"BOOSTED LUBRICATION" IN SYNOVIAL JOINTS BY FLUID ENTRAPMENT AND ENRICHMENT

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The manner in which a human load-bearing synovial joint is able to carry the applied loads has been the subject of speculation for many years. In the past, a number of theories have been advanced each using as a basis one of several modes of lubrication well known to mechanical engineers. More recently some of the more unique characteristics of human cartilage have been recognized, and theories have been modified accordingly.

Thus MacConaill (1932) proposed an explanation based upon a type of lubrication known to engineers as "hydrodynamic", Charnley (1960) proposed an explanation based upon "boundary lubrication", and McCutchen (1962, 1966) explored the possibilities of "weeping lubrication". In the light of further study an explanation has been proposed by Linn (1967). Davies, Barnett, Cochrane, and Palfrey (1962) and Edwards (1967) have investigated the properties of articular surfaces. Negami (1964) along with Davies (1966) has studied the rheological properties of synovial fluid. Rydell (1965) and Paul (1967) have investigated the forces which act through joints in normal circumstances.

Certainly, if an understanding is to be reached concerning the role of synovial fluid in a human load-carrying joint, the physical characteristics of the articular surfaces, in addition to those of the synovial fluid, must be taken into account.

In the present study, a number of friction experiments were designed to investigate the extent to which the various modes of lubrication were present in physiological conditions. The overall geometry of the fluid-filled gap between the mating articular surfaces has been investigated, and the microscopic surface quality of cartilage has been recorded.

On the basis of these observations, the features of normal joint lubrication are described and the factors which encourage full fluid film lubrication are listed. "Boosted lubrication", the name given to a mode of lubrication not previously described,

is suggested as an explanation for the load-carrying capability of weight-bearing synovial joints.

Theoretical Considerations

Some of the various types of lubrication which are known to mechanical engineers are shown in Fig. 1.

(1) Fluid Film Lubrication

The description implies that the two solid surfaces are separated by the lubricant at all times. The film thickness is sufficiently great to prevent any isolated asperity on one surface from touching a similar peak on the other surface. In "hydrodynamic lubrication" (Fig. 1*i*) the classical representation is that of two rigid surfaces set at an angle to each other producing a wedge-shaped gap. When one surface is caused to move tangentially relative to the other in the direction shown, the fluid which is present is drawn in to the diminishing gap by viscous forces. A pressure is generated within the fluid of a magnitude sufficient to support a transverse load.

If the working conditions become more arduous, the pressure within the fluid may rise to such an extent that elastic deformation may take place in the bounding solids. If the deformation is sufficient to alter the overall geometry to a significant degree, the description "elastohydrodynamic lubrication" is used. Softer, or more elastic, boundaries have the effect of allowing a greater volume of fluid to be drawn into the converging gap, thus resulting in an enhanced lubricant film thickness. It can be shown that the film thickness is given by an equation of the form:

$$h = C_1 \sqrt{\frac{R\eta u}{E}} \quad \dots \text{Equation 1}$$

where h is the film thickness

R is the effective radius of curvature between the two surfaces

η is the viscosity of the lubricant

u is the mean surface sliding speed

E is a measure of the elastic properties of the surfaces

C_1 is a constant

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Fig. 1.—Types of lubrication between two surfaces, loaded together

It follows, therefore, that the film thickness increases with increases in the relative radius of curvature, the viscosity, the sliding speed, and the softness of the materials. Elastohydrodynamic lubrication is represented in Fig. 1ii.

A further type of fluid film lubrication is covered by the term “squeeze film lubrication”, represented diagrammatically in Fig. 1iii. In this case, the upper solid is caused to approach the lower in a normal direction without transverse movement being necessarily present. The approaching solids tend to squeeze out the intervening fluid, but this action is strongly resisted by viscous forces. Fluid pressures are generated and in normal circumstances solid-to-solid contact does not occur until a long time has elapsed. Moore (1965) gives the equation which defines the time required for the fluid film thickness to reduce from h_0 to h . Where the contact is of a circular shape,

$$t = C_2 \frac{\eta D^4}{P} \left[\frac{1}{h^2} - \frac{1}{h_0^2} \right] \dots \text{Equation 2}$$

where t is the time
 D is the contact diameter
 P is the load
 η is the viscosity

It will be seen that the time taken is very sensitive to the diameter of the contact D and that, theoretically, the time required is infinite if the final thickness, h , is set to zero.

