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An Electrohydrodynamic Lubrication of Synovial Lubricant on Human Body

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ABSTRACT

A living and non-living material bodies exhibit several arthritis problems, friction etc. So one can control the friction by hydrodynamic principle. Simply lubrication method by just pouring good lubricant wherever over rubbing or by moving relative links or parts. This paper deals with solution to the above problem is usually lubricant, lubricator and lubrication method. Also further study is carried over non-living material example is on heavy duty plants driers for journal bearings. Synovial acts as lubricant for living body. The synovial fluid exhibits a non-Newtonian pseudo plastic behavior.

Keyword: Methods of lubrication, human skeleton synovial joints, FEA

I. INTRODUCTION

The skeleton makes up almost one-fifth of a healthy body's weight. This flexible inner framework supports all other parts and tissues, which would collapse without skeletal reinforcement. It also protects certain organs, such as the delicate brain inside the skull. Bones are reservoirs of important minerals, especially calcium, and also make new cells for the blood.About one person in 20 has an extra rib. Bone is an active tissue, and even though it is about 22 per cent water, it has an extremely strong yet lightweight and flexible structure. A similar frame made of high-technology composite materials could not match the skeleton's weight, strength, and durability. It's as strong as steel but light as aluminum. It can repair itself if damaged and can remodel its bones to thicken and strengthen them in areas of extra stress, when persons do extreme sports. The brain is surrounded by bones that form part of the skull. The heart and lungs are located within the thoracic cavity, and the vertebral column provides structure and protection for the spinal cord.Nowadays many people su_er of osteoarthritis, a joint disease caused by several factors, such as aging, trauma or intense sport activities. The disturbance increases when the joint surfaces slide excessively on each other, causing cartilage deterioration and, consequently, direct contact between the bones, which could produce deformation, wear and pain.

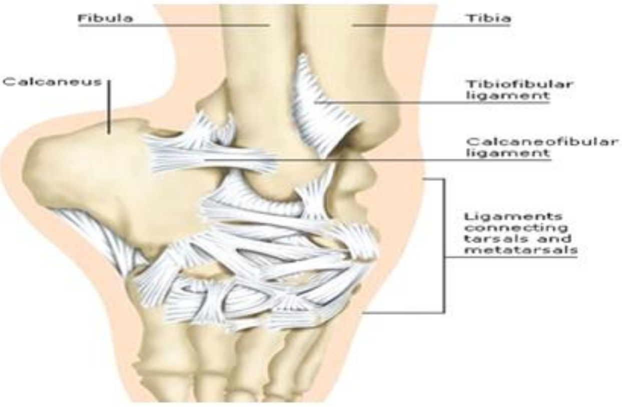
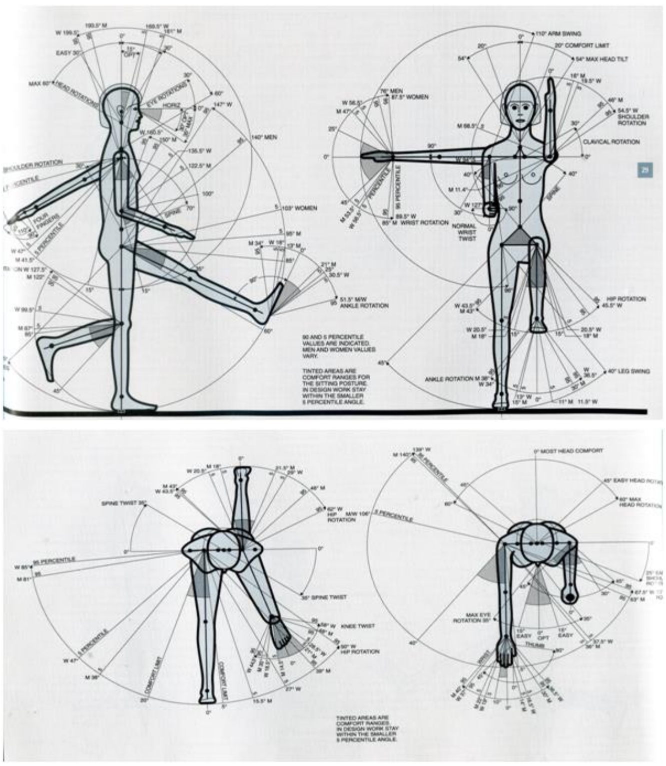
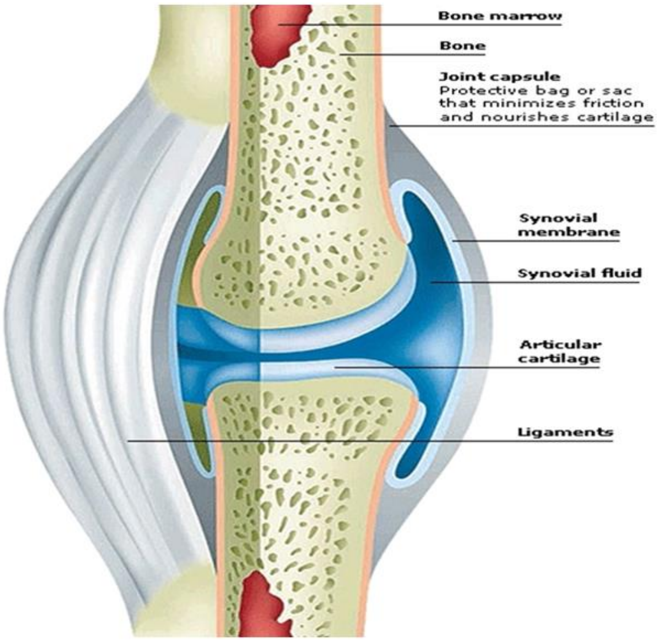


