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Creating hydrodynamic lubrication in metal-on-polyethylene hip joints using surface microtexture

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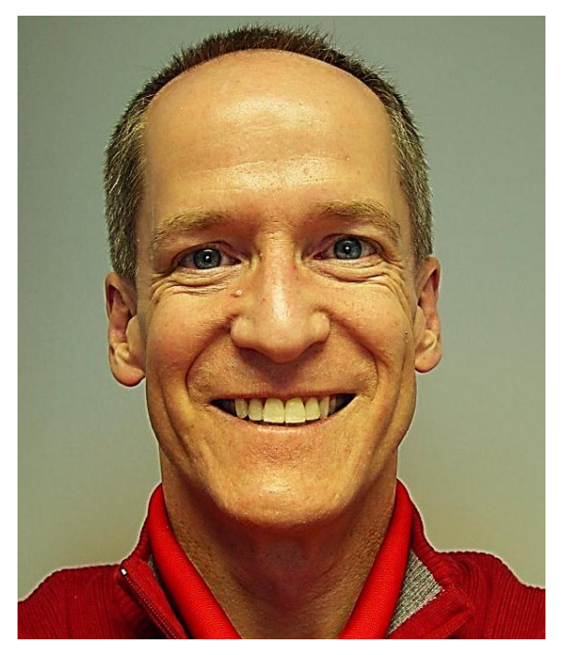
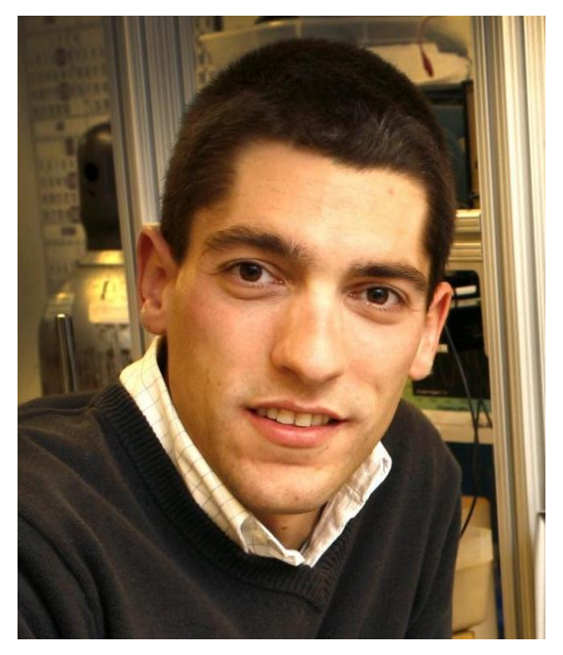

Anthony Sanders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INTRODUCTION

Problem

More than 200,000 total hip replacement (THR) surgeries are performed in the US each year. Presently, the statistical survivorship of these implants declines dramatically after 10 years of use. This lack of durability has unacceptable effects, such as riskier revision surgery or surgery postponement with its attendant pain and disability, which are rooted in the same cause: wear. Even short term wear can cause inflammatory reaction, tissue necrosis, osteolysis, and instability caused by wear debris.

Scope

This research focuses on the metal-on-polyethylene (MOP) bearing type, which is most commonly used in the US.

Background

Microtexturing is a well-known approach to create hydrodynamic lubrication, resulting in substantial reductions in friction and wear. The microtexture is manufactured using laser surface texturing (LST) and forms a dense array of dimples which compresses the natural lubricant in the joint (synovial fluid). This increase in pressure increases the separation between the sliding surfaces (Fig. 1), which induces hydrodynamic lubrication between the sliding surfaces at a reduced sliding velocity compared to an untextured bearing surface, thus reducing friction and wear.

