09/04/20

BIO TRIBOLOGY

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BIO-TRIBOLOGY

- Tribology comes from the Greek word “tribos,” which means “to rub.”
- Tribology is generally defined as the study of three areas — friction, lubrication and wear.
- Generally, friction is produced when two sliding surfaces come into contact, resulting in wear.
- The purpose of tribological research is to minimize friction and wear.
- Bio-tribology is a relatively new term, a multidisciplinary subject covering the areas of engineering, material science, biological science, physical science and medicine.

SHOULDER WEAR TEST

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09/04/2018

INTRODUCTION

- Shoulder Joint Replacement is the third most common ortho-paedic joint replacement after hip joint replacement.
- There are two type of SJR. Total Shoulders and Reverse Shoulder.
- Most SJRs generally employ a cobalt Chromium component rubbing against Ultra-High Molecular Weight Polyethylene (UHMPWE) as an articulation
- Wear of this polyethylene glenoid component elicits and osteolytic response to the wear particles, leading to aspetic loosening of the joint.

Testing

<u>Newcastle Shoulder Wear Simulator</u>

The first multi-station shoulder simulator capable of applying physiological motion in three axes with physiological loading.

The three axes of physiological are

Flexion/Extension, Abduction/adduction, Intenal-external rotation

It was used to wear test commercially available JRI Orthopaedics 42mm diameter Reverse VAIOS shoulders using three axes of physiological motion with physiological loading. In addition to it, translational sliding motion was therefore added to the simulator to wear test

Mechanism (Newcastle Shoulder Wear Simulator)

- It has 5 articulating stations and one static control station.
- Axial loading to each implant is applied using a pneumatic cylinder.
- Three pneumatic cylinders with integral position encoders move five glenohumeral prostheses simultaneously in the flexion-extension, abduction-adduction, and internal-external rotation axes.
- A mechanism with a rotational centre eccentric to the internal-external axis, and driven by the internal-external motion was built into the components between loading cylinder and lubricant bath to provide translational sliding motion to each test station.

EXPERIMENT

- A 5 million cycle wear test was performed with JRI orthopaedics Total VAIOS shoulder.
- These consist of a CoCr humeral head articulating against an UHMWPE glenoid component.
- Five 42 mm diameter Total shoulder were tested and a sixth was subject to dynamic loading in the control station.
- Lubricant employed was newborn calf serum diluted to give a protein content and maintained at ambient temperature.
- Gravimetric measurements were used to determine the weight change and thus the wear of components.

EXPERIMENT

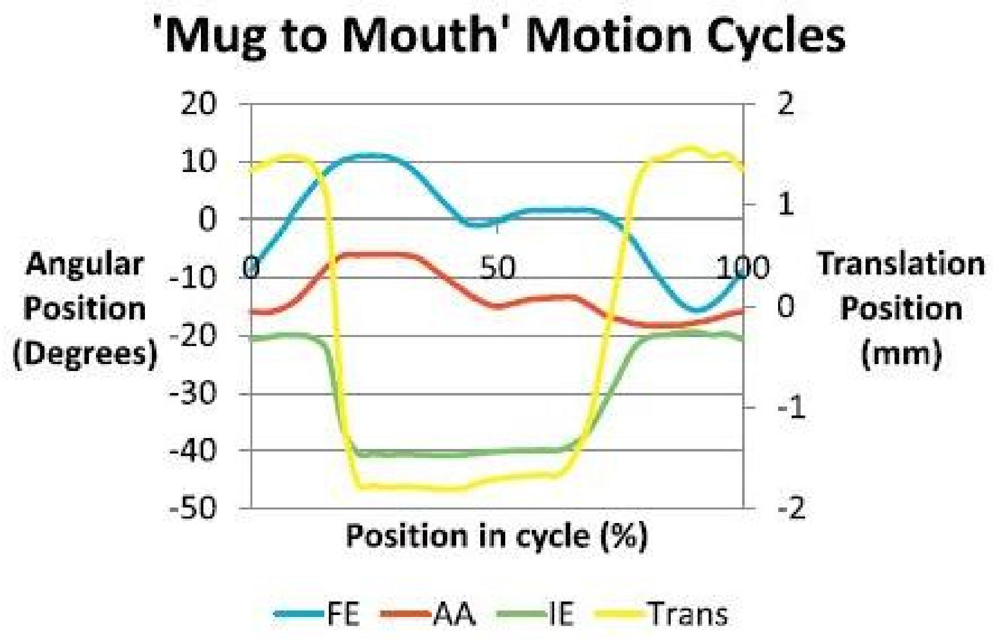


Fig. 2. Motions applied in the shoulder simulator for testing Total shoulder prostheses. FE = flexion/extension; AA = abduction/adduction; IE = internal-external rotation; Trans = translational.

EXPERIMENT

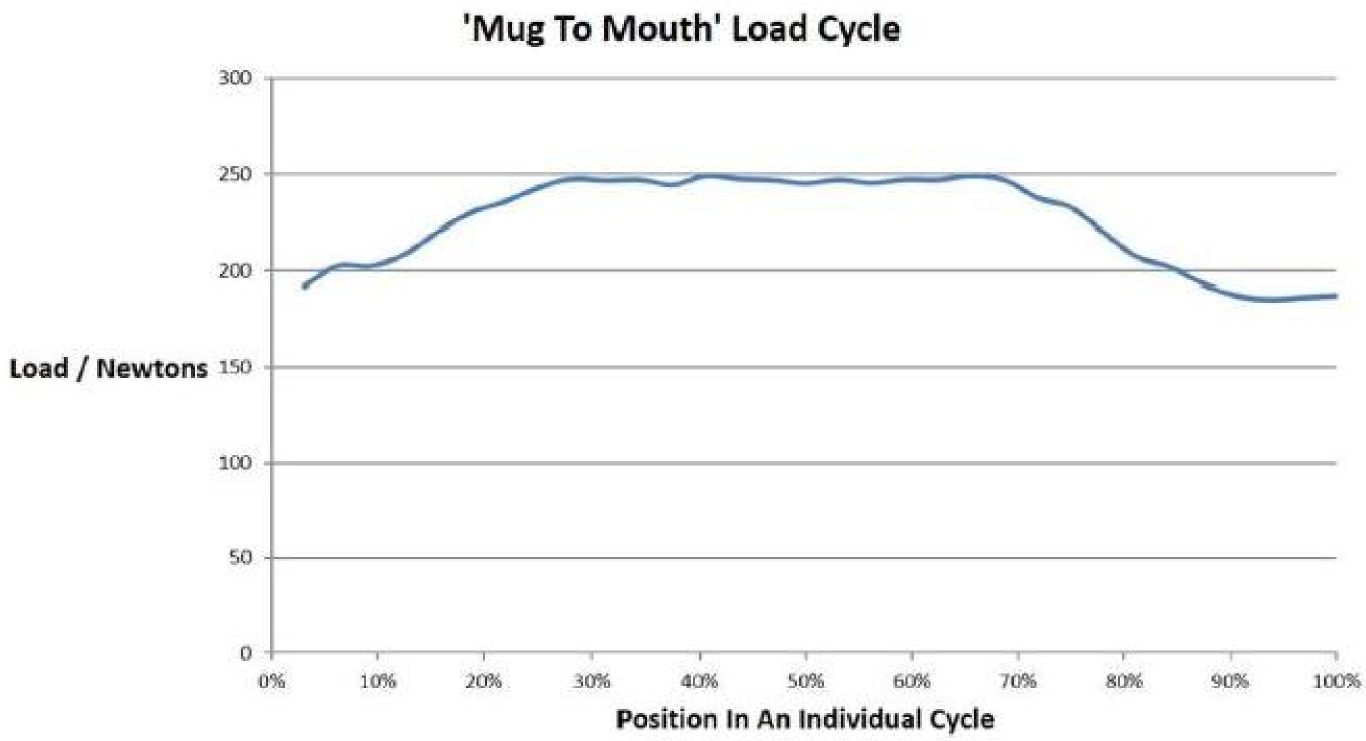
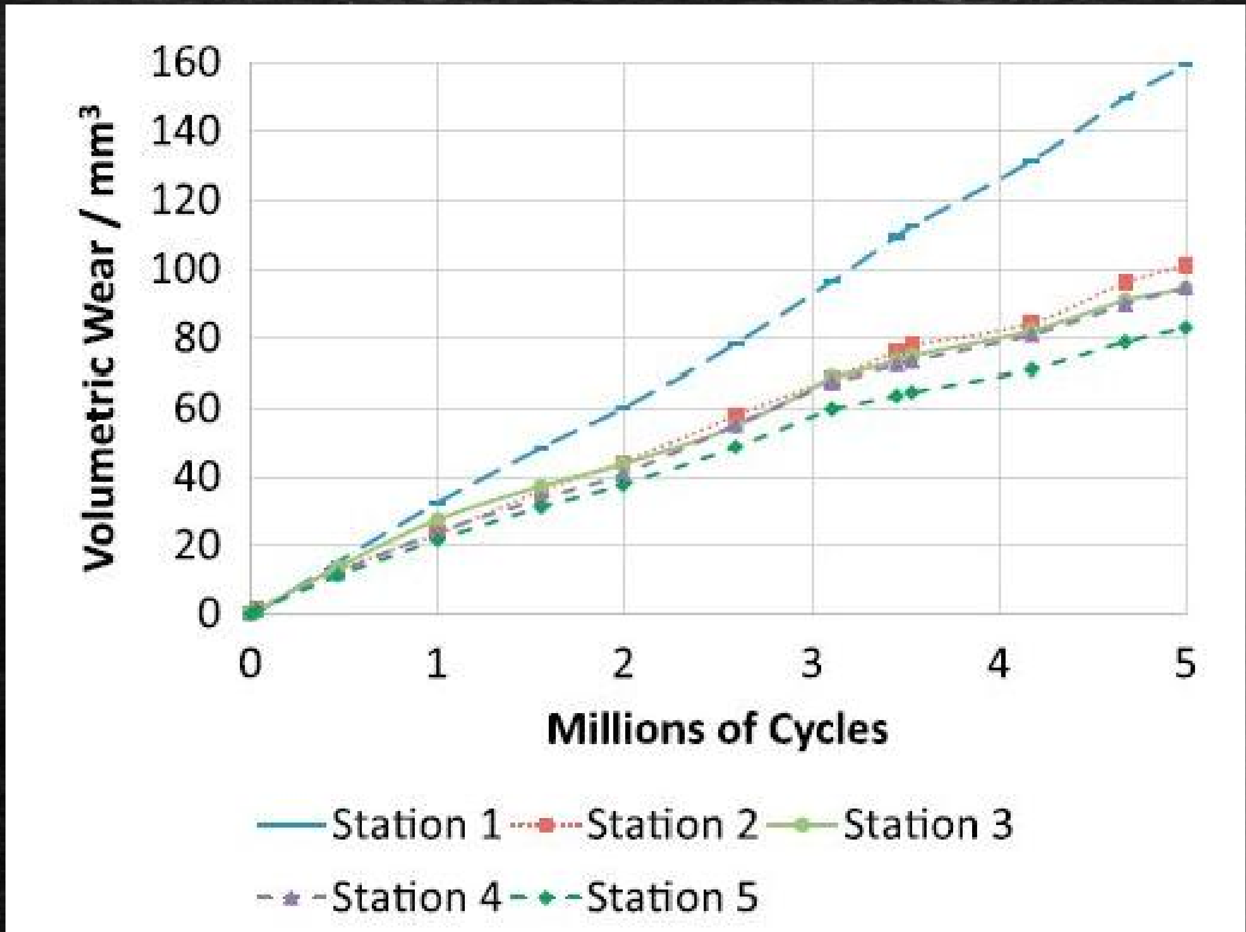


Fig. 3. Loading applied in the shoulder simulator during "mug to mouth".

