Journal of Visualized Experiments

A Training and Testing System for Performing Vascular Reconstruction In Vitro

--Manuscript Draft--

Article Type:	Methods Article - Author Produced Video
Manuscript Number:	JoVE60141R3
Full Title:	A Training and Testing System for Performing Vascular Reconstruction In Vitro
Section/Category:	JoVE Medicine
Keywords:	vascular reconstruction, training system, testing system, magnetic tractor, magnetic suture puller, polypropylene suture damage
Corresponding Author:	Yue Wang Xi'an Jiaotong University Medical College First Affiliated Hospital Xi'an, Shaanxi Province CHINA
Corresponding Author's Institution:	Xi'an Jiaotong University Medical College First Affiliated Hospital
Corresponding Author E-Mail:	ywang9822@163.com
Order of Authors:	Yue Wang
	Lijun Mu
	Wei Zhang
	Huan Chen
	Qingshan Li
	Aihua Shi
	Bo Tang
	Xiaogang Zhang
	Dinghui Dong
	Yi Lv
Additional Information:	
Question	**Response**
Please indicate whether this article will be Standard Access or Open Access.	Standard Access (US$1200)

Powered by Editorial Manager® and ProduXion Manager® from Aries Systems Corporation

September 22, 2019

RE: Revised JoVE60141 "A Training and Testing System for Performing Vascular Reconstruction In Vitro" by Wang, Mu, Zhang, Chen, Li, Shi, Tang, Zhang, Dong and Lv.

Dear Bajaj, PhD:

Thank you very much for your email dated September 19, 2019 in which you informed us that our manuscript has been editorially reviewed. We also appreciate for your excellent edit work and your critical comments. The comments, our point-by-point responses to them, and changes made in the text (which are highlighted by red font) are listed in separate file.

We sincerely hope that the changes made in the revised manuscript and video meet with your approval, and our manuscript and video can be published in the JoVE. If there are any further questions, please do not hesitate to contact us.

Sincerely yours,

Yi Lv, MD, PhD
First Affiliated Hospital of Xi'an Jiaotong University
Email: Luyi169@126.com

Manuscript Click here to access/download;Manuscript;60141_R3_Rev.docx

TITLE:

A Training and Testing System for Performing Vascular Reconstruction In Vitro

AUTHORS AND AFFILIATIONS:

Yue Wang[1,2], Lijun Mu[3], Wei Zhang[1,2], Huan Chen[1,2], Qingshan Li[1,2], Aihua Shi[1], Bo Tang[2], Xiaogang Zhang[1,2], Dinghui Dong[1,2], Yi Lv[1,2]

[1]National Local Joint Engineering Research Center for Precision Surgery and Regenerative Medicine, First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi Province, China
[2]Department of Hepatobiliary Surgery, First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi Province, China
[3]Department of General Surgery, First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi Province, China

Corresponding Author:
Yi Lv (Luyi169@126.com)

Email Addresses of Co-authors:
Yue Wang (ywang9822@163.com)
Lijun Mu (sasukedeai@163.com)
Wei Zhang (zw12345lf@163.com)
Huan Chen (zychenhuan@163.com)
Qingshan Li (mohenqingshan@163.com)
Aihua Shi (shiaihua2000@126.com)
Bo Tang (magnetic_tb@163.com)
Xiaogang Zhang (47608867@qq.com)
Dinghui Dong (dongdinghui1988@stu.xjtu.edu.cn)

KEYWORDS:
vascular reconstruction, training system, testing system, magnetic tractor, magnetic suture puller, polypropylene suture damage

SUMMARY:
Here we present a training and testing system where a trainee can complete manual vascular reconstruction in vitro individually using a magnetic anchoring technique. The system can also be used to test the quality of reconstruction.

ABSTRACT
Manual vascular reconstruction training is essential for a beginner surgeon. However, an optimal training system for vascular reconstruction in vitro has yet to be developed. In this study, we introduce an in vitro training and testing system using a magnetic anchoring technique with which a trainee can practice manual vascular reconstruction individually. Additionally, this system can also be used to test the quality of the reconstruction. The described system includes a vascular reconstruction training machine, magnetic tractors, and

a magnetic suture puller. In this manuscript, we detail an end-to-end vein anastomosis using porcine right and left iliac veins. To identify the potential damage caused by a magnetic suture puller on the suture, we created three groups with six segments of 4-0 polypropylene sutures each: a control group with no intervention on the polypropylene suture, a group in which the polypropylene suture is manually pulled with sterile gloves 20x, and a magnetic puller group in which the magnetic puller pulled the polypropylene suture 20x. These groups were tested by light microscopy and breaking strength tests, and the effect of reconstruction was assessed. In the light microscopy test, the control group was less likely to be damaged ($p < 0.05$) and the number of damaged points of the manual group and magnetic puller group were similar ($p > 0.05$). The results of the breaking strength test were compared across groups and no significant difference was observed ($p > 0.05$). The end-to-end anastomosis of the porcine iliac veins was successfully performed using this training system, and the reconstructed veins could undergo 2.0 kPa perfusion pressure. Using this training and testing system the trainee can practice manual vascular reconstruction in vitro individually with the aid of magnetic tractors and a magnetic suture puller, and the quality of the reconstruction can be tested.

INTRODUCTION:

Vascular reconstruction is a basic skill required for surgeons. Although Obora[1] and Holt[2] invented several mechanical reconstruction methods to simplify the reconstruction of small vessels (diameters <10 mm), these methods are not commonly applied in macrovascular anastomosis. Manual vascular anastomosis is still performed in many operations, including vascular surgery[3], emergency surgery[4], and solid organ transplantation[5]. Thus, it is essential for surgeons to practice manual vascular anastomosis. However, an optimal training system for vascular reconstruction in vitro is uncommon, and inexperienced surgeons must undergo considerable training in vivo on large animals[6] before they can master the technique. Because failure is inevitable during initial training, many animals are likely to die of vascular complications, which is concerning regarding animal welfare. Further, during the procedure of end-to-end vascular reconstruction, to avoid mistakes in stitch positions or loose sutures, the surgeon needs at least one assistant to expose the posterior vascular wall and pull the suture. Thus, vascular reconstruction usually cannot be performed by the surgeon individually, and the efficiency of preparation is usually limited by the proficiency of the assistant.

Magnetic anchoring surgery has become a topic of interest in recent years[7–11]. The clinical trial by Rivas et al.[7] showed that with his magnetic surgical instrument and following the principle of magnetic anchoring, surgeons can perform reduced-port laparoscopic cholecystectomy. The use of this instrument also allows for a reduced role for the assistant during open surgery. Through the magnetic field, the magnetic device is adsorbed onto an anchoring point. This magnetic anchoring device can act as a mechanical arm, grasping and retracting the tissue or organ, exposing the surgical field, and simplifying the operation. Based on this rationale, we invented magnetic tractors to retract the vascular wall and suture, and a magnetic suture puller to pull the polypropylene sutures.

The use of a vascular reconstruction training machine was another milestone in this study. It consists of an operating floor and a control panel: the vasculature is fixed on the operating floor, and the trainee can practice on it. After anastomosis, the trainee can set the perfusion parameters on the control panel in order to test the quality of anastomosis. Compared to previous vascular anastomosis training systems[6,12–14], the use of this system provides two main advantages: First, magnetic devices can be used to expose the surgical field, so that the trainees can practice on it individually. Second, the trainee can check the effect of anastomosis using a perfusion test.

In the present study, we introduce a training and testing system where the trainee can complete manual vascular reconstruction in vitro individually using a magnetic anchoring technique and the quality of reconstruction can also be tested. Limited by the design and size of the water inlet and water outlet on the operating floor, the training system can only perform end-to-end reconstruction on vessels with a >5 mm diameter.

PROTOCOL:

The protocol was carried out in accordance with the Guidelines for the Care and Use of Laboratory Animals and was approved by the Committee on the Ethics of Animal Experiments of Xi'an Jiaotong University, Xi'an, Shaanxi Province, China.

1. Preparation prior to the training

NOTE: The vascular reconstruction training machine is shown in **Figure 1**. It consists of a control panel and an operating floor.

1.1. Click the **Clean** button on the control panel to clean and drain the residual liquid from the operating floor.

1.2. Click the **Add Liquid** button on the control panel and add 0.9% saline into the machine from the operating floor until the prompt "**The testing liquid is adequate"** appears on the control panel.