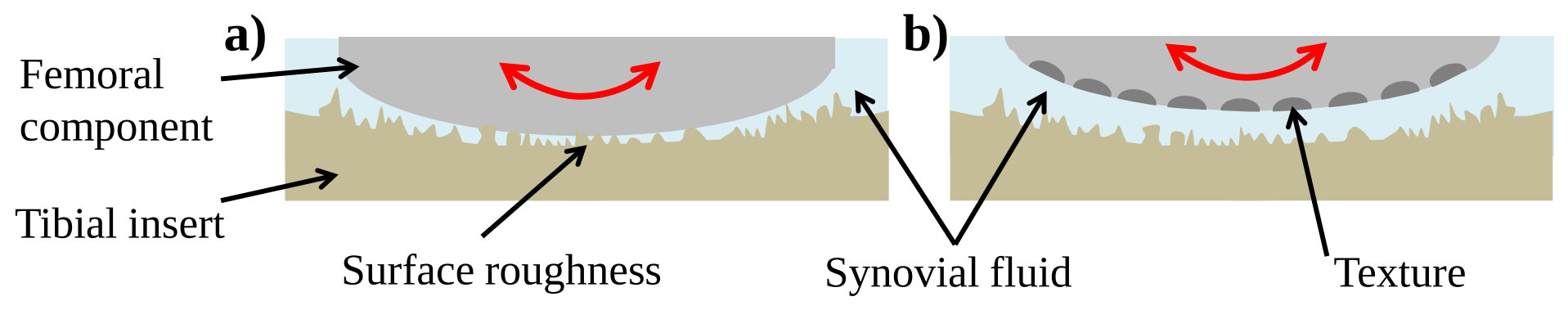

Fig. 1 Sliding interface (a) without and (b) with microtexture

Objective

The current engineering paradigm for femoral head design is to manufacture ever smoother surfaces. This research aims to break this paradigm and attempts to achieve hydrodynamic lubrication in MOP hips by adding microtexture to the smooth bearing surface (Fig. 2).

