Proceedings of 2017 IEEE
International Conference on Mechatronics and Automation
August 6 - 9, Takamatsu, Japan

Effects of the Transverse Micro–vibration on Guide Wires for Endovascular Therapy

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Abstract **- The vascular minimally invasive intervention is a new type of medical technology with medical catheter and guide wire as the main surgical equipment which is for remote minimally invasive treatment of vascular disease. It is widely used for its advantages, such as smaller trauma, shorter recovery and less pain. But there are many deficiencies limiting the continued development of vascular intervention surgery: Serious damage of X-ray to the doctor during the surgery; high dependence on the doctor's experience and technique; low surgical efficiency and safety. Through the study and analysis of the interventional operation, the doctors will usually be subjected to the resistance when operating the catheter and the guide wire during the surgery. In some special condition, the suffered resistance would be larger. The improper operation will cause blood vessel damage. In the course of the actual operation, the catheter and the guide wire in the human blood vessels will suffer the viscous resistance from the blood. It affects the operation and efficiency of the doctors, as well as the safety of surgery. At the same time, the research about the viscous resistance of the catheters and the guide wire during the surgery in the field is still in a blank, and there is no research method that can reduce this resistance. In order to solve these problems, this paper has carried on the research on the mechanism of the viscous force of the catheter and the guide wire in surgery, and pioneers a method to supplement the micro-vibration in the proximal end of the guide wire. This method can reduce the viscous force of the catheter and the guide wire exerted by the blood during the push process, improve the surgical safety and the smoothness of the operation.**

Index Terms–Vascular interventional surgery; Radial micro vibration; Viscous force

I. Introduction

The minimally invasive vascular interventional surgery is a major medical procedure that used to diagnose and treat cardiovascular and cerebrovascular disorder. As an advanced technology in the medical domain, it is based on the medical catheter and the guide wire as the main surgical equipment. This treatment method is a new medical technology to provide remote minimally invasive treatment for the thrombosis, vascular foreign body, tumor and other vascular diseases. Currently, during the process of pushing the catheter, a more common practice is done by hand of the skilled operators directly to insert the catheter in the X-ray images or other gray image monitoring and guidance.

During the operation, a catheter is inserted into the blood vessels with the completion of the guide wire. Firstly, the surgeon makes a puncture on the femoral artery or the subclavian vein, following put the guide wire into the target vessels or target organ via the puncture point. Next, the surgeons push the guide wire carefully by the guidance of the digital subtraction angiography images and hand feeling until it arriving the specific section, and then pull out of the guide wire to complete the appropriate course of treatment[1]-[6]. So it can provide the patients with smaller trauma, shorter recovery time and less pain compared to open surgery. And for surgeons, less time consumption, higher precision, more securer and higher success rate are better than traditional operation.

However, with the increasing of surgery patients, the lack of traditional minimally invasive interventional surgery also gradually exposed. Traditional surgery generally uses X-ray image-assisted or CCD camera to obtain real-time image of the anatomical structure of the patient's surgical spot[7]. And the resulting image information is mostly two-dimensional, and the organizational structure is not obvious, cannot provide the realistic three-dimensional organizational structure information well. But also requires doctors to have a wealth of experience in image recognition[8]-[16].

As a new technology, it also takes lots of the operating skills. The traditional surgical tools are often larger in size and have the rigid structure, because of its limited degree of freedom and rigidity; only the experienced physician can make the catheter and the guide wire quickly and accurately reach the target position. There is a long time for the doctors to have an operation in the x-ray radiation, not only will give doctors a lasting sense of fatigue, this process would cause considerable radiation injury to the patient and physician. In general, the traditional minimally invasive intervention surgery still has many deficiencies. Poor operability of the surgical tools, high dependence on the doctors, and the auxiliary information is not intuitive and comprehensive, during surgery the patient's safety is difficult to protect.