1.3. Prepare the magnetic tractor, which consists of a circular permanent magnet with a diameter of 20 mm and a thickness of 1 mm, an acrylonitrile butadiene styrene (ABS) plastic casing, a spiral spring, a 30 cm nylon traction wire, and a stainless-steel clamp with plastic sleeves or a vascular clamp.

1.3.1. Glue the circular magnet and the plastic casing together using an acrylate adhesive. The traction force will increase with the lengthening of the traction wire. Use a universal testing machine to test the association between the length of the traction wire and the traction force (**Figure 2**).

1.3.2. Fix the clamp and the plastic casing on the upper holder and the lower holder of the universal testing machine, respectively. Gradually elevate the upper holder to stretch the traction wire between the two holders. Test the strength of the traction wire while it is being stretched.

NOTE: The magnetic suture tractor and magnetic vascular tractor are shown in **Figure 3**.

1.4. Prepare a magnetic suture puller.

1.4.1. Use a quasi-oval polylactic acid board with a thickness of 2 mm, a major axis diameter of 10 cm, a minor axis diameter of 2 cm, three magnetic balls with a diameter of 5 mm, and three magnetic cylinders with a diameter of 5 mm and a height of 5 mm.

1.4.2. Punch three holes with a diameter of 3 mm and a depth of 0.5 mm on the polylactic acid board, so that the magnetic balls can cling to the board by magnetic attraction force from the magnetic cylinders under the board.

NOTE: The magnetic suture puller is shown in **Figure 4**.

1.5. Fix the suture under the magnetic ball after one stitch. This plays the role of a suture puller, preventing the previous suture from loosening. Extract the end with the suture needle with a force of about 0.3 N, closely in parallel to the polylactic acid board, and continue the next stitch.

1.6. Ligate all the vein branches using 3-0 silk sutures to avoid leakage after anastomosis. Use tissue scissors to trim the ends of the veins and clear the excess tissue on the wall of the veins to make the veins smooth.

NOTE: The vasculature used in this study included the right and left iliac veins (diameter ~10 mm) harvested from Bama pigs weighing 50–60 kg. To simplify the reconstruction, only a few branches of the iliac veins were picked, and the two veins were similar in size. The vasculature was kept at -20 °C. Before training, it was immersed in 0.9% saline at room temperature.

2. Fix the veins on the operating floor

2.1. Tie the two veins on the water inlet and water outlet of the training machine with 2-0 silk sutures.

NOTE: This study uses the two-point vascular anastomosis[5].

2.2. Adjust the length of the water outlet of the training machine and ensure that the ends of the two veins are tension-free in a parallel direction.

2.3 Straighten the veins and lay two 4-0 polypropylene traction sutures at the 6 o'clock and 12 o'clock positions.

2.4. Insert the needle of the traction sutures from the outside of the vein and then insert from the inside of the other vein.

2.4. Wet the surgical glove and sutures to avoid damaging the sutures. Gently tie at least five knots to avoid tearing the walls of the veins.

2.4. Use the two stainless-steel clamps of the magnetic suture tractor to grasp the traction sutures and attract the circular magnets of the magnetic suture tractors to the ferromagnetic stainless-steel operating floor. Adjust the position of magnetic attraction and ensure that the ends of the two veins are stretched in a vertical direction.

2.5. Use the two vascular clamps of the magnetic vascular tractor to clamp the anterior wall of the veins and attract the circular magnets of the magnetic vascular tractors on the operating floor. Adjust the position of attraction and ensure that the anterior walls of the veins are retracted, and the posterior walls of the veins are clearly exposed.

3. Anastomosis of posterior walls

3.1 Use the two stainless-steel clamps of the magnetic suture tractor to grasp the traction sutures and attract the circular magnets of the magnetic suture tractors on the ferromagnetic stainless-steel operating floor. Leave the tail segment of the polypropylene suture at the 12 o'clock position for the traction suture and use the segment with the needle for continuous suture.

3.2 Ensure intima-to-intima contact between the two veins.

3.3. Insert the first suture from the outside of the vein to the inside.

3.4. In subsequent sutures, insert the needle from the inside of the vein and then insert from the outside of the other vein.

3.5. Check that the sutures are not loose.

3.6. After one suture, ensure that the polypropylene suture is hung on the magnetic suture puller and pull the polypropylene gently until the magnetic ball presses the polypropylene.

3.7. Extract the end with the needle of the suture with a force of about 0.3 N, closely in parallel to the polylactic acid board, and continue the next stitch.

NOTE: By using this technique, the tail of the polypropylene suture will be sufficiently tight. As the sutures continue, the polypropylene suture will become shorter. According to the length of the suture, select the most suitable of the three magnetic balls, and then manually press the suture under it.

3.8. Insert the last suture from the inside of the vein to the outside to ensure intima-to-intima contact between the two veins.

3.9. Avoid stenosis after anastomosis by two means: Keep same, proper margin and needle spacing when stitching, and keep the "growth factor"[15] when knotting.

NOTE: The "growth factor" is the reserved space away from the vessel wall when tying the first knot after the anastomosis so that vessels can remain flexible rather than stenose.

3.9.1 Maintain the same suture margin and needle spacing.

NOTE: In this study, iliac veins with a diameter of approximately 10 mm were used, so the suture margin and needle spacing was about 1 mm.

3.9.2 Keep the "growth factor"[15] when tying the knots. After anastomosis of the posterior walls, tie the end of the suture and the tail segment of the suture at the 6 o'clock position together away from the vein wall in order to prevent suture stenosis. Use the standard method for tying knots.

4. Anastomosis of anterior walls

4.1 After anastomosis of the posterior walls, remove the magnetic vascular tractor, leave the tail as a traction suture, and use the segment with the needle at the 6 o'clock position for the anastomosis of the anterior walls.

4.2 Insert the needle from the outside of the vein and then insert from the inside of the other vein.

NOTE: The methods used in the anastomosis of the posterior walls to ensure the intima-to-intima contact between the two veins (the suture not being loose and avoiding stenosis after anastomosis) were followed in the anastomosis of the anterior walls[5,15].

4.3 After anastomosis of the anterior walls, cut off two traction sutures using suture scissors.

5. Test the effect of anastomosis

5.1 Set the test parameters.

5.1.1 Set the perfusion pressure as 2.0 kPa on the control panel.

NOTE: The normal vein pressure will not exceed 2.0 kPa.

5.1.2 Set the duration of peak pressure as 5 s on the control panel.

5.1.3 Set the temperature as 25 °C on the control panel.

5.1.4 Set the pressure deviation as 0.1 kPa on the control panel.

5.2 Click the **Test** button and observe the time and pressure on the control panel and whether the reconstructed vein leaks.

NOTE: If the vein does not leak during the peak pressure, the anastomosis is successful. If leaks are found, the leakage position should be located and sutured, and then the test should be performed again. The results of the test in this video are shown in **Figure 5**.

6. Checking the safety of the magnetic suture puller

NOTE: To test whether the magnetic suture puller damaged the polypropylene suture, perform the breaking strength and light microscopy tests. In this experiment, three groups with six segments of 4-0 polypropylene suture in each were tested: a control group with no intervention on the polypropylene suture, a manual group in which the polypropylene suture was manually pulled with sterile gloves 20x, and a magnetic puller group in which the magnetic puller pulled the polypropylene suture 20x.

6.1 Test the breaking strength of the polypropylene suture on the universal testing machine. Fix the two ends of the polypropylene suture on the upper holder and the lower holder of the universal testing machine. Gradually elevate the upper holder. Test the strength of the polypropylene suture while it is being stretched. Set the breaking strength as the tension force when the suture snaps. Compare the breaking strength among the three groups and perform pairwise comparisons.

6.2 Observe the damage of the polypropylene suture under a light microscope. Define the number of damage points as the number of fibrous or coarse fracture points visible at 200x magnification. Compare the number of damage points among the three groups and perform pairwise comparisons.

REPRESENTATIVE RESULTS

The vascular reconstruction training machine is shown in **Figure 1** and includes two main parts: the operating floor and the control panel. The operating floor consists of a water inlet, a water outlet, and a water storage basin. The two ends of the vasculature are tied to the water inlet and water outlet to test the effect of anastomosis. The length of the water outlet is adjustable, and we set the parameters (e.g., the perfusion pressure, duration of peak pressure, temperature, and pressure deviation) on the control panel. In addition, we can observe the pressure curve on the control panel when the vasculature is tested.