Results



Volumetric Wear / mm³
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
Millions of Cycles
Station 1
Station 2
Station 3
Station 4
Station 5

Results

Table 1
Surface Roughness measurements of the five CoCr humeral heads and five UHMWPE glenoid cups at zero cycles prior to testing and after 5,000,000 cycles of wear testing.

Station	CoCr	CoCr	UHMWPE	UHMWPE
	Humeral head	Humeral head	Glenoid cup	Glenoid cup
	Zero cycles	5,000,000 cycles	Zero cycles	5,000,000 cycles
	Sa (nm)	Sa (nm)	Sa (nm)	Sa (nm)
1	13	56	1064	73
2	22	32	1288	51
3	20	59	954	74
4	20	31	779	92
5	19	37	712	93
Mean ± S.D.	19 ± 3	43 ± 13	959 ± 230	77 ± 17

Results

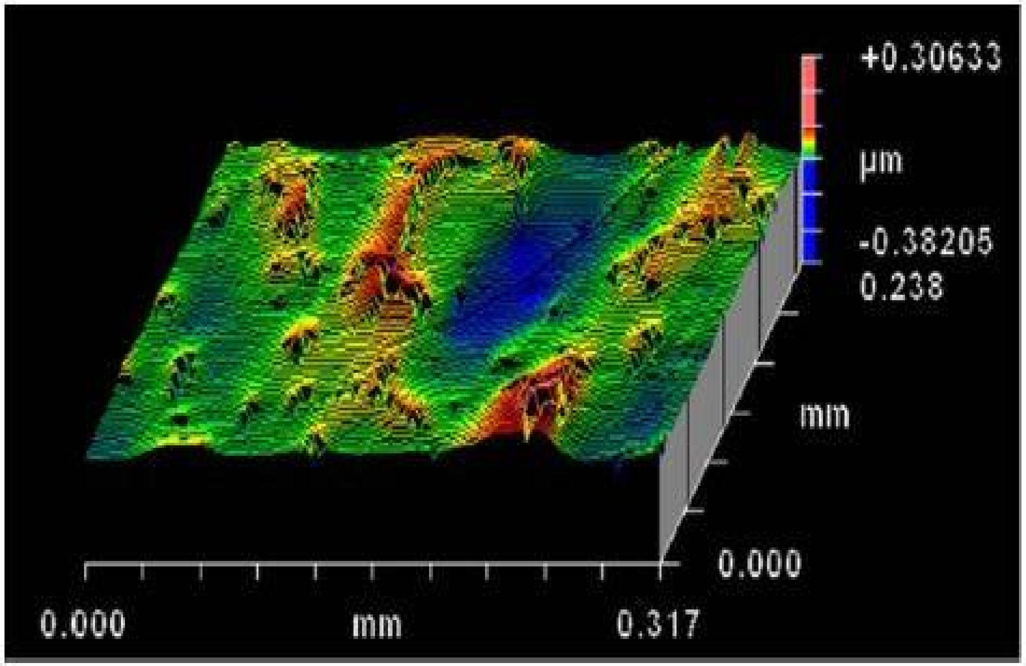


Fig. 5. An image of the surface of the unworn humeral head from station 3, Sa = 20 nm, taken prior to testing using the Zygo profilometer.

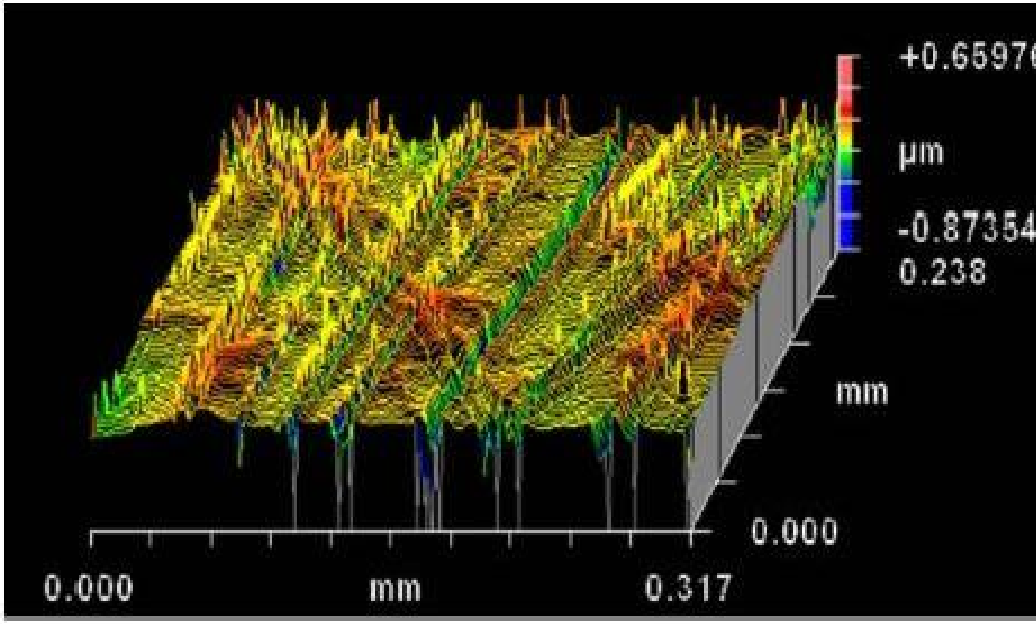


Fig. 6. An image from the Zygo profilometer of the surface of the same humeral he
from station 3, Sa = 59 nm, taken after 5 million cycles of testing. Note numerous i
gular scratches.

CONCLUSION

- The total VAIOS shoulders, tested with the addition of translational motion, exhibited a 50% larger wear rate.
- CoCr joints articulating against UHMWPE operate in a mixed lubrication regime where the majority of the load across the joint is carried by asperity contact hence wear of the joint is typical of a boundary lubrication regime where Lancaster equation is applicable.

$V = kPx$

V- Volume of the material removed by wear

k – wear factor

P – Applied load

x – Sliding distance

Questions

1. In Newcstle shoulder wear simulator, a load of 25N is applied and the translational distance of 3 cm was found. If the coefficient of wear factor is 0.3 calculate the wear volume rate.

2. Why newborn calf serum is used as lubricant in the experiment?

A. This lubricant supplies protein which get precipitated at higher temperature which reduces the wear.

CARTILAGE AND JOINT LUBRICATION - BIOTRIBOLOGY

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09/04/18

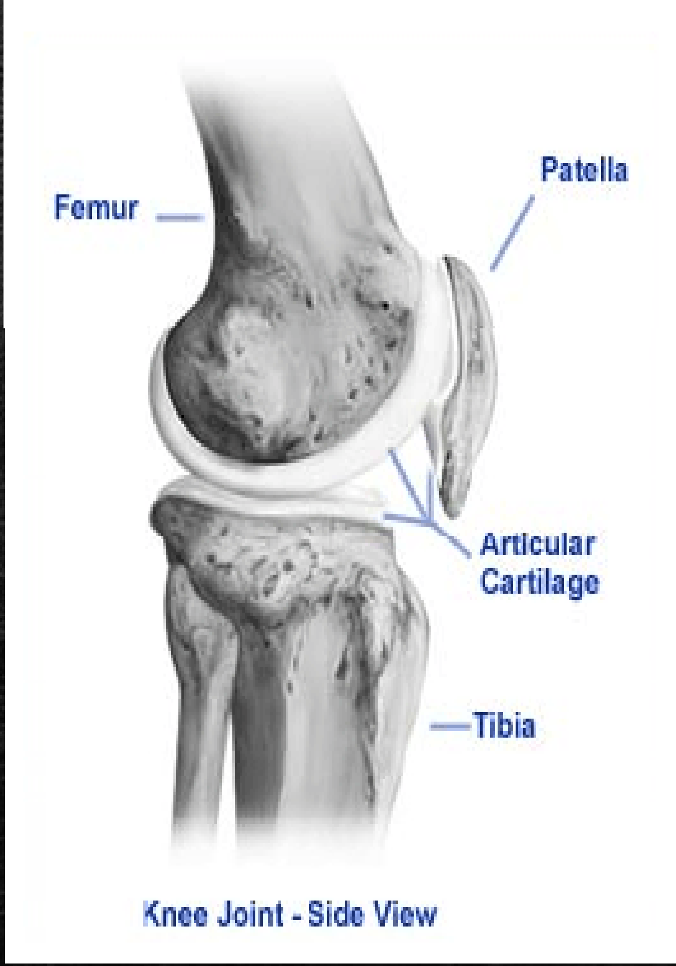
INTRODUCTION

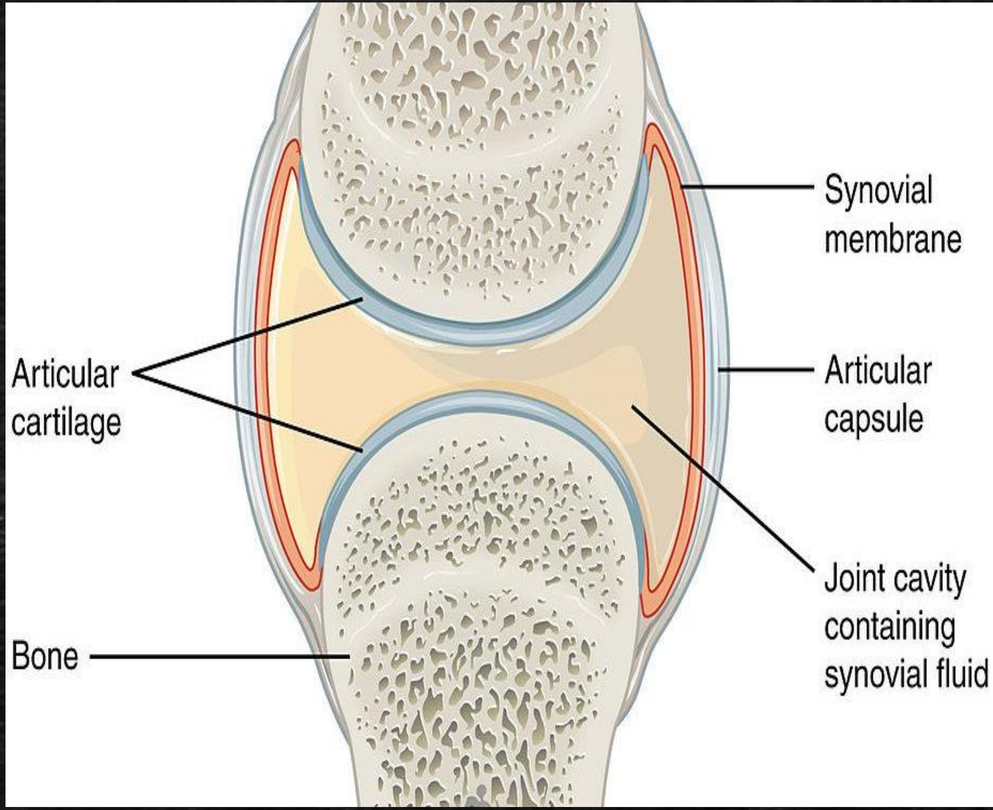
- Cartilage is highly stressed material
- Articular cartilage is found in synovial joints
- Provides remarkably low friction coefficients under wide range of load and speed conditions
- However when loading over longer time scales, these low initial friction coefficients increased by more than an order of magnitude as the applied load slowly wrung the interstitial fluid from the tissue (dehydration)

