Lubrication of synovial membrane

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Cooke, A. F., Dowson, D., and Wright, V. (1976). *Annals of the Rheumatic Diseases*, 35, 56–59. Lubrication of synovial membrane. (1) An apparatus has been constructed to measure the coefficient of friction of synovial membrane against a glass slider. (2) Provision was made to vary the load on the specimens. (3) The coefficient of friction varied from 0.006 to 0.07. (4) A presentation similar to that used in the Sommerfeld analysis of journal bearings indicated that in these experiments synovial membrane was lubricated in the hydrodynamic regimen.

The stiffness of normal joints measured in the mid-range of motion appears to be due to various tissues—skin 2%, tendons 10%, muscle 41%, and capsule 47% (Wright, Longfield, and Dowson, 1969). Similarly, the increased stiffness of joints with osteoarthritis seems to be due mainly to changes in the capsule (Goddard and others, 1969). Some of these tissues ride over the joint on the synovial membrane and consequently lubrication of the membrane is important when considering joint function.

The only available data on the lubrication of the synovial membrane are those of Radin and others (1971), who loaded specimens of bovine synovial membrane against a moving glass slider. The coefficient of friction between the membrane and glass was independent of the speed of movement and viscosity of the lubricant. From these results the authors concluded that the synovial membrane was operating in the boundary lubrication regimen—the boundary lubricant being the hyaluronic acid present in the synovial fluid. However, the variation of friction with load was not investigated and the non-newtonian properties of synovial fluid were not taken into account.

To study this problem further a special soft-tissue friction testing machine was designed and constructed, and the results from this apparatus are presented in this paper.

Materials and methods

Specimens of synovial membrane were dissected from human cadaveric knees. From the geometry of the knee joint it is apparent that different sections of the membrane will operate under different conditions. Calculations based on the data of Smith (1972) and Morrison (1967) showed

a speed range for the synovial membrane between 0 and 450 mm/s during a normal walking cycle (Cooke, 1974). On the basis of these data, apparatus (Fig. 1) was designed with a range of operation similar to that under normal physiological conditions.

Specimens of synovial membrane were loaded against the moving glass slider (Fig. 2) in the presence of bovine synovial fluid. The early experiments indicated that the variation of frictional force with time was insignificant. The majority of experiments, therefore, were conducted with specimens under load for a short period, normally 1 minute; then the load was released for approximately 10 seconds, during which time the load was changed and the specimens were reloaded against the sliding surface. The frictional torque was measured during the motion of the slider.

Theoretical considerations

A general guide to the mode of lubrication, which is frequently used in engineering situations, is illustrated in Fig. 3. This is known as the Sommerfeld analysis. The coefficient of friction of the bearing when plotted against the variable, $\text{viscosity} \times \text{speed} \div \text{load}$, results in the general form of curve shown. This curve can be divided into three regimens—boundary, mixed, and hydrodynamic lubrication. In the hydrodynamic regimen of lubrication the two sliding surfaces are separated by a film of fluid. The coefficient of friction is dependent on the viscosity of the lubricant, the sliding speed, and the applied load. In the boundary regimen the load applied to the bearing is supported by contact between asperities on the two mating surfaces. The friction is consequently dependent on the properties of the surfaces in contact and on any boundary lubricant which may be attached to these surfaces, but is independent of the bulk properties of the lubricant. In between these two extremes there is a regimen of mixed lubrication in which the applied load is supported partially by a film of fluid and partially by surface interactions.

FIG. 1 Apparatus for measuring synovial membrane friction

FIG. 2 Details of specimen holder

Results

The results from an oscillatory experiment conducted on a specimen of synovial membrane from a 22-year-

FIG. 3 Sommerfeld analysis for different lubrication regimens

old subject, loaded against glass and lubricated with bovine synovial fluid are shown in Figs. 4 and 5. The results indicate that the coefficient of friction was dependent on the maximum speed during the oscillation rather than the frequency of the oscillation. They also show that the coefficient of friction

FIG. 4 Coefficient of friction related to reciprocal load for synovial membrane from a 22-year-old woman

FIG. 5 Coefficient of friction related to maximum speed for synovial membrane from a 22-year-old woman

FIG. 6 Sommerfeld analysis of results in Figs. 4 and 5.

increased with speed and decreased as the applied load increased.

The results obtained from the specimen of synovial membrane were plotted in a manner similar to a Sommerfeld analysis (Fig. 6)—the viscosity term being omitted, because of its shear rate dependence. The results shown in Fig. 6 when compared with Fig. 5 indicate that the synovial membrane is lubricated in the hydrodynamic regimen.

The variation of the coefficients of friction of other specimens of synovial membrane lubricated with bovine synovial fluid are shown in Fig. 7. From all the results presented, it seems that under normal physiological conditions the synovial membrane is lubricated in the hydrodynamic regimen of lubrication.

Discussion

In considering the lubrication of joints most workers have investigated the cartilage-on-cartilage situation. The capsule, lined with synovial membrane, however, forms an important part of synovial joints and capsular changes seem to account for a major part of stiffness of diseased joints, particularly in the articular gelling of osteoarthritis (Wright and others, 1969). Only Radin and others (1971) have studied the lubrication of synovial membrane. They concluded that the membrane was lubricated in the boundary regimen, although it was noted that the coefficient of friction increased when a more viscous fluid (silicone) was used as the lubricant.

The results obtained in the present study on a specially designed sensitive soft-tissue friction machine indicate that synovial membrane is lubri-

FIG. 7 Sommerfeld analysis for synovial membranes from women aged 22, 26, 49, and 70 years, from a 54-year-old man, and from bovine fetus

cated in the hydrodynamic regimen. The viscosity of synovial fluid is very dependent on the concentration and polymerization of hyaluronate in the fluid, and the hyaluronate is more likely to function in this way in a regimen of hydrodynamic lubrication than as a boundary lubricant.

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