Clarification of Heparin Lubrication Mechanism for Low-Friction Catheter on a Polyurethane Surface

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1. Introduction

Catheters are commonly used in modern medicine for treating diseases during cardiovascular procedures. The schematic of catheterization in the vessel is shown in Fig. 1. A low-friction surface is required for medical devices such as catheters or guidewires that are inserted into blood vessels. Without low friction, introducing these devices into the body can cause pain and poses a risk of damaging the mucous membranes or the intima of the blood vessels, potentially burdening patients. Therefore, it is thought that the low friction between the catheter's inner wall and guidewire is important, especially at bifurcation points and bends in blood vessels. This research focuses on friction between a guidewire and a catheter's inner wall. It is necessary to know the conditions under which a certain friction coefficient can be achieved regardless of the surface contact pressure. Heparin is a widely used anticoagulant that can act as a lubricant and form a film on polyurethane surfaces. Saline containing heparin is often injected between the guidewire and catheter as lubrication. In surgery, safe and quick operation is important to reduce the burden on patients, and it is essential to develop materials and products that can faithfully meet the demands of the field (Nishimura et al., 2018). Catheter and guidewire are inserted through blood vessels and are gradually passed into the arteries of a heart to treat disease and complete surgery. For the procedure of cardiovascular, low friction property of the surface is required for these medical devices. Heparin can be an additive to the saline and adhere to the surface (Nagaoka et al., 1995) The evaluation of the friction properties between polyurethane (material of guidewire, PU) and polytetrafluoroethylene (PTFE) under different conditions is unknown, thus this study aims to clarify the lubrication mechanism and friction properties of PU against PTFE in saline solution for a long life of heparin lubrication. According to the Stribeck curve, the friction coefficient exhibits different trends depending on the lubrication regime. Therefore, experiments of this research were to determine the lubrication regime of PU against PTFE. Temperature-induced changes in liquid viscosity can affect lubrication. This study examined three temperatures to assess the impact of viscosity. Friction tests under different normal loads were also conducted on dry conditions to simulate the disappearance of lubrication in blood vessels.

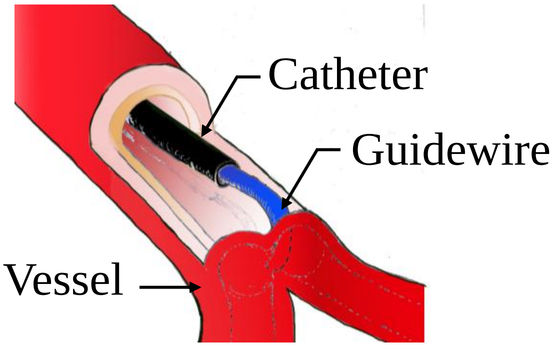

Fig. 1 Schematic of catheterization in the vessel

2. Experimental method

In this study, an experimental apparatus for in-vitro measurement of static and dynamic friction coefficient of guidewire surface and catheter surface was developed. Tribometer was designed and constructed to work in oscillation motion with exchangeable friction materials and various normal loads. A water bath has been designed to hold guidewire specimens for a wet condition to mimic in-vivo process, a leaf spring is fixed to the test bench, while the other end is equipped with a jig holding a roller. A strain gauge is attached to the leaf spring. When a load is applied or the motor drives the water bath to move, the force is transmitted through the strain gauge, converting it into a voltage signal that is sent to the computer. The software then processes this signal to determine the relationship between the normal load and the friction force, which is shown in Fig. 2. A commercially available guidewire made from PU with hydrophilic coating was used to test against a PTFE roller

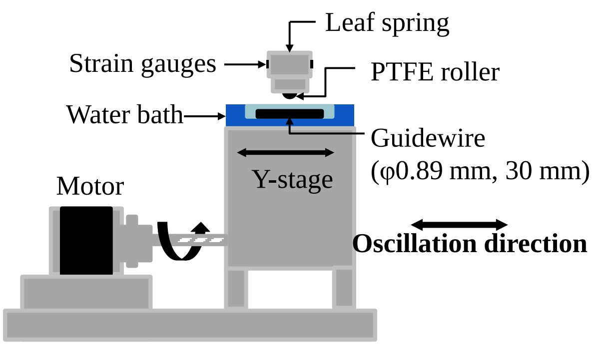

Fig. 2 Schematic of oscillation friction tester

Table 1 Test conditions

Condition	
Normal load W, N	0.02, 0.05, 0.1, 0.2
Sliding time T, s	20
Sliding speed V, mm/s	0.1, 0.2, 0.5
Environment	Saline/Dry/Saline with heparin
Temperature $Temp$, °C	23, 37, 50

surface, which is one of the most commonly used catheters materials as the shape of the sheath. Friction tests were performed under various normal loads by way of point contact in dry, saline, and saline with heparin conditions at room temperature. The temperature of the solution in the water bath can be changed by preheating the saline solution to 37 or 50 degrees. The conditions for the friction tests are shown in Table 1.

