IJC Heart & Vasculature 47 (2023) 101241

Contents lists available at ScienceDirect

IJC Heart & Vasculature

journal homepage: www.sciencedirect.com/journal/ijc-heart-and-vasculature

The Null technique as a novel, potential first-line method of device delivery for complicated lesions during percutaneous coronary intervention

Takashi Akima [a,b,*], Yasuo Sakurai [c], Kazuaki Nakajima [a], Takashi Koyama [a,b]

[a] Department of Internal Medicine, Saitama Municipal Hospital, Saitama, Japan
[b] Department of Cardiology, Saitama Municipal Hospital, Saitama, Japan
[c] Division of Mechanical Engineering, Ashikaga College, Tochigi, Japan

ARTICLE INFO

Keywords:
Percutaneous coronary intervention
Device delivery
Contrast medium
Stribeck effect
Calcified stenosis
Other technique
Stable angina

ABSTRACT

Aim: During percutaneous coronary intervention (PCI), complicated lesions in the target coronary artery often hinder device delivery. Fluid lubricants have commonly been used to reduce friction between adjacent solid materials in manufacturing, thus achieving smoother action. This *ex vivo* experimental study examined whether a contrast medium could function as a fluid lubricant during PCI.

Methods and results: We used two different coronary artery lesion models with distinct complexities made from silicon. Each model was fit into the *ex vivo* PCI-simulation system. This *ex vivo* laboratory equipment consisted of ordinary PCI instruments and an aorta model from the Valsalva sinus to the descending aorta. A Wolverine™ cutting balloon catheter was advanced through each lesion model via a guide catheter set into the system. The maximum force required to push the catheter through the lesion models was measured while the vessel system was filled with either normal saline or contrast medium. The maximum force required was significantly lower with the contrast medium (1.38 ± 0.21 N in the normal-saline condition vs. 0.92 ± 0.05 N in the contrast-medium condition in the lesion model A, $p < 0.001$; 1.30 ± 0.07 N in the normal-saline condition vs. 1.14 ± 0.04 N in the contrast-medium condition in the lesion model B, $p < 0.001$).

Conclusions: The contrast medium for vessel system filling reduced the force required to push the devices through the lesion models. This contrast medium represents a potential candidate for a liquid lubricant to facilitate device delivery for complicated coronary lesions.

1. Background

Complicated lesions, such as long lesions, calcified lesions, or those with severe irregularity in the target coronary artery, often hinder device delivery during percutaneous coronary intervention (PCI) procedures. Several techniques are currently available to deliver the device against such lesions, including the active backup technique, buddy wire technique [1], anchor balloon technique [2], mother-and-child catheter technique [3–5], leopard-crawl technique [6], and passive backup technique. Although these techniques help deliver the device, their performance requires additional equipment, such as another guide wire, microcatheter, another balloon catheter, or another guide catheter. In addition, they may even cause some undesirable injuries to the vessel walls.

Apart from medicine, fluid lubricants have commonly been used in machinery industries to reduce friction between adjacent solid materials, thus achieving smoother action of the objects. The phenomenon in which fluid lubricants reduce friction between adjacent solid materials had been well described by Stribeck in 1902 [7–9]. According to this theory, the more viscous the liquid lubricant is, the less friction between solid materials develops. In practice, specific requirements for the materials and lubricants must be met for this phenomenon to occur. Notably, based on this theory, an iodine contrast medium could be used as a liquid lubricant during device delivery in PCI procedures because the contrast medium is more viscous than whole blood. Therefore, we hypothesized that temporarily replacing blood with an iodine contrast medium during device delivery reduces friction between the vessel walls and a device, thus helping deliver the device, particularly in complicated coronary lesions. To test this hypothesis, *ex vivo* experiments using an artificial blood vessel system were conducted to examine whether an iodine contrast medium could reduce the frictional force developed during device delivery. We also present representative clinical cases in

* Corresponding author at: Department of Internal Medicine, Saitama Municipal Hospital, 2460 Mimuro, Midori-ku, Saitama City, Saitama 336-8522, Japan.
E-mail address: takashiakima@gmail.com (T. Akima).

https://doi.org/10.1016/j.ijcha.2023.101241
Received 6 April 2023; Received in revised form 30 May 2023; Accepted 19 June 2023
Available online 8 July 2023

which device delivery was successful with this approach.