- These unusual tribological properties are primarily attributable to its unique biphasic structure i.e., interstitial fluid phase and porous permeable solid phase
- To understand the cartilage response to stress: compression, tension and shear are considered

Functions of Articular Cartilage :

- Increases load distribution area
- Allow movement while reducing friction and wear


Femur
Patella
Articular
Cartilage
Tibia
Knee Joint - Side View


Synovial
membrane
Articular
cartilage
Articular
capsule
Joint cavity
containing
synovial fluid
Bone

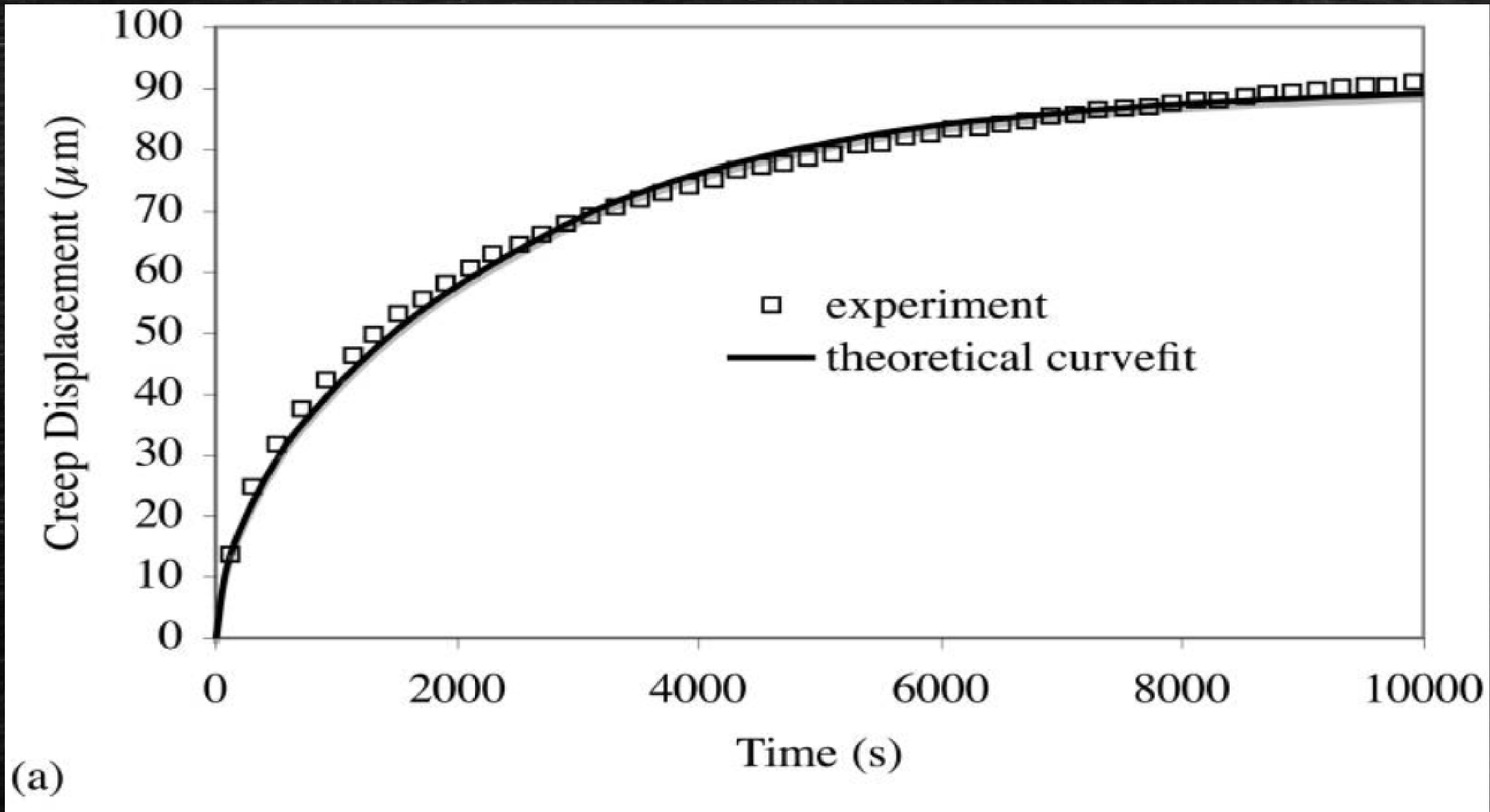
- Hydrodynamic lubrication plays an important role in lubricating the joints
- Because of the fibrillar nature of the collagen matrix, and since fibrils can resist tensile loads much better than compressive loads, cartilage exhibits a much higher stiffness in tension than compression, a phenomenon that has been called tension-compression nonlinearity
- Creep is the tendency of a solid material to move slowly or deform permanently under the influence of mechanical stresses. It can occur as a result of long-term exposure to high levels of stress that are still below the yield strength of the material

Interstitial fluid load support concept

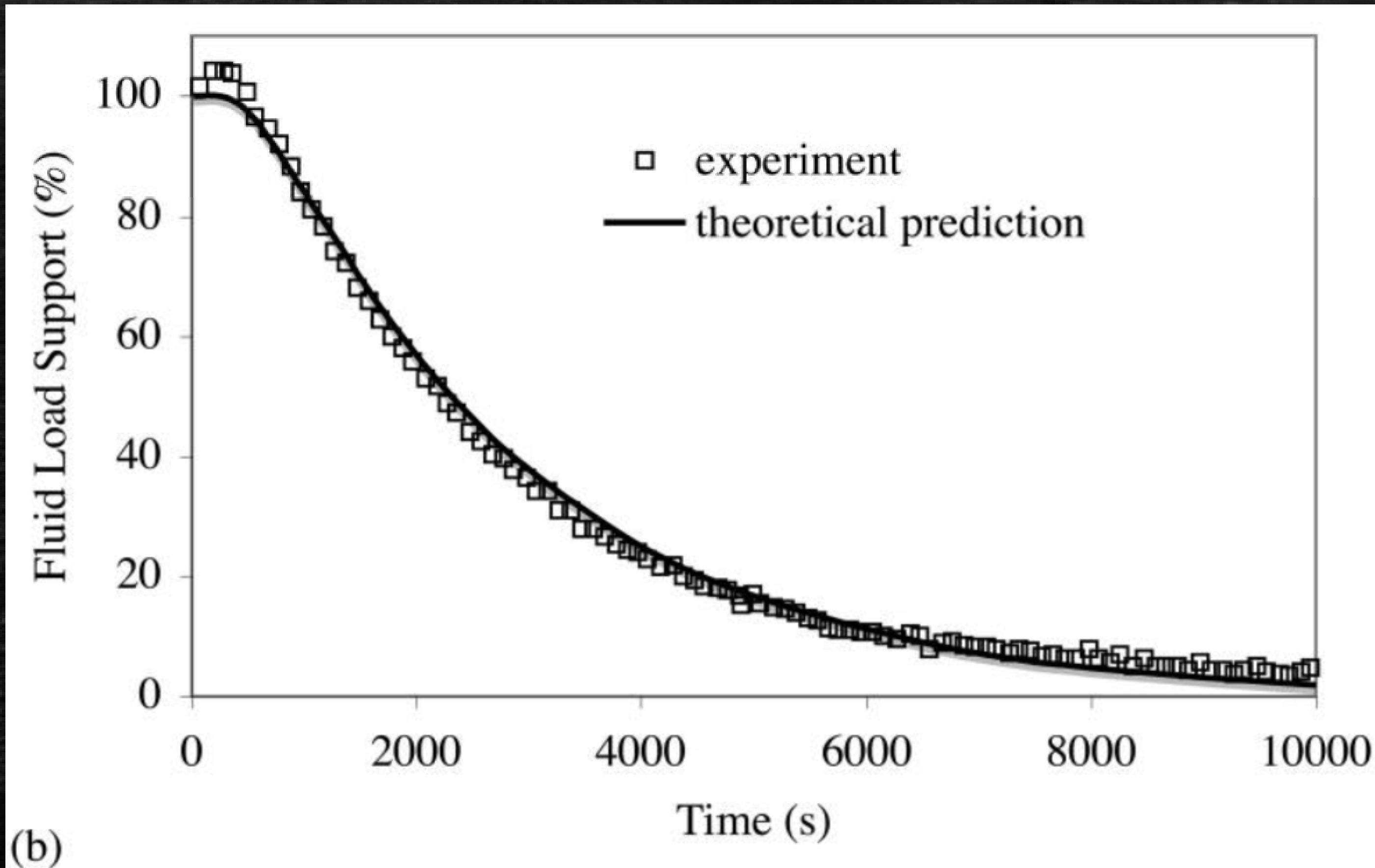
- In a creep test, upon the application of a constant load, the pressure was observed to rapidly rise to a value equal to applied compressive stress, before slowly subsiding back to zero at a rate comparable to that of the creep deformation
- Since the fluid pressure is equal to the applied stress upon the initial load application, whereas the creep deformation is zero, we can conclude that all of the applied load is initially supported by the pressurized interstitial fluid, and none by solid matrix deformation

- As the time progresses, the pressurized interstitial fluid flows out of the tissue, through the porous indenter, leading to a progressive reduction in the fluid pressure and increase in solid matrix deformation
- Thus, the load becomes progressively more supported by the solid matrix.
- This concept of load sharing between the solid and fluid matrix is called interstitial fluid load support, which plays an important role in the friction response of articular cartilage
- Ratio of interstitial fluid pressure to applied stress is called Fluid load support