The magnetic suture tractor and the magnetic vascular tractor are shown in **Figure 3**. The length of the traction wire is 30 cm, and the traction force increases with the lengthening of the traction wire (**Figure 2**). The range of the magnetic tractor's traction force is 0–1.8 N, which covers the range of traction force required for suture and vascular traction.

Photos of the magnetic suture puller are shown in **Figure 4A,B**. The three magnetic balls have a diameter of 5 mm, and the magnetic cylinders have a diameter of 5 mm and a height of 5 mm. These can be replaced by smaller or bigger ones. The suture pulling force will change accordingly.

In testing the effect of anastomosis, a time-perfusion pressure curve was generated and is shown in **Figure 5**. The perfusion pressure ascended to 2.0 kPa, which we set as the peak pressure. This was maintained for 5 s, which was set as the duration of peak pressure.

Regarding the safety of the magnetic suture puller, we tested whether the magnetic suture puller damaged the polypropylene suture using a breaking strength test and a light microscope. As shown in **Figure 6**, the breaking strength test results of the three groups were compared pairwise, and no significant difference was observed ($p > 0.05$). As shown in **Figure 7**, the control group was less likely to be damaged ($p < 0.05$), but the number of damaged points in the manual group and the magnetic puller group were similar ($p > 0.05$).

FIGURE LEGENDS

Figure 1: The vascular reconstruction training machine's two main parts. The operating floor and the control panel.

Figure 2: The association between the length of the traction wire and the traction force. The length of the traction wire was 30 cm, and the range of traction force that the magnetic tractor could provide was 0–1.8 N.

Figure 3: The magnetic suture tractor and the magnetic vascular tractor. (**A**) Magnetic suture tractor. (**B**) Magnetic vascular tractor.

Figure 4: The magnetic suture puller. (**A**) Front view. (**B**). Lateral view. The magnetic suture puller consists of a quasi-oval polylactic acid board with a thickness of 2 mm, a major axis diameter of 10 cm, a minor axis diameter of 2 cm, three magnetic balls with diameter of 5 mm, and three magnetic cylinders with a diameter of 5 mm and a height of 5 mm.

Figure 5: Time-perfusion pressure curve. The perfusion pressure ascended to 2.0 kPa, which we set as the peak pressure. It was maintained for 5 s, indicating that the anastomosis was successful.

Figure 6: The breaking strength test. (**A**) The association between the length of the polypropylene suture and the tension. (**B**). Comparison of the breaking strength among the three groups. There was no significant difference in the three groups ($p > 0.05$).

Figure 7: The light microscope tests. (**A**) Control group. (**B**) Manual group. (**C**) Magnetic puller group. (**D**) Comparison of the number of damage points among the three groups. The control group had fewer damage points ($p < 0.05$), but there was no significant difference between

the manual group and the magnetic puller group ($p > 0.05$). The black arrow points to the damage point. The asterisk represents the significant difference.

DISCUSSION:

With the help of magnetic tractors and a magnetic suture puller, a trainee can complete vein anastomosis individually and precisely. Magnetic tractors pull the tissue that blocks the anastomosis field and provide suitable strength for stretching the veins in a vertical direction, thus achieving clear exposure for vein anastomosis. In traditional manual anastomosis, at least one assistant is required for surgical exposure. The use of magnetic tractors could achieve the required exposure and substitute for assistants. In addition, the traction force of the magnetic tractor was dependent on the length of the traction wire, so we could adjust the site that the magnetic tractor was adsorbed onto in order to change the length of the traction wire to obtain a suitable traction force. In contrast to traditional manual anastomosis, the traction force in this study was quantifiable by the length of the traction wire. This allowed us to avoid some issues resulting from too heavy or too light a traction force, such as tearing of the vasculature and unclear exposure.

The magnetic suture puller was another novel invention in this study. It replaced the requirement for an assistant to pull the suture to prevent the previous suture from loosening, resulting in anastomotic leakage. Because it pressed the polypropylene suture, we tested the degree of damage caused by the magnetic suture puller and compared it to intact and manual pulling. Although the number of damage points in the magnetic puller group was more than in the control group (intact polypropylene sutures), it was similar to that observed in the manual pull that is widely used in clinical practice. Moreover, the breaking strength test showed a similar breaking strength among the three groups. With the microscope, we found that the changes caused by the magnetic puller were too small to damage the strength of the polypropylene suture.

It must be emphasized that the tension on the vertical and parallel directions of the vasculature during anastomosis is significant. Therefore, it is vital to adjust the length of the water outlet of the training machine as well as the position of the magnetic tractors. In addition, as we add sutures, we pick the most suitable magnetic ball to press the suture so that the tension on the suture is moderate. Moreover, to avoid stenosis after anastomosis, it is essential to keep the same suture margin, needle spacing, and "growth factor".

If the trainee wishes to practice anastomosis using vasculature with a greater or smaller diameter, the magnetic balls and cylinders of the magnetic suture puller should be replaced by bigger or smaller ones, so that the pulling force changes accordingly. Simultaneously, the test parameters after anastomosis should be adjusted. In the current version of the vascular reconstruction training machine, the diameter of the inlet and outlet is only 5 mm, making it difficult to use on smaller diameter vessels. Fortunately, the inlet and outlets are detachable, so the current inlet and outlet can be replaced by smaller ones that allow changes in vessel size.

Beside the sizes of the inlet and outlet, there are still some limitations to this training system. Because there is only one water inlet and one water outlet, this training and testing system is only applicable to end-to-end anastomosis, and trainees cannot practice end-to-side or side-to-side anastomosis using this system. Additionally, the surgical instruments used in this video (e.g., the needle holder and scissors) are ferromagnetic stainless steel. They were absorbed by the magnetic tools occasionally, which could interfere with the training progress. If conditions permit, the surgical instruments can be replaced with non-ferromagnetic titanium instruments.

Open surgical vascular simulators are generally divided into two types: in vivo and in vitro. Tang[6] developed a novel technique for vascular reconstruction in vivo using ewes as animal models. Although this technique provided a more realistic operation scene, the use of in vivo animal models is both inconvenient for training and costly. Shimizu[12] and Maluf[13] invented in vitro training devices for cerebrovascular anastomosis, while Bismuth[14] introduced a vascular surgery course named Cardiovascular Fellows Bootcamp for cardiovascular surgery education. Although the rationale of our training system is similar to those outlined in these studies, no previous study has recommended the use of a device to assist in exposing surgical field and maintaining the tension of the suture. Thus, the training previously described must be completed by at least two trainees. Also, previous researchers did not introduce a way to precisely check the quality of anastomosis. Therefore, compared to these open vascular simulators, our technique is economical, convenient to practice individually, and effective in terms of feedback training quality.

We intend to add smaller water inlets and water outlets to the vascular reconstruction training instrument so that trainees can practice other types of anastomosis. We expect that magnetic tractors and suture pullers will be used to help surgeons expose the surgical field in routine clinical operations in the future.

In summary, we introduce a training and testing system where the trainee can complete manual vascular reconstruction in vitro individually with the aid of magnetic tractors and a magnetic suture puller.

DISCLOSURES:

The authors have nothing to disclose.