Fig. synovial membrane movement

Fig. synovial membrane movement with cartilage

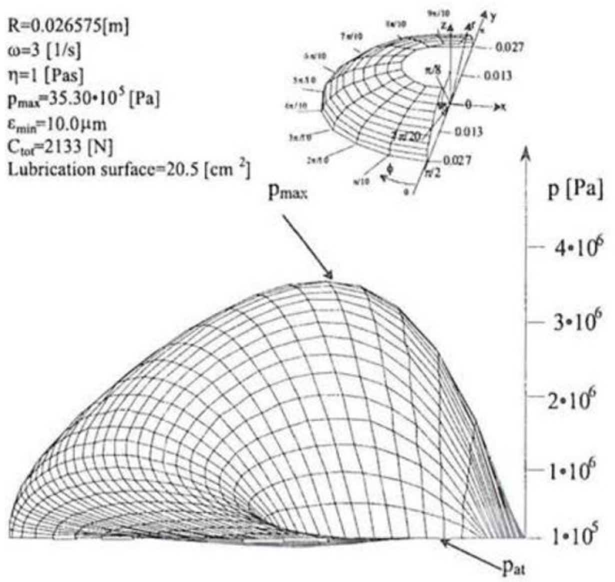


Synovial joints are enclosed by a protective outer covering –the joint capsule.The capsule’s inner lining, called the synovial membrane, produces slippery, oil-like synovial fluid that keeps the joint well lubricated so that the joint surfaces in contact slide with minimal friction and wear.There are around 230 synovial joints in the body.

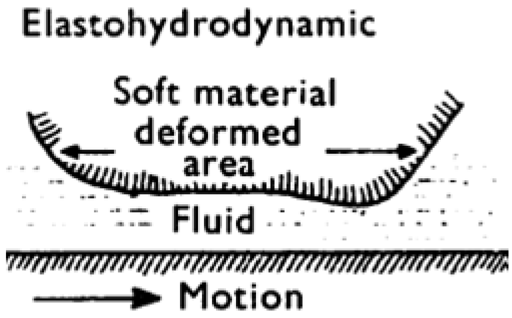


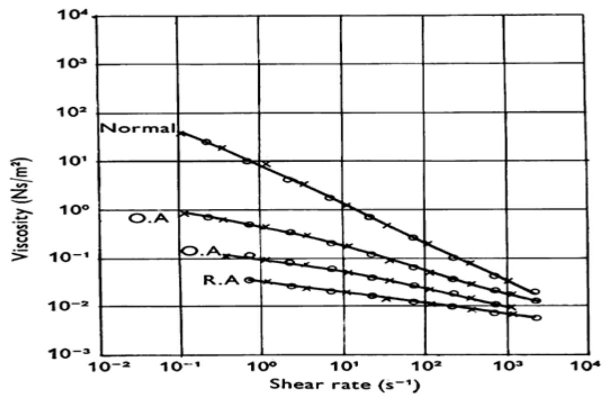
Problem definition: To present the mathematical estimation of the terms of basic partialdifferential non-linear equations of second order, for the fluid flow in t he thinjoint gap between two bone surfaces for various geometry.

2.2 To formulate the theorems which describe the unification and the analyticalmethod of solution of partial differential non-linear equations for axialsymmetrical andunsymmetrical flow of synovial fluid in human joint gap.



Elastohydrodynamic lubrication- In the elastohydrodynamic lubrication model the protection fluid film is maintained at an appropriate thickness by the elastic deformation of the articular surfaces. Elastohydrodynamic lubrication is a hydrodynamic process in which fluid film pressure causes elastic deformation of the Synovial Joints and Lubrication mechanisms 33 bearing surfaces which in turn modify the pressure in the film region. In other words, the elastic cartilage deforms slightly to maintain an adequate layer of fluid between the opposing joint surfaces. The elastohydrodynamic action can maintain a fluid film under conditions of heavy loading. The fluid film thickness is in the range 10-5 to 10-4 cm. In general, the elastic distortion provides a greater geometrical conformity than normally exists in the contact region, and this, in turn, provides a much thicker lubricating film for a given load. Furthermore, this high pressure may cause a substantial increase in lubricant viscosity. This viscosity effect further increases the thickness of the lubricating film [6]. The minimum film thickness is a function of the same parameters as in hydrodynamic lubrication with the addition of the effective elastic modulus [2].





Synovial fluid is non-Newtonian in that its viscosity decreases with increasedshear rate (Davies & Palfrey, 1969; Vos & Theyse, 1969). The viscosity-shear raterelationships of normal and disease synovial fluid are shown in Figure 4.

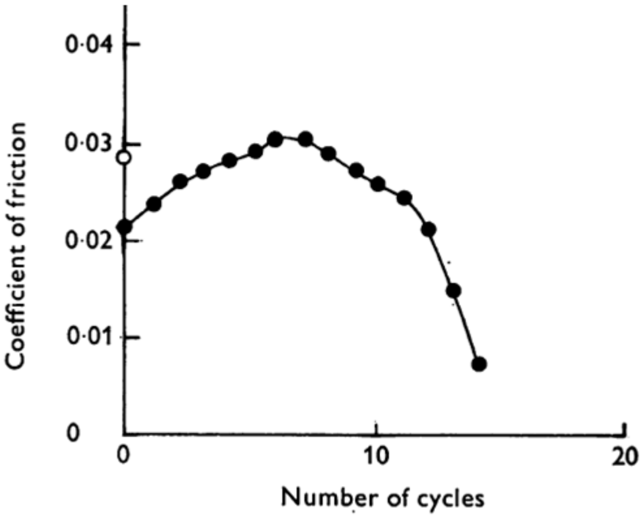


Fig. 6. Hip joint lubricated with synovial fluid – suddenly applied loads (213 N).

