# Joint Lubrication
# "Biphasic lubrication" is weeping lubrication

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In 1959 I proposed that the articular cartilage of joints provided self-pressurized hydrostatic, or weeping lubrication. The cartilage is a deformable, micro-pored sponge that weeps fluid if squeezed, as happens when it carries load. The fluid carries most of the load without friction. I showed experimentally in a model system that self-pressurized hydrostatic lubrication is not forbidden by nature, and Peter Lewis and I, mostly Peter, showed that extracellular fluid did, indeed, come out of squeezed cartilage.

Research I reported in Wear in 1962 showed that when wet cartilage was rubbed against glass the friction was at first very low, but rose as the fluid inside the cartilage became depleted, which transferred more and more of the load from fluid support to solid-solid contact. I measured the stiffness and flow permeability of cartilage, and did the mathematics of the wringing out of the cartilage under load, and of the resoaking when its rubbing surface was exposed to free fluid. The latter, a one-dimensional diffusion equation, contained a non-fatal error that was repaired by 1974.

Synovial fluid lubricated the cartilage better than water or physiological saline, but its lubricating advantage faded as time passed and more and more of the load was transferred to solid-solid contact.

At this point the dependence of joint lubrication on the physical properties of cartilage was understood. It remained to learn how synovial fluid improved the lubrication. With James Wilkins I pushed a little way into this problem, but it needed chemists, not a physicist like me.

A group at Leeds University in England under Duncan Dowson produced a rival theory, boosted lubrication, followed by other theories, and Van Mow's group at Rensselaer Polytechnic Institute produced many equations and many blunders. The latter included the mechanical pumping effect, which disobeyed the conservation of energy by a factor of one hundred million, and the self-generating mechanism, which produced no hydrostatic pressure at the rubbing surfaces.

I tried to persuade NIH, my employer, not to support Mow's work. I prepared a criticism of the mechanical pumping effect and managed to get NIH to have it reviewed by an external evaluator of its choice. The evaluator, Lyle Mokros, agreed with me that the work was erroneous, but grant money kept on flowing to Mow (such that by 2009, laden with honors and appointments, he had written over 700 papers and book chapters, almost always with co-authors), while the group that had made the most progress on synovial fluid lubrication lost its NIH support.

Weeping's rival theories took up an amazing twenty years. Then Leeds and the Mow group threw in the towel, the former all the way, the latter admitting that self-pressurization occurs, but not that fluid flows out of the surface of loaded cartilage.

Meanwhile something else had been going on. I use the term "poroelastic" to describe cartilage because it is elastic and fluid flows through its pores. Starting about 1980 the Mow group called it "biphasic" because it is comprised of solid and fluid. Nothing to argue about there, one might think. They also rederived the consolidation theory of M. A. Biot, which they already knew about, and renamed it the KLM model from their initials. With the death of boosted lubrication and the self-generating mechanism, "biphasic lubrication," provided by a biphasic material and studied with the KLM model,

was born. Only the names are new, but names are important (ask ad agencies). People who want to get ahead know which names to use.

Thus a chapter by John Fisher, of Leeds, in Modern Tribology Handbook (2001, Ed. Bharat Bhushan) has separate paragraphs labelled “Weeping Lubrication” and “Biphasic Lubrication.” In the former Fisher agrees with me that weeping flow occurs “. . . once the contact has entered the mixed regime,” i. e., once high spots on opposing surfaces touch each other. In the latter he blends reality and discipline politics in the delightful sentence, “Biphasic lubrication theories, which are consistent with the original self-pressurized concept of McCutchen, are now emerging as one of the most important mechanisms.”

This rewriting of history has consequences beyond grant-getting. People may think the different names refer to different theories, and waste time trying to find a difference.

Gerard Ateshian, of Mow’s group, recently published a review article, “The role of interstitial fluid pressurization in articular cartilage lubrication” (Journal of Biomechanics, 2009, Vol. 42, pp. 1163-1176). It does not mention the mechanical pumping effect or the self-generating mechanism.

The review properly credits me with discovering the self-pressurized hydrostatic lubrication of cartilage, but says, “Starting from the late 1970s, porous media models of cartilage were formulated which could be used to predict interstitial fluid pressurization from theory.” And, “The ability to predict the pressurization and flow of this internal fluid from theory was considerably advanced with the application of porous media theories to the analysis of cartilage mechanics, most notably, the biphasic theory for articular cartilage (Mow *et al*, 1980).”

The Mow group used porous media theory; it did not invent it.

I prepared a comment that listed what I had done and when I did it, including, "The ability to predict the pressurization and flow of this internal fluid . . . ."

My comment also explained when and which way fluid flows through the surface of cartilage, something that Ateshian’s accounts regularly obscure, and further explains that a calculation in his review is false because it is based on a false assumption. (I have no reason to doubt Ateshian’s experiments, or his mathematics per se.)

These were proper points to raise, but when I submitted the comment to the Journal of Biomechanics I received no response at all, nor were my telephone calls returned when I asked what had gone wrong. As I am 80 years old, spending years fighting with journals is not practical, so I post the comment on the Internet.

The second article arose out of a phone conversation with Ateshian, for which thanks. He believes, or did, that the bumps on cartilage are completely flattened when load is applied. I doubt this, but some flattening is inevitable, so I calculated the effect the compressibility of the bumps would have on weeping flow. The manuscript was rejected by referees at the Journal of Biomechanics, who seemed not to understand it. Rebuttal was unsuccessful. The marked alterations were made after the review.