In order to improve the technical constraints and shortcomings, the scholars at home and abroad introduce the computer and robot technology to the medical field. The master-slave catheter operating system proposed which provide more easier and accurate manipulation of the catheter insertion and reduce the harm caused by the X-ray the physician and medical staff. This system separate the doctors from the patients, after receiving the instruction from the slave side, doctors operate the main system side for the interventional procedures on the patients with the catheter, while from the various sensors installed on the slave side to get the specific information in the body especially intravascular. Since the middle of the last century, the United States and other developed countries have begun to explore the vascular intervention surgery robot. And the researches about the surgical tools, intervention devices, guide images and systems have made many fruitful results. The vascular intervention surgery robot from the system began to mature, to gradually enter the market and the hospital. The introduction of robot technology can improve the life expectancy, focus on training the doctors of the intervention operation. At the same time, it can effectively reduce the radiation injury to the doctors and the cost of the surgery. In addition, it also avoids the lack of the workers, and promotes the development of the interventional surgery availably[17]-[19].

But the vascular intervention surgery robot system still has a lot of problems, such as expensive price, and the positioning accuracy and the stability of the surgical system have yet to be further improved. None of these systems provide haptic feedback or any sort of force/impedance control of the catheter tip.

However, both the manual operation of doctors and the introduction of robotics technology are lacking the accurate research of the catheter and the guide wire resistance in a blood vessel and the corresponding resistance reduction measures are missing. During the actual operating, the force of the catheter and the guide wire and tactile information require physicians to have enough practical experience to judge. The catheter and guide wire cause trauma to the vascular wall, only by the experience of the doctors to perceive, there is no accurate data based. In addition, the operation performed inside the body cannot be directly monitored. At the same time, the contact force between the catheter and the blood vessel cannot be detected[20]-[24]. At the same time, in the course of surgery, the biggish resistance of the catheter and the guide wire in the blood vessels will affect the efficiency and safety of surgery. The clinical results show that, because the smaller diameter of the cerebra vascular, excessive force by the doctors could easily lead to the severe cerebral vascular injury.

The errors or repetitive operations might cause some damage to the patients, when the catheter inserted into the vessel, bring a certain amount of risk to the surgery. Therefore, improving the safety of vascular intervention surgery is an important and core issue and focus of cardiovascular and cerebrovascular interventional robotic techniques[25]-[30].

Through the study and analysis of the interventional operation, it is found that the pushing resistance of the catheter and the guide wire is large in the push process, which is easy to cause blood vessel injury and affect the operation efficiency and safety. At the same time, the research about the viscous resistance of the catheters and the guide wire during the surgery in this field is still a blank, and there is no corresponding research method that can reduce this resistance. In order to solve these problems, this paper has carried on the research on the mechanism of the viscous force of the catheter and the guide wire in surgery, and pioneers a method to supplement the micro-vibration in the proximal end of the guide wire. This method can reduce the viscous force of the catheter and the guide wire exerted by the blood during the push process, improve the surgical safety and the smoothness of the operation.In Section II, the corresponding method is described. An experimental setup is used to validate the proposed method, the viscous force of the guide wire measurement and the experimental results are presented in Section III. The effects of the radial micro–vibration on the interventional guide catheter and guide is then discussed in Section IV. Section V concludes the paper with suggestions for future research.

II. Method

As the blood viscosity, the catheter and the guide wire in the human blood vessels will be subjected to the viscous resistance. The corresponding effective resistance detection and drag reduction measures, not only can improve the efficiency of surgery, but also protect the patient from harm

However, there is little research on viscous resistance at this stage, and there is no equipment and method for reducing the viscous force of the catheter during intravascular movement. Therefore, in this part, the viscous resistance is first studied, and then the drag reduction method based on micro vibration is introduced[31]-[34].