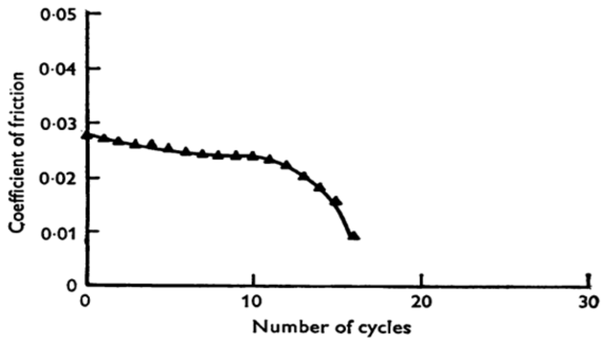


Fig. 7. Hip joint lubricated with synovial fluid – static (continuously) loaded (800 N).

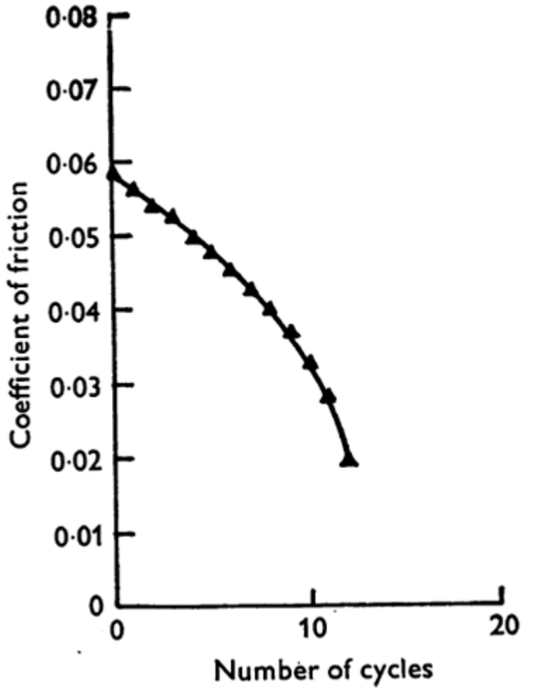


Fig. 9. Hip joint dry – static (continuously) applied loads (800 N).

There is evidence to believe, therefore, that a variety of types of lubricationoperate in human synovial joints (Fig. 10). At heel-strike a squeeze film situationmay develop, leading to elastohydrodynamic lubrication and possibly both squeezefilm and boundary lubrication, while hydrodynamic lubrication may operate duringthe free swing phase of walking.

Test Fluids

A total of 18 OA patient samples were aspirated prior to implantation of primarytotal knee arthroplasty (OA, N = 18). In addition, 18 fluid samples were aspirated frompatients before they underwent a revision surgery of a total knee arthroplasty (Rev SF,N = 18). All human samples were obtained at the Department of Orthopaedic Surgeryat the Magdeburg University Hospital after given written consent. Institutional reviewboard (IRB) approval for the study was provided by the local Ethical Committee of theOtto-von-Guericke University Medical School, Magdeburg, prior to commencement ofthe study (IRB No. 25_17). All SF samples were stored at □80 _C after aspiration untilfurther use.Hip simulator test fluid (serum) was prepared according to ISO 14243-1:2014 by dilutingcalf serum (BioWest, Nuaillé, France) to a protein concentration of 20 g/L, adding 10 mL/Lgentamycin, 250 _g/mL amphotericin B (both p.a. Biochrom GmbH, Berlin, Germany),and 20 mM/L EDTA (Carl Roth GmbH, Karlsruhe, Germany) [5]. The used lot number ofcalf serum was used for hip implant tests before and generated reasonable wear rates.In order to determine an applicable model to mimic the properties of human SF,components and compositions of synthetic SF were varied. The protein composition wasmodified for pure bovine serum albumin (BSA Fraktion V, AppliChem GmbH, Darmstadt,Germany) and calf serum (BioWest, Nuaillé, France) in different concentrations from 10 to40 g/L. In addition, the HA concentration (molecular weight 1.7 _ 106 Da, Euro OCTPharma GmbH, Bönen, Germany) was varied from 0.25 to 6 g/L. The influence of saltswas investigated by balancing either with Ringer solution (composition: 8.6 g/L sodiumchloride, 0.3 g/L potassium chloride, and 0.33 g/L calcium chloride, Fresenius Kabi AG,Bad Homburg, Germany) or with deionized water (B. Braun Melsungen AG, Melsungen,Germany). Four milliliters of each fluid sample was generated, and 44 different sampleswere tested (see Table A1). All test fluids were prepared in sterile conditions and stored at□80 _C until they were used for measurements.