“Hydrostatic lubrication” occurs when a supply

of fluid is injected between a pair of opposing surfaces. An external pump is used to build up a fluid pressure sufficient to prevent contact between the surfaces. In the case of a porous material, such as articular cartilage, fluid may seep away through the matrix, thus reducing the load-carrying capacity for a given supply of lubricant.

(2) Boundary Lubrication

It has been found that certain substances, when added in small proportions to the lubricating fluid, migrate to the solid boundaries and form protective layers on the surfaces. In many cases, an additive concentration of only 1 per cent. is sufficient to provide a tenacious coating. It is believed that the long chain molecules of the additive become attached at one end to the surfaces in the manner shown in Fig. 1v. In this way, intimate contact between the rubbing surfaces may often be prevented, thus minimising the possibility of damage. It is worthy of note that the proportion of hyaluronic acid—protein complex in synovial fluid is much greater than the proportion of additive normally used in engineering applications.

(3) Wear

Three types of wear have been identified in situations where components are rubbed together while under load:

“Adhesive wear” takes place when direct contact occurs between asperities. If the strength of the

junction is greater than that of the underlying material, a fragment will be removed from one surface and adhere to the other. Such a fragment may well become detached at a later stage to become a free particle of wear debris. This type of wear is particularly likely to take place when the rubbing components are metallic.

"Abrasive wear" may occur in two different ways. If one of the surfaces is significantly harder than the other, particles may be scraped or ploughed off the softer surfaces by the harder surface. Alternatively, the presence of loose hard particles in the space between the surfaces may result in a scouring action.

"Fatigue wear" occurs when a material is repeatedly loaded and unloaded. Repetitions of a stress cycle may result in material failure at stress levels well below those required under static loading. Certainly, this type of loading is present in human hip and knee joints.

Material and Methods

The characteristics of surfaces used in engineering applications are commonly assessed with the aid of a stylus instrument. A very lightly loaded diamond having a tip radius of 0.0001 in. is drawn across the surface under inspection. An electrical signal representing the undulations of the surface is amplified and may be displayed on graph paper using appropriate scales. While in many engineering cases it is possible to work directly with the surface under scrutiny, in the present investigation castings of the articular surfaces were made with an acrylic material. Subsidiary tests were made to confirm that the acrylic casting reproduced the true

profile of the articular cartilage to a sufficient accuracy. Castings were taken of cartilage surfaces of hips and knees immediately after opening the joints at autopsy. Before pouring the casting material on to the cartilage, the surface was cleaned with tissue moistened with saline. Typical results are shown in Fig. 2.

In order to determine the geometry of the cavity between the acetabulum and the femoral head, the joint was exposed. The casting material was then poured in and the joint was returned to a natural position. The hardened cast was removed after about 30 minutes.

Friction experiments were carried out using a modified sledge microtome (Fig. 3, opposite). Essentially, the specimen was held at the end of a pivoted arm and loaded against a reciprocating flat glass plate. The maximum speed of the reciprocating glass plate could be varied between 0.3 and 4 in. per sec., and the load from zero to 8 lb. The pivoted arm was supported in a "frictionless" air bearing, the extreme end being restrained by a load transducer which recorded the force of friction acting on the specimen.

Geometry

A. Surface Quality

Fig. 2 shows stylus tracings taken from acrylic castings of subjects ranging from an 8-month foetus to a 57-year-old man. On each trace a straight centre line has been drawn. The graphs have been drawn to scales of $\times 1,000$ and $\times 100$ in the vertical and horizontal directions respectively for convenience in reproduction. A frequently-used measure of the magnitude of the undulations on surfaces is the "centre line average" (c.l.a.). The c.l.a. value for a surface is an indication of the average height

Fig. 2.—Typical Talysurf traces taken from acrylic castings of cartilage.