ACKNOWLEDGEMENTS:

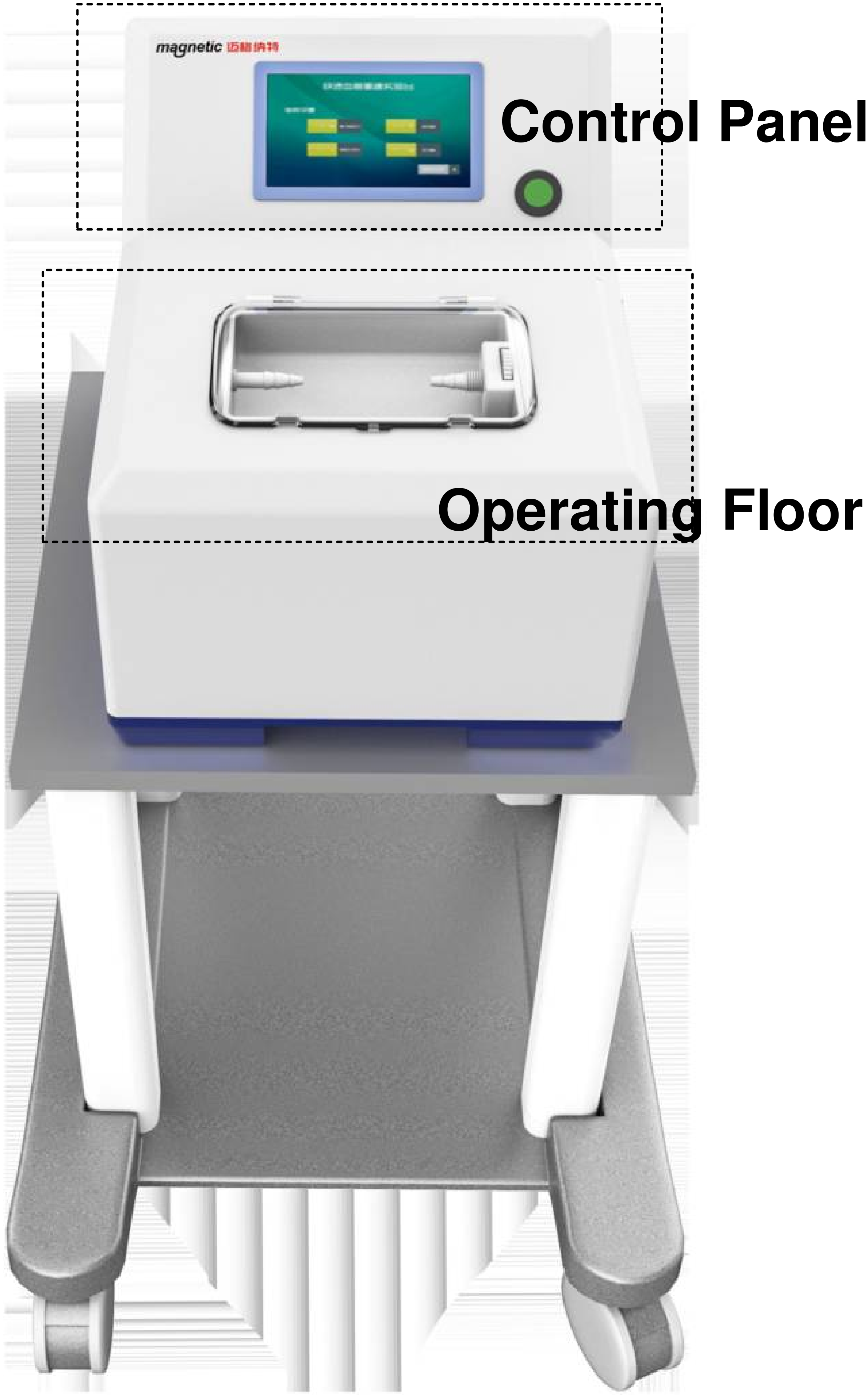
This work was supported by grants from the Ministry of Education Innovation Team Development Program of China (No. IRT1279).

REFERENCES:

1. Obora, Y., Tamaki, N., Matsumoto, S. Nonsuture microvascular anastomosis using magnet rings: preliminary report. *Surgical Neurology*. **9** (2), 117–120 (1978).
2. Holt, G. P., Lewis, F. J. A new technique for end-to-end anastomosis of small arteries. *Surgical Forum*. **11**, 242–243 (1960).

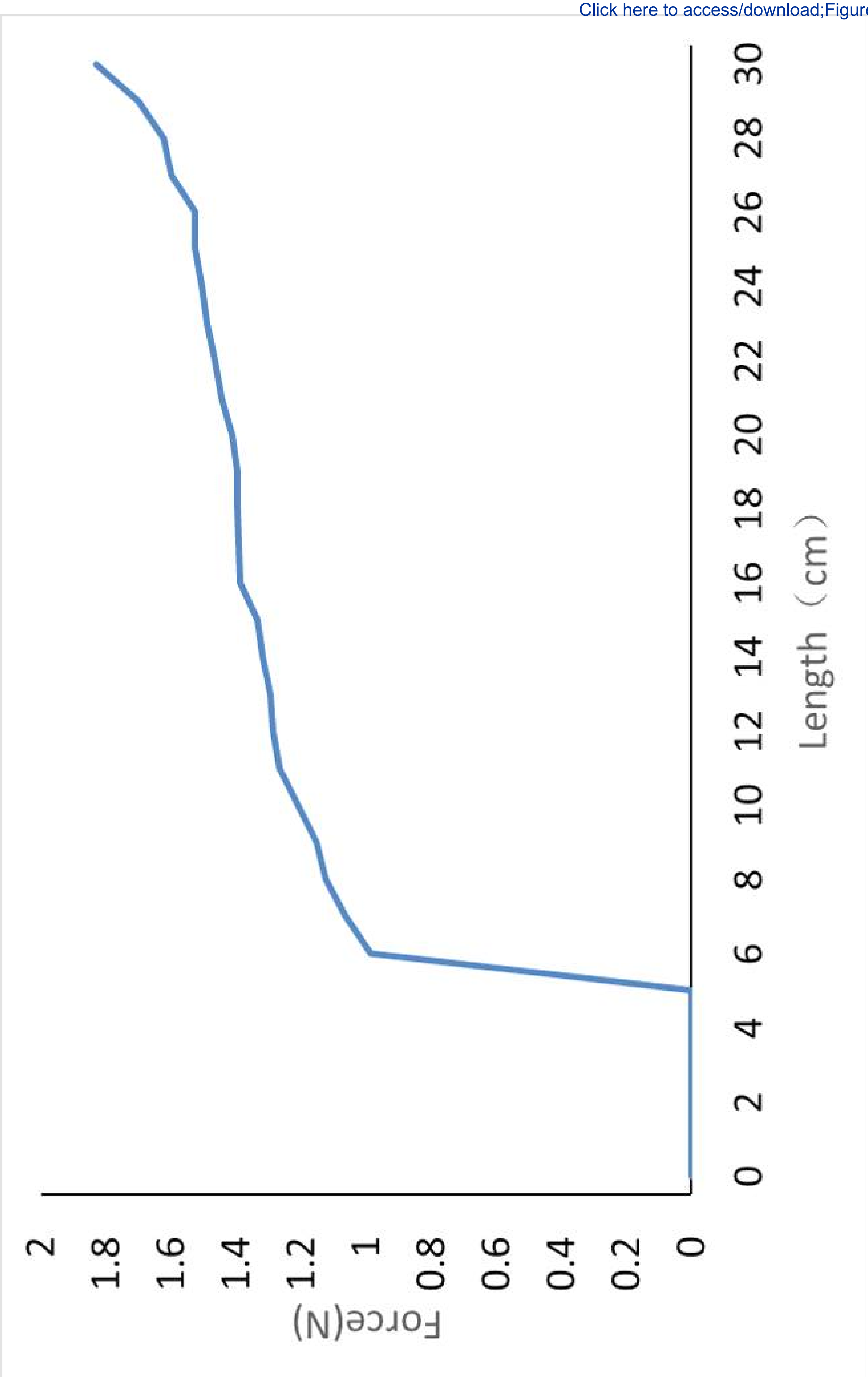
3. Enzmann, F. K. et al. Trans-Iliac Bypass Grafting for Vascular Groin Complications. *European Journal of Vascular and Endovascular Surgery*. (xxxx), 1–6 (2019).
4. Bala, M. et al. Acute mesenteric ischemia: Guidelines of the World Society of Emergency Surgery. *World Journal of Emergency Surgery*. **12** (1), 1–11 (2017).
5. Makowka, L. et al. Surgical Technique of Orthotopic Liver Transplantation. *Gastroenterology Clinics of North America.* **17** (1), 33-51 (1998).
6. Tang, A. L. et al. The elimination of anastomosis in open trauma vascular reconstruction: A novel technique using an animal model. *Journal of Trauma and Acute Care Surgery*. **79** (6), 937–942 (2015).
7. Rivas, H. et al. Magnetic Surgery: Results from First Prospective Clinical Trial in 50 Patients. *Annals of Surgery*. **267** (1), 88–93 (2018).
8. Arain, N. A. et al. Magnetically Anchored Cautery Dissector Improves Triangulation, Depth Perception, and Workload During Single-Site Laparoscopic Cholecystectomy. *Journal of Gastrointestinal Surgery*. **16** (9), 1807–1813 (2012).
9. Mortagy, M. et al. Magnetic anchor guidance for endoscopic submucosal dissection and other endoscopic procedures. *World Journal of Gastroenterology*. **23** (16), 2883–2890 (2017).
10. Cho, Y. B. et al. Transvaginal endoscopic cholecystectomy using a simple magnetic traction system. *Minimally Invasive Therapy and Allied Technologies*. **20** (3), 174–178 (2011).
11. Dong, D. H. et al. Miniature magnetically anchored and controlled camera system for trocar-less laparoscopy. *World Journal of Gastroenterology*. **23** (12), 2168–2174 (2017).
12. Shimizu, S. et al. Moist-condition training for cerebrovascular anastomosis: A practical step after mastering basic manipulations. *Neurologia Medico-Chirurgica*. **55** (8), 689–692 2015).
13. Maluf, M. A., Massarico, A., Nova, T. V., Lupp, A., Cardoso, C., Gomes, W. Cardiovascular Surgery Residency Program: Training Coronary Anastomosis Using the Arroyo Simulator and UNIFESP Models. *Revista Brasileira de Cirurgia Cardiovascular*. **30** (5), 562–570 2015).
14. Bismuth, J., Duran, C., Donovan, M., Davies, M. G., Lumsden, A. B. The Cardiovascular Fellows Bootcamp. *Journal of vascular surgery*. **56** (4), 1155-1161.e1 (2012).
15. Starzl, T. E., Iwatsuki, S., Shaw, B. A Growth Factor in Fine Vascular Anastomoses. *Surgery Gynecology And Obstetrics*. **159** (2), 164–165 (1984).