Chemical Composition SF

Total Protein Concentration of SF

Hyaluronic Acid Concentration in SF

rotational rheometer

a rotational rheometer (MCR 502, Anton Paar, Graz, Austria) with a parallel platesystem was used with a 0.2 mm gap at 30 °C to determine the rheological properties ofseven OA and seven Rev SF test fluids. A minimum aspired volume of 7 mL determinedthe selection of the 14 fluid samples from the total study group (N = 36). The top plate(radius 25 mm, V4A) rotated on the fixed lower part. The viscosity was calculated from the measured torque. The shear rate dependence of the viscosity was measured under a logarithmic shear rate increase from 0.001 to 1000 s−1 over 500 s (Figure 1A). The retention time of one measuring point was one second. After a rest time of 5 min, each sample was measured in triplicate

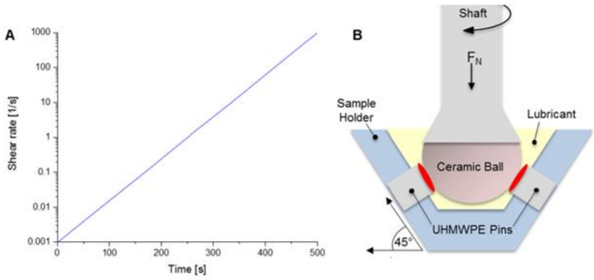


Figure 1. Details on the performed rheological and friction tests. (**A**) Measurement protocol for the flow behavior of the tested fluids with linear shear rate increase. (**B**) Ball-on-three plates test setup for friction tests with the hard/soft pairing of ceramic against UHMWPE.

II. THERAPIES FOR ARTHRITIS

1. Enema therapy

A) Ozone enema
B) Bowel stimulating enema
C) Disposable enema
D) Barium enema
E) Rectal corticosteroids
F) Alcohol enema
G) Pre-delivery enema
H) Tobacco smoke enema
I) Coffee enema

2. Gel therapy

A) Hydro gel therapy
B) Organo gel therapy
C) Xerogel therapy
D) Aero gel therapy

1. Currently used as scaffolds in tissue engineering. When used as scaffolds, hydrogels may contain human cells to repair tissue.
2. Hydro gel-coated wells have been used for cell culture.
3. Environmentally sensitive hydrogels which are also known as 'Smart Gels' or 'Intelligent Gels'. These hydrogels have the ability to sense changes in pH, temperature, or the concentration of metabolite and release their load as result of such a change.
4. As sustained-release drug delivery systems.
5. Provide absorption, desloughing and debriding of necrotic and fibrotic tissue.
6. Hydrogels that are responsive to specific molecules, such as glucose or antigens, can be used as biosensors.
7. Used in disposable diapers where they absorb urine, or in sanitary napkins
8. Contact lenses (silicone hydrogels, polyacrylamides, polymacon)
9. EEG and ECG medical electrodes using hydrogels composed of cross-linked polymers (polyethylene oxide, polyAMPS and polyvinylpyrrolidone)
10. Water gel explosives
11. Rectal drug delivery and diagnosis
12. Encapsulation of quantum dots, breast implants and in glue.
13. Now used in granules for holding soil moisture in arid areas. Dressings for healing of burn or other hard-to-heal wounds. Wound gels are excellent for helping to create or maintain a moist environment.
14. Reservoirs in topical drug delivery particularly for ionic drugs, delivered by iontophoresis.

15. For nucleus pulposus replacement, cartilage replacement, and synthetic tissue models.

16. In fiber optics communications, a soft gel resembling "hair gel" in viscosity is used to fill the plastic tubes containing the fibers.

These have common ingredients e.g. polyvinyl alcohol, sodium polyacrylate, acrylatepolymers and copolymers with an abundance of hydrophilic groups and natural hydrogelmaterials are being investigated for tissue engineering; these materials include agarose,methylcellulose, hyaluronan, and other naturally derived polymers. motor oil, friction modifier, friction additive, gel, silicons, flourocarbons, ect. Greases,Oils.Penetrating Lubricants,Dry Lubricants.A good lubricant generally possesses the following characteristics:A high boiling point and low freezing point (in order to stay liquid within a wide range of temperature),A high viscosity index,Thermal stability,Hydraulic stability,Demulsibility,Corrosion prevention,A high resistance to oxidation

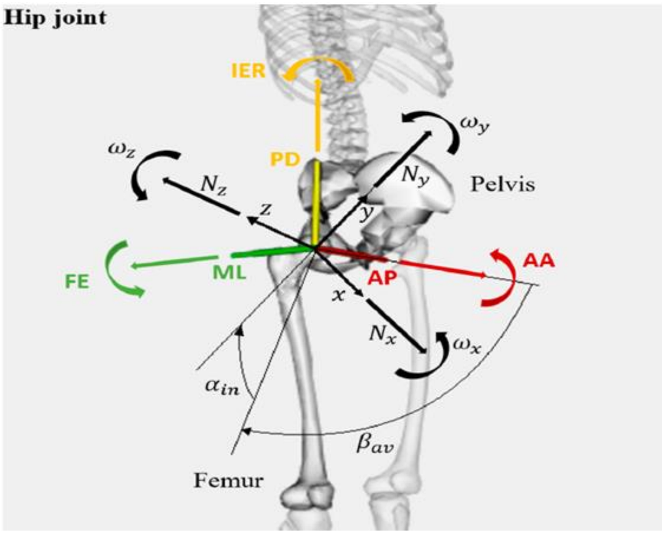
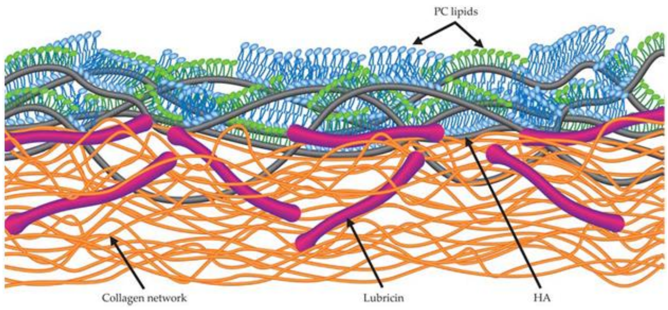
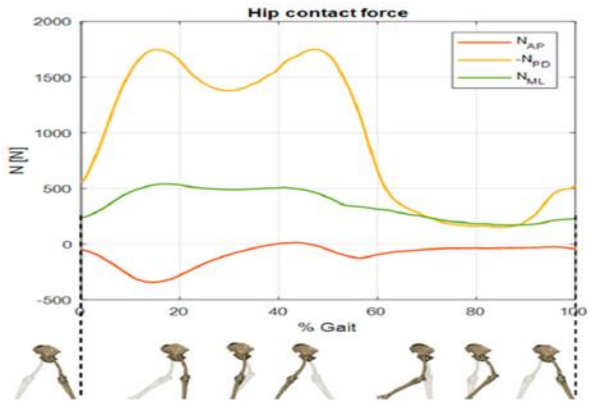
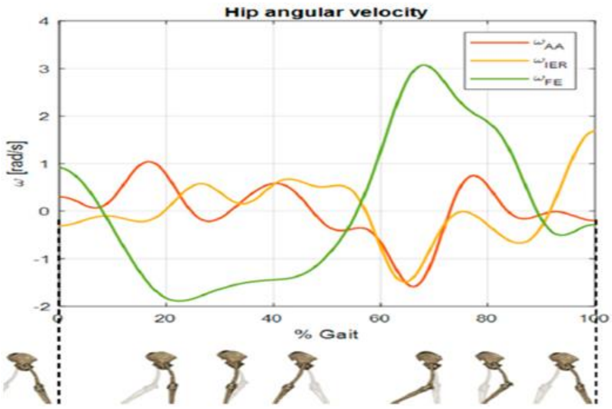