(a) Creep deformation versus time

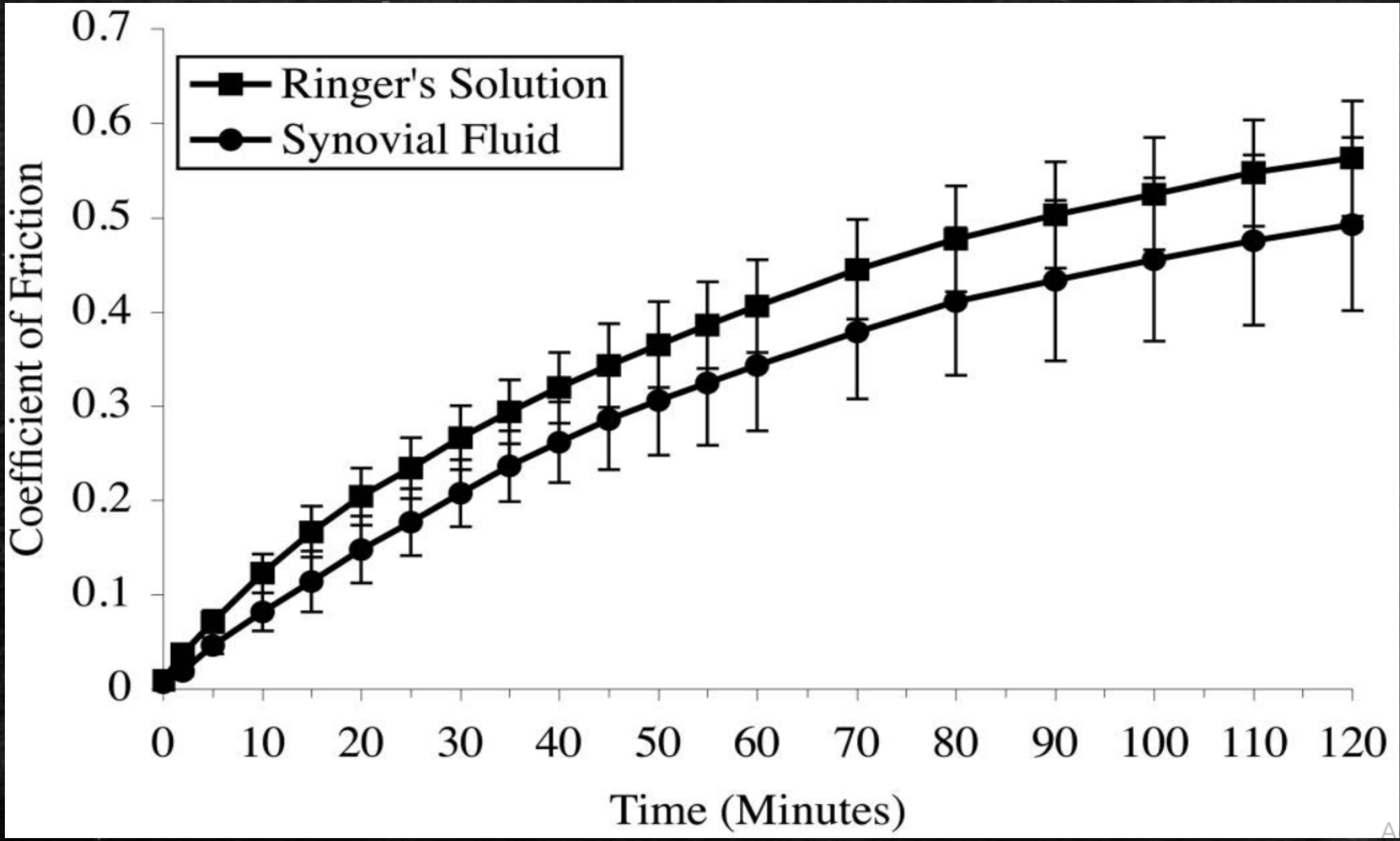


(b) Ratio of interstitial fluid pressure to applied stress



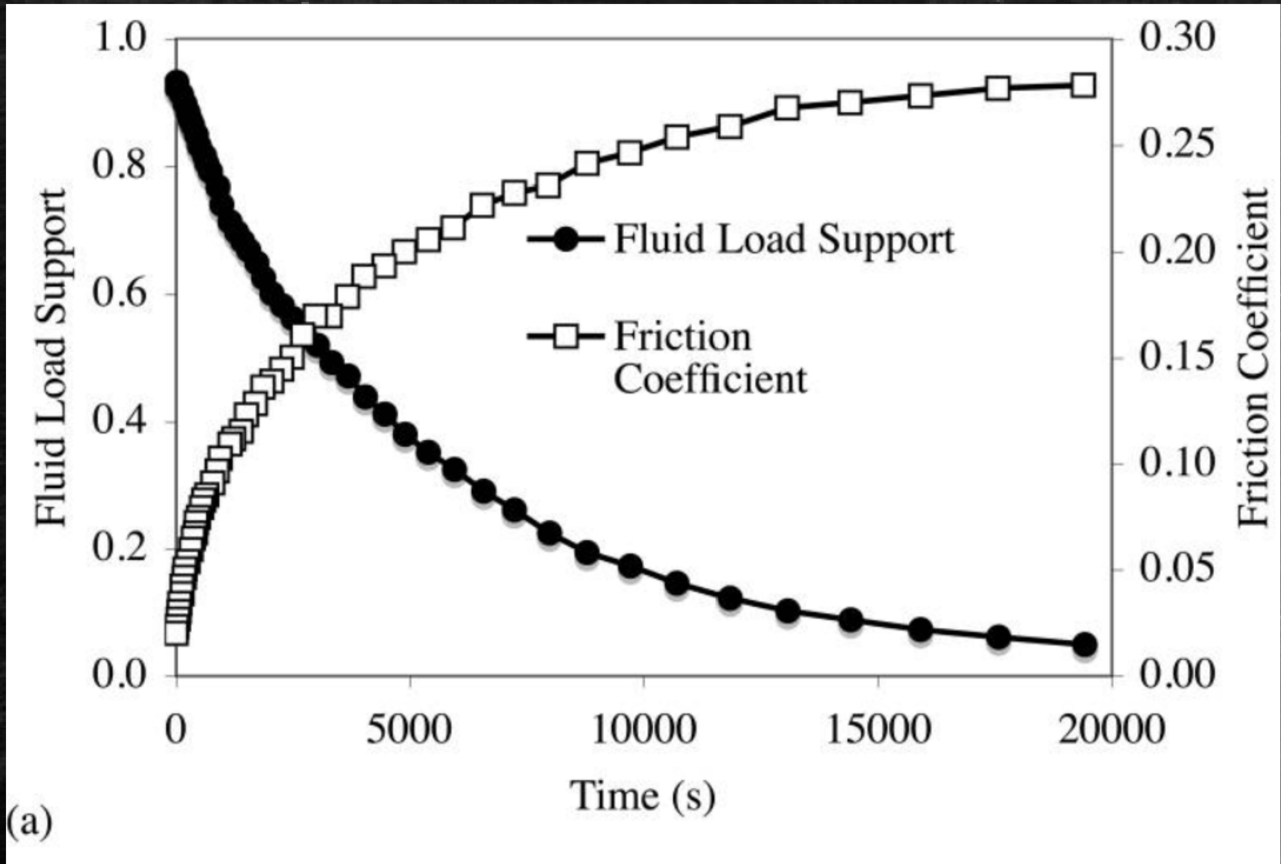
- Some experiments were done to measure the frictional response of cartilage against cartilage, using bovine shoulder joints with a variety of testing conditions, including variations in the magnitude and temporal profile of the applied load, the sliding velocity, and the role of synovial fluid versus saline as a lubricant. Based on the experimental observations, the response of cartilage could be attributed to the biphasic nature of cartilage.
- The results conclude that the friction force at the articular surface was proportional to the load carried by the solid phase.

Time-dependent response of the friction coefficient of articular cartilage plugs (Ø9 mm) against a metal counterface, under a constant applied load of 30 N

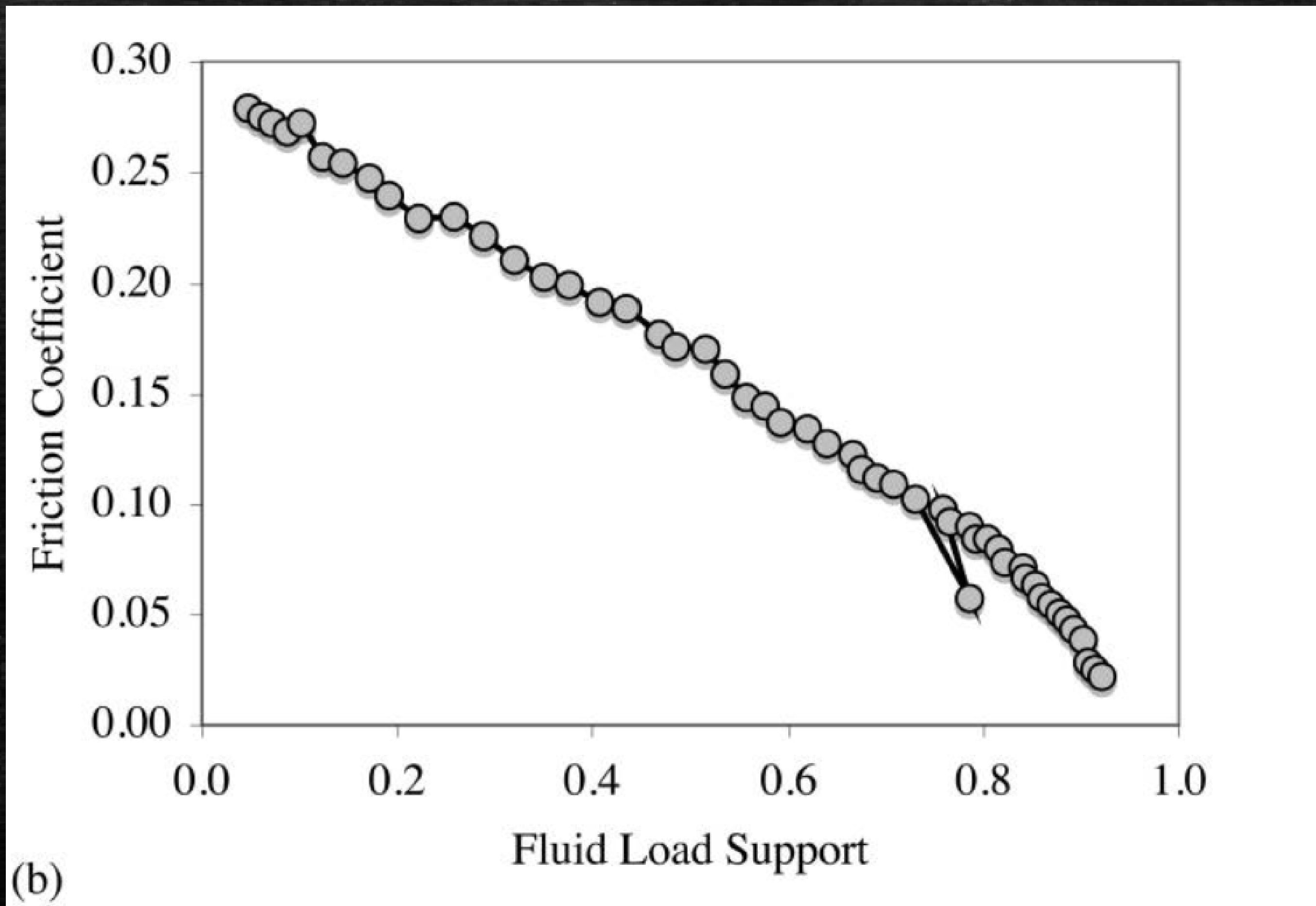


- Experiments also performed by testing the frictional response of cylindrical bovine cartilage plugs against glass, under unconfined compression creep. It was observed that the friction coefficient of cartilage rises over time, from an average of $\mu_{\mathrm{min}} = 0.010$ to $\mu_{eff} = 0.24$ over a median time of 75 minutes. Furthermore, they observed that the interstitial fluid load support (W^p/W), simultaneously decreased from 89% to 9%.
- Variation of both friction coefficient and interstitial fluid load support with time is shown below

(a) Time-dependent response of the friction coefficient μ_{eff} and interstitial fluid load support W^p/W of articular cartilage plugs against glass under constant load of 4.5 N