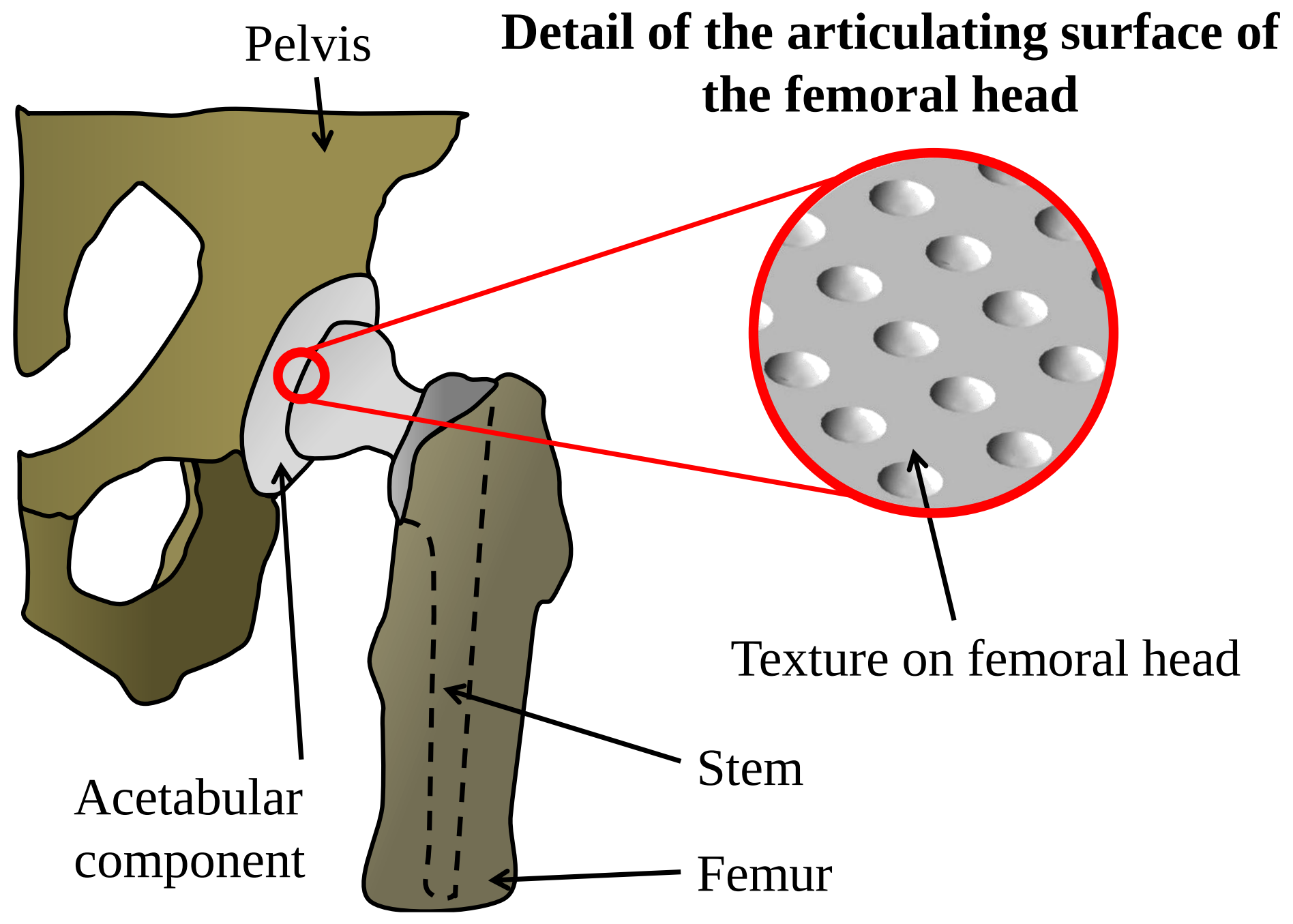

Fig. 2 THR with microtexture on femoral head

METHODS & MATERIALS

