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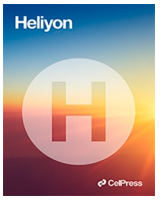

Research article

Safety and effectiveness of the sutureless integrated stented graft prosthesis in an animal model

Lu Dai [a,1], Chenyu Zhou [a,1], Liang Zhang [b], Juntao Qiu [a], Shen Liu [c], Jiawei Qiu [a], Rui Zhao [a], Enzehua Xie [a], Jian Song [a], Cuntao Yu [a,*]

[a] *Department of Aortic Surgery, Fuwai Hospital, Chinese Academy of Medical Sciences & Peking Union Medical College/National Clinical Research Center for Cardiovascular Diseases, Beijing, China*
[b] *Department of Aortic Surgery, Anhui Chest Hospital, Hefei, Anhui, China*
[c] *Department of Cardiac Surgery, Peking University International Hospital, Peking University Eighth Clinical Medical School, Beijing, China*

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ABSTRACT

Background: Prolonged circulatory arrest time is an independent risk factor for postoperative adverse events of type A aortic dissection (TAAD) surgery. Further reduction of the circulatory arrest time is essential to improve surgical outcomes. This study aimed to evaluate the safety and effectiveness of the novel Sutureless Integrated Stented (SIS) graft prosthesis in an animal experiment.

Materials and methods: Straight type of the SIS graft prosthesis was implanted into the descending aorta of 10 adult male sheep, and the use of the device was scored on a scale of 1–10. Aortic digital subtraction angiography (DSA) was performed at 4, 14, and 26 weeks to investigate the prostheses. After 26 weeks, the animals were sacrificed for histological analysis.

Results: The immediate success rate of the surgery was 100 %, and the overall mean score of the use of the device was 9.65 ± 0.99. Three animals died from non-device-related causes during follow-up. Aortic DSA showed filling defects in 5 animals. Histological analysis revealed that all prostheses were intact. Except for 2 early deaths, the other 8 prostheses were endothelialized with mild inflammation, foreign body reactions, and intimal fibrosis. The mean cross-sectional area of the sutureless region was reduced by 26.4 % (range, 1.3–39.1 %).

Conclusions: The safety and effectiveness of the novel SIS graft prosthesis were acceptable, and the delivery system exhibited a promising performance. Using the SIS graft prosthesis in TAAD surgery was expected to simplify the procedures and shorten the circulatory arrest time. Further large-scale clinical trials are required to verify these findings.

1. Introduction

With the progress of population aging and the incidence of hypertension, the morbidity rate of aortic dissection is increasing in China [1]. The annual incidence of acute aortic dissection in Chinese mainland is about 2.8 cases per 100,000 individuals [2]. Acute

* Corresponding author. Department of Aortic Surgery, Fuwai Hospital, Chinese Academy of Medical Sciences & Peking Union Medical College/National Clinical Research Center for Cardiovascular Diseases, No. 167 North Lishi Road, Xicheng District, Beijing, 100037, China.
E-mail address: cuntaoyu_fuwai@163.com (C. Yu).
[1] Lu Dai and Chenyu Zhou contributed equally to this work.

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aortic dissection is a lethal disease with rapid onset, requiring timely intervention. Patients with type B aortic dissection whose lesions are limited to the descending aorta basically receive medical therapy, and for complicated cases, thoracic endovascular aortic repair (TEVAR) is considered, in which TEVAR possesses the advantages of minimal invasion and satisfactory outcomes [1,3]. As for type A aortic dissection (TAAD) that involves the ascending aorta with or without aortic arch, the current treatment is to surgically replace the