Fig. 3.—Reciprocating friction machine.

of the peaks or depths of the valleys from the geometrical centre line of the profile. The c.l.a. value is almost always found electrically from the stylus signal. It is to be expected that an average peak-to-valley height will be two or three times greater than the c.l.a. value for the surface. The c.l.a. value for engineering bearing surfaces lies normally in the range 5 to 15 μ in. The c.l.a. value of the articular surfaces ranged from a minimum of about 30 μ in. to more than 200 μ in. for cases showing evidence of chondromalacia or osteoarthritis. Specimens from younger subjects displayed an undulating surface of wavelength about 0.001 in. with a c.l.a. of about 30 μ in. With advancing age, the wavelength of the undulations increased up to about 0.01 in., superimposed upon which were smaller scale roughnesses.

B. Overall Geometry

So far as lubrication is concerned, it is not realistic to consider the curvatures of the acetabulum or the femoral head separately. It is rather the geometry of the gap between the two opposing surfaces which influences the action of the joint. The determination of the geometry of the gap rather than that of the solids led to a measure of the nominal contact area. The acrylic castings taken from the cavities between articular surfaces in the hip and knee were measured at a number of points to determine the local thickness. Contour maps were then drawn to indicate the variation in surface-to-surface distance.

The load-bearing area of normal hip joints was observed to be of a horse-shoe shape disposed near the periphery of the acetabulum. In the centre of the joint, between the top of the femoral head and the acetabulum, there was a cavity of average width 0.02 in. under conditions of no load. Assuming that no gross distortion takes place when body weight is applied to the joint, it was concluded that when standing or walking the area of close contact will be about 0.75 sq. in. Consequently the nominal contact pressure may be expected to rise to about 450 lb./sq. in.

The corresponding figures for the knee joint were harder to assess because of the double contact at the two condyles. A further difficulty arose because the opposing surfaces conform less closely than those of the hip. Consequently the synovial fluid will be squeezed out more easily and the area of contact may be more dependant on the duration of loading. With these reservations, a typical total contact area was observed to be about 0.3 sq. in. with a maximum pressure of about 900 lb./sq. in.

These estimations of the contact pressures were used to determine the test conditions in the friction experiments.

Frictional Characteristics

A. Boundary Lubrication

The first experiments were carried out to determine the coefficient of friction between cartilage and glass under conditions which could reasonably be described as boundary lubrication. The test specimens were discs of cartilage cut from human femoral condyles. The discs were thick enough to include a substantial amount of the bony structure below the surface. The nominal surface area at the end of the cylindrical specimen was 0.02 sq. in. Synovial fluid, usually taken from the same joint as the cartilage, was used as the lubricant and was applied liberally to the glass plate at the start of a test. The reciprocating glass plate was set in motion with a maximum cycle speed of 1 in./sec. and a load of 8 lb. was applied. Under this compressive load, the fluid within the pores of the cartilage was gradually squeezed out over a period of about 30 min. Values of the friction force were then measured for a range of loads, allowing 10 min. at each stage for conditions to stabilize. The falling curve shown in Fig. 4 is plotted through a number of points corresponding to the different loads. It will be observed that the coefficient of friction diminished as the load was increased. Further tests up to a pressure of 1,000 lb./sq. in. yielded coefficients of friction in the region of 0.1. When the test was repeated for a specimen saturated with synovial fluid, the coeffi-

cient of friction was observed to have a value of about 0.01.

The rising curves of Fig. 4 show the variation in the frictional shear stress with the nominal contact pressure for four specimens of cartilage taken from different subjects. In all cases, the frictional shear stress rose fairly steeply to a point where the nominal contact pressure reached about 150 lb./sq. in. Thereafter, the frictional shear stresses tended towards a constant value of about 60 lb./sq. in.

These results may be used to draw conclusions concerning the *real* area of contact as opposed to the *nominal* area. The theory of elasticity predicts that if an elastic body possessing a number of spherical asperities on the surface is pressed on to a flat rigid plate, then the real area of contact is proportional to $(\text{load})^n$, where n is a number lying between $2/3$ and 1 (Archard, 1957). It will now be assumed that the ultimate shear strength of the surface film in boundary lubrication conditions remains constant. In this event, the friction force is also proportional to $(\text{load})^n$ while the asperities are being flattened under increasing load. After the point when the asperities have been compressed out of existence, intimate contact between the elastic solid and the rigid plate takes place over the whole area of nominal contact. Thereafter, the friction force is insensitive to further load increases.