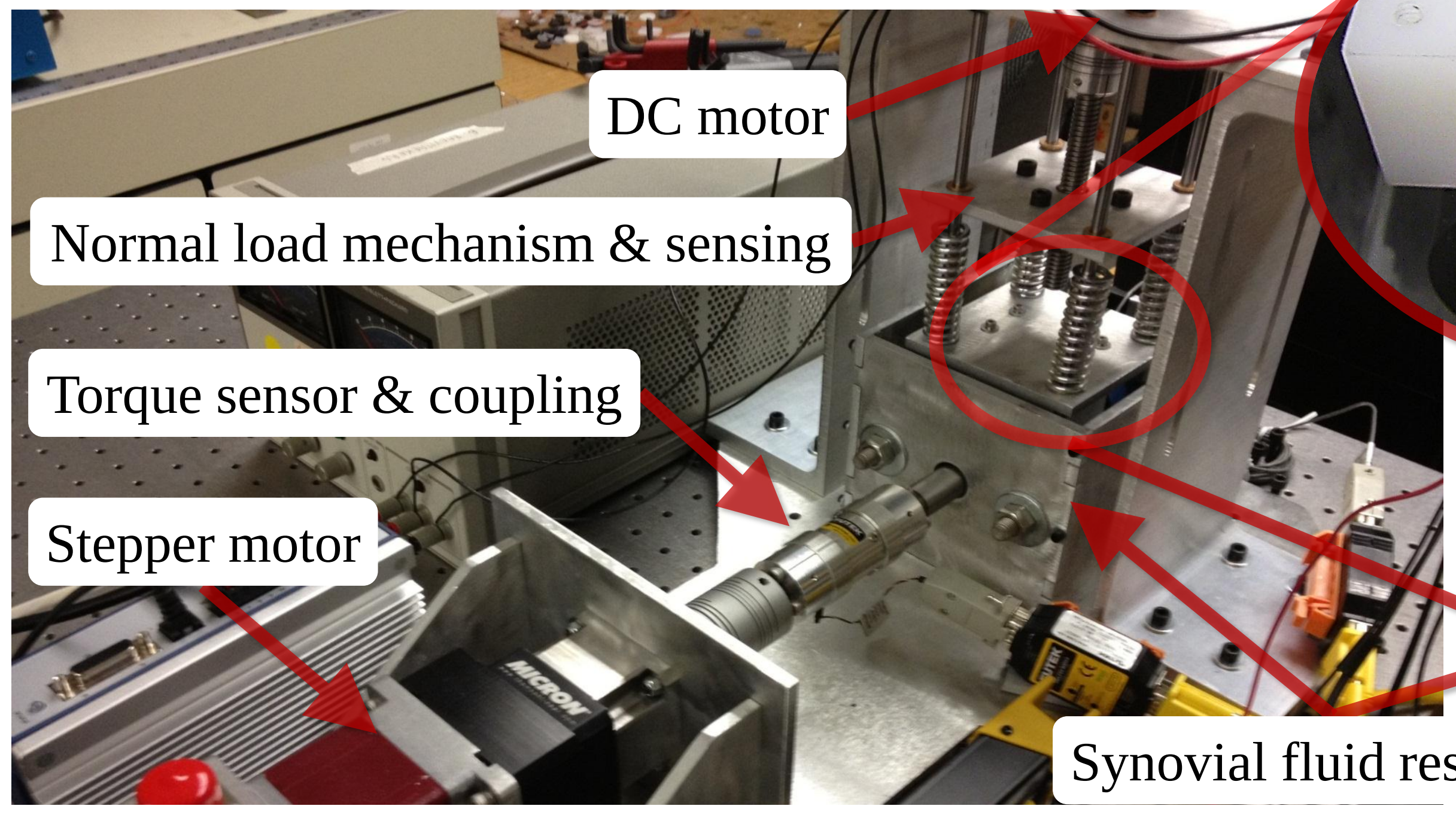

Fig. 3 Experimental apparatus

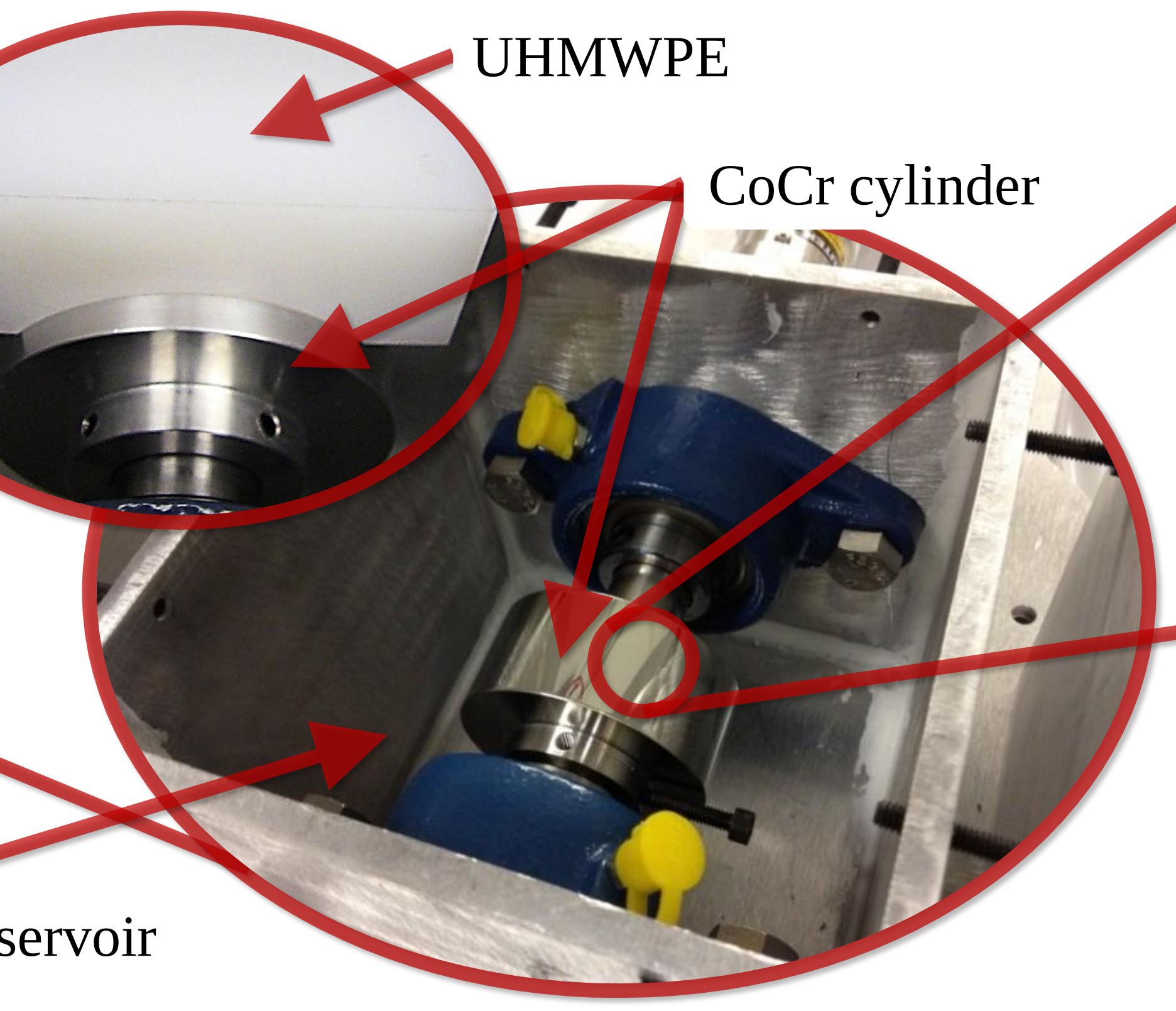