2. Methods

2.1. Ex vivo experiments.

We used two types of coronary artery lesion models with distinct complexities made from silicon (KE-1606, Shin-Etsu Chemical Co., Ltd., Tokyo, Japan) for *ex vivo* experiments—namely, model A (a single, short, and regular lesion with severe stenosis) and model B (tandem, long, and regular lesions with severe stenosis) (Fig. 1). Table 1 shows the lesion characteristics of these two models determined by a quantitative coronary angiography system (QAngio XA 7.3.96.0-x86, Medis Medical Imaging System Inc., Tokyo, Japan).

Each coronary artery lesion model was fit into the *ex vivo* PCI-simulation system manufactured by the Institute for Advancing Science (Boston Scientific Co., Ltd., Miyazaki, Japan; Fig. 2). This *ex vivo* laboratory equipment consists of ordinary PCI instruments, including the guide catheter (Mac-1™, FL3.5, 7F; Boston Scientific Co., Ltd., Tokyo, Japan), Y-connector (Goodtec®, NIPRO Corp., Osaka, Japan), and aorta model from the Valsalva sinus to the descending aorta. The guide catheter was inserted into the aorta model and fixed to the same backboard, which was connected to the aorta model so that the catheter axis could not be displaced during balloon catheter insertion.

The guide catheter and coronary artery lesion model were filled with either normal saline or contrast medium (Iopamidol 370®, Fuji Pharma Co., Ltd., Tokyo, Japan). The guide wire (ASAHI SION®, ASAHI INTECC Co., Ltd., Aichi, Japan) was inserted into the coronary artery lesion model through the guide catheter. Via the guide wire, a Wolverine™ cutting balloon catheter with a 2.0-mm diameter and 10-mm length (Boston Scientific Co., Ltd., Tokyo, Japan) was manually advanced to the proximal end of each coronary artery lesion model. The catheter was then connected to a horizontal motorized stand (IMADA MH-1000 N, IMADA Co., Ltd., Tokyo, Japan) equipped with electronic precision weighing force gauge instrument (FG-5000A, A-Gas Japan Co., Ltd., Tokyo, Japan). This equipment allowed us to move the catheter automatically across the lesion and simultaneously measure the force required for device delivery. This weighing force gauge instrument, generally used in the precision instrument industry, can measure up to the second decimal place (unit: N).

The cutting balloon catheter was advanced automatically through each coronary artery lesion model at a rate of 28 mm/s (Supplementary Videos 1 and 2). The maximum force required during the process was recorded. In each coronary artery lesion model, the pass-through experiments were performed with the vessel system filled with either normal saline (viscosity, 0.72 mPa-s) or contrast medium (viscosity, 9.1 mPa-s). Each experiment was repeated at least seven times, and the mean values of the maximum force measured were compared.

2.2. Representative clinical cases

We present cases in which we had failed to deliver a device even with the buddy wire technique or mother-and-child catheter technique but eventually succeeded in delivery using our new technique. Our new approach employed a simple manual injection of 2–3 mL of contrast medium into the target coronary artery during device delivery to reduce friction resistance. Because this technique used no additional devices or specific manipulations other than contrast medium injection, we named this technique the 'Null technique'.