Click here to access/download;Figure;Fig1.eps



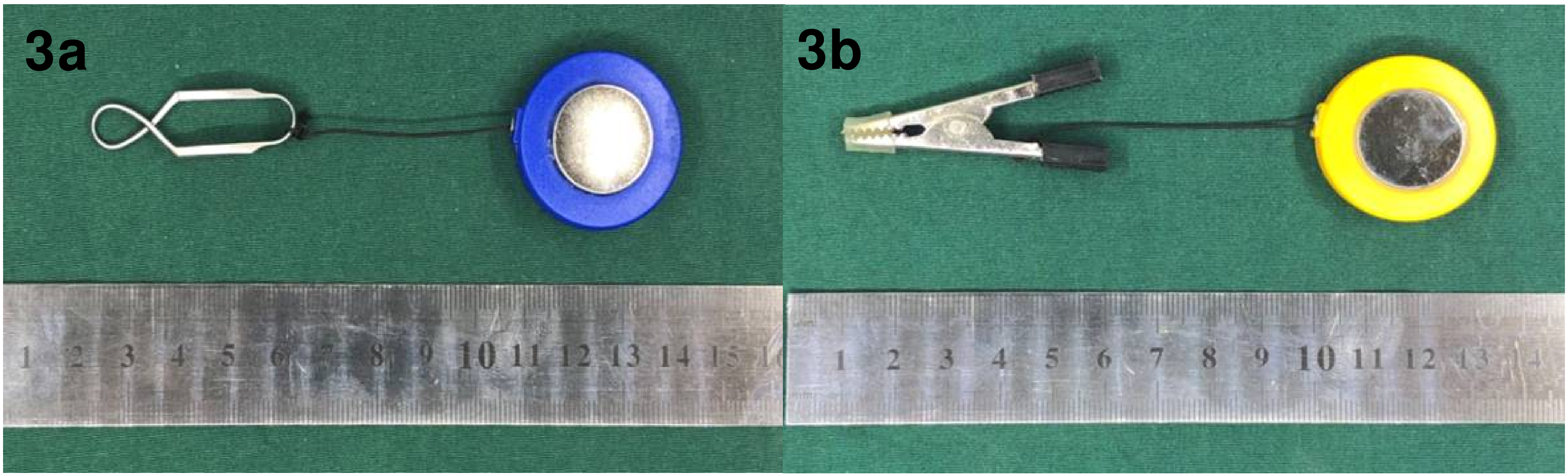
Figure

Click here to access/download;Figure;Fig2.eps



Figure

Click here to access/download;Figure;Fig3.eps



Figure

Click here to access/download;Figure;Fig4.eps

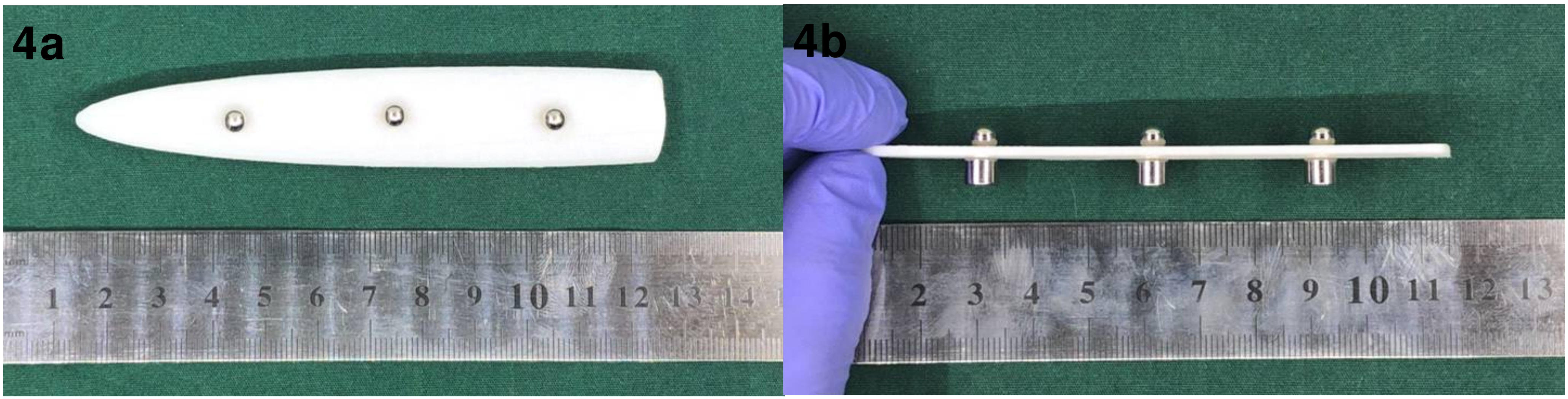
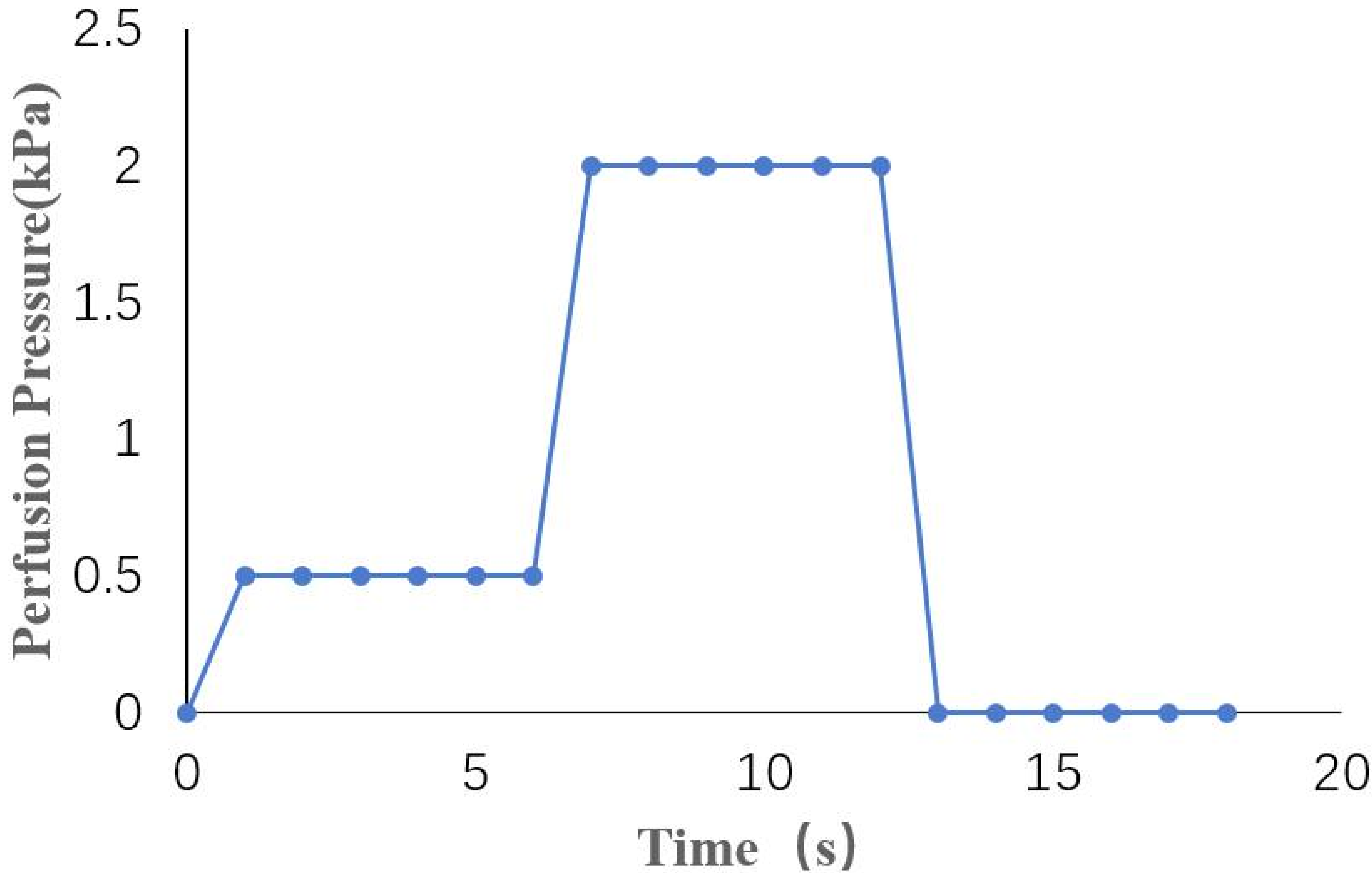