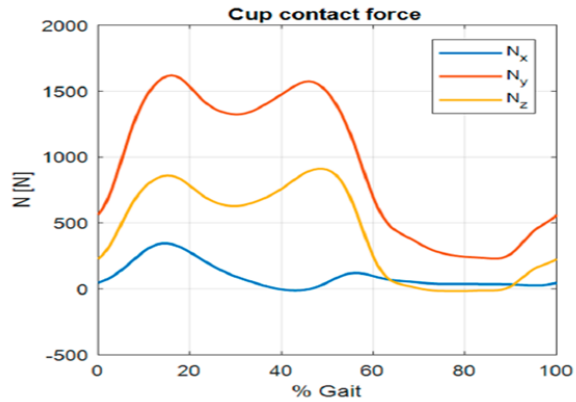
Figure 1. Hip joint reference frames. FE: Flexion–Extension rotation; ML: Medio–Lateral axis; AA: Adduction–Abduction rotation; AP: Anterior–Posterior axis; IER: Internal–External Rotation; PD: Proximo–Distal axis

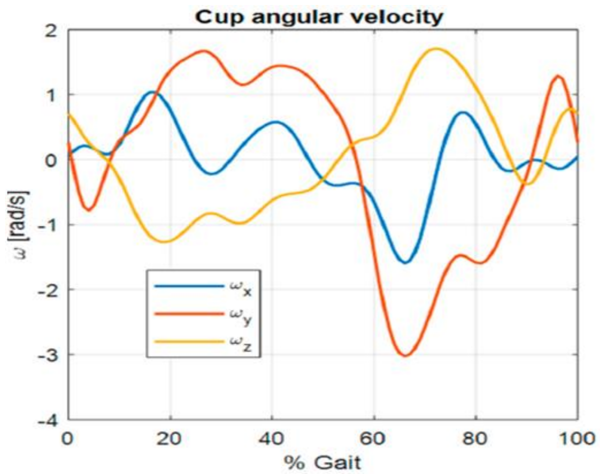


- Dark, leafy vegetables.
- Omega-3 fatty acids (found in salmon, mackerel, and flaxseeds)
- Anti-inflammatory foods that have curcumin in them (a compound found in turmeric)
- High antioxidant foods (onions, garlic, green tea, and berries)
- Nuts and seeds









For every movement we make with our body, we create friction between the joints used. Through our lifetime, we generate enough friction to cause enough damage to our bone structure to leave us physically unable to function. It is however because of our body's ability to reduce friction between our joints that we can continue on our day to day tasks.One key component responsible for reducing joint friction is synovial fluids, a wonder of our body that helps keep our joints alive by lubricating it. What makes synovial fluids so special is that they are able change in viscosity when force is applied on it during movement. However, like anything that has to endure friction and wear, synovial fluids in our joints will eventually reduce in quantity, resulting in issues such as arthritis .Synovial fluid is essentially the lubricant that reduces friction between joints in our body. It is made up of a mix of hyaluronic acid, lubricin, proteinases and collagenases. This combination of fluid is usually found surrounding the tendons and tendon sheaths such as the knee joint. The fluid is typically surrounded by a membrane known asthe synovial membrane which keeps it in the right space for reduction of movement friction.

In its natural structure of a non-newtonian liquid held by a membrane between joints, the synovial fluid creates a tiny gap of liquid space between the bones at the joint. This gap and space is essential for our daily lives as it stops the bones from grinding into each other which is typical of arthritis. This also forms a protection surrounding the tendons, reducing inflammation of the joints such as found in worn out knees. Parts of the synovial fluid such as lubricin are also very important as it reduces friction between opposing surfaces of cartilage. It can be summed that the two functions of synovial fluids and its components are to first reduce friction and second protect the parts of the joint synovial fluids are naturally created in our body, specifically in the locality of each joint where it resides. Within the joints of our body you will find synovial cavities where synovial fluids reside, between the cartilages. As your body moves, the fluids are squeezed out in order to create a space between the cartilage, hence reducing the friction between joints. It is in this very same space within the synovial joints and cavities that synovial fluids are secreted, by the synovium.Being a key component in healthy movement, our body secretes the synovial fluids using proteins derived from blood plasmas. These blood plasmas are usually taken from cells within the joint tissue itself, making each joint a self-contained production for their own synovial fluids