Fig. 4 CoCr cylinder and UHMWPE in reservoir

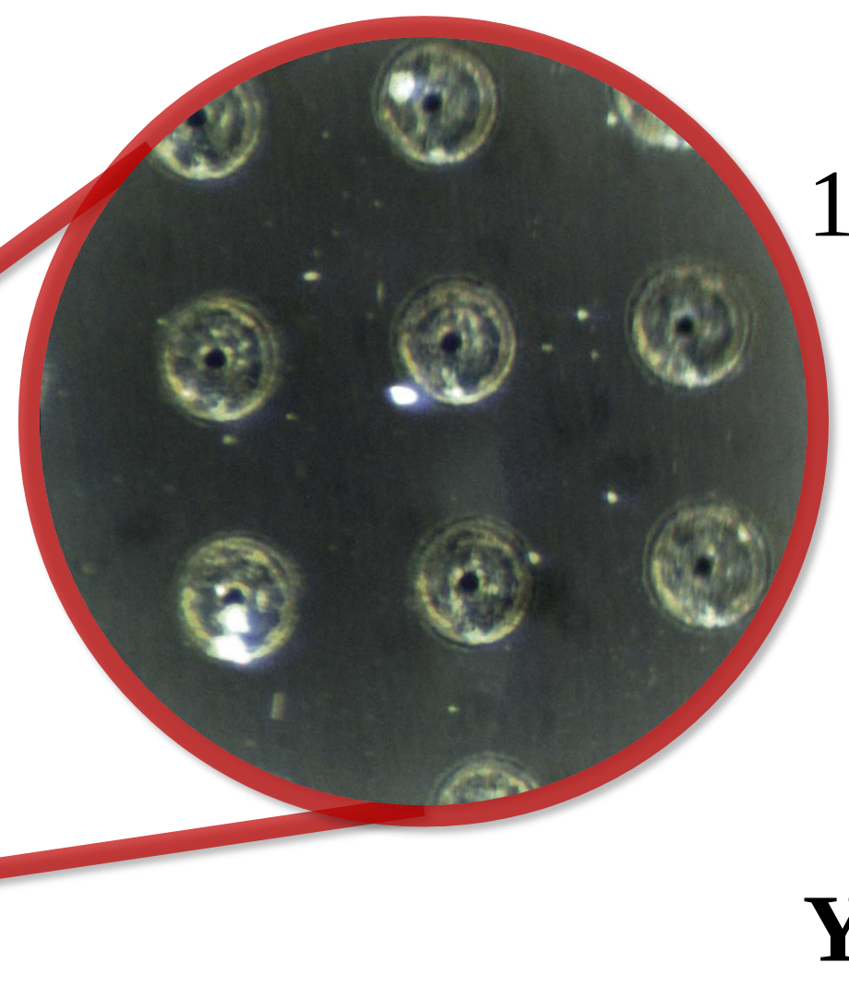

Fig. 5 Microtexture (optical microscopy)

