated in vastly reduced magnitude the gigantic flow out of and back into cartilage from the previous, even more unreal, mechanical pumping effect. Only in the nineties (See Ateshian, 2009) did the group publish the rubbing of theoretical cartilage against an impervious surface, as I had done in 1962 and 1975, and rediscover self-pressurized hydrostatic (*i. e.,* weeping or biphasic) lubrication.[1]

The next paragraph includes:

"Ten years after the publication of the biphasic paper, Mow and co-workers (42) [Mow *et al.* 1991] published a paper that included a treatment of ions in the interstitial liquid and charges fixed to the porous-permeable solid matrix. This paper received the best paper award of the Bioengineering Division of the ASME in 1991 and appears to be changing the paradigm on the theory for soft-hydrated-charged tissues."

The paper introduced triphasic theory, which added to Donnan effect a "chemical expansion effect" caused by mutual repulsion of the fixed charges.[2] In circumstances where Donnan theory applies it already accounts for this mutual repulsion, so adding it separately would double-count its effect (McCutchen, 1992).

[1.] As noted in "NIH Fact-Finding," in 1986 Professor W. Michael Lai told me that his graduate student Adimora Uzowihe had done this impervious surface calculation and found the pore pressure against the surface to be about the same as the applied loading. Professor Lai said this finding had not been submitted for publication. I mentioned it in "Joint lubrication: Lysenko Revisited," The Kroc Memorial Lecture, Massachusetts Institute of Technology Jan. 17, 1990.

[2] Page 233 of the Mow/Huiskes book has a section labelled "Triphasic swelling theory," but the chemical expansion term is missing from section's mathematics.

But whenever Donnan theory does not apply, there must be a correction that, added to the erroneous Donnan prediction, yields the observed material properties. Is the chemical expansion effect this corection? Apparently not. In imagination, Huyghe *et al*. (2009) sent a sample with properties given by triphasic theory around a closed, Carnot-like cycle where the strain was varied at constant salt concentration in the bathing fluid, then the salt concentration was varied at constant strain and so on. A change in free energy resulted, which would violate the the second law of thermodynamics. See a reply (Mow *et al.* 2009) and a rebuttal (Huyghe *et al.* 2010).

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