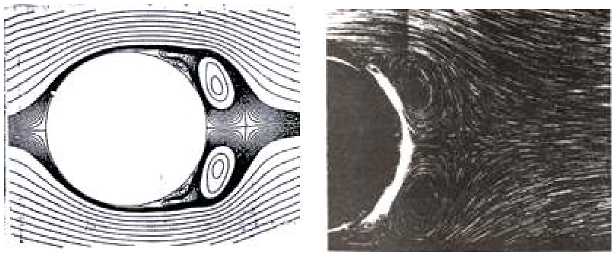
At present, the method of applying the vibration on the interventional catheter and the guide wire is mainly used for peripheral and coronary chronic occlusions. In axial vibration, an axially translating or vibrating motion is used to mechanically disrupt the occlusion by (axially directed) mechanical impact forces, commonly known as vibrational angioplasty. Adjusting the frequency and amplitude of the translations allows for the adaptation to, as well as the ability to cross and disrupt different tissue types. Radial vibration is proposed for acute occlusions, in radial vibration, a radial vibrating or translating motion is used to mechanically disrupt the occlusion by (radially directed) mechanical impact forces. Just as in axial vibrating tools, the radial vibrating tools can adapt and disrupt different tissue types based on the frequency and amplitude of the translations.

The viscous force is a relatively moving interaction between the two layers of fluid that impedes relative motion, and the viscous resistance to the object moving in the viscous fluid is that the fluid velocity on the surface of the object is zero and attached to the object, with the adjacent fluid produced by the relative movement, will hinder the movement of objects. The viscous resistance of the catheter guide wire is:

$$f_{\mathrm{v}} = \eta A \frac{\mathrm{dv}}{\mathrm{dy}} \tag{1}$$

There is a linear relationship between the size of the viscous resistance and the contact area A, the viscosity coefficient η of the fluid and the velocity gradient (dv /dy) of the fluid. The viscosity coefficient is determined by the nature of the fluid itself, which is related to the factors such as the type of fluid and the temperature of the fluid. The direction of the viscous force is parallel to the direction of the contact surface.

If want to reduce the viscous resistance of the catheter and the guide wire in the vascular movement caused by blood viscosity, can be achieved by reducing the contact area, and this paper can achieve this goal by applying the micro-vibration on the catheter and the guide wire.



(1) The movement of objects in the liquid forms turbulence (b) Schematic diagram

Fig.1 Fluid vacuum zone.

First, the catheter guide wire in the process of movement of the blood vessels, the speed is relatively stable, and when the micro-vibration on the catheter guide wire, due to the vibration of the entire guide wire body will cause local interference of the points, resulting in more "vacuum" area, which is no longer subject to the role of viscous resistance, in the overall reduction of the viscous force.

Furthermore, the vibration of the catheter guide wire will cause the catheter guide wire to move relative to the blood layer attached, to reduce the area of the liquid layer attached to its surface, thereby reducing the viscosity force size of the catheter guide wire in the blood.

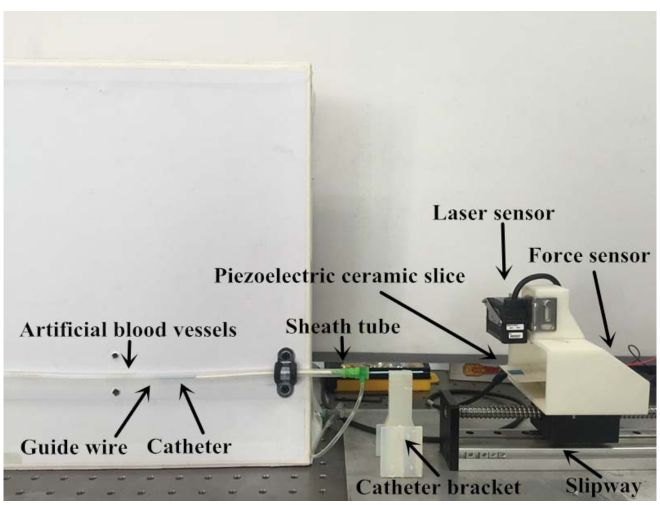


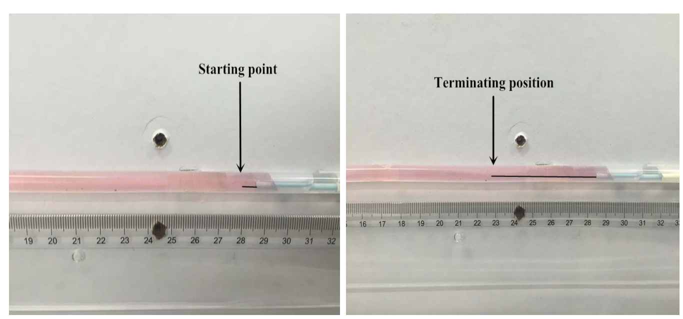
Fig.2 The experimental setup for the viscous force detection of the transverse micro-vibration guide wire.