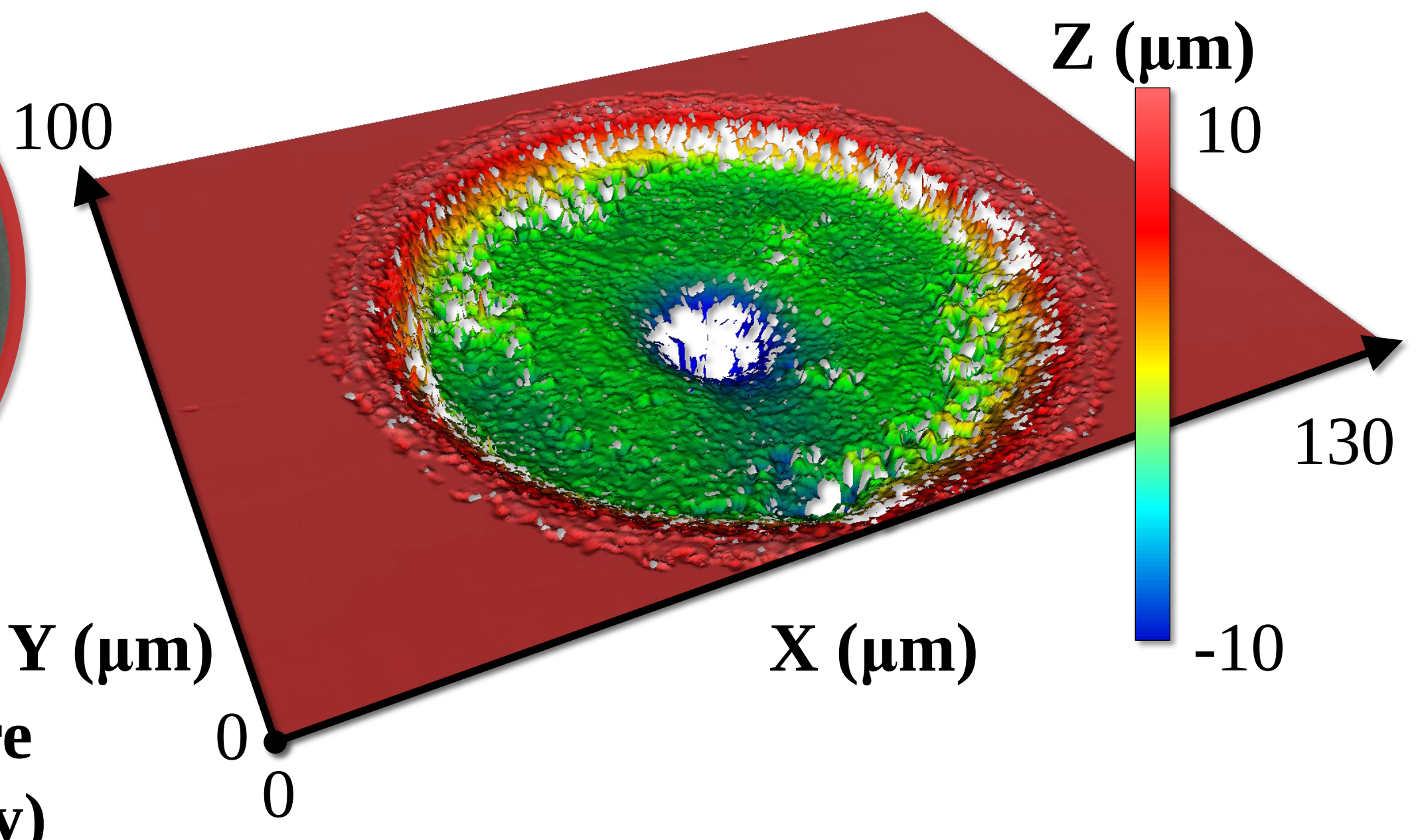

Fig. 6 Single dimple 3-D topography (white light interferometry)

Experimental apparatus

The platform comprises a convex CoCr cylinder (ASTM F1537-08) mated against a concave, EtO-sterilized Ultra High Molecular Weight PolyEthylene (UHMWPE) cylinder (ASTM F648) (Fig. 4). The CoCr cylinder is mounted on the shaft of a computer-controlled stepper motor (Fig. 3) that creates a sliding motion between the CoCr and UHMWPE parts (Fig. 7).

Experimental protocol

- A textured CoCr cylinder is mounted in the apparatus (Figs. 5, 6).
- The contact interface is lubricated with bovine serum, an analog for synovial fluid (17.5 g/l protein concentration according to ISO 14242-1).
- The reciprocating sliding motion mimics gait (Fig. 7).
- The normal load N and tangential load F_w are continuously measured (Fig. 7), and the friction coefficient is calculated as F_w/N.

