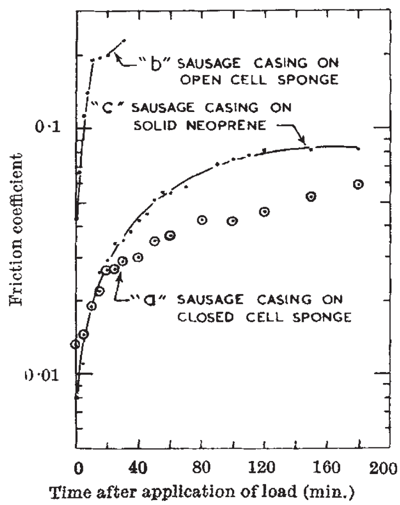

Fig. 2. Friction of various types of surface against themselves when lubricated with soapy water

using surfaces and lubricants which do not give exceptionally low friction under boundary lubrication conditions. (The animal-derived sausage casing used showed entirely ordinary friction coefficients once the excess lubricant had been wrung out.) Animals joints could operate in this way. In the following communication evidence is presented to suggest that they do.

C. W. McCutchen

Cavendish Laboratory,
Cambridge. Aug. 4.

[1] Charnley, J., *The New Scientist*, **6**, No. 138, 61 (July 9, 1959).

Experimental Evidence for Weeping Lubrication in Mammalian Joints

From existing reports[1] it is clear that the structure and mechanical properties of articular cartilage are just what are required for weeping lubrication to be possible. Its outer surface is formed by a narrow layer of flattened cartilage cells and below this is a relatively acellular zone extending for some hundreds of microns down to the calcified tissue. What cells there are in this zone are arranged in columns, well separated by wide areas of intercellular matrix, which probably has a structure orientated normal to the surface layer. Articular cartilage is easily deformed by pressure but is very resilient, being almost perfectly elastic to intermittent pressures ; and it has been suggested that this elasticity is due to exudation and re-absorption of fluid[2]. Thus articular cartilage appears to resemble a rather stiff sponge, with an internal structure which would permit easy expression of fluid up to a smooth, presumably porous, outer surface.

Structural evidence alone is inadequate ; so a few simple experiments have been made on articular surfaces from freshly opened joints of a number of mammals. Thin shavings were analysed for sodium and potassium with a flame photometer. The ratio of sodium to potassium found was of the order of 12–15 on a molar basis ; so articular cartilage must contain a very high proportion of extracellular fluid, as suggested by histological preparations. Exudation of only a small fraction of this total extracellular fluid would provide an adequate lubricating film. That the superficial layer of flattened cartilage cells is freely permeable to small molecules is easily shown by dropping aqueous solutions of dyes on to a freshly exposed surface. Dyes such as eosin, for example, rapidly penetrate to a depth of at least a hundred microns. Furthermore, if excess dye is washed off, some of that which has penetrated can be re-extracted by pressing filter paper firmly against the articular surface. The pore size in this superficial layer is probably quite small, since a graphite suspension with a particle size of rather less than 1μ did not appear to penetrate.

If an articular surface which has been well dried with filter paper is placed against a glass slide and the point of contact examined through the glass with a microscope, fluid can be seen to exude as pressure is applied. The amount of fluid exuded was estimated by placing a small piece of filter paper of known area on an articular surface and applying pressure for a brief period of time (less than a second). The sodium content of the filter paper was then measured with a flame photometer and the volume of exuded fluid calculated on the assumption that it had the same sodium content as extracellular fluid. Both dry and moist filter paper were used with substantially similar results. When the pressure applied was only sufficient to bring the filter paper into intimate contact with the cartilage, the amount of sodium collected was insignificant. As the pressure was raised, however, the amount collected increased, and for pressures in the range to be expected in normal operation of the joint the volume of fluid exuded was calculated to be sufficient to form a layer 15–35μ thick over the area of contact. Between two articulating surfaces twice as much fluid should be available, which ought to be sufficient for adequate lubrication by the mechanism suggested in the previous communication.

Weeping lubrication could equally well occur where tendons change direction (for example, the patella at the knee joint), for the cartilage surface concerned appears to have the same properties as that in the joint proper.

One possible disadvantage of weeping lubrication is the occurrence of a slow outward seepage of fluid from between the apposed surfaces, which might eventually come into contact. Joints seldom remain in a fixed position for very long when they are bearing a load. Animals which sleep standing up, for example horses, are said always to change their position at least every half an hour, and examples are quoted in the previous communication of model bearings which retain their low friction for at least this length of time. The rate of seepage would be markedly affected by the microstructure of the articular surface, but unfortunately little is known about this.

It has not proved possible to devise a crucial experiment which would prove conclusively whether or not 'weeping' lubrication is an important factor in reducing joint friction. Nevertheless, the evidence put forward here strongly suggests that all the necessary conditions are present ; so it would be strange indeed if this type of lubrication did not in fact occur.

P. R. Lewis
C. W. McCutchen

Anatomy School and
Cavendish Laboratory,
Cambridge. Aug. 11.

[1] Bauer, W., Ropes, M. W., and Waine, H., *Physiol. Rev.*, **20**, 272 (1940). Gardner, E., *Physiol. Rev.*, **30**, 127 (1950).
[2] Benninghoff, A., *Z. ges. Anat.* (Abt. 1), **76**, 43 (1925).