Deficiency:

The most common cause of synovial fluid deficiency is inflammation in the joint area caused usually by overuse of specific joint areas such as knees in running, It can also be caused by repetitive high-stress movements caused by lifting heavy weights.These conditions result in the inflammation of the joint area, specifically in the synovium due to an abnormal immune response.This abnormal immune response in joints will eventually lead to cartilage loss, resulting in the damage of joint surfaces. Once joint surfaces have been damaged, a person will experience stiffness that is specific to the joint that is overused or put under severe stress. The same stiffness will also cause movement restriction at the affected joint. This varies in degrees depending on the damage. Aside from stiffness, arthritis patients commonly experience pain in various degrees. In some cases, pain is localised during specific movement whereas some experience pain that is constant until movement ceases.foods increase synovial fluidOne way you canimprove the production of synovial fluid in your joints is simply by eating specific food types that will boost its production.

The most accessible of these food types are leafy greens such as spinach and broccoli. Leafy greens being high in antioxidants will assist your body in strengthening the cartilage that synovial fluids are protecting, helping them to withstand daily wear better. Pairing these greens with a serving of fish two to three servings per week will introduce another key player in joint health – omega3these fatty acids are anti-inflammatory agents that promote better joint health through the reduction of inflammation in jointFish such as salmon or sardines will do the trick just fine. If fish is not to your taste, you can consider avocados or walnuts as they contain both antioxidant mono-unsaturated oils and essential fatty acids that work as anti-inflammatory agents as well.Additionally, there are seasonings, herbs and even oils we consume daily that are great for aiding the function of synovial fluids and joint health.

Turmeric, commonly found in indian food, contains curcumin which is an anti-inflammatory agent. Supplementing your usual cooking oil with extra virgin olive oil is another easy fix as it has been shown to block inflammationFor antioxidants, you can consider red onion and garlic which are consumed daily by most. Finally, for those tea lovers out there, green tea is a great alternative that is proven to provide great sources for antioxidants

Exercise increase synovial fluid

It is a common misconception that exercise is the reason for decrease in synovial fluid. In fact, exercise is one of the prescriptions given by experts to better allow your joints to generate synovial fluid. Studies have shown that joint pain is reduced after a session of exercise as physical activity encourages the circulation of synovial fluid through the synovial joints and lubricates the joint areas. Exercise also effectively removes water molecules that put weight on joints and ushers in oxygen and nutrients to the joints, even removing blockages.One additional benefit of physical exercise is the removal of wastes from the added boost in blood circulation through the joints. Through this process, damaged cells and harmful wastes are flushed awayfrom the joints through the body's natural waste-removal capabilities, reducing pain and joint stiffness.It is however recommended that these exercises are minimal in impact such as those experienced in running & sprinting. Jogging, walking, swimming, usage of lighter weights for strengthening are all great forms of exercises that will boost joint health

Supplements can be taken to lubricate our joints:

Outside of the above mentioned food sources where natural building blocks for synovial fluid can be found, you can choose to take supplements to further improve your joint health. The most common of these supplements are glucosamine and chondroitin. These supplements are widely used and commonly referred to when joint health is the concern. They are easily found in most if not all pharmacies and usually come with additional supplementary elements included. Glucosamine is useful for supporting the recovery of connective tissues such as cartilage, providing it with the nutrient blocks needed to rebuild and strengthen cartilage. Chondroitin on the other hand is also easily accessible and helps with strength and stability of cartilage in joints. Primary components for these two pharmaceutical products are typically shellfish shells for glucosamine and as for chondroitin, they are typically made from bone or shark cartilage. Depending on your health requirements and perhaps joint conditions, dosage may vary, these products however typically come in either 500mg or 1000mg tablet form

III. PATIENT DATA OF HUMAN SAMPLES

Parameter	OA	Rev SF
Number of patients	18	18
Age (years)	59 ± 13 (26–80)	72 ± 9 (56–84)
Gender		
Female	6 (33 %)	9 (50 %)
Male	12 (67 %)	9 (50 %)
KLS/Implant material of each component	Grade 2 (N = 7) Grade 3 (N = 7) Grade 4 (N = 4)	Femur: Co-28Cr-6Mo (N = 18) Tibia: Ti-6Al-4V (N = 10), Co-28Cr-6Mo (N = 8) Inlay: UHMWPE (N = 18)
Implantation time (years)	n.a.	8.5 ± 6.4 (1–17)
Side of the joint		
Left	10 (56%)	12 (67%)
Right	8 (44%)	6 (33%)
BMI (kg/m^2)	32.3 ± 6.6 (24.5–50.3)	30.7 ± 5.2 (22.4–38.7)

Table :Patient demographics of the aspirated SF samples (values are given as mean _ SD).

	Protein [g/L]	HA [g/L]	Number of Samples
OA	38.1 ± 8.9 (21.5–55.3)	2.8 ± 1.1 (0.4–5.9)	N = 18
Rev SF	40.5 ± 9.8 (24.1–59.3)	1.7 ± 1.5 (0.2–5.2)	N = 18

Table :"Protein and HA concentration of the tested human joint fluids (values given as mean _+ SD(minimum–maximum)).