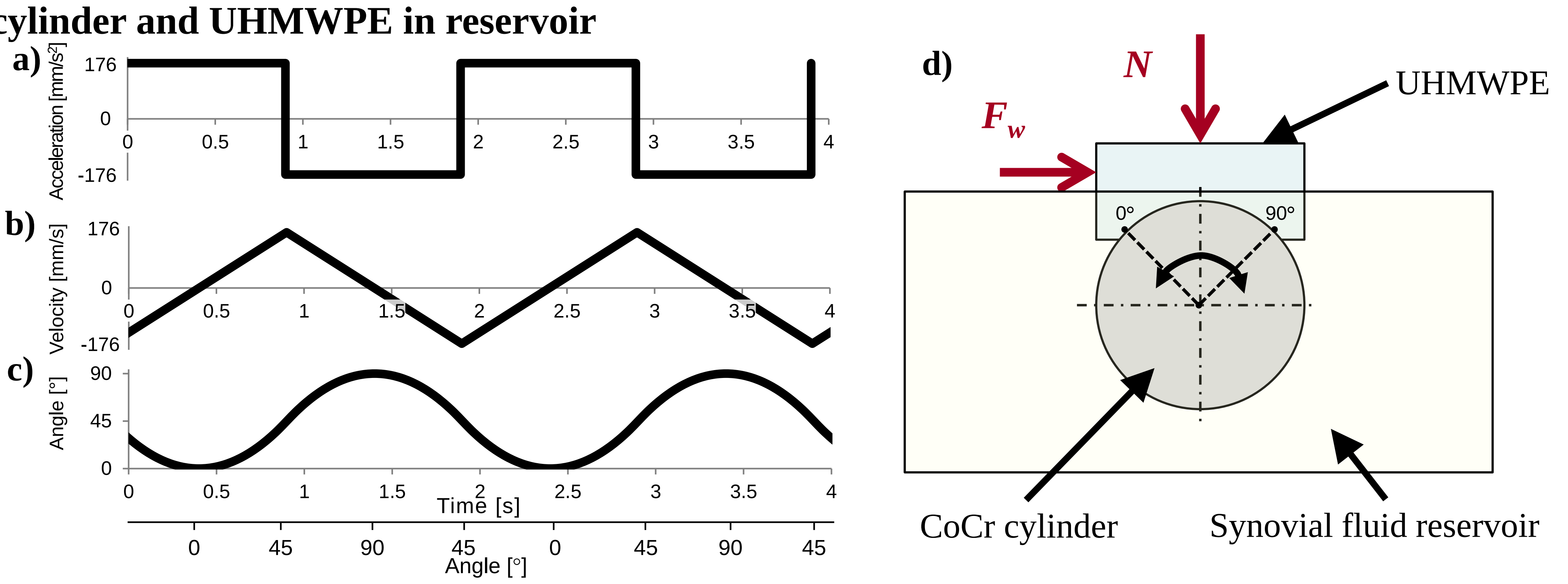

Fig. 7 CoCr cylinder experimental protocol: (a) acceleration at surface, (b) velocity at surface, (c) angle, (d) schematic

RESULTS

Simulation

The pressure $p(x,y,t)$ in the bearing between the tibial insert and the textured femoral component is simulated using the incompressible two-dimensional Reynolds equation:

$$\frac{\partial}{\partial x}\left(h^3\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(h^3\frac{\partial p}{\partial y}\right)=6\mu_a U(t)\frac{\partial h}{\partial x}+12\mu_a\frac{\partial h}{\partial t}$$

$h(x,y,t)$: local spacing height between the bearing surfaces

$U(t)$: relative sliding velocity between the bearing surfaces

μ_a: fluid absolute viscosity

x, y: Spatial coordinates

A textured femoral component can be simulated by just one column of several dimples, because the pressure becomes periodic over a set of dimples, and boundary effects disappear quickly. A model containing a column of ten dimples is used to optimize the microtexture.

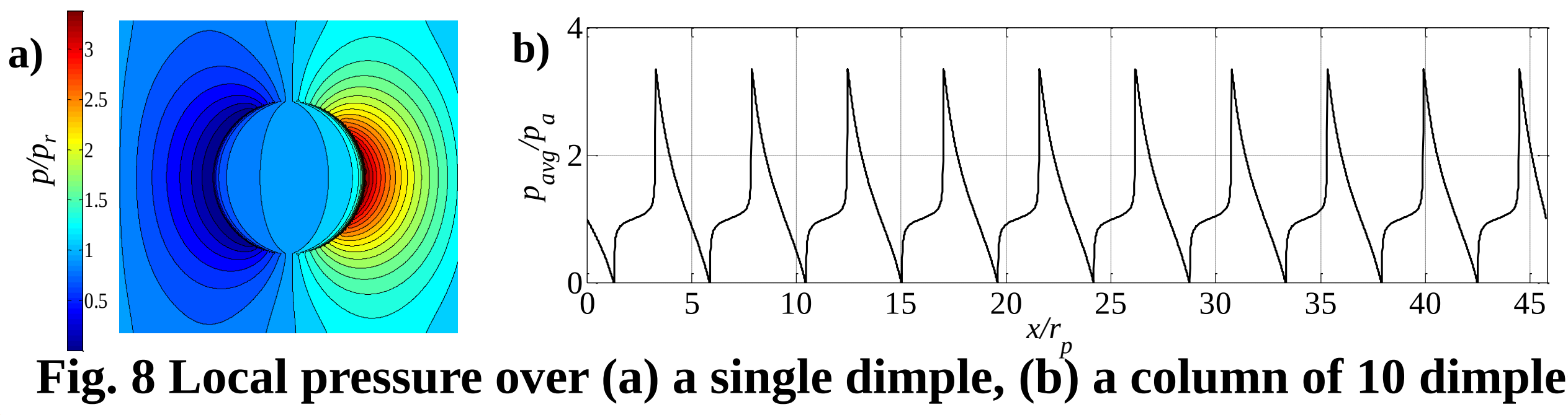

Fig. 8 Local pressure over (a) a single dimple, (b) a column of 10 dimples.

Experiment

The ratio of the friction coefficient and the static friction coefficient for the textured and smooth (average roughness 50 nm per ISO 7206-2) CoCr cylinders is shown in Fig. 9:

- A sharp drop in the normalized friction coefficient after the onset of sliding is observed for the textured CoCr cylinder compared to the smooth CoCr cylinder (e.g. green circles).
- A larger portion of the gait cycle operates in hydrodynamic lubrication for the textured CoCr cylinder.
- The reduction in friction promises reduced wear.
- Wear reduction guarantees more durable implants.