3. Friction test results

The main factors influencing friction are the normal load, insertion speed, and the viscosity of the lubricating solution. Four different normal loads were applied in this study to investigate how the normal load affects the friction coefficient. Figure 3 compares the average dynamic friction coefficients with time for dry, saline, and saline with heparin conditions at different normal loads. Dry condition has more stable values, saline shows a first increase and then a decrease, while the saline with heparin condition first achieves a very low average dynamic friction coefficient of about 0.027 at 0.02 N, but as the normal load increases, the low friction disappears and converges with the other two conditions to the same value.

The curve showing the change in the average dynamic friction coefficient with speed is shown in the Fig. 4. The four curves represent the speed-friction coefficient curves under different normal loads in saline solution at room temperature. Overall, the friction coefficient decreases as the speed increases, with the minimum value of μ = 0.008, occurring at a normal load of 0.05 N and a speed of 0.5 mm/s. At sliding speeds of 0.1 and 0.2 mm/s, the change in the friction coefficient with increasing normal load follows a pattern of increase-increase-decrease. When the speed increases to 0.5 mm/s, the pattern becomes decrease-increase-increase. It is speculated that at low speeds, the lubrication regime transitions from mixed lubrication to boundary lubrication, whereas at higher speeds, the system remains near the minimum point of mixed lubrication. After adding 0.4 mL of heparin sodium solution (containing 400 units of heparin) to saline, friction experiments were conducted under normal loads of 0.05 N and 0.1 N at different solution temperatures, as shown in Fig. 5. The friction coefficient is lowest at 37 °C and highest at 50 °C. This means that changes in viscosity caused by temperature changes will affect the friction coefficient.

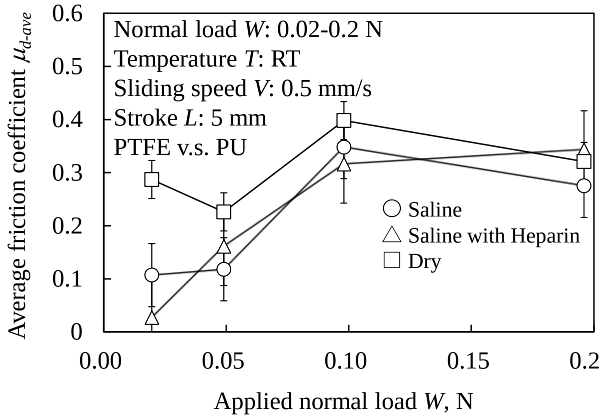

Fig. 3 Effect of normal load on $\mu_{d\text{-}ave}$

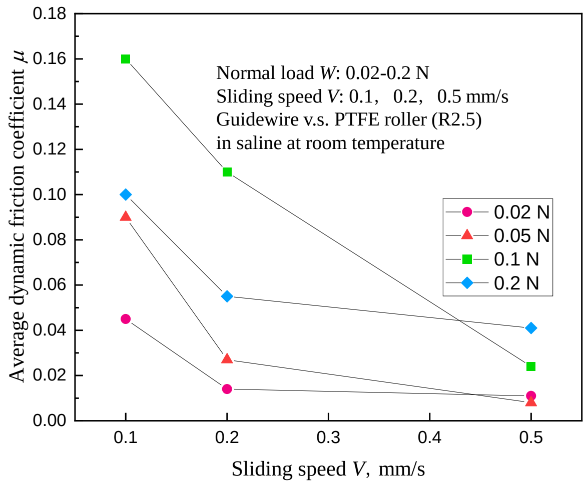

Fig. 4 Effect of sliding speed on $\mu_{d\text{-}ave}$

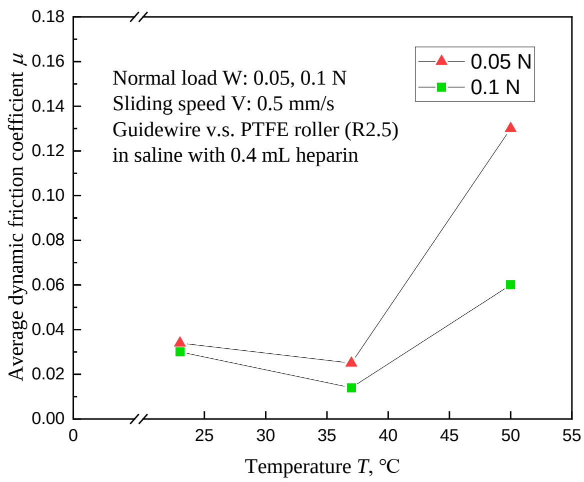

Fig. 5 Effect of temperature on $\mu_{d\text{-}ave}$

4. Discussion and conclusion

Friction experiments conducted under varying normal loads, sliding speeds, and temperatures revealed that polyurethane and PTFE exhibit two lubrication regimes: boundary lubrication and mixed lubrication. A low friction coefficient (μ = 0.008) was observed at higher sliding speeds, lower normal loads, and with high-viscosity lubricants. In contrast, increased normal loads, reduced sliding speeds, and changes in surface lubricant viscosity influence the retention of heparin on the surface, thereby affecting the friction coefficient. This study highlights the importance of evaluating both the mechanical properties of soft biomaterials and their lubrication behavior to address the complex challenges in biomedical applications.

References

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