Rheological and Tribological Characterization of Different Lubricants and Model Fluids for In Vitro Implant Stability Testing

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ABSTRACT

The mechanical stability of implants is essential for their functional performance and long-term success. Reliable *in vitro* methods are needed to predict implant stability under controlled and reproducible conditions. This study investigates motor oil-based model systems for implant stability testing, complemented by greases and aqueous/biological-like fluids. Rheological and tribological tests were used to characterize flow behavior, viscosity, friction, and lubrication under implant-relevant conditions. The results demonstrate that motor oil-based systems provide high reproducibility and controllability, while greases and aqueous media offer complementary representations of viscoelastic and physiological conditions. Overall, the study proposes a framework for selecting and tailoring model lubricants to improve the standardization and predictability of in vitro implant stability testing. These systems also provide a cost-effective alternative to biological testing media.

MATERIALS & METHODS

TRIBOLOGICAL MEASUREMENTS

- Anton Paar MCR 302 rheometer
- Ball-on-three-pins geometry
- Sliding speed of the ball: 1·10-8 m/s–0.1 m/s
- Tribological normal force (FN): 5 N

Friction force:

$F_f = \frac{M}{3 \cdot R \cdot \sin \alpha}$, where R is the ball radius and α is the angle of the pins relative to the direction of the normal force (45°).

Tribological normal force: $F_{N;tribo} = \frac{F_N}{3 \cdot \sin \alpha}$

Coefficient of friction: $\mu = \frac{F_f}{F_{N;tribo}}$

Sample code	Designation
HLP-46	WSW Proding Hydro HLP-46
NaCl 0.9 wt.%	Sodium chloride 0.9% 100ml
I5W-40	CASTROL GTX I5W-40
Silicone Spray	Mannol Silicone Spray 9953 200ml
WD-40	WD-40 Route 66 300ml
SBF A & SBF B	Mixture of SBF A and SBF B solution
WSW Lithium	WSW Lithium EP-2 Blue
Vaselinium album	Vaselinium album (External) 50g

VISCOSITY MEASUREMENTS

- Anton Paar MCR 302 rheometer
- Temperature control system (24° C)
- Shear rate range of 1 – 100 s-1
- Deformation amplitude 0.01-100 %
- Angular frequency of 10 rad/s.

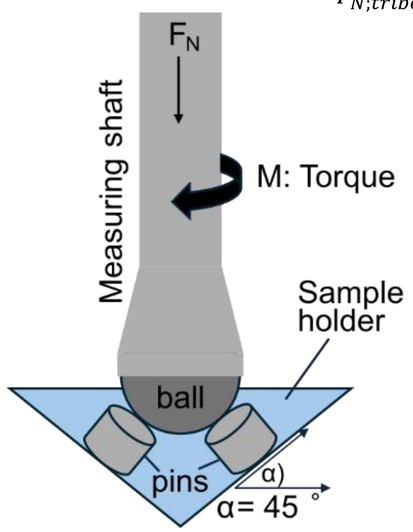


Figure 1. *Schematic illustration of the tribological measurement setup: ball on three pins*

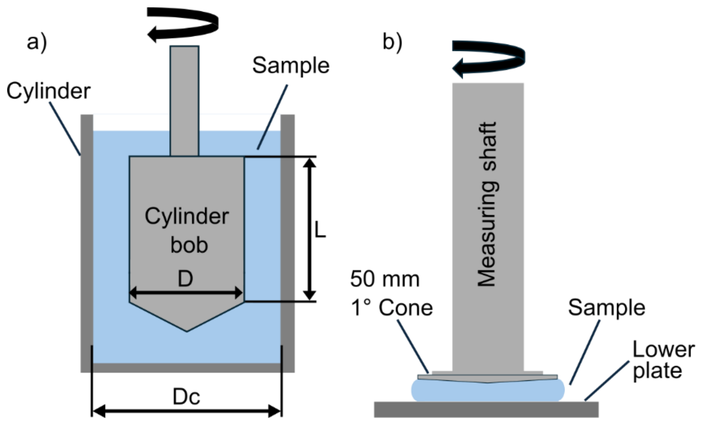


Figure 2. *Schematic overview of the rheological measurement setup: a) Cylinder CC27 scheme b) Cone-plate (CP50-1) scheme*