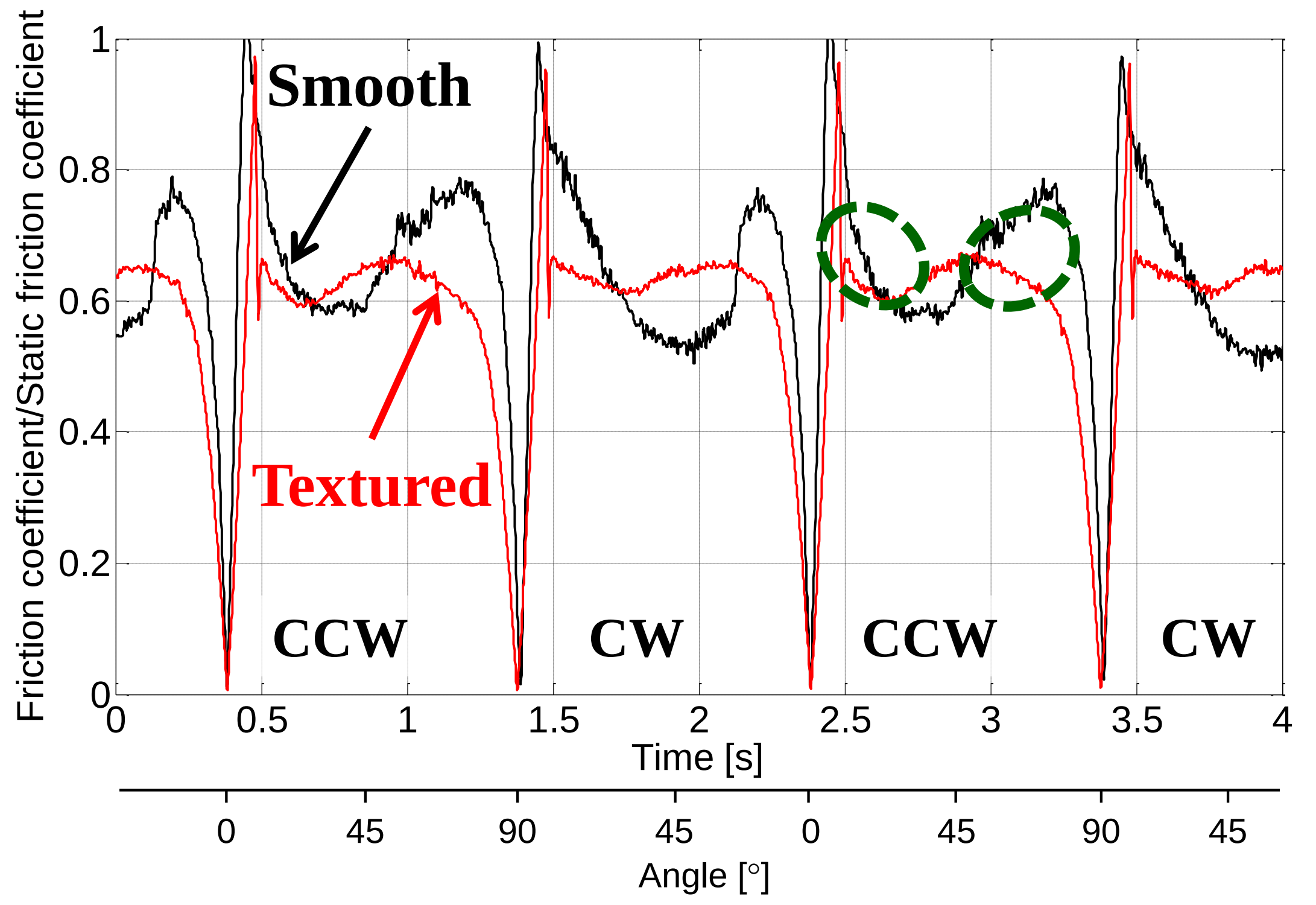

Fig. 9 Normalized friction coefficient versus time and angle

CONCLUSIONS

- The results suggest that with the microtexture, hydrodynamic lubrication is established earlier in the cycle, at a lower sliding speed, and thus is maintained over a larger portion of the gait cycle.
- It is especially important that the texture reduces friction during the start and stop phases because daily human hip joint activities include frequent starts/stops, and it is during those typically high-friction periods that most wear tends to occur.

FUTURE RESEARCH

In future research, the patterned microtexture will be optimized in terms of maximizing bearing pressure using the model discussed. Further experiments will validate the model, and provide proof of friction reduction over the entire hip gait cycle resulting from microtexture.

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