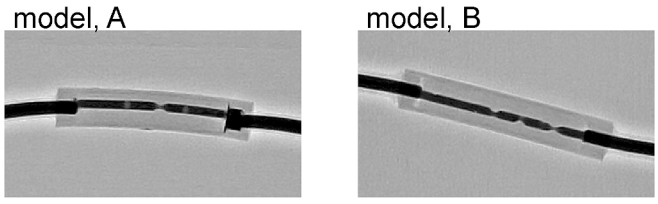

Fig. 1. X-ray images of the two coronary artery lesion models Both coronary artery lesion model A and model B were filled with contrast medium (Iopamidol 370®, Fuji Pharma Co., Ltd., Tokyo, Japan), and imaged with an angiographic x-ray system.

Table 1
Lesion characteristics of the two coronary artery lesion models.

	Model A	Model B
Obstruction diameter, mm	1.03	1.01
Reference diameter, mm	1.94	1.96
Diameter stenosis, %	46.8	48.1
Area stenosis, %	71.7	73.1
Obstruction length, mm	6.0	20.3
Number of stenotic portions	Single	Tandem
Length	Short	Long
Contour	Regular	Regular

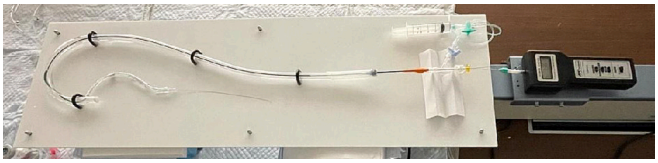

Fig. 2. Artificial blood vessel system with guide catheter inserted.

The study was approved by the Ethics Committee of Saitama Municipal Hospital (approval no. R3-69) and performed in accordance with the provisions of the Declaration of Helsinki. Written informed consent was obtained from each patient.

Statistical analysis.

The Shapiro–Wilk normality test was used to analyse whether continuous variables were normally distributed. All values of the maximum forces required during pass-through experiments were normally distributed and thereby presented as mean ± standard deviation and compared using an unpaired Student's *t*-test between the normal-saline group and the contrast-medium group. A p-value < 0.05 was considered statistically significant. All statistics were performed using EZR version 1.55 [10], a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). EZR is a modified version of R commander, which was designed to add statistical functions frequently used in biostatistics.

3. Results

3.1. Ex vivo experiments

Fig. 3 presents a comparison of the maximum forces required to push the cutting balloon catheter through the lesion models under two different conditions in which the vessel system was filled with a contrast medium or normal saline. The required maximum force was significantly lower in the contrast-medium condition than in the normal-saline condition both in the lesion model A (1.38 ± 0.21 N in the normal-saline condition vs. 0.92 ± 0.05 N in the contrast-medium condition, $p < 0.001$) and in the lesion B (1.30 ± 0.07 N in the normal-saline condition vs. 1.14 ± 0.04 N in the contrast-medium condition, $p < 0.001$).

4. Clinical cases

Case 1. *A 50-year-old man presented to our hospital for chest discomfort while climbing stairs. Exercise stress electrocardiography revealed ST depression in the left-sided pre-cordial leads with mild to moderate exercise intensity. He underwent coronary angiography, which revealed 90% stenosis at the proximal portion of the left circumflex artery* (Supplementary Video