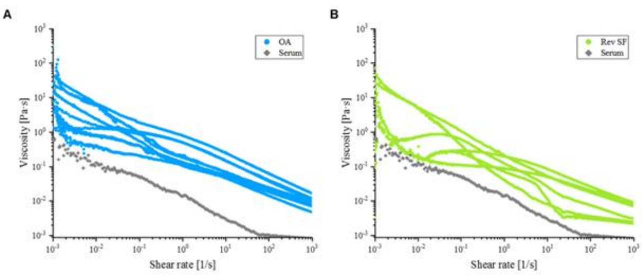


Figure Shear rate dependent flow curves of the different tested fluids at 30 °C. (**A**) Osteoarthritic synovial fluid samples (N = 7) and serum. (**B**) Patient samples from revision surgery (N = 7) and simulator test serum.

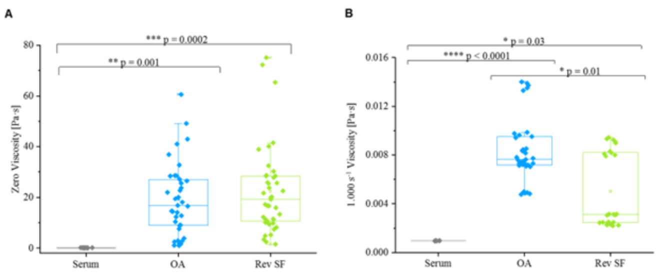
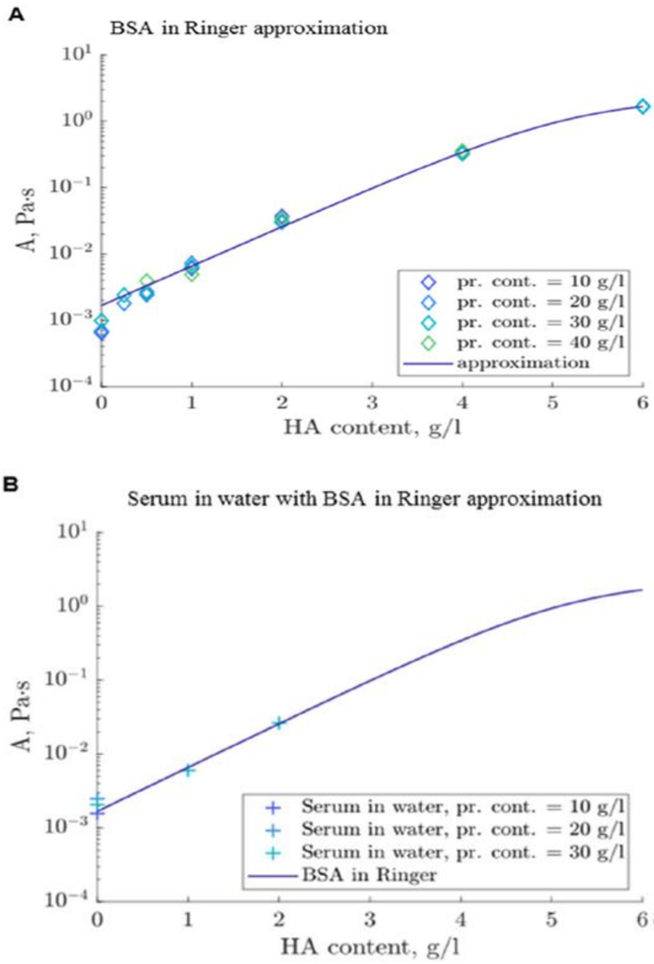
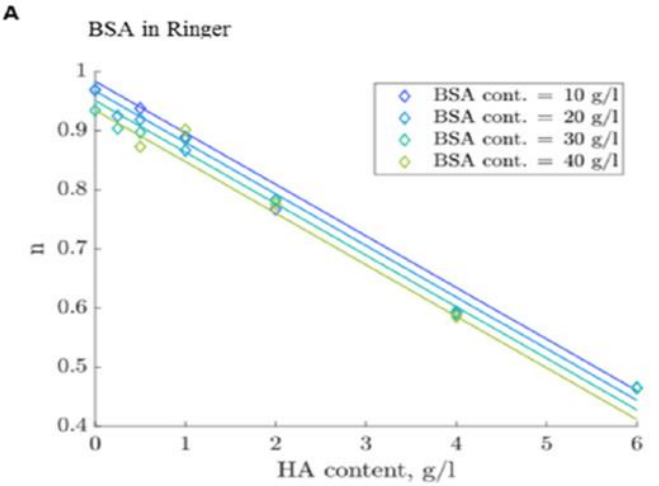
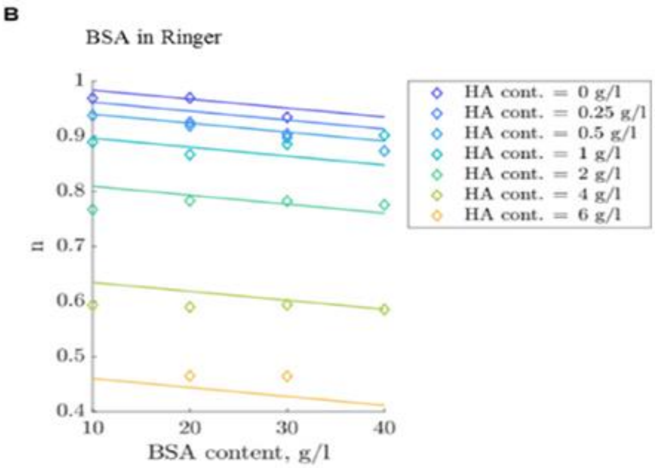


Figure. Results of the viscosity measurements for OA (N = 7) and Rev SF (N = 7) as well as serum test fluid at 30 _C (data as median). (**A**) Zero viscosities at a shear rate of 0.001 s1 exhibit significant differences between the test groups (p < 0.01, ANOVA with Holm–Šidák post-hoc test). (**B**) Viscosities at a shear rate of 1000 s1 converge in magnitude and significant differences are present in all study groups (p < 0.01, Kruskal–Wallis with Dunn's test).