Examination of the rising curves shown in Fig. 4 suggests that the cartilage behaved elastically up to a nominal contact pressure of about 150 lb./sq. in. Beyond that pressure, the area of real contact approximated to that of nominal contact. A value in the region of 60 lb./sq. in. is seen to be the ultimate frictional shear stress when boundary lubrication occurred between cartilage and glass.

Tests conducted with diseased cartilage yielded results which did not differ significantly from those of healthy cartilage. It is presumed that the synovial fluid provided similar boundary lubrication.

Similar tests carried out with rubber specimens of the same geometry gave values for the ultimate shear stress greater than those for cartilage by about 30 per cent. It was concluded that synovial fluid was acting as a boundary lubricant for rubber on glass.

(B) Fluid Film Lubrication

Further experiments were carried out in order to detect whether or not a fluid film could be generated between cartilage and glass. A "converging wedge contact" was made from a portion of femoral condyle of one inch radius of curvature. The specimen was loaded and held against the reciprocating glass plate until the friction force had reached a constant

Fig. 4.—Boundary lubrication. The specimens of cartilage came from human femoral condyles, lubricated with synovial fluid, sliding on glass, reciprocating motion with maximum speed 1 in./sec.

value. At this stage, as in previous tests, it was assumed that most of the fluid contained in the pores of the cartilage had been squeezed out. The force of friction was then observed as the speed was increased for various loads. In all cases the friction force diminished as the speed was increased, indicating the presence of at least some hydrodynamic load carrying capability.

Subsequently, the specimen was trimmed with a scalpel to form a flat-ended contact face which was essentially parallel to the glass plate. The measured friction forces were found to be three or four times greater than those occurring when a wedge profile was present. Under these circumstances it was concluded that parallel contact surfaces could not generate a full fluid film.

(C) Squeeze Films

Specimens of cartilage affixed to bone were cut from femoral condyles and the cartilage cut away leaving an area of 0.02 sq. in. The specimen was positioned in the reciprocating friction machine and the cartilage lowered on to a pool of synovial fluid so that complete soaking and adsorption occurred.

When the specimen was now loaded against the reciprocating plate and friction plotted against time, the frictional force rose steadily until a limit was reached when the maximum amount of fluid had been wrung out from the cartilage at that load. In these experiments, the value of friction at any stage during the wringing out process was called the "boundary value" of friction at that stage of wringing out.

To obtain squeeze film results at any stage, the cartilage specimen was lifted clear of the glass plate

to allow synovial fluid to enter the space between the surfaces, friction readings being recorded.

After a short run with the cartilage fully saturated, the friction reading was taken to be the first "boundary value". The cartilage was momentarily lifted from the plate and the motion of the plate continued until the friction values became greater than the first "boundary value". The friction force reached was called the second "boundary value".

Another squeeze film test was done, reaching and exceeding the second boundary value, as before. The experiment proceeded in this way until the limiting friction force at full wring-out was reached. Squeeze film curves for healthy cartilage from a 26 year old subject are shown in Fig. 5. The most striking feature of the results is the large squeeze film times.

It is of great interest to estimate the average operating viscosity of the synovial fluid, using the standard Reynolds equation for parallel sinkage, an iso-viscous incompressible fluid and a circular contact (Equation 2 in Theoretical Considerations). A typical time of 40 sec. is substituted. The minimum film thickness can be estimated by considering that the surfaces are separated only by hyaluronic acid-protein complexes, which under load can be expected to give a separation of about $10\text{ }\mu\text{in.}$ The average viscosity works out to be about 20 poises, which is very large indeed, and many times greater than any value which has been measured for synovial fluid rheologically. This result suggests that a very viscous substance has formed on the cartilage surface during the squeezing process. For comparison, experiments were carried out with various rubbers and it was found that the squeeze film times were consistently about 0.5 sec., compared with the values of up to 100 sec. for cartilage. The same result was obtained when a rubber replica was made of cartilage surface. The average viscosity of the synovial fluid works out to be about 0.2 poise, which is an average figure from rheological measurements.