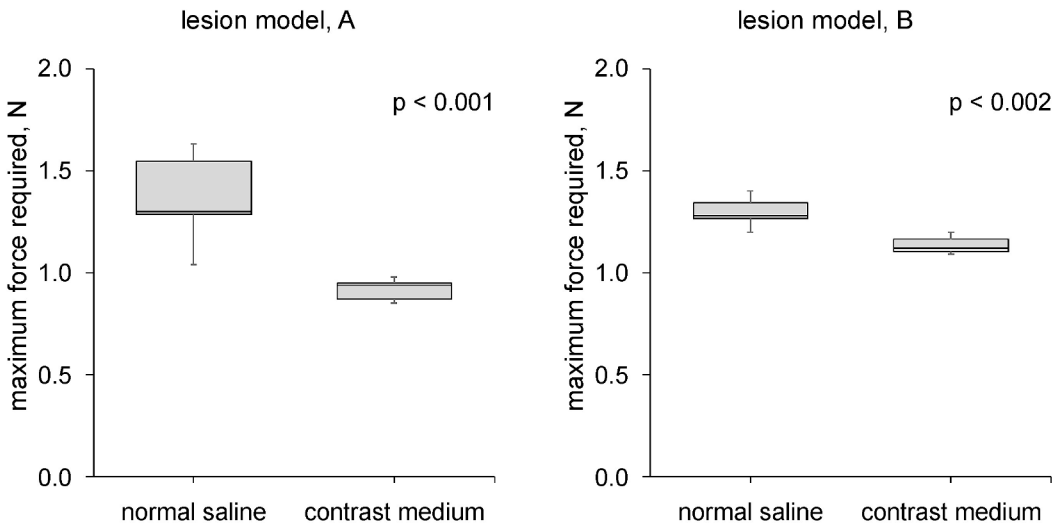

Fig. 3. Comparison of the maximum forces required to push the device through each lesion model between normal-saline condition and contrast-medium condition The left panel shows the results obtained in lesion model A. The right panel shows the results obtained in lesion model B. Data are presented with the box-and-hide diagram. The horizontal line inside the rectangle represents the mean value.

3A). *This lesion appeared angiographically similar to our experimental lesion model A. The fractional flow reserve was* 0.75, *and the SYNTAX score was calculated as* 12 *points. Subsequently, PCI was performed. A* 6*F guide catheter (Heartrail® II, BL*3.0, *Terumo Corp., Tokyo, Japan) was introduced and engaged in the ostium of the left coronary artery. A* 0.014*-inch guide wire (ASAHI SION® blue ES™, ASAHI INTECC Co., Ltd., Aichi, Japan) was inserted into the left circumflex artery via the guide catheter. On our first attempt, we failed to deliver a Wolverine™ cutting balloon catheter with a* 2.0*-mm diameter and* 10*-mm length (Boston Scientific Co., Ltd., Tokyo, Japan) to the lesion because of lesion complexities. Therefore, we introduced another guide wire (ASAHI SION®, ASAHI INTECC Co., Ltd., Aichi, Japan) into the obtuse marginal artery, attempting the buddy wire technique* (Supplementary Video 3B). *However, we failed to deliver the cutting balloon catheter again. We then tried the Null technique, and the cutting balloon catheter was successfully advanced to the lesion while the contrast medium was injected into the coronary artery* (Supplementary Video 3C).

Case 2. *A* 67*-year-old man presented to our hospital for chest discomfort, which was provoked by his daily activities. Coronary angiography revealed a diffuse irregular lesion with* 90% *stenosis at the proximal to middle portion of the left anterior descending artery. This lesion appeared angiographically similar to our experimental lesion model B* (Supplementary Video 4A). *Fractional flow reserve was calculated as* 0.67. *Subsequently, the patient underwent PCI. A* 6*F guide catheter (Heartrail® II, BL*3.5, *Terumo Corp., Tokyo, Japan) was introduced and engaged in the ostium of the left coronary artery. A* 0.014*-inch guide wire (ASAHI SION® blue ES™, ASAHI INTECC Co., Ltd., Aichi, Japan) was inserted into the left anterior descending artery via the guide catheter. Pre-dilation was performed using a semi-compliant balloon with a* 2.0*-mm diameter (Ryurei®, Terumo Corp., Tokyo, Japan). Subsequently, we planned to examine the lesion characteristics using intravascular ultrasound (IVUS) (OptiCross™ Imaging Catheter, Boston Scientific Co., Ltd., Tokyo, Japan). However, we could not deliver the IVUS catheter to the lesion. We then used an alternative method called the mother-and-child catheter technique, in which a guide-extension catheter (*6*F of GuideLiner™, Teleflex Medical Corp., Sinjuku, Japan) was used to obtain additional backup force. However, we could not advance the IVUS catheter across the lesion. Therefore, we used the Null technique and eventually succeeded in IVUS delivery* (Supplementary Video 4B). *Subsequently, a stent with a* 3.0*-mm diameter and* 24*-mm length (SYNERGY™ XD, Boston Scientific Co., Ltd., Tokyo, Japan) was also successfully delivered using the Null technique* (Supplementary Video 4C) *after failed delivery without any specific techniques (i.e., simple delivery method). Stenting was then performed, and the PCI was completed.*

