Taking a PEEK at cartilage resurfacing

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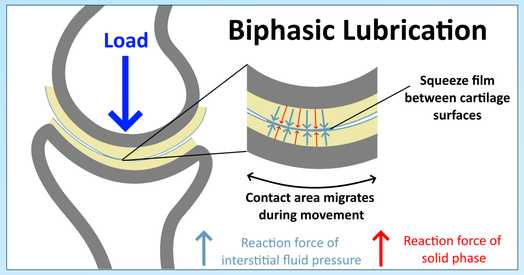
1. Introduction

By 2030 it is predicted up to **half of total joint replacement recipients will be aged 65** or under, and for many in this age group (up to 20%) the **implants will fail in their lifetime,** requiring costly revision surgeries with poorer functional prognosis[1].

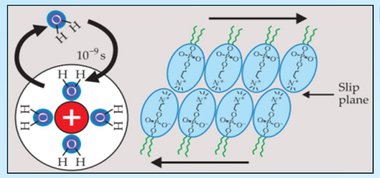
Articulating surfaces of natural synovial joints are covered with soft and hydrated articular cartilage – **a natural bearing unparalleled by engineered materials**. Synovial lubrication is multimodal, combining:

Biphasic Lubrication



Sustained fluid film lubrication and interstitial water pressure bears up to 90% of the load.

Hydration Lubrication

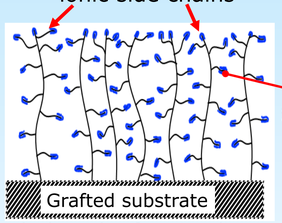


Hydrated macromolecules in synovial fluid act as highly efficient boundary lubricants enabled by hydration lubrication.

H_2O molecules behave fluidly and exchange rapidly under shear to dissipate friction[2]

2. Biomimetic soft lubrication

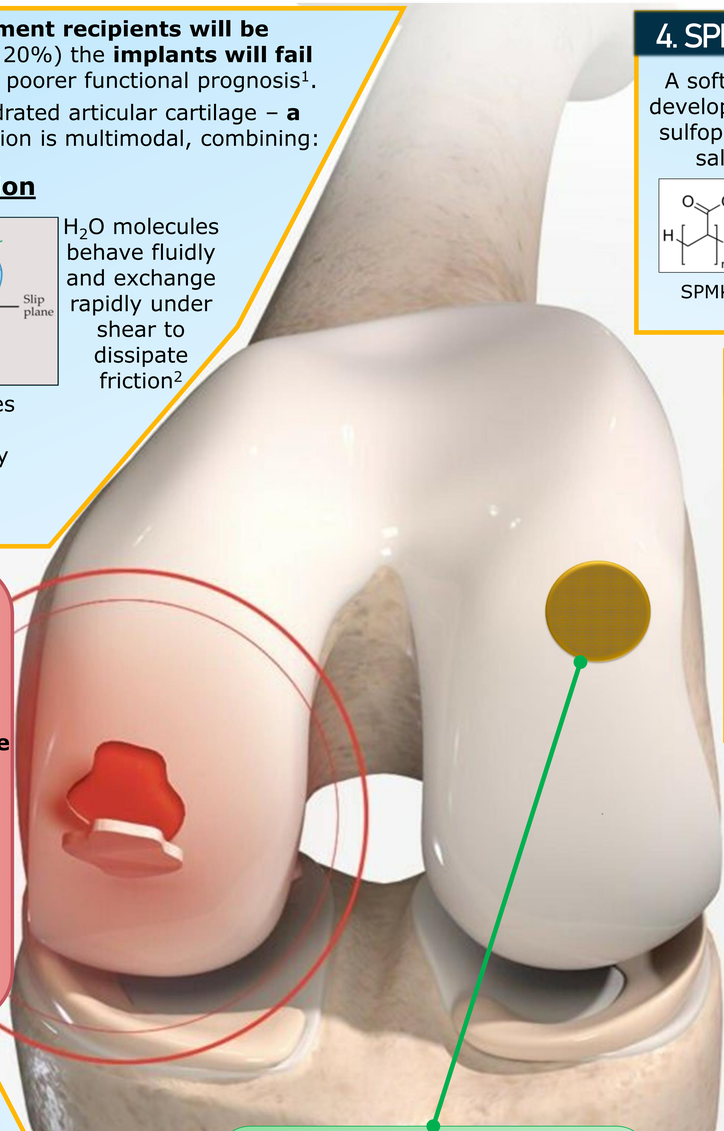
Poly-electrolyte functionalised surfaces can be tuned to **mimic the natural biphasic and hydration lubrication** modes of synovial joints.



Polyelectrolye functionalisation

New materials are required for younger patients who otherwise face total knee replacements to:

- **Replace focal cartilage defects and preserve bone**
- **Support natural cartilage function and health**
- **Provide immediately load bearing implants**
- **Fill treatment gap for patients unsuitable for tissue scaffolds**



Soft cartilage repair plugs:

- ✓ **Maintain healthy joint function and tribology**
- ✓ **Minimise strain and wear on mating cartilage**

3. Samples and methods

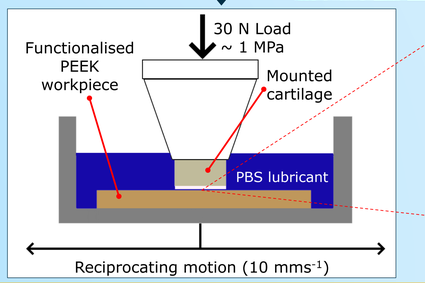
Polished PEEK samples are functionalised via UV self initiated grafting-from photpolymerisation