It is concluded that the surface of the cartilage plays an essential part in prolonging the squeezing out of fluid from between the surfaces.

The magnitude of the squeeze film times for actual joints are considered in relation to the results of the experiments. In the hip joint, if the contact area is 1 in 2 and the load 200 lb., the squeeze film time should be at least twenty times the experimental ones. It is hard to make a similar estimate for the knee because of the uncertainty of the area of contact, but it seems that squeeze film times will be at least as great as the experimental ones so that boundary lubrication will be prevented during walking.

Fig. 5.—Squeeze film times to reach boundary lubrication conditions at stages during "wring-out", for cartilage with synovial fluid on glass. The dark spots are at the values of boundary frictional shear stress. The times marked on the curves are those at the full load of 400 lbf/in².

For specimens of diseased cartilage, the squeeze film times at full wring-out were similar to those for healthy cartilage, but at low wring-out they were much less. The reason for this is probably because the fluid was able to escape easily through the large surface roughnesses during the squeeze film process, so that boundary lubrication could much more easily occur.

Discussion

Lubrication Mechanism

Little attention has been paid in the literature to the fundamental geometry of joint surfaces. Nevertheless the effective radius of curvature is well known to be an important feature in the operation of mechanical bearings. Profile recordings taken from acrylic castings of joints have shown that articular surfaces are extremely rough compared with bearing surfaces used in normal engineering practice. In general terms, the smoother articular surfaces were found to be from 3 to 15 times more rough than an engineering bearing surface. Osteoarthrotic cartilage was observed to be between 20 and 200 times as rough.

Synovial fluid has been described as a dialysate of blood plasma, with the addition of a mucopolysaccharide, hyaluronic acid, most of which is bound to protein. Ogston and Stanier (1951) have suggested that the resulting molecules, when suspended in a liquid, are spherical in shape and have a diameter

of about 20 $\mu\text{in.}$ or 0.5 $\mu.$ Consequently, if the fluid film thickness between cartilage surfaces falls below about 40 $\mu\text{in.}$, these large molecules can be expected to influence the sliding behaviour and, perhaps, to act as a boundary lubricant. The present experiments suggest that a substantial measure of boundary lubrication action will only occur if the opposing cartilage surfaces are loaded together sufficiently long for the fluid to be squeezed out of the pores. It has been observed that this situation will seldom develop in healthy joints. Nevertheless it appears to be probable that boundary lubrication will always be present to protect to some extent the highest peaks of the cartilage surface.

The experimental results support the deductions made by Dowson (1967), that elastohydrodynamic action is unlikely to occur in the knee or hip joints during the weight-bearing phase in walking. On the other hand, during periods of sliding under low load, as in an unloaded swing of the leg, a substantial fluid film is likely to be generated between the surfaces. The fluid present between the cartilages would then act as a squeeze film during subsequent application of load. Indeed the squeeze film experiments provide very strong evidence that this type of fluid film lubrication is the predominant means by which joint surfaces are lubricated.

The possibility that, under pressure, a gel formed of concentrated synovial fluid collects on the cartilage surface has been suggested by Maroudas (1967). The present experiments provide data to substantiate this interpretation and it is further supported by studies of the cartilage surface and synovial fluid with a scanning electron microscope (Walker, Sikorski, Dowson, Longfield, and Wright, 1968). When two cartilage surfaces (Fig. 2) are placed in close proximity, contact will take place between the peaks and the opposite surface. As the surfaces are pressed together under load, the area of contact will increase, and further peaks of lesser height will touch the opposite surface. Over the whole area of nominal contact, many such peaks will make contact as the load is increased. Alternatively, it can be said that the nominal contact area is sufficiently large to contain a large number of substantial depressions in the cartilage surface. This implies that there will be trapped pools of synovial fluid as illustrated in Fig. 6 (opposite). It is suggested that these pools will develop a high concentration of hyaluronic acid-protein complex because of the diffusion of water and low molecular weight substances through the cartilage pores and from the edges of the contact area.