RESULTS

TRIBOLOGICAL MEASUREMENTS

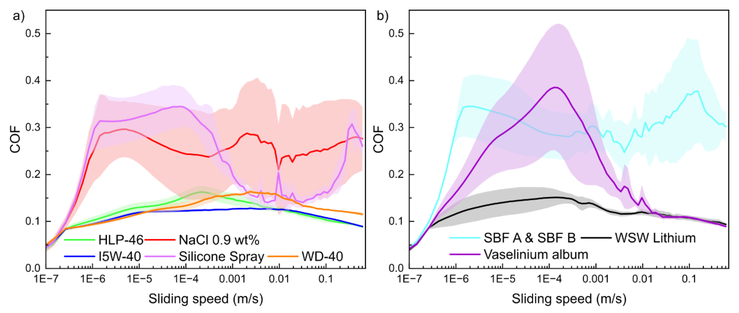


Figure 3. *Stribeck curve of different lubricants presented with average COF values standard deviations: a) liquid and spray samples; b) special systems*

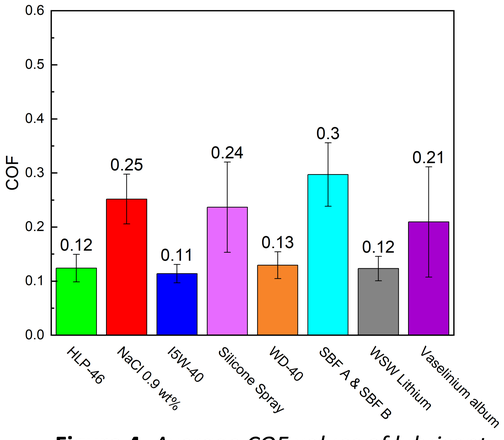


Figure 4. *Average COF values of lubricant samples along with their corresponding SD*

VISCOSITY MEASUREMENTS

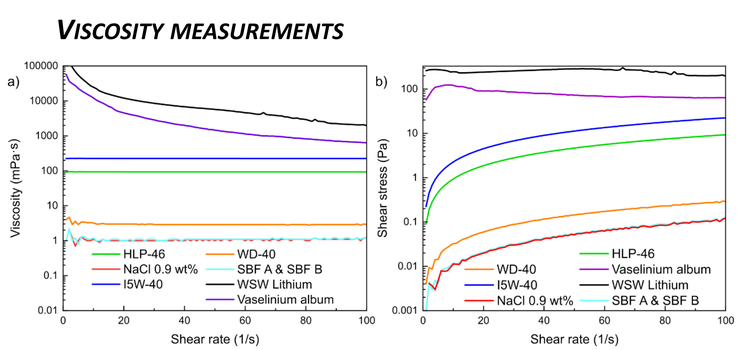


Figure 5. *Rheological investigation of different lubricants: a) Viscosity-shear rate curves; b) Shear stress curves*

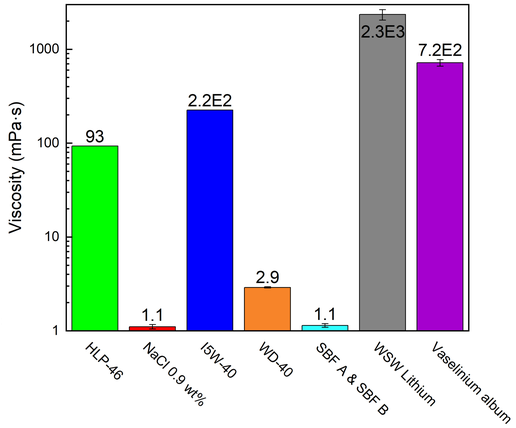


Figure 6. *Comparison of viscosity values for different lubricant samples, shown as mean values with corresponding SD*

CONCLUSIONS

- WSW Lithium is well suited for simulating high-load and cyclic implant conditions.
- Newtonian oils, such as engine oil (I5W-40) and hydraulic oil (HLP-46), provided stable viscosity and effective film formation.
- Low-viscosity fluids and aqueous solutions (NaCl 0.9wt.%, WD-40, SBF A & SBF B) showed limited load-carrying capacity and elevated friction.

The use of synthetic lubricants provides a cost-effective alternative to more complex biological testing media in *in vitro* implant testing methodologies.

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