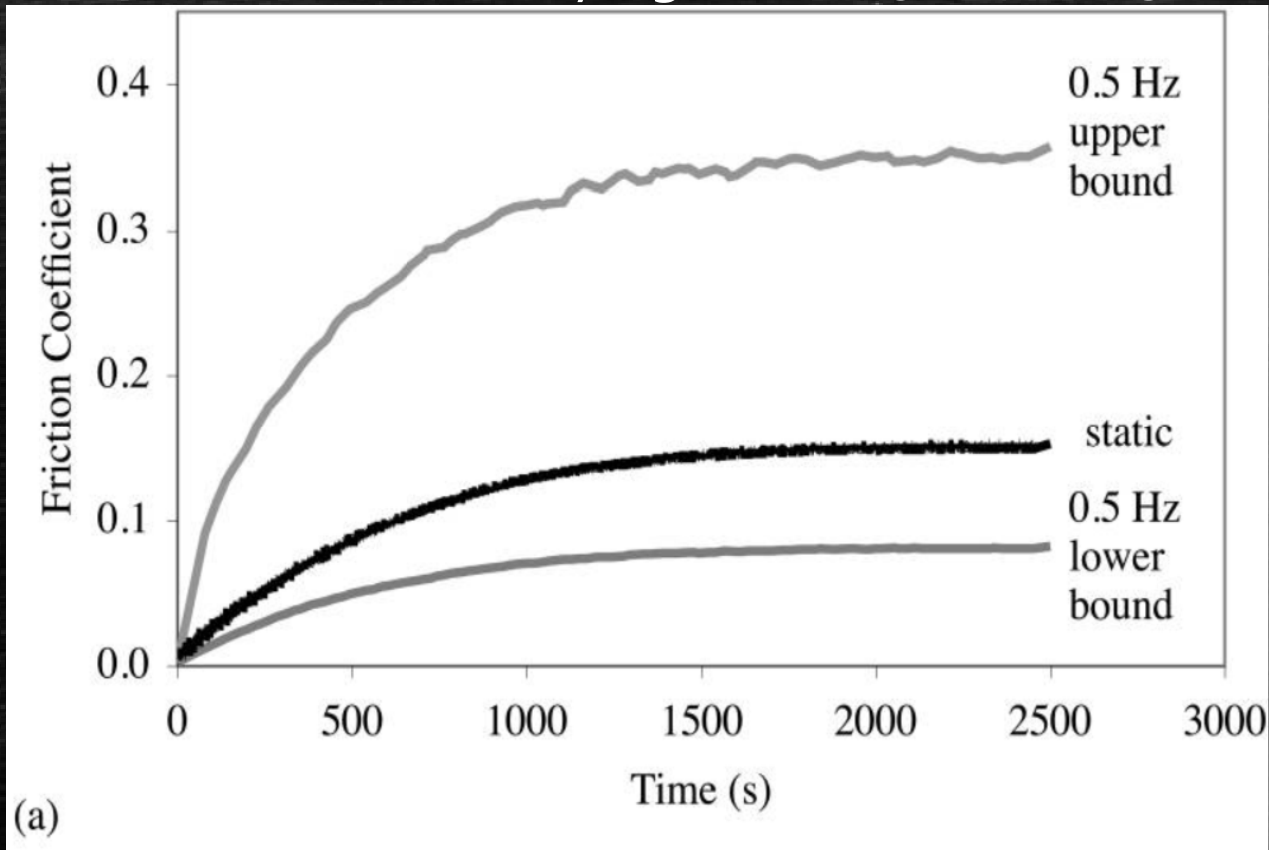


(b) A plot of μ_{eff} versus W^p/W yields a linear variation

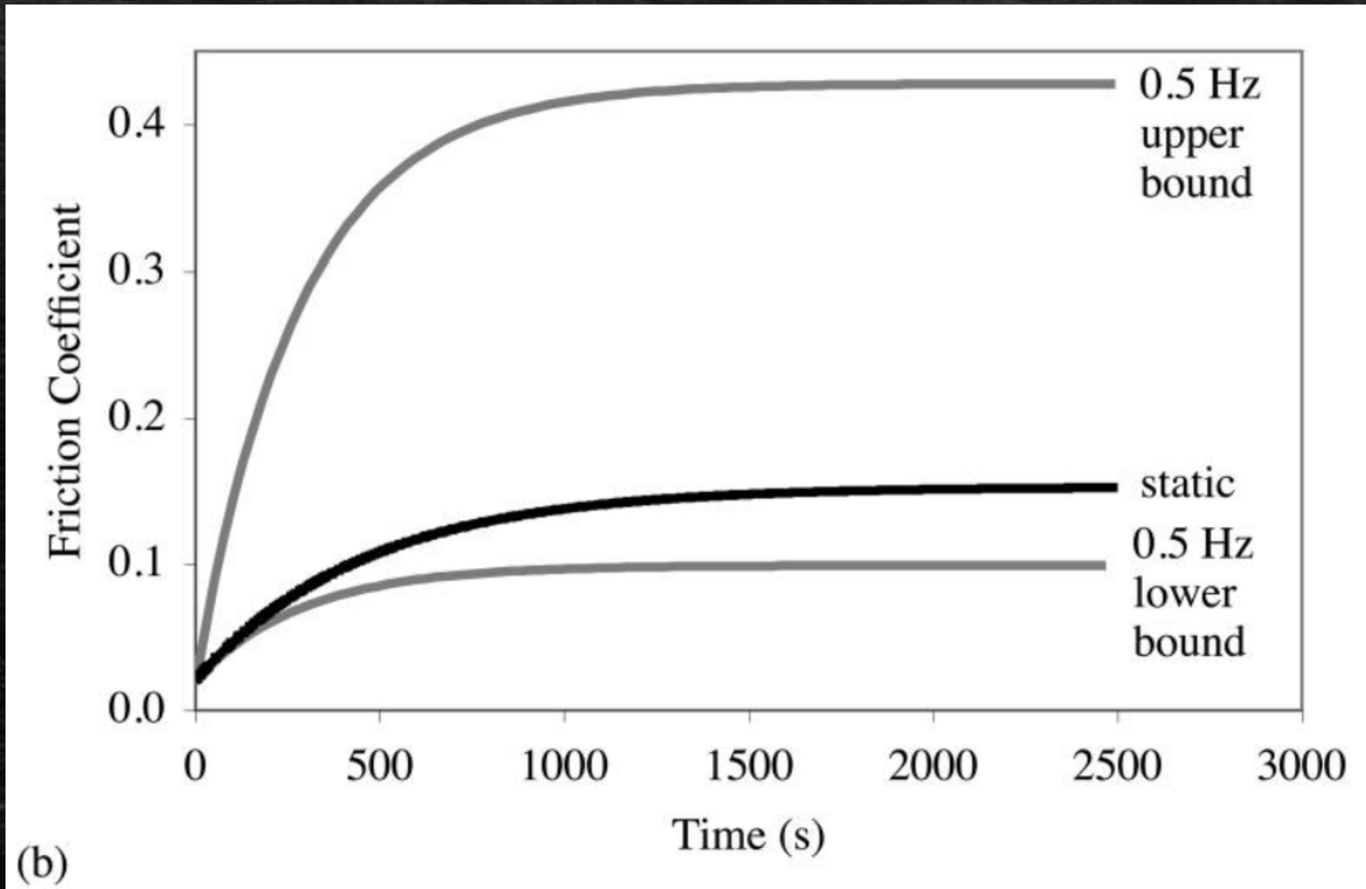


- Since physiological loading conditions generally involve cyclical and intermittent loads, it was hypothesized that dynamic compressive loading of a disk of cartilage may sustain dynamic interstitial fluid pressurization indefinitely, always keeping the friction coefficient low.
- This hypothesis was tested experimentally and, contrary to expectation, the friction coefficient of cartilage against glass under dynamic loading was observed to rise at the same rate as under static loading, while fluctuating above and below the static loading value.
- For example, under cyclical loading at 0.5 Hz, static loading produced an equilibrium friction coefficient of $\mu_{eq} = 0.15$, while dynamic loading achieved a steady-state cycle where μ_{eff} fluctuated from 0.08 to 0.36.

(a)Experimental measurements of the coefficient of friction of a cartilage plug (Ø4.8 mm) against glass, under a constant load of 13.4 N, or a sinusoidal load varying from 4.5 N to 22.3 N



(b) Theoretical predictions of the friction coefficient



- If the hydrodynamic pressure in the vessels increases, blood pressure increases due to which the blood supply will be low and hence the cartilage degenerates

- If the hydrostatic pressure increases, accumulation of fluid takes place due to which swelling of the part happens and thus the bone movement reduces

Questions

1. Which lubrication plays an important role in lubricating the joints?

A. Hydrodynamic (interstitial) lubrication plays an important role because it takes pressure after synovial fluid flows out under application of load.

2. Why did cartilage exhibits a much higher stiffness in tension than compression?

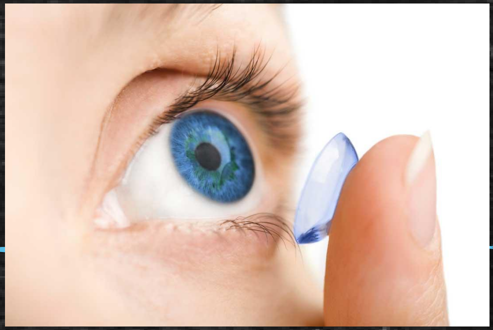
A. Because of the fibrillar nature of the collagen matrix, and since fibrils can resist tensile loads much better than compressive loads, cartilage exhibits a much higher stiffness in tension than compression.

3. Upon application of constant load, why does the interstitial pressure falls to zero after rapid rise?

A. Interstitial pressure falls to zero because after reaching to value equal to applied compressive stress, the pressurized interstitial fluid flows out of the tissue through porous intender, leading to a progressive reduction in the fluid pressure and increase in solid matrix

OCULAR TRIBOLOGY

Introduction



- Ocular tribology is concerned with the mechanisms of contact lens lubrication
- A contact lens is a small lens worn directly on the surface of the eye to aid or correct defective vision.
- Modern contact lenses are of two main types – soft and rigid gas permeable (RGP)
- They are considered as medical devices and can be worn to correct vision, for cosmetic or therapeutic reasons.
- The average age of contact lens wearers globally was 38 years old as of now.

Types of contact lenses

- Soft contact lenses
- Rigid gas permeable (RGP) contact lenses
- Daily wear contact lenses
- Extended wear contact lenses
- Toric contact lenses
- Decorative (Plano) contact lenses

Contact Lenses material

- Hydrogels have been used as the primary material in the fabrication of contact lenses.
- A hydrogel is a cross-linked hydrophilic polymer network filled with liquid which behaves like both solid and liquid under applied stress.
- Because of this hydrophilic characteristics, the water content of various hydrogel contact lenses can range from approximately 38% to 75%.
- The water content of soft lenses allows oxygen to pass through the lenses and keep the cornea healthy during contact lens wear.
- **Silicone hydrogel lenses** are an advanced type of soft contact lenses that are more porous than regular hydrogel lenses and allow even more oxygen to reach the cornea.

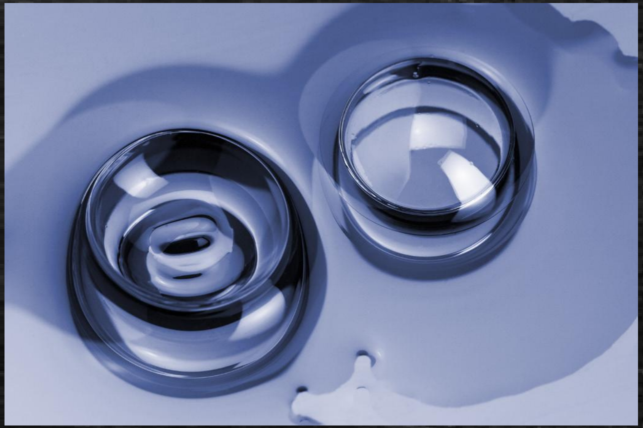
Material Used In Contact Lenses (Continued)

- Availability of hydrogel soft lenses (Based on their water content)

    1. Low content (Less than 40%)

    2. Medium water content (50%)

    3. High water content (More than 60%)



- Other types:
  - **Hybrid contact lenses**
  - **PMMA lenses** - made from a transparent rigid plastic material called polymethyl methacrylate (PMMA

Tribological Issues

- The insertion of a contact lens forms two interfaces with the natural eye, one with the lid wiper (pre-lens) and the other with the ocular surface (post-lens).
- Both relative motion and loading are involved at these two interfaces and therefore tribology plays an important role in the blinking of the eye as well as the successful function of a contact lens.
- Feeling itchiness if the friction between eyelid and eyeball is very high.If the friction is very low, the lens might slip out.
- Dynamic friction/static friction plays very important role to design new lenses.
- Friction changes when the lens starts to dry out.
- Lens property changes when it is dipped in contact lens solution overnight.
- The lens should remain lubricated so that the mechanical friction and associated pressures from the eyelid do not impact the lens and cornea negatively.