It will be seen that the cartilage surfaces will be more effectively preserved when there is a film of

thick or viscous fluid between them. The opposing joint surfaces, particularly in the hip, are sufficiently congruent to form large areas of nominal contact. This geometry results in very long squeeze film times. Since the cartilage has pronounced undulations on the surface, trapped pools of fluid are formed which take a significant time to leak away. This explanation of the action of a weight-bearing joint, depending on the formation of trapped pools of synovial fluid, has been termed "boosted lubrication".

Wearing of Cartilage

It has been concluded that the cartilage surfaces of normally functioning joints do not suffer damage because they are separated by a fluid film. It is suggested that the occurrence of boundary lubrication is an important factor in producing surface damage because it imposes relatively high shear forces along the surfaces. Meyer (1931) has observed that small flaps or strips were lifted from the surface of the cartilage. Zarek and Edwards (1963) showed that, even in normal use, tensile stresses are set up along the surface because of cartilage deformation. The addition of a shear stress of magnitude approximately 60 lb./sq. in. may well be sufficient to rupture the surface.

Boundary lubrication of the whole or part of the nominal contact area might occur in several different ways. If a joint remains statically loaded for a considerable time and then is caused to move suddenly, boundary lubrication may occur. Goodfellow and Bullough (1967) have shown that those areas of cartilage which are not normally load-bearing become gradually softer and the structure becomes open or "feathery" as in chondromalacia. If such a surface is used for load-bearing purposes, boundary lubrication is likely to occur with subsequent wear.

Boundary lubrication may also occur in the hip when the muscular forces which push the femoral head into the acetabulum are weakened for any reason. There will then be a tendency for the femoral head to "ride on the rim", imposing greater contact pressures. If this is accompanied by smaller overall contact areas, then the squeeze film times will be reduced significantly.

The success of osteotomies may be due, at least in part, to the restoration of larger contact areas by reseating the femoral head in the acetabulum with a return once more to a squeeze film type of lubrication rather than boundary lubrication.

Summary

The overall geometry of the articular surfaces of the hip and knee joints has been determined by

Fig. 6.—Pictorial representation of the lubrication of cartilage with synovial fluid.

acrylic castings. A stylus instrument tracing has determined the surface quality of the cartilage and shown that normal joint surfaces are three to fifteen times as rough as normal engineering bearings, while osteo-arthrosic joints are twenty to two hundred times as rough.

Contour maps of the load-bearing area show that in the hip this is horseshoe-shaped, disposed near the

periphery of the acetabulum. It has been deduced that the contact pressure will rise to maximum values of 450 lb./sq. in. in the hip and 900 lb./sq. in. in the knee.

A reciprocating friction machine has been designed and used to study different modes of lubrication of cartilage on glass. It has been shown that under conditions of boundary lubrication the coefficient of friction falls as load increases and that at 1,000 lb./sq. in. load it is in the region of 0.1. Under boundary conditions, a value of about 60 lb./sq. in. is the ultimate frictional shear stress. Synovial fluid also acted as a boundary lubricant for rubber on glass.

A converging wedge contact produced fluid film lubrication between cartilage and glass. During a period of sliding under low load, such as the swing phase of a leg, a substantial fluid film is likely to be generated in the joint.

Large squeeze film times were obtained experimentally. By substituting these values in the standard Reynold's equation, very high values for the viscosity of synovial fluid were obtained. It is suggested that this occurs by fluid entrapment between irregularities of the cartilage surface, the squeezing of water through the small pores of the cartilage, and the production of concentrated synovial fluid on the cartilage surface. It is proposed that this action is important in the load-bearing phase of joint action, and the mechanism of fluid entrapment and enrichment has been termed "boosted lubrication".

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"Lubrication de renfort" des articulations synoviales par emprisonnement et enrichissement du liquide

RÉSUMÉ

On a déterminé la géométrie complète des surfaces articulaires de la hanche et du genou à l'aide des moulages acryliques. Un tracé obtenu par un instrument pourvu d'une pointe fine de diamant a permis l'évaluation de la surface du cartilage. On a observé que la surface du cartilage normal est trois à quinze fois plus rugueuse que celle des billes pour roulement et dans l'osteoarthrose cette rugosité est 20 à 200 fois plus accentuée.