Figure Click here to access/download;Figure;Fig5.eps



Figure

Click here to access/download;Figure;Fig6.eps

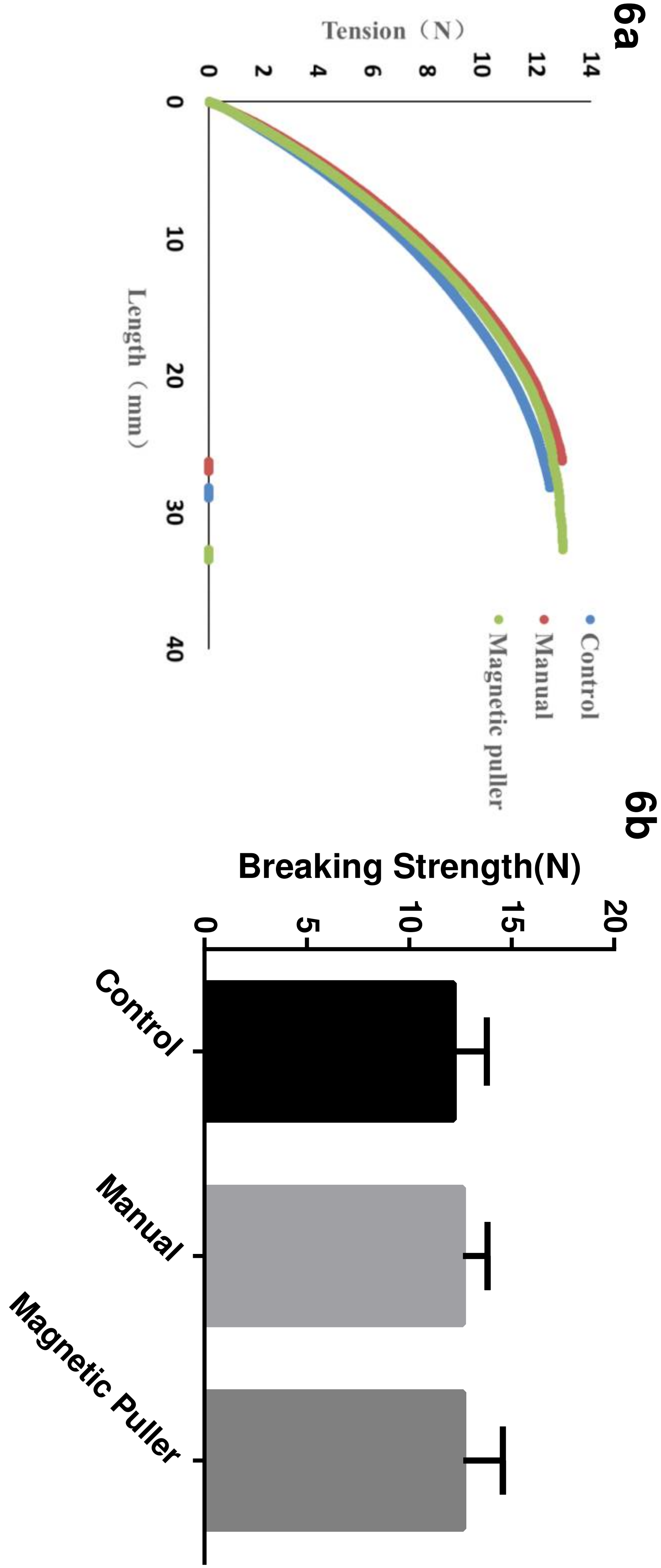
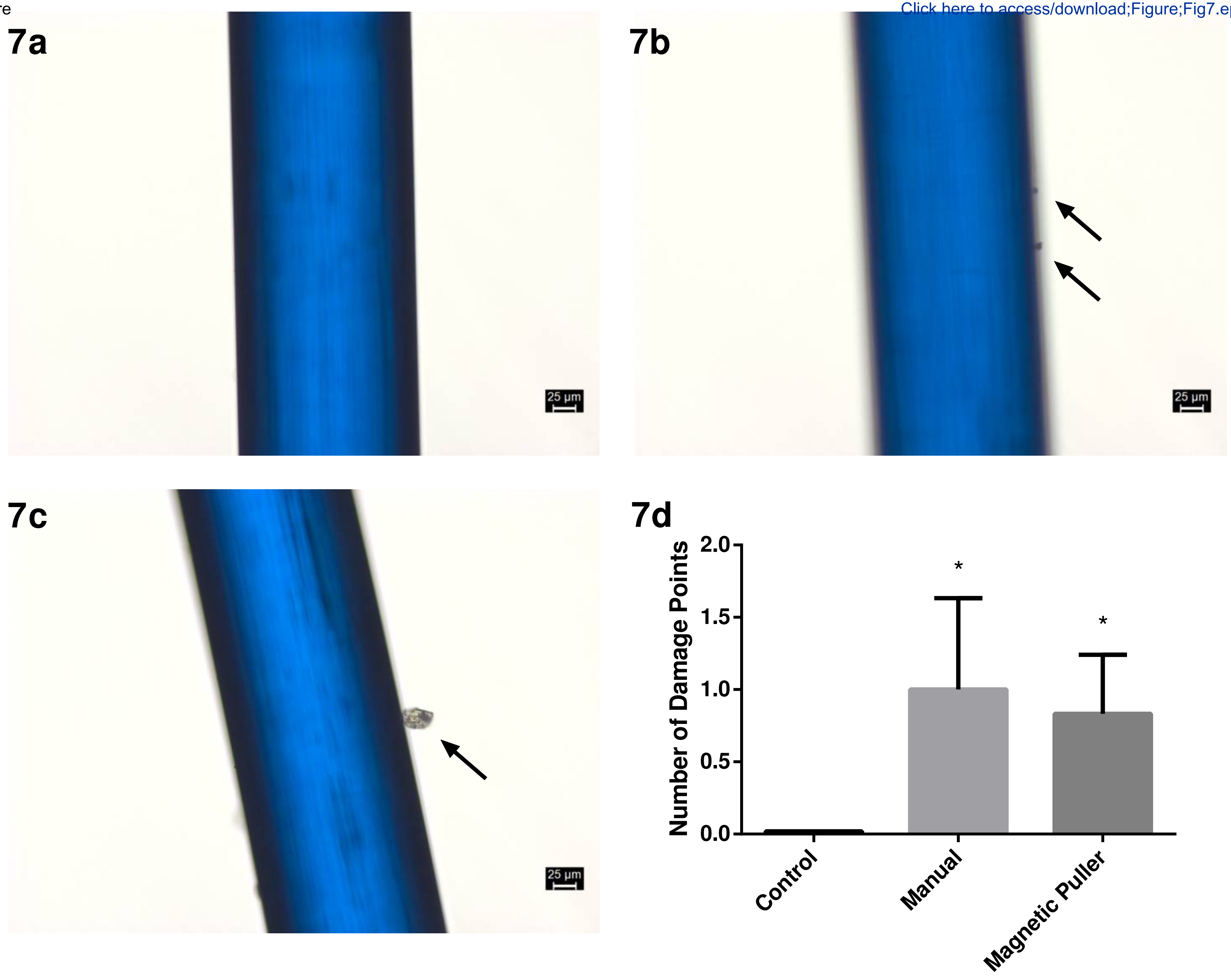