5. Discussion

Our study showed that the maximum force required to push the cutting balloon catheter through the coronary artery lesion models was significantly lower when the lesion models were filled with a contrast medium than when they were filled with normal saline. We also demonstrated two clinical cases in which this phenomenon might explain successful device delivery in complicated lesions during PCI procedures.

The Stribeck effect was first reported by Stribeck from the German Iron and Steel Institute in 1901 [7–9]. When two adjacent solid materials move against each other, frictional force develops between them. However, frictional force can be reduced by adding a viscous liquid lubricant between these solid materials. Furthermore, the degree of the reduction depends on the lubricant viscosity. According to Stribeck's theory, liquid lubricants with higher viscosities tend to reduce friction between solid materials further because higher volumes of such lubricants could remain between solid materials, thereby generating a thicker layer of the liquid and making rough surfaces smoother. In practice, specific requirements regarding the surface roughness of the materials and lubricants must be met for this phenomenon to occur. According to the Stribeck curve, the reduction in viscosity depends on the product of the speed of the passing-through-device and the viscosity of the lubricant. However, relationship between the resistance in friction and viscosity of the lubricant is sometimes proportional and sometimes inversely proportional, so raising the viscosity does not necessarily mean a reduction in friction. By encapsulating a high-viscosity lubricant, the reduction of frictional resistance could be reproduced coronary artery lesion model under certain conditions. However, the precise physical explanation is beyond the scope of this manuscript. In the context of the current study, Stribeck's theory was applicable to the observed results. The strength of this study was that, given this theoretical background, an iodine contrast medium could be used as a liquid lubricant during device delivery in PCI procedures. Because the contrast medium has a higher viscosity than the whole blood, the contrast medium will alter the frictional characteristics between a device and vessel walls with certainty. Whether this change in frictional characteristics benefits the device delivery in each complicated lesion could only be determined empirically.

Our study had some limitations. First, the coronary artery lesion models used in this study were not highly complicated. In this regard, the lesion contour was smooth and regular in both lesion models.

Therefore, whether these results could be extrapolated to more complex lesions remain uncertain. Second, we need some additional contrast medium for this new technique. It may be harmful for some cases with renal dysfunction, however, the volume it needs is only two or three ml of contrast medium for this technique, therefore it may make little adverse effects on the renal function. Third, PCI in the clinical setting is performed under coronary artery perfusion conditions, however, this ex vivo study was conducted in a static environment rather than a perfusion environment, as it was difficult to create a reflux device. Therefore, it would be desirable to investigate this phenomenon in the perfusion coronary artery lesion model. This result imply that the products of the delivery speed and the viscosity of the lubricant may affect the resistance friction during lesion passage according to the Stribeck's effect, however, the precise mechanism is not. Forth, we employed normal saline (viscosity, 0.72 mPa-s) as a control instead of whole blood (viscosity, 3–4 mPa-s), which is more viscous than normal saline. However, the contrast medium (viscosity, 9.1 mPa-s) is much more viscous than whole blood. Therefore, during difficulties in device delivery, a contrast medium may be worth using as a liquid lubricant to facilitate device delivery.

In conclusion, a contrast medium may be used as a fluid lubricant to facilitate device delivery in complicated coronary lesions during PCI procedures.