Un tracé du contour de la surface d'appui montre que dans la hanche elle est en fer de cheval et qu'elle est située vers la périphérie de l'acétabulum. On a calculé que la pression de contact peut atteindre un maximum de 31,5 kg. par cm² dans la hanche et 63 kg. par cm² dans le genou.

On a construit une machine à mouvement alternatif pour étudier la friction du cartilage contre le verre sous différents modes de lubrification. Dans les conditions de lubrification limitrophe le coefficient de friction tombe à mesure que la charge augmente et se trouve dans la région de 0,1 avec une charge de 70 kg./cm². Dans les mêmes conditions, 4,2 kg./cm² constituant la dernière limite de cisaillement frictionnel. Le liquide synovial fonctionnait aussi comme lubrifiant pour la friction du caoutchouc contre le verre.

Un contact par coin convergent produisait une couche lubrifiante liquide entre le cartilage et le verre. Pendant le glissement sous un poids bas, par exemple lors de l'oscillation de la jambe, une couche appréciable peut être engendrée dans l'articulation.

On a étudié expérimentalement le temps nécessaire pour exprimer du cartilage le liquide synovial par friction et on a trouvé ce temps très long. En introduisant les valeurs ainsi obtenues dans l'équation de Reynold on a observé que les chiffres pour la viscosité du liquide synovial étaient très élevés. On suggère que cela se produit parce que le liquide se trouve emprisonné entre les irrégularités de la surface cartilagineuse, l'eau est exprimée par les petits pores du cartilage laissant à la surface un liquide synovial concentré. On énonce la proposition que cette action est importante lorsque l'articulation en mouvement supporte une charge et à ce mécanisme d'emprisonnement et d'enrichissement du liquide on donne le nom de "boosted lubrication" ("lubrication de renfort").

"Lubricación de refuerzo" en las articulaciones sinoviales por encarcelación y enriquecimiento del líquido

SUMARIO

Se estableció la geometría completa de las superficies articulares de la cadera y de la rodilla con la ayuda de moldes acrílicos. Un trazado obtenido con un instrumento provisto de una puntilla de diamante permitió la valoración de la calidad de la superficie del cartilago. Se observó que la superficie del cartilago normal es tres a quince veces más áspera que la de una bola metálica industrial; en la osteoartritis esta asperidad es 20 a 200 veces mayor.

Un trazado del contorno de la superficie de apoyo en la cadera muestra que este contorno reviste la forma de herradura y que está situado en la periferia del acetábulo. Fué estimado que la presión de contacto puede alcanzar un máximo de 31,5 kg. por cm² en la cadera y 63 kg. por cm² en la rodilla.

Se ha construido una máquina de movimiento alternativo para estudiar la fricción del cartilago contra el vidrio bajo diferentes condiciones de lubricación. En las condiciones de lubricación limitrofe el coeficiente de fricción baja cuando la carga aumenta. Con una carga de 70 kg./cm² este coeficiente se halla en la región de 0,1. En las mismas condiciones, una carga de 4,2 kg./cm² constituía el último límite del esfuerzo cortante friccional. El líquido sinovial actuó también como lubricante en la fricción del caucho contra el vidrio.

Un contacto en forma de cuña convergente producía una tela lubricante líquida entre el cartilago y el vidrio. Durante una acción de deslizamiento, con una carga baja, por ejemplo cuando la pierna oscila, una tela apreciable puede formarse en la articulación.

Se estudió experimentalmente el tiempo necesario para exprimir del cartilago, por movimiento de fricción, el líquido sinovial y se halló este tiempo muy largo. Se sustituyeron los datos así obtenidos en la ecuación de Reynold y se hallaron muy altas cifras para la viscosidad del líquido sinovial. Se sugiere que estos fenómenos ocurren porque el líquido se ve encerrado entre las irregularidades de la superficie cartilaginosa, el agua exprimida por los pequeños poros del cartilago, dejando en la superficie un líquido sinovial muy concentrado. Se enuncia la proposición de que esta acción es importante cuando una articulación móvil lleva una carga; a este mecanismo de encarcelación y de enriquecimiento del líquido se da el nombre de "boosted lubrication" ("lubricación de refuerzo").