The method of adding micro-vibration reduces the viscous resistance of the catheter guide wire, which is beneficial to the doctor's manipulation of the catheter and reduces the resistance of the catheter. It can reduce the risk of operation and improve the safety of the operation, to achieve the effect of assisted the doctor in surgery operation.

In this paper, the micro-vibration of the guide wire was oriented by the method of connecting the piezoelectric ceramic slice. Experiments used PVC pipes and prepared the liquid simulated blood viscosity to product the model of the artificial blood vessels. With inputting the different vibration signals to the piezoelectric ceramic slice, the guide wire will be the certain amplitude, a variety of frequency transverse vibration, while the use of laser sensors in real time for the guide wire vibration detection. And then the experiments controlled the slide to drive the vibration of the guide wire in the artificial blood vessel model with the forward and backward movement. It is noteworthy that the movement processes need to keep the guide wire linear motion. It is for preventing the catheter and the guide wire to touch the wall. It can simulate the viscous resistance situation of the catheter and the guide wire movement in the real blood vessels of the body. The viscous force in the vascular model of the guide wire was measured by mechanical sensor, and the effect of the transverse micro-vibration guide wire on the intervention operation was analysed.

III. Experiments and Results

Based on our previous work, we designed a new type device that applying the micro-vibration on the guide wire, and can measure the size of the viscous force of the guide wire in real time. Figure 2 shows the experimental setup for the viscous force detection of the transverse micro-vibration guide wire. It has two main parts, one is the model of the artificial blood vessels in the left side of the image with the overall white background. In order to facilitate observation and obtain a clear experimental image, this paper selected highly transparent 25 × 31mm PVC plastic tube with the length of 35mm to simulate the real human blood vessels. The tube was full of a liquid prepared with the density of 1.050 g/cm^3 that simulated the body blood viscosity. It is compounded the glycerine solution with the density of 1.263 g/cm^3 with and normal saline. Both together made up the model of the artificial blood vessels. The motion state of the guide wire is monitored using a camera that acquires images with a resolution of 640 × 480, such that can provide the morphological image information of the catheter and the guide wire in the experimental processes.



(a) Starting point (b) Terminating position

Fig.3 The movement position of the guide wire in the PVC tube.

On the other side is the guide wire engenders the transverse micro-vibration followed with the piezoelectric ceramic slice that can control the guide wire forward and back in the simulated blood vessel model by the slipway. In order to measure the real-time actual viscous resistance of the guide wire in the liquid that simulated the blood, a micro force sensor (LA-S2, CN) is fixed to the experimental stage with a custom printed adapter connected with the piezoelectric slice.

TABLE I

THE VISCOUS RESISTANCE OF THE GUIDE WIRE AT THE DIFFERENT VIBRATION FREQUENCY

f (HZ)	F_f (N)	F_s (N)
0	-0.0175	0.0116
50	-0.0151	0.0082
100	-0.0130	0.0083
500	-0.0177	0.0133
1k	-0.0148	0.0097
5k	-0.0132	0.0129
10k	-0.0122	0.0120
15k	-0.0139	0.0137
20k	-0.0144	0.0156
25k	-0.0125	0.0136
30k	-0.0129	0.0117
35k	-0.0155	0.0076

With inputting the different vibration signals to the piezoelectric ceramic slice, a 1Fr guide wire will be certain amplitude, a variety of frequency transverse micro-vibration, while the use of laser sensor (IL-030, KEYENCE) in real time for the guide wire vibration detection. It is also fixed on the custom printed adapter. The guide wire is actuated by the manipulator to get through a 5Fr catheter.