Surface properties of contact lenses with a Nano Tribometer

- Measurement of coefficient of friction (CoF) of contact lenses using the Anton Paar Nano Tribometer.

- Test conditions :
  - pressure (contact pressure created by the eyelid during the blinking was estimated at 3.5 to 4.0 kPa)
  - sliding speed (blinking average speed was estimated to 12 cm/s)
  - Blinking is assumed to be the primary force

- Experimental setup:
  - specially designed contact lens holder and the Hemispherical sapphire ball(3 mm diameter) used as counter body

Contact lens holder & testing procedure

The presence of liquid on the surface of the hydrogel is known to affect dramatically its frictional properties. So, the amount of the liquid was monitored during the tests.

The contact pressure was calculated using Hertz solution for spherical contact:

$P=F/(\pi a^2)$ where F = normal applied load,

$a^3=3FR/(4E)$ a = contact radius, E =Young's Modulus

R = radius of the hemispherical counter body

Young's modulus of the contact lenses was considered 50 kPa for all calculations.

Experimental conditions	
Normal applied load	1 to 10 mN
Reciprocating amplitude	1 mm
Stop condition	20 cycles
Sliding speed	0.31 mm/s
Sampling rate	10 Hz
Sapphire ball diameter	3 mm

Results:

- Plot of friction coefficient as a function of linear position.
- The applied load varied between 1 and 10 mN while the sliding speed was set to 0.31 mm/sec in all cases.
- These vibrations would lead to errors in the friction coef measurements.
- The CoF values were expected to decrease with load which is not the case here (the coefficient of friction was not decreasing with the load increase).

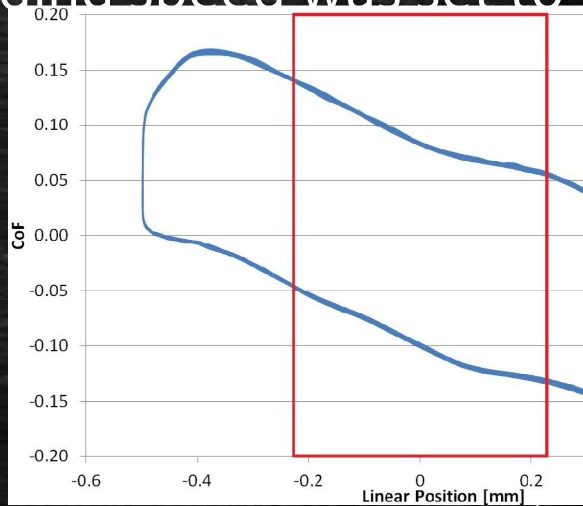


Fig. 6: Ten superposed cyc
CoF versus linear position

Conclusion:

Complexity of the frictional behavior of soft contact lenses and knowing that different parameters (liquid content, sliding speed, material chemistry, applied load etc.) can have important impact on the results.

Methods of Measuring Friction

Microtribometer

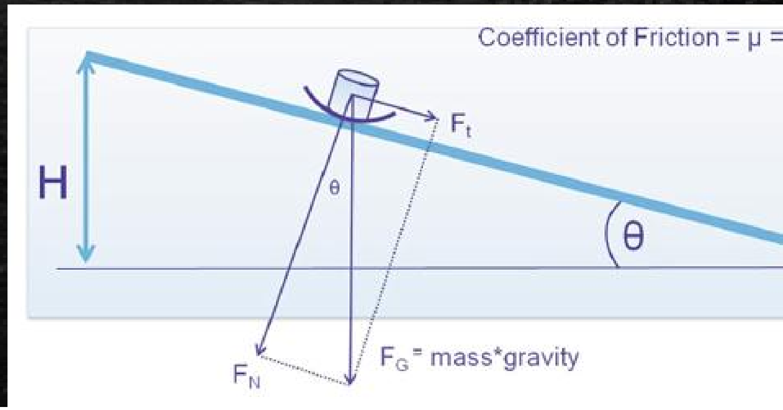
- A microtribometer is an instrument that directly measures the frictional force and the normal for
  in order to calculate the coefficient of friction.

Sliding speed: Test speeds have a large effect on the measured COF

Low speed as 0.01 mm/sec[13] used to measure "boundary lubrication"

Higher speeds used[10] to measure "mixed" or "hydrodynamic lubrication"

Normal Force Pressure: eyelid pressures are typically estimated at 1-7 kPa



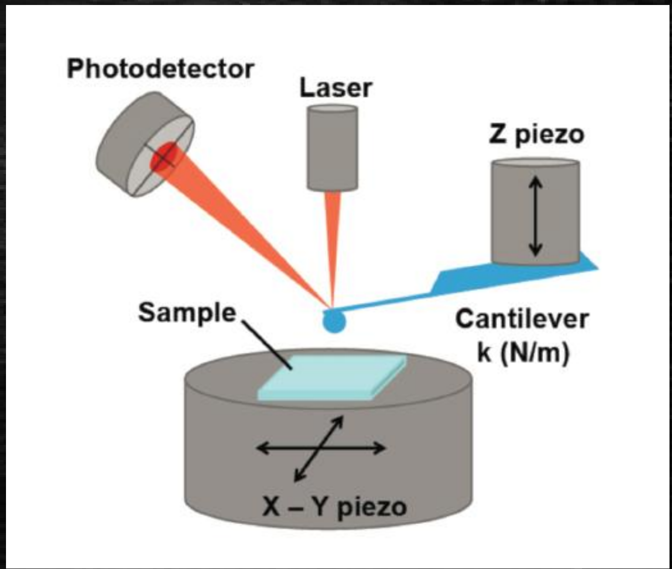
Inclined Plane Method

A quantitative method of determining contact lens friction using a PBS solution.

A clean glass plate is adjusted to a desired angle in a PBS bath.

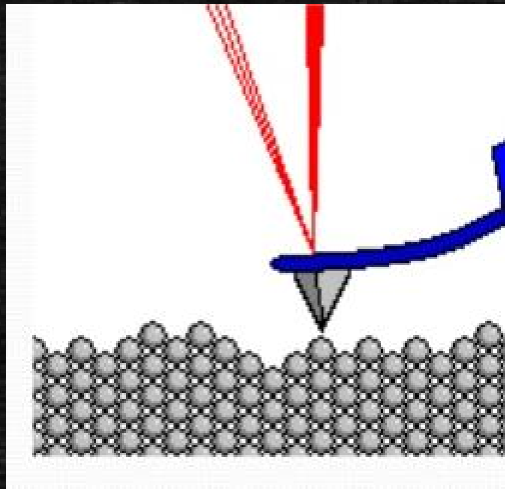
The contact lens under test is placed at the top of the glass plate and a 0.8 gram stainless steel ferrule (0.88 kPa) is placed on the lens to initiate movement.

The tangent of the critical angle is a measure of the kinetic coefficient of friction



Measurement of surface topography

- Atomic force microscopy (AFM) is mainly used in the topographic analysis of material surfaces on the nanometer scale.
- This technique works by detecting the deflection of a weak cantilever, which supports a probe tip, as a function of the programmed motion across a sample surface.
- AFM is a very powerful tool for high-resolution examination of the contact lens surface and also permits the analysis of surface topography and roughness by means of a non-destructive methodology



Lubrication: Lubrication between the contact lens and the eye is critically important

Finger Lubricity Method

- A qualitative "finger rubbing" method has been described to determine contact lens lubricity.
- **Procedure :**
  - In this method, contact lenses were rinsed overnight in a phosphate buffered saline (PBS) solution to remove any packaging solution, and the investigator rubbed the lens between their thumb and index fingers.
- **Rating:** Lubricity was rated on Zero (most lubricious) to 4 (least lubricious) scale.
- **Advantages:**

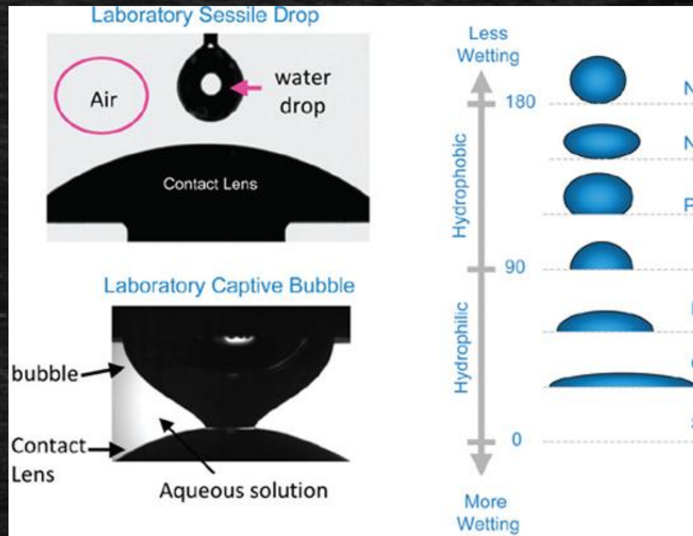
  a simple, quick method that does not require any sophisticated instrumentation.
- **Disadvantages:**

  limited qualitative scale and not all lens types can be differentiated with this technique.

Contact Lens Wetting

- Wettability is based on contact angles, which measure the area between the non-adhering part of a droplet and the surface on which it sits.
- Contact angles can range from 0° (complete wetting) to 180° (non-wetting).
- For silicone hydrogel materials, wettability is more difficult

nd challenging to measure because when silicone hydrogel aterials are exposed to air, there is rapid rotation of oxane bonds and migration of these groups to the ns-air interface.



Measure Contact Angles:

- **Sessile drop method - measures the contact angle between a drop of water and a contact lens surface exposed to air.**
- **Dynamic captive bubble technique -measures the contact angle between an air bubble and a contact lens surface in an aqueous environment.**

Wetting agents

- New soft contact lens materials with high water content surfaces or incorporated wetting agents such as poly(vinylpyrrolidone) (PVP) or poly(vinyl alcohol) (PVA) have been developed to reduce friction between the contact lens surface and the lid-wiper.
- Wetting agents such as water-soluble surface-brushes are introduced, particularly for dry eye patients

Problems with Conatct Lenses

1.Tight lense syndrome

This may be because of tight fitting of lenses, or it may be related to increase in dryness of the lenses with the eye.

2.Corneal Ulcer

Over wear of lenses, improper cleaning of lenses leads to surface breakdown

3. Corneal swelling

Cornea becomes smothered by the lenses.

4. Eye redness

uestions??

What is importance of Tribology in medical devices or biological components ?

s: Many medical devices are involved with relative moving parts, either in contact to the native tissues o
thin the biomaterials, and often under loading. Important issues, such as friction and wear of the movin
rts, Lubrication will not only affect the functions of these devices but also the potential adverse effects
e natural tissues.