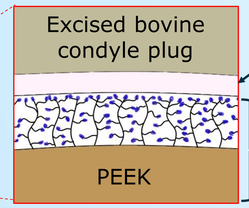
Having a butchers: Extraction of cartilage plugs from bovine femoral condyles

Pin-on-plate (Bruker UMT)
Test regime:

10 mms-1
20 mm stroke
30 N Load
~ 1 MPa pressure
2.5 hours

✓ Gait-like parameters





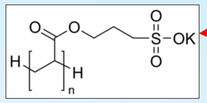
Hydrated cartilage layer

Functionalised SPMK-PEEK

Hydrated sliding interface
Polyelectrolyte (SPMK) is swollen in PBS

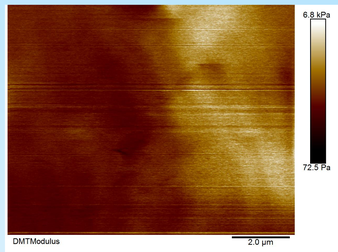
4. SPMK functionalised surfaces

A soft lubrication coating has been developed by grafting **SPMK** (poly(3-sulfopropyl methacrylate potassium salt)) onto a PEEK substrate.



SPMK monomer

Hydrophilic sulfonic acid anionic functional group

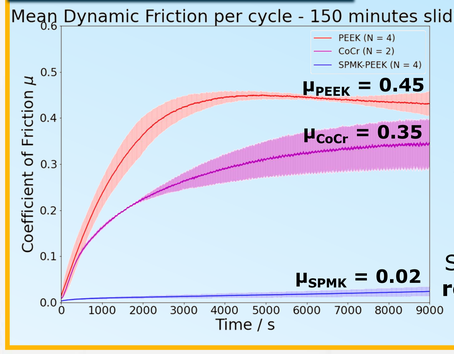


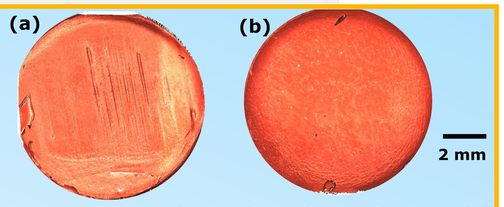
Nanomechanical AFM showing elastic (DMT) modulus of SPMK-PEEK in H_2O

Low SPMK water contact angle (< 20 °)

- ✓ Highly **hydrated**
- ✓ **Low elastic modulus** (~ 10^1 kPA) and can support loads akin to those in joints

5. Friction Measurements

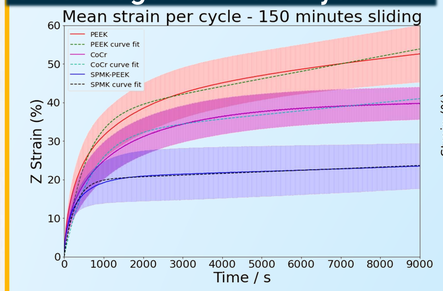


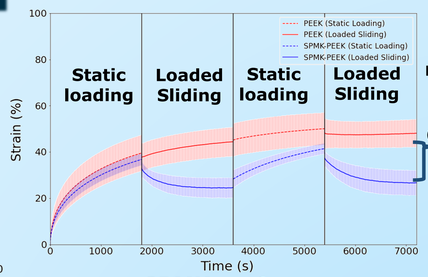


Accutrans images showing cartilage plug surface post 2.5 hour sliding test. **(a)** notable wear on cartilage sliding against PEEK **(b)** no wear observed for SPMK-PEEK

SPMK surfaces **minimises surface damage and reduces shear force on the cartilage plugs by over 95%** compared to untreated PEEK.

6. Cartilage strain and hydration





Dynamic rehydration recovery

Over 40% of compressed cartilage height recovered

$$\text{Strain}(t) = m(1 - e^{-\tau t}) + bt$$

One phase exponential for cartilage biphasic creep time constant (τ)

Observed linear strain response

	Final Strain %	T: Time Constant s^{-1}	b: Linear Increase
PEEK	53	523	1.9 x10^{-3}
CoCr	38.8	268	1.0 x10^{-3}
SPMK-PEEK	23.5	653	0.4 x10^{-3}

Table: Fitted cartilage strain function parameters

SPMK surfaces promote and maintain cartilage hydration

- SPMK surfaces exhibited the lowest total strain and strain rate
- Low strain rate is attributed to SPMK effectively aiding cartilage rehydration
- Sliding induced cartilage rehydration has been observed without requiring a convergent wedge model

7. Conclusions

SPMK-PEEK maintains cartilage health, reduces tissue damage, and minimises friction:

- ✓ Exploiting natural synovial biphasic and hydration biotribology
- ✓ Reducing damage to cartilage compared to untreated biomaterials
- ✓ Minimising shear stress and strain to preserve cartilage health
- ✓ Maintaining the hydration state and natural function of cartilage

Functionalised Cartilage Plug

1. Bayliss, Lee E., et al. "The effect of patient age at intervention on risk of implant revision after total replacement of the hip or knee: a population-based cohort study." *The Lancet* 389.10077 (2017): 1424-1430. 2. Klein, Jacob. "Hydration lubrication." *Friction* 1.1 (2013): 1-23.