Figure Click here to access/download;Figure;Fig7.eps



 Click here to access/download;Table of Materials;JoVE_Table_of_Materials.xlsx

Name of Material/Equipment	Company	Catalog Number
Circular permanent magnet	Hangzhou Permanent Magnet Group Co.LTD	20*1mm
Magnetic balls	Hangzhou Permanent Magnet Group Co.LTD	5mm
Magnetic cylinders	Hangzhou Permanent Magnet Group Co.LTD	5*5mm
Polypropylene suture	Johnson and Johnson	PROLENE 4-0
Silk suture	SILK	2-0,　3-0
Surgical insturments	Jinzhong Shanghai	JZ-2018
Universal testing machine	Zwick GmbH&Co	Z010

Comments/Description

Magnetic tractor

Magnetic suture puller

Magnetic suture puller
Used for anastomosis
Used for fixing vascular and ligation
Suture scissors, tissue scissors， forceps，needle and needle holder
Used for testing the association between the length of traction wire and the traction force

Responses to Editorial comments

Editorial comments:

1. The editor has formatted the manuscript to match the journal's style. Please retain the same.

We appreciate for your excellent work. We retain this format in the revision.

2. Please address specific comments marked in the manuscript text.

According to comments, the changes (which are highlighted by red font in the manuscript) are made in the manuscript text (Lines 30-31, 127-130, 140-141, 147-149, 178, 198, 212-213, 216-218, 220-224, 231, 244-245, and 281-283).
And we address some specific comments in the comment text (Lines 84, 108, 140, 147-148, 161, 190, 217, 231, and 236).

3. Please proofread the manuscript well before submission.

Thanks for your suggestion. We have proofread the manuscript text carefully.

Video:
The narration, while being consistently understandable, sounds very compressed. It is also low in volume (It should be peaking between -6 and -12 dB) and will need to be raised. Raising the volume will only amplify the issues with the audio quality. We would recommend re-recording with a better microphone.

We thank you for pointing out this important issue. We re-recorded the audio using a better microphone.

0:16 and 9:58 interviews - The audio is very low on these interviews. Like the narration, it should be peaking between -6 and -12 dB. But also, simply raising the audio will only amplify issues with the audio quality. We recommend reshooting the interviews, if possible, and either using a body microphone or placing the camera closer to the subject.

We thank you for pointing out this important issue. We re-shot the interviews using a better microphone.

We recommend sequential whole numbering for section title cards, rather than having Step 2 (1:28), Step 3 (4:34) and Step 4 (7:34) followed by 3. Representative Results (9:11). This will better correspond with our website chaptering system when the video is published.

We apologize for making these mistakes. We delete the numbering of the subheadings in the revised video.

 Click here to access/download;Author License Agreement (ALA);ALA (1).pdf

jove JOURNAL OF VISUALIZED EXPERIMENTS
1 Alewife Center #200
Cambridge, MA 02140
tel. 617.945.9051
www.jove.com

ARTICLE AND VIDEO LICENSE AGREEMENT

Title of Article: A novel training and test system where the trainee can complete vascular reconstruction in vitro individually

Author(s): Yue Wang, Lijun Mu, Wei Zhang, Huan Chen, Qingshan Li, Aihua Shi, Bo Tang, Xiaogang Zhang, Dinghui Dong, Yi Lv

Item 1: The Author elects to have the Materials be made available (as described at http://www.jove.com/publish) via:

- [x] Standard Access
- [ ] Open Access

Item 2: Please select one of the following items:

- [x] The Author is **NOT** a United States government employee.
- [ ] The Author is a United States government employee and the Materials were prepared in the course of his or her duties as a United States government employee.
- [ ] The Author is a United States government employee but the Materials were NOT prepared in the course of his or her duties as a United States government employee.

ARTICLE AND VIDEO LICENSE AGREEMENT

1. **Defined Terms.** As used in this Article and Video License Agreement, the following terms shall have the following meanings: "**Agreement**" means this Article and Video License Agreement; "**Article**" means the article specified on the last page of this Agreement, including any associated materials such as texts, figures, tables, artwork, abstracts, or summaries contained therein; "**Author**" means the author who is a signatory to this Agreement; "**Collective Work**" means a work, such as a periodical issue, anthology or encyclopedia, in which the Materials in their entirety in unmodified form, along with a number of other contributions, constituting separate and independent works in themselves, are assembled into a collective whole; "**CRC License**" means the Creative Commons Attribution-Non Commercial-No Derivs 3.0 Unported Agreement, the terms and conditions of which can be found at: http://creativecommons.org/licenses/by-nc-nd/3.0/legalcode; "**Derivative Work**" means a work based upon the Materials or upon the Materials and other pre-existing works, such as a translation, musical arrangement, dramatization, fictionalization, motion picture version, sound recording, art reproduction, abridgment, condensation, or any other form in which the Materials may be recast, transformed, or adapted; "**Institution**" means the institution, listed on the last page of this Agreement, by which the Author was employed at the time of the creation of the Materials; "**JoVE**" means MyJove Corporation, a Massachusetts corporation and the publisher of The Journal of Visualized Experiments; "**Materials**" means the Article and / or the Video; "**Parties**" means the Author and JoVE; "**Video**" means any video(s) made by the Author, alone or in conjunction with any other parties, or by JoVE or its affiliates or agents, individually or in collaboration with the Author or any other parties, incorporating all or any portion of the Article, and in which the Author may or may not appear.

2. **Background.** The Author, who is the author of the Article, in order to ensure the dissemination and protection of the Article, desires to have the JoVE publish the Article and create and transmit videos based on the Article. In furtherance of such goals, the Parties desire to memorialize in this Agreement the respective rights of each Party in and to the Article and the Video.

3. **Grant of Rights in Article.** In consideration of JoVE agreeing to publish the Article, the Author hereby grants to JoVE, subject to **Sections 4** and **7** below, the exclusive, royalty-free, perpetual (for the full term of copyright in the Article, including any extensions thereto) license (a) to publish, reproduce, distribute, display and store the Article in all forms, formats and media whether now known or hereafter developed (including without limitation in print, digital and electronic form) throughout the world, (b) to translate the Article into other languages, create adaptations, summaries or extracts of the Article or other Derivative Works (including, without limitation, the Video) or Collective Works based on all or any portion of the Article and exercise all of the rights set forth in (a) above in such translations, adaptations, summaries, extracts, Derivative Works or Collective Works and(c) to license others to do any or all of the above. The foregoing rights may be exercised in all media and formats, whether now known or hereafter devised, and include the right to make such modifications as are technically necessary to exercise the rights in other media and formats. If the "Open Access" box has been checked in **Item 1** above, JoVE and the Author hereby grant to the public all such rights in the Article as provided in, but subject to all limitations and requirements set forth in, the CRC License.

4. **Retention of Rights in Article.** Notwithstanding the exclusive license granted to JoVE in **Section 3** above, the Author shall, with respect to the Article, retain the non-exclusive right to use all or part of the Article for the non-commercial purpose of giving lectures, presentations or teaching classes, and to post a copy of the Article on the Institution's website or the Author's personal website, in each case provided that a link to the Article on the JoVE website is provided and notice of JoVE's copyright in the Article is included. All non-copyright intellectual property rights in and to the Article, such as patent rights, shall remain with the Author.