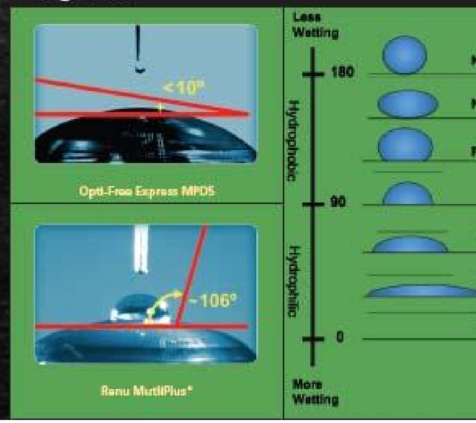
What is the importance of lubrication in contact lens ?

s: Lubrication between the contact lens and the eye is critically important. Fluid film lubrication in the
esence of the tear film ensures minimum friction, minimum Shear stress, smooth motion and negligible
mage in the eye during blinking.

Brief about Wettability of contact lens ?

s: "Wettability" refers to the ability of the tear film to cover and maintain itself
er the contact lens surface and is used to characterize the adherence of fluid
the lens surface. Wettability is determined by measuring the contact angle;
e smaller the contact angle the greater the wettability and vice-versa.

Figure 3



SPHERICALLY CAPPED MEMBRANE PROBES FOR LOW CONTACT PRESSURE TRIBOLOGY

Clint Antony 131501008
09/04/2018

Introduction

- Low contact pressure measurements are needed for biotribology studies on cells, cell layers, and tissues.
- Such studies typically require low forces to achieve kPa range contact pressures, but such methods frequently come at the expense of contact area and, in turn, relevance.
- In seeking lower contact pressures, the corresponding contact areas can become too small to be physiologically relevant or important.
- This method creates probes that are thin spherical shells, specifically designed to create low contact pressures.

Application

- The cornea is made up of moist epithelial cells that form a thin stratified layer on the exterior surface of the eye. This layer is protected by a mucinated aqueous tear film, and both vision and ocular health are
dependent upon the stability of the tear film.

- Under conditions of contact lens use, disruption of the tear film can lead to discomfort and cell damage .

- Contact lens design and material selection balances contact pressure and lubricity in an effort to maintain comfort and function over a wide range of sliding conditions during ocular movements while minimizing damage to the epithelia .

- The contact pressures exerted on the cornea by the eyelid are estimated to be 1 –5 kPa and may increase to 12 –18 kPa with the inclusion of a soft hydrogel-based contact lens.

- Matching the contact pressure conditions is essential for in vivo, ex vivo, and in vitro studies that aim to collect physiologically relevant friction measurements

Constraints

- In vitro biotribological experiments using a spherical probe sliding against a cellular monolayer are desirable for in situ studies.
- However, even the softest hydrogel materials have been observed to severely damage the cellular monolayer during sliding due to high contact pressures that result from the Hertzian mechanics of a solid spherical probe.
- As an example, a hydrogel probe with an elastic modulus on the order of 20 kPa and a diameter of a few millimeters can routinely produce contact pressures in excess of 10 kPa at normal loads below 500 μN .
- For cells grown in culture, setup of in situ experiments often involves metrology that is not optimal for high-precision tribological experiments, and small misalignments in setup over long sliding distances can cause large variations in contact pressure.

Geometry Adopted

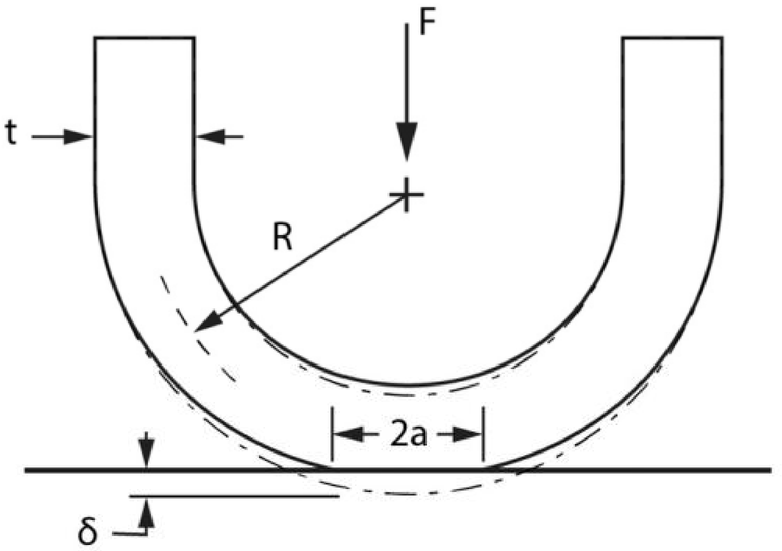


Fig. 1. Schematic of the spherical shell probe with thickness t and radius R. The probe is pressed against a glass-bottom culture dish with a normal force F, and with the resulting contact width $2a$. The deflection of the probe tip is given by δ.

- This geometry capitalizes on the mechanics of the geometry such that, at low forces (µN) and strains, the contact pressure is predicted and found to be constant and independent of the applied load.
- Such a probe allows the contact area to fluctuate with variations in applied load without changing the average contact pressure.

Material Preparation

Method 1- Casting in a Mold:

- Molding is done using standardised polymerisation technique with 1mm nylon rod inserted into the mold.
- Probes were made of 7.5% (w/w) polyacrylamide and were doped with 25 nm green fluorescent beads prior to polymerization.
- The embedded fluorescent beads allowed the probes to be imaged
  by a confocal microscope when submerged in water.
- Elasticity Modulus of approximately 20 kPa.
- The rod and probe were then removed from the mold and the molded probe was fitted to a nylon fastener

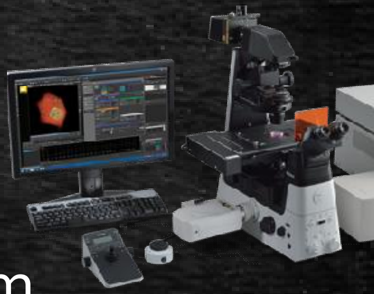
Material Preparation

Method 2- 3D Printing in a soft granular microgel media liquid-like Solid (LLS)

- Used polyethylene glycol (PEG) hydrogel.
- PEG hydrogels were prepared at
  - ~11 wt% poly(ethylene glycol) acrylate monomethyl ether
  - ~2.5 wt% poly(ethylene glycol) diacrylate concentration in ultrapure water (18.2 M Ω)
  - less than 0.05 wt% Irgacure D-2959 was added as an ultraviolet (UV) photoinitiator.
- The probe was printed in a microgel medium made of 0.1% ETD2020 carbomer suspended in ultrapure water. A steel needle with a 190 µm inner diameter was used for printing, and the resulting printed probes were cured for 5 min under UV illumination.
- The probe was removed from LLS media, swelled to equilibrium in ultrapure water for 24 h.

Procedure

- Indentations were performed on a custom micro-indenter described in Schulze et al. attached to a Nikon C2 Eclipse Ti confocal laser scanning microscope.



- Z- stack:1300 µm × 1300 µm × approximately 2 mm
- The hydrogel probe was then loaded against a glass-bottom culture dish coated with Pluronic® F-127 to minimize adhesion effects under submerged conditions (Fig. 2b).
- The applied load was monotonically increased from 50 µN to 1000 µN through load-controlled, closed-loop feedback control.
- At each discrete indentation load, confocal imaging with fluorescein isothiocyanate filtering was used to reconstruct a 3D representation of the deformation and contact area using the embedded fluorescent green particles

Observations

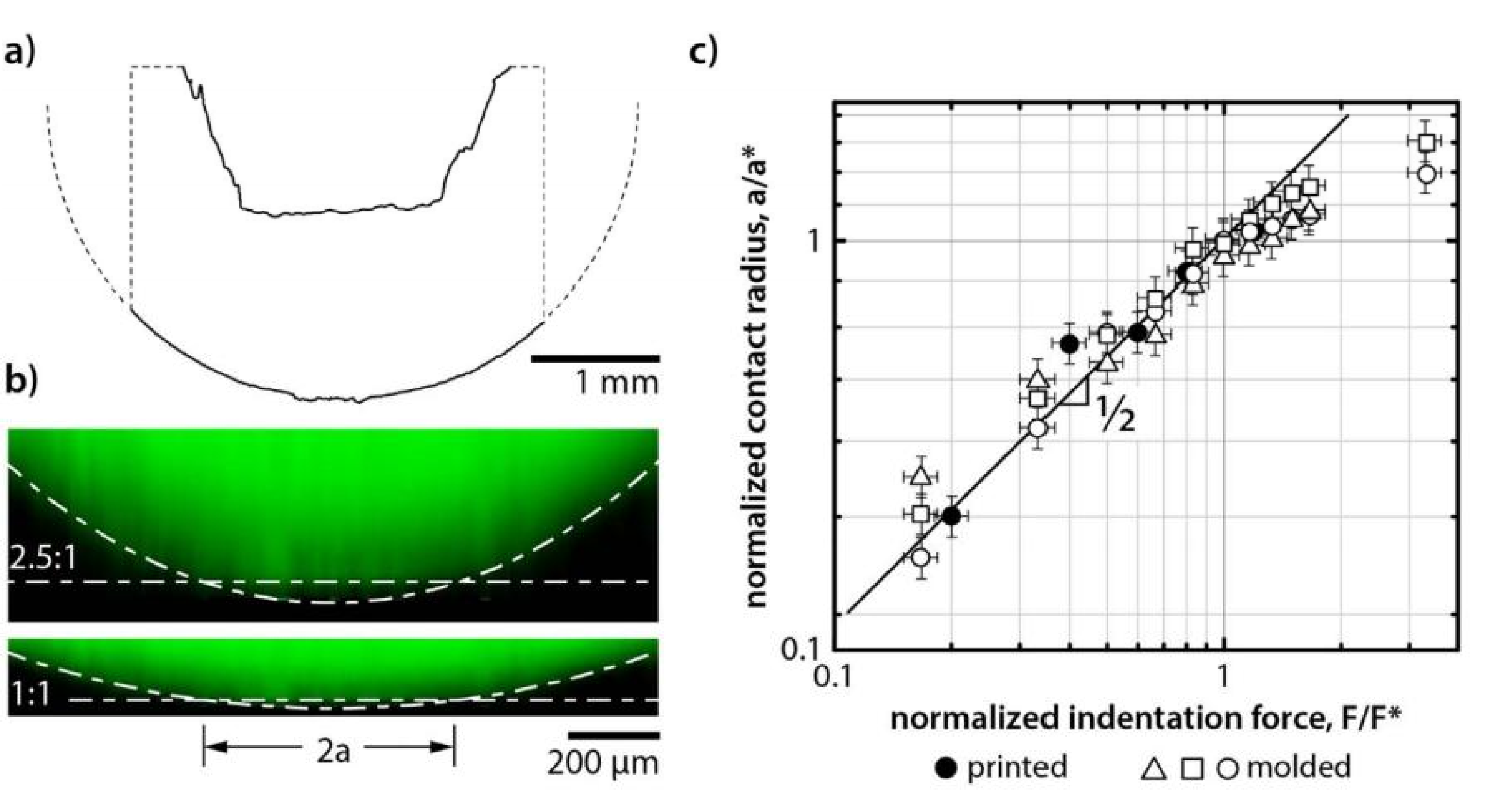


Fig. 2. (a) Line profile of a molded spherical shell probe from a confocal 3D reconstruction. (b) Confocal imaging of a probe (E ~ 20 kPa) indenting a glass surface under 250 μN of load. The contact region is shown. The hydrogel contains fluorescent beads to allow imaging. (c) Log-log plot of normalized indentation force F/F^* *versus* the normalized contact radius a/a^*. Before a critical point, the probe acts as a gentle, constant pressure interface dictated by its elastic modulus. Exceeding this normal force, the spherical shell probe no longer acts as a constant pressure system.