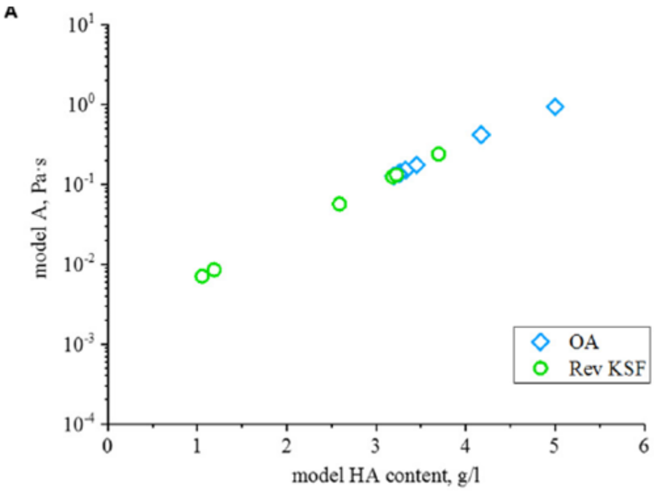
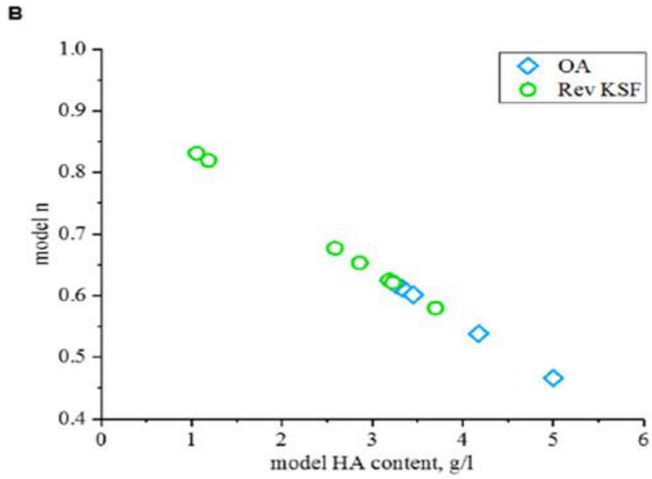


Fig. Chemical composition of synthetic fluid



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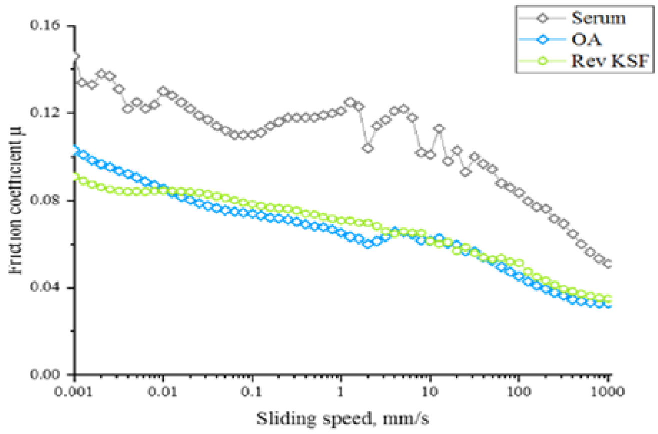

Fig. Chemical composition of synthetic fluid With speed

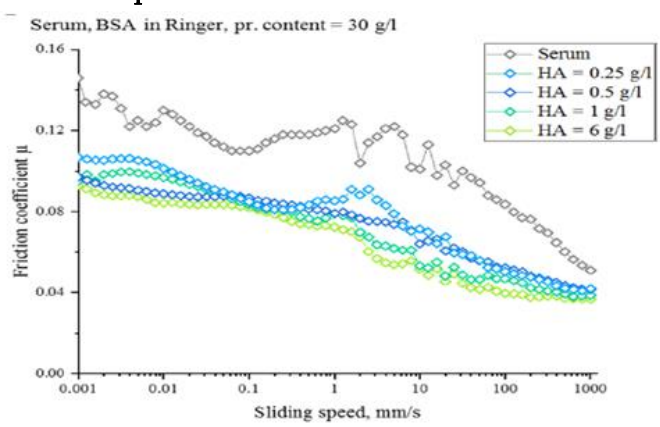

Fig. Chemical composition of synthetic fluid With speed

IV. CONCLUSION

Asolution currently adopted is the replacement of the unhealthy joint with a prosthesis, an implant made of biomaterials designed to improve stability, load capacity and mobility, and to guarantee minimal friction and wear. you can choose to take supplements to further improve your joint health. The most common of these supplements are glucosamine and chondroitin Examples of actual implants are represented by hip and knee artificial joints, which are the mainhuman joints replaced: several surgical strategies and techniques are adopted in terms of total orpartial replacements The lubrication of a natural human synovial joint is a complex mix of elasto-hydrodynamic, fullfilm and boundary lubrication modes Regarding the artificial joint, the lubrication phenomenon can be analyzed by considering acombination of Boundary Lubrication (BL), Mixed Lubrication (ML), Hydrodynamic Lubrication (HL)and Elasto-Hydrodynamic Lubrication (EHL) depending on load and motion conditions The synovial fluid pressure profile in this zone substantially follows the Hertzian pressure, andthe minimum film thickness is located at the exit of this area, causing the well-known pressure spike.

The combination of high load and low relative motion could lead to contact between the articulatedsurfaces despite their deformation, so that in these contact areas the contact pressure rises and in thiscase the regime is referred to as Mixed Elasto-Hydrodynamic Lubrication (MEHL).

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