6. Impact on daily practice

The Null technique is simple, with no additional devices or specific manipulations; no injury to the vessel wall is expected, in contrast to other techniques, such as the buddy wire technique or anchoring balloon technique. Therefore, the Null technique can be attempted first when difficulty in device delivery is encountered. In cases of failure, other techniques requiring some additional devices should be subsequently attempted. This step-up approach is safe and cost-effective and may benefit the patients.

Authors contributions

TA conceived the idea of the study. TA and KN performed this experiment. TA developed the statistical analysis plan and conducted statistical analyses. YS contributed to the interpretation of the results. TA drafted the original manuscript. TK supervised the conduct of this study. All authors reviewed the manuscript draft and revised it critically on intellectual content. All authors approved the final version of the manuscript to be published.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements:

The authors thank Dr. Naoki Sako (Institute for Advancing Science, Boston Scientific Co., Ltd., Miyazaki, Japan) for lending us the *ex vivo* laboratory equipment.

Source of funding

None.

Conflict of interest

The authors whose names are listed above certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Registration number of this study

The clinical part of this study was approved by the Ethics Committee of Saitama Municipal Hospital (approval no. R3-69) and performed in accordance with the provisions of the Declaration of Helsinki. Written informed consent was obtained from each patient.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcha.2023.101241.

References:

[1] F. Burzotta, C. Trani, M.A. Mazzari, R. Mongiardo, A.G. Rebuzzi, A. Buffon, G. Niccoli, G. Biondi-Zoccai, E. Romagnoli, V. Ramazzotti, G. Schiavoni, F. Crea, Use of a second buddy wire during percutaneous coronary interventions: a simple solution for some challenging situations, J. Invasive Cardiol. 17 (2005) 171–174.
[2] S. Fujita, H. Tamai, E. Kyo, K. Kosuga, T. Hata, M. Okada, T. Nakamura, T. Tsuji, S. Takeda, H.F. Bin, N. Masunaga, S. Motohara, H. Uehata, New technique for superior guiding catheter support during advancement of a balloon in coronary angioplasty: the anchor technique, Catheter Cardiovasc. Interv. 59 (2003) 482–488.
[3] S. Takahashi, S. Saito, S. Tanaka, Y. Miyashita, T. Shiono, F. Arai, H. Domae, S. Satake, T. Itoh, New method to increase a backup support of a 6 French guiding coronary catheter, Catheter Cardiovasc. Interv. 63 (2004) 452–466.
[4] M.A. Mamas, F. Fath-Ordoubadi, D. Fraser, Successful use of the Heartrail III catheter as a stent delivery catheter following failure of conventional techniques, Catheter Cardiovasc. Interv. 71 (2008) 358–363.
[5] A. Shirota, T. Nomura, H. Kubota, S. Taminishi, R. Urata, T. Sugimoto, Y. Higuchi, T. Kato, N. Keira, T. Tatsumi, Successful percutaneous coronary intervention with GuideLiner® catheter for subtotal occlusive lesion in the right coronary artery with anomalous origin from the left sinus of Valsalva: a case report, J. Med. Case Rep. 9 (2015) 163.
[6] K. Ashida, T. Hayase, T. Shinmura, Efficacy of lacrosse NSE using the "leopard-crawl" technique on severely calcified lesions, J. Invas. Cardiol. 25 (2013) 555–564.
[7] R. Stribeck, Die wesentlichen Eigenschaften der Gleit- und Rollenlager (Characteristics of Plain and Roller Bearings), Zeit des VDI 46 (1902) 1341–1348.
[8] B. Jacobson, The Stribeck memorial lecture, Tribol Int. 36 (2003) 781–789.
[9] M. Woydt, R. Wäsche, The history of the Stribeck curve and ball bearing steels: The role of Adolf Martens, Wear 268 (2010) 1542–1546.
[10] Y. Kanda, Investigation of the freely available easy-to-use software 'EZR' for medical statics, Bone Marrow Transplant. 48 (2013) 452–458.