Calculation

- Roark's analysis of a simply supported circular plate along the edge with a point load gives the maximum deflection δ as shown by:

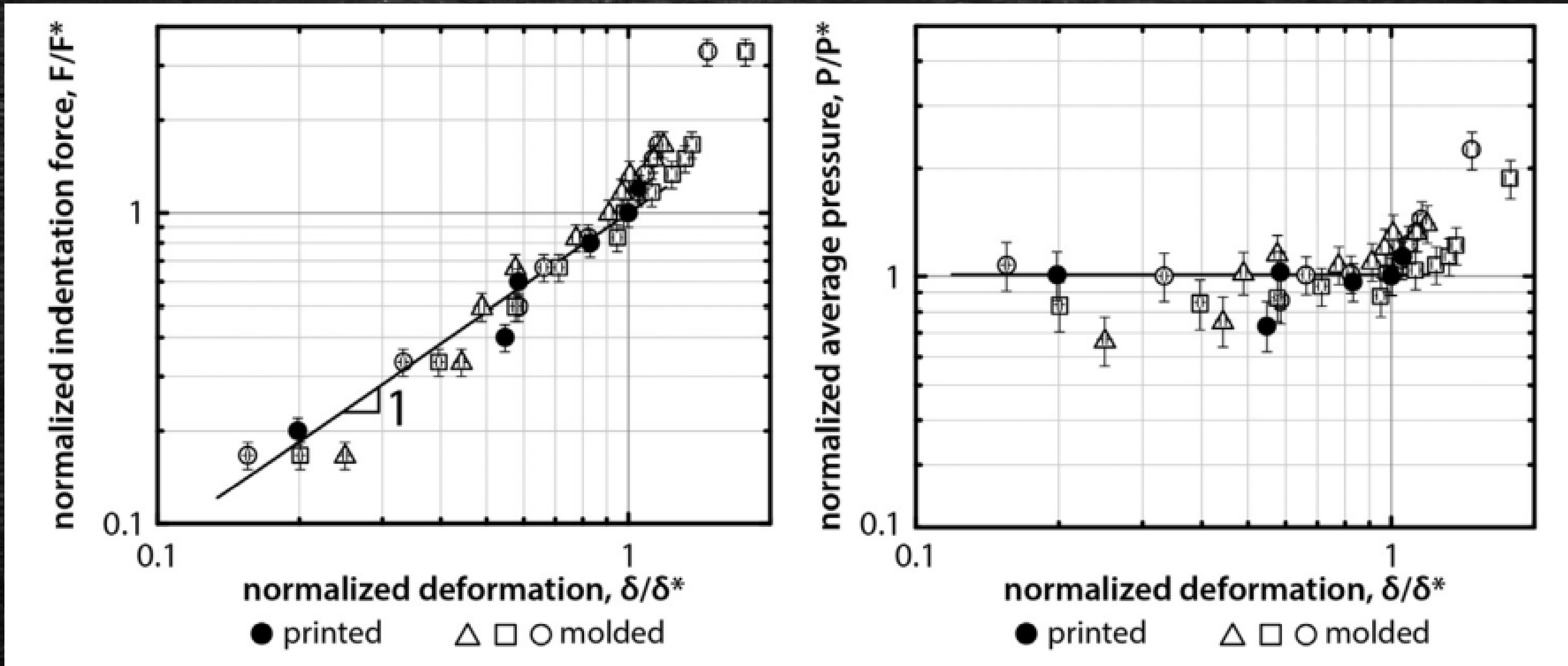
$$\delta = \frac{FR}{4\pi E t^2} \cdot 3(1-\nu^2)$$

  where F is the force, R is the radius of curvature, E is the elastic modulus, t is the thickness of the spherical shell, and ν is the Poisson ratio.

- Pressure is independent of contact area.

$$P \propto E\left(\frac{t}{R}\right)^2$$

Results



normalized indentation force, F/F*
1
0.1
0.1
1
1
normalized deformation, δ/δ*
● printed
△ □ ○ molded
normalized average pressure, P/P*
1
0.1
0.1
1
normalized deformation, δ/δ*
● printed
△ □ ○ molded

Result:

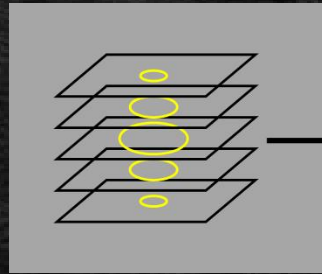
- Pressure is independent of the applied force and the contact area (under low deformation) which has been proved theoretically and experimentally.
- Low contact pressures were achieved. At the critical force of 300μN (for molded) and 250μN (for 3D printed) and critical radius of 300μm, the contact pressure was less than 2kpa.
- Usage of this technique can avoid pressure variation.

Questions

- What is the advantage of using shell structured probe?

  The shell structured probe can produce very low contact stresses by controlling its geometric parameters alone and is independent of the applied load and contact area for low loads.

- What is meant by z – stack?



  By recording images at different focal planes the entire sample volume can be rendered and visualized. These images constitute a Z-stack (see fig). These “Z stacks” are generated by incrementally stepping through a sample using a focal drive. These images are then processed to give a higher depth to the image.

Current Research

- Currently, biotribology is one of the most exciting and rapidly growing areas of tribology.
- Here a short review of the current status of biotribology research and highlights future directions are discussed.
- Three specific examples of biotribology research are considered; joint, skin and dental, while other areas are briefly discussed.

- As of 7th February 2015 a total counts of 422

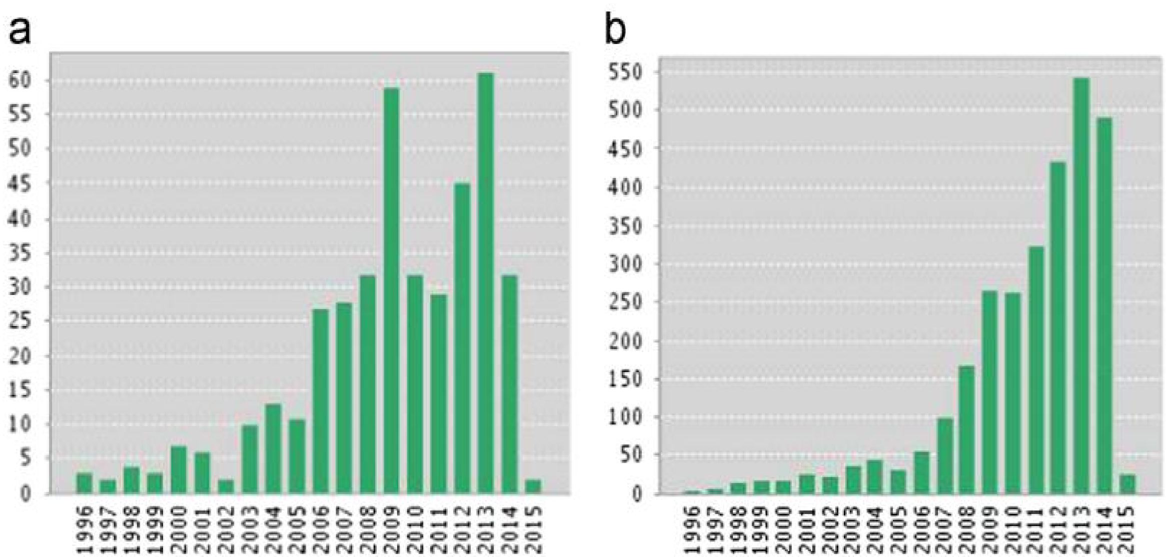


Fig. 1. Number of counts (a) and number of citations (b) in the last 20 years, searched on Web of Science, using topic (TS) as (BIOTRIBOLO* or BIO-TRIBOLO*), on 7 February, 2015.

Current Research

- In addition, about 10 scientific books or edited volumes such as:
  - Advance in Medical Tribology,
  - Human Joints and Their Artificial Replacements,
  - Bioengineering of the Skin,
  - Biological Micro- and Nano-tribology,
  - Dental Biotribology

have been written on this subject since the 1970s

Current Research

- A number of international forums, workshops and symposia have been held on biotribology or related to biotribology. For example, in 1967, the symposium on Lubrication and Wear in Living and Artificial Human Joints was arranged and held in London by the Institution of Mechanical Engineers in collaboration with the British Orthopaedic Association, which attracted over 160 delegates (The Institution of Mechanical Engineers 1967).
- In 1996, are port from a workshop on dental tribology by Lloyd et al was published. Eighty delegates contributed to a valuable discussion, the purpose of which was to bring together tribologists , clinicians and dental material scientists to gather to discuss the fundamental mechanisms of wear and how to obtain manifestations and conduct measurements of wear in dentistry.

Classifications and focuses of current research

- Generally categorised as:

Table 1
Classifications of representative biotribology research and associated research focuses.

Classification type	Major investigations
Joint tribology	Hip joint; knee joint; articular cartilage; joint fluid; restorative materials of joints; implant interfaces; etc.
Skin tribology	Skin friction-induced perception; skin care; synthetic skin; skin in contact with articles (such as tactile texture, shaving devices, shoes, socks) for daily use, various medical as well as sport devices, medical and cosmetic treatment; skin friction and grip of objects; skin irritation and discomfort; etc.
Oral tribology	Natural teeth; tongue; mandibular joints; saliva; implant teeth; toothpaste; swallow; dental restorative materials; etc.
Tribology of the other human bodies or tissues	Hairs; bone; cells; contact lenses; ocular surfaces; capillary blood flow; etc.
Medical devices	Scalpel; operation forceps; urinary catherters; gastroscope, artificial cardiovascular system; medical gloves; etc.
Animal tribology	Gecko adhesion; animal locomotion; pangolin scale; skin of fish and shark; feather of birds; water strider; earthworm; ants; beetle, butterfly's wing; seashell; snails; etc.
Plant tribology	Lotus leaf; diatoms; etc.

Important Topics:

Table 2
Topics and number of presentations from two international conferences on Biotribology (ICoBT 2011 and 2013).

	Number of presentations ICoBT 2011	**Number of presentations ICoBT 2013**
Joint tribology	47	48
Skin tribology	26	13
Oral tribology	10	11
Tribology of the other human bodies or tissues	18	11
Medical Devices	4	2
Animal Tribology	0	4
Others: review, etc	10	16
Total number of oral presentations	**115**	**105**

References:

- Spherically Capped Membrane Probes For Low Contact Pressure Tribology by
  Samantha L. Marshalla, Kyle D. Schulzea, Samuel M. Harta, Juan Manuel Urueñaa, Eric O. McGheea, Alexander I. Bennetta, Angela A. Pitenisa, Christopher S. O'Bryana, Thomas E. Angelinia, W. Gregory Sawyer

- Biotribology: Recent progresses and future perspectives by
  Z.R. Zhoua,n, Z.M. Jin

- Cartilage and joint Lubrication: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2758165/

- Ocular: https://www.clspectrum.com/supplements/2013/june-2013/the-world-x0027;s-first-and-only-water-gradient-c/font-color-000000-special-edition-2013-font-(9), https://www.clspectrum.com/supplements/2011/september-2011/special-edition-2011/font-color-000000-special-edition-2011-font-(10).

- Shoulder: https://www.sciencedirect.com/science/article/pii/S2352573817300495.