5. **Grant of Rights in Video – Standard Access.** This **Section 5** applies if the "Standard Access" box has been checked in **Item 1** above or if no box has been checked in **Item 1** above. In consideration of JoVE agreeing to produce, display or otherwise assist with the Video, the Author hereby acknowledges and agrees that, Subject to **Section 7** below, JoVE is and shall be the sole and exclusive owner of all rights of any nature, including, without limitation, all copyrights, in and to the Video. To the extent that, by law, the Author is deemed, now or at any time in the future, to have any rights of any nature in or to the Video, the Author hereby disclaims all such rights and transfers all such rights to JoVE.

6. **Grant of Rights in Video – Open Access.** This **Section 6** applies only if the "Open Access" box has been checked in **Item 1** above. In consideration of JoVE agreeing to produce, display or otherwise assist with the Video, the Author hereby grants to JoVE, subject to **Section 7** below, the exclusive, royalty-free, perpetual (for the full term of copyright in the Article, including any extensions thereto) license (a) to publish, reproduce, distribute, display and store the Video in all forms, formats and media whether now known or hereafter developed (including without limitation in print, digital and electronic form) throughout the world, (b) to translate the Video into other languages, create adaptations, summaries or extracts of the Video or other Derivative Works or Collective Works based on all or any portion of the Video and exercise all of the rights set forth in (a) above in such translations, adaptations, summaries, extracts, Derivative Works or Collective Works and (c) to license others to do any or all of the above. The foregoing rights may be exercised in all media and formats, whether now known or hereafter devised, and include the right to make such modifications as are technically necessary to exercise the rights in other media and formats. For any Video to which this **Section 6** is applicable, JoVE and the Author hereby grant to the public all such rights in the Video as provided in, but subject to all limitations and requirements set forth in, the CRC License.

7. **Government Employees.** If the Author is a United States government employee and the Article was prepared in the course of his or her duties as a United States government employee, as indicated in **Item 2** above, and any of the licenses or grants granted by the Author hereunder exceed the scope of the 17 U.S.C. 403, then the rights granted hereunder shall be limited to the maximum rights permitted under such statute. In such case, all provisions contained herein that are not in conflict with such statute shall remain in full force and effect, and all provisions contained herein that do so conflict shall be deemed to be amended so as to provide to JoVE the maximum rights permissible within such statute.

8. **Protection of the Work.** The Author(s) authorize JoVE to take steps in the Author(s) name and on their behalf if JoVE believes some third party could be infringing or might infringe the copyright of either the Author's Article and/or Video.

9. **Likeness, Privacy, Personality.** The Author hereby grants JoVE the right to use the Author's name, voice, likeness, picture, photograph, image, biography and performance in any way, commercial or otherwise, in connection with the Materials and the sale, promotion and distribution thereof. The Author hereby waives any and all rights he or she may have, relating to his or her appearance in the Video or otherwise relating to the Materials, under all applicable privacy, likeness, personality or similar laws.

10. **Author Warranties.** The Author represents and warrants that the Article is original, that it has not been published, that the copyright interest is owned by the Author (or, if more than one author is listed at the beginning of this Agreement, by such authors collectively) and has not been assigned, licensed, or otherwise transferred to any other party. The Author represents and warrants that the author(s) listed at the top of this Agreement are the only authors of the Materials. If more than one author is listed at the top of this Agreement and if any such author has not entered into a separate Article and Video License Agreement with JoVE relating to the Materials, the Author represents and warrants that the Author has been authorized by each of the other such authors to execute this Agreement on his or her behalf and to bind him or her with respect to the terms of this Agreement as if each of them had been a party hereto as an Author. The Author warrants that the use, reproduction, distribution, public or private performance or display, and/or modification of all or any portion of the Materials does not and will not violate, infringe and/or misappropriate the patent, trademark, intellectual property or other rights of any third party. The Author represents and warrants that it has and will continue to comply with all government, institutional and other regulations, including, without limitation all institutional, laboratory, hospital, ethical, human and animal treatment, privacy, and all other rules, regulations, laws, procedures or guidelines, applicable to the Materials, and that all research involving human and animal subjects has been approved by the Author's relevant institutional review board.

11. **JoVE Discretion.** If the Author requests the assistance of JoVE in producing the Video in the Author's facility, the Author shall ensure that the presence of JoVE employees, agents or independent contractors is in accordance with the relevant regulations of the Author's institution. If more than one author is listed at the beginning of this Agreement, JoVE may, in its sole

jove JOURNAL OF VISUALIZED EXPERIMENTS

1 Alewife Center #200
Cambridge, MA 02140
tel. 617.945.9051
www.jove.com

ARTICLE AND VIDEO LICENSE AGREEMENT

discretion, elect not take any action with respect to the Article until such time as it has received complete, executed Article and Video License Agreements from each such author. JoVE reserves the right, in its absolute and sole discretion and without giving any reason therefore, to accept or decline any work submitted to JoVE. JoVE and its employees, agents and independent contractors shall have full, unfettered access to the facilities of the Author or of the Author's institution as necessary to make the Video, whether actually published or not. JoVE has sole discretion as to the method of making and publishing the Materials, including, without limitation, to all decisions regarding editing, lighting, filming, timing of publication, if any, length, quality, content and the like.

12. **Indemnification.** The Author agrees to indemnify JoVE and/or its successors and assigns from and against any and all claims, costs, and expenses, including attorney's fees, arising out of any breach of any warranty or other representations contained herein. The Author further agrees to indemnify and hold harmless JoVE from and against any and all claims, costs, and expenses, including attorney's fees, resulting from the breach by the Author of any representation or warranty contained herein or from allegations or instances of violation of intellectual property rights, damage to the Author's or the Author's institution's facilities, fraud, libel, defamation, research, equipment, experiments, property damage, personal injury, violations of institutional, laboratory, hospital, ethical, human and animal treatment, privacy or other rules, regulations, laws, procedures or guidelines, liabilities and other losses or damages related in any way to the submission of work to JoVE, making of videos by JoVE, or publication in JoVE or elsewhere by JoVE. The Author shall be responsible for, and shall hold JoVE harmless from, damages caused by lack of sterilization, lack of cleanliness or by contamination due to the making of a video by JoVE its employees, agents or independent contractors. All sterilization, cleanliness or decontamination procedures shall be solely the responsibility of the Author and shall be undertaken at the Author's expense. All indemnifications provided herein shall include JoVE's attorney's fees and costs related to said losses or damages. Such indemnification and holding harmless shall include such losses or damages incurred by, or in connection with, acts or omissions of JoVE, its employees, agents or independent contractors.

13. **Fees.** To cover the cost incurred for publication, JoVE must receive payment before production and publication of the Materials. Payment is due in 21 days of invoice. Should the Materials not be published due to an editorial or production decision, these funds will be returned to the Author. Withdrawal by the Author of any submitted Materials after final peer review approval will result in a US$1,200 fee to cover pre-production expenses incurred by JoVE. If payment is not received by the completion of filming, production and publication of the Materials will be suspended until payment is received.

14. **Transfer, Governing Law.** This Agreement may be assigned by JoVE and shall inure to the benefits of any of JoVE's successors and assignees. This Agreement shall be governed and construed by the internal laws of the Commonwealth of Massachusetts without giving effect to any conflict of law provision thereunder. This Agreement may be executed in counterparts, each of which shall be deemed an original, but all of which together shall be deemed to me one and the same agreement. A signed copy of this Agreement delivered by facsimile, e-mail or other means of electronic transmission shall be deemed to have the same legal effect as delivery of an original signed copy of this Agreement.

A signed copy of this document must be sent with all new submissions. Only one Agreement is required per submission.

CORRESPONDING AUTHOR

Name:	Yi Lv
Department:	Department of hepatobiliary Surgery
Institution:	First Affiliated Hospital of Xi'an Jiaotong University
Title:	Professor
Signature:	yilv
Date:	2019-4-16

Please submit a **signed** and **dated** copy of this license by one of the following three methods:

1. Upload an electronic version on the JoVE submission site
2. Fax the document to +1.866.381.2236
3. Mail the document to JoVE / Attn: JoVE Editorial / 1 Alewife Center #200 / Cambridge, MA 02140