The clarification of Heparin Lubrication Mechanism for Low-friction Catheter on a Polyurethane Surface

Yujie Zhao*, Takayuki Tokoroyama*, Noritsugu Umehara*, Ruixi Zhang*, Takayuki Yorozu**, Yusuke Ito**, Junichi Uchida**

*Nagoya University, **Nihon Parkerizing Co., Ltd

1. Introduction

Catheters are commonly used in modern medicine for treating diseases during cardiovascular procedures. 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. 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. 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.

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.

2. Experimental methods

A low friction coefficient is a good solution to facilitate the movement of the catheter tip. 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. 1. A commercially available guidewire made from PU with hydrophilic coating was used to test against a PTFE roller surface, which is one of the most commonly used catheter 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.

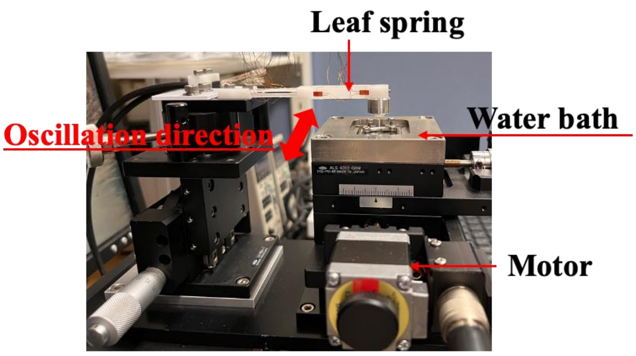

Fig. 1 - Image of friction tester

3. Experimental results

The results are shown in Fig. 2, Panel (a) illustrates that at a normal load of 0.02 N, there are significant differences in friction coefficients across the three tested conditions. At the initial moment (time = 0), which represents the static friction coefficient, the value under dry conditions is 1.4, in contrast to approximately 0.02 for the saline with heparin condition. Additionally, there is a notable disparity between the average dynamic friction coefficients in dry conditions and those in saline with heparin conditions. Panel (b) indicates that upon increasing the normal load to 0.05 N, the static friction coefficient under dry conditions decreases, aligning more closely with those observed in the other two wet conditions. However, the friction coefficient in saline condition becomes larger and more unstable, even exceeding the value of dry under the same condition. The friction coefficient in saline with heparin also has an increase. At this normal load, static friction coefficients under these three conditions are almost similar, which the value is about 0.35. And the lowest dynamic friction coefficient is under saline with heparin, which the average value is about 0.15. Panel (c) represents that at a normal load of 0.1 N, friction coefficient increased again in dry condition, with a static friction coefficient of about 0.7 and an average dynamic friction coefficient of about 0.5. Saline and saline with heparin showed no significant change in static friction coefficient under this loading of 0.1 N and both values were about the same at 0.4. As for dynamic friction coefficient, there was a tendency for the saline condition to increase with time, with an average value of about 0.6, while the saline with heparin condition was much more stable, with a value of about 0.35, but After 9 seconds of sliding under both wetting conditions, the average dynamic friction coefficient of both conditions converged with a value of about 0.28. Panel (d) indicates that upon increasing the normal load to 0.2 N, in comparison to the 0.1 N case, the static friction coefficient in the dry condition is essentially the same, about 0.7, but then the friction coefficient decreases and stabilizes. In contrast, the static friction coefficient for the saline condition increases to 0.5, and the static friction coefficient for the saline with heparin decreases to approximately 0.35. After sliding for one second, the friction coefficients decrease for both the dry and saline conditions, while the saline with heparin remains essentially unchanged, with average dynamic friction coefficient of approximately 0.35, and after 4 seconds sliding, the dynamic friction coefficient of saline had a small increase to 0.5 and then stabilized at 0.45, while in the dry condition, the value of average dynamic friction coefficient tended to be the same as that of saline with heparin, which was approximately 0.35. The lowest average dynamic friction coefficient between the PU and PTFE was measured in saline and heparin condition at a normal load of 0.02 N. The value is approximately 0.027. However, at 0.02 N normal load, dry condition shows a significantly high static friction coefficient and the average dynamic friction coefficient has a large gap with that of dry, saline and saline with heparin condition.

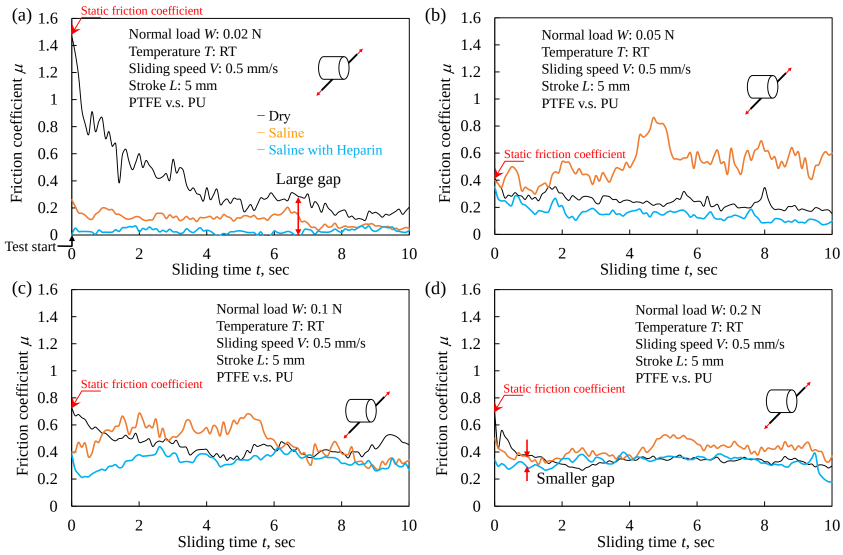

Fig. 2 - Static and dynamic friction coefficient comparison among saline, dry and saline including heparin at 0.02 N to 0.2 N

4. Discussion and conclusion

In this study, we established an oscillation friction tester to conduct friction tests of PU against PTFE under saline solution, with the goal of better understanding the role of normal load and, most importantly, the function of heparin on interfacial friction. The effects of normal load and environment on the friction properties against PTFE were examined through friction experiments. The experimental results show that adding heparin at a sliding speed of 0.05 mm/s and a normal load of 0.02 N can achieve low friction (μ = 0.027) under saline with heparin. Changes in normal load affect the friction coefficient at the PU surface, and the addition of heparin effectively reduced and stabilized the friction coefficient under certain conditions.

References

1) Nishimura F, Doke Y, Division M. Friction measuring device for catheter. Tribologist 2015; 60:606–8.al Materials, 84 (2018) 12.
2) Nagaoka S. Surface treatment for Vascular Catheters. Surf Technol 1995; 46:44–7.