In order to study the effect of applying the micro-vibration on the guide wire to the viscous force, the experiment processes try to ensure that the guide wire is a linear motion, to avoid collision with the blood vessel wall. And the catheter is fixed on the printed catheter bracket. The catheter passed through the 2.5mm diameter medical sheath tube to simulate the guide wire movement within the blood vessels in the human body. The sheath is mounted on the right end of the soft tube to ensure the linear movement of the catheter and the guide wire. The catheter is the deflectable shaft that the distal part is out of the soft tube.

In order to verify the suitability of the proposed methods, this paper designed 12 different frequencies of micro vibration applying on the guide wire. The guide wire is actuated by manipulator to get through the medical soft tube with the 30mm distance reciprocating motion to simulate the guide wire movement within the blood vessels in the human body. The require date viscous force F included the forward force F_f and the setback force F_s measured by the force sensor is collected at a sampling rate of 40Hz.

The performance of the method for reducing the viscous resistance to the catheter and the guide wire is evaluated experimentally.

Aim to avoid measurement errors caused by the misuse of the operator, the guide wire is controlled to push and back for ten times of the different frequencies with recording the viscous force information generated on the body of the guide wire, and obtaining the average value as the viscous force detected by the force sensor. The result is shown in the Table I.

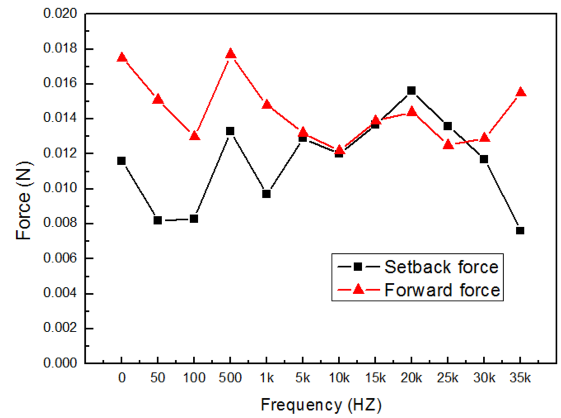


Fig.4 The viscous force results of the guide wire at different frequency vibration.

From the analysis in Figure 4, in the forward process, the frequency segment from 1 kHz to 35 kHz is obvious effect, the average viscosity decreased by 21.78%. Among them, the effect of 35 kHz vibration frequency is the best, the maximum can be reduced by 30.28%. And in the process of retreat, is still the best effect of the 35 kHz frequency vibration, up to 34.52%, but the low frequency band 50HZ to 100HZ better, viscous force can be reduced by an average of 29.10%.

IV. DISCUSSIONS

1) There are glitches and outliers in the experimental data, which are caused by the low sampling accuracy of the force sensor itself. And the zero drift of the sensor also cause the error of the experimental data.
2) The presence of some unavoidable mechanical vibration and mechanical friction in the experimental setup, can affect the reading of the mechanical sensor, or even cause abnormal experimental data, experimental error is generated.
3) In the future work should increase the number of experimental sampling data to reduce the experimental data error.
4) Force Sensor has its own optimum operating temperature. As the experiment progresses, the sensor will continue to produce heat-induced temperature rise, thus affecting the measurement precision of the force sensor, resulting in the experimental error.

V. CONCLUSIONS

Through the study and analysis of the interventional operation, it is found that the pushing resistance of the catheter and the guide wire is large in the push process, which is easy to cause blood vessel injury and affect the operation efficiency and safety. At the same time, the research about the viscous resistance of the catheters and the guide wire during the surgery in this field is still a blank, and there is no corresponding research method that can reduce this resistance. In order to solve these problems, this paper has carried on the research on the mechanism of the viscous force of the catheter and the guide wire in surgery, and pioneers a method to supplement the micro-vibration in the proximal end of the guide wire. This method can reduce the viscous force of the catheter and the guide wire exerted by the blood during the push process, improve the surgical safety and the smoothness of the operation.

ACKNOWLEDGEMENTS

This research is supported by National High Tech. Research and Development Program of China (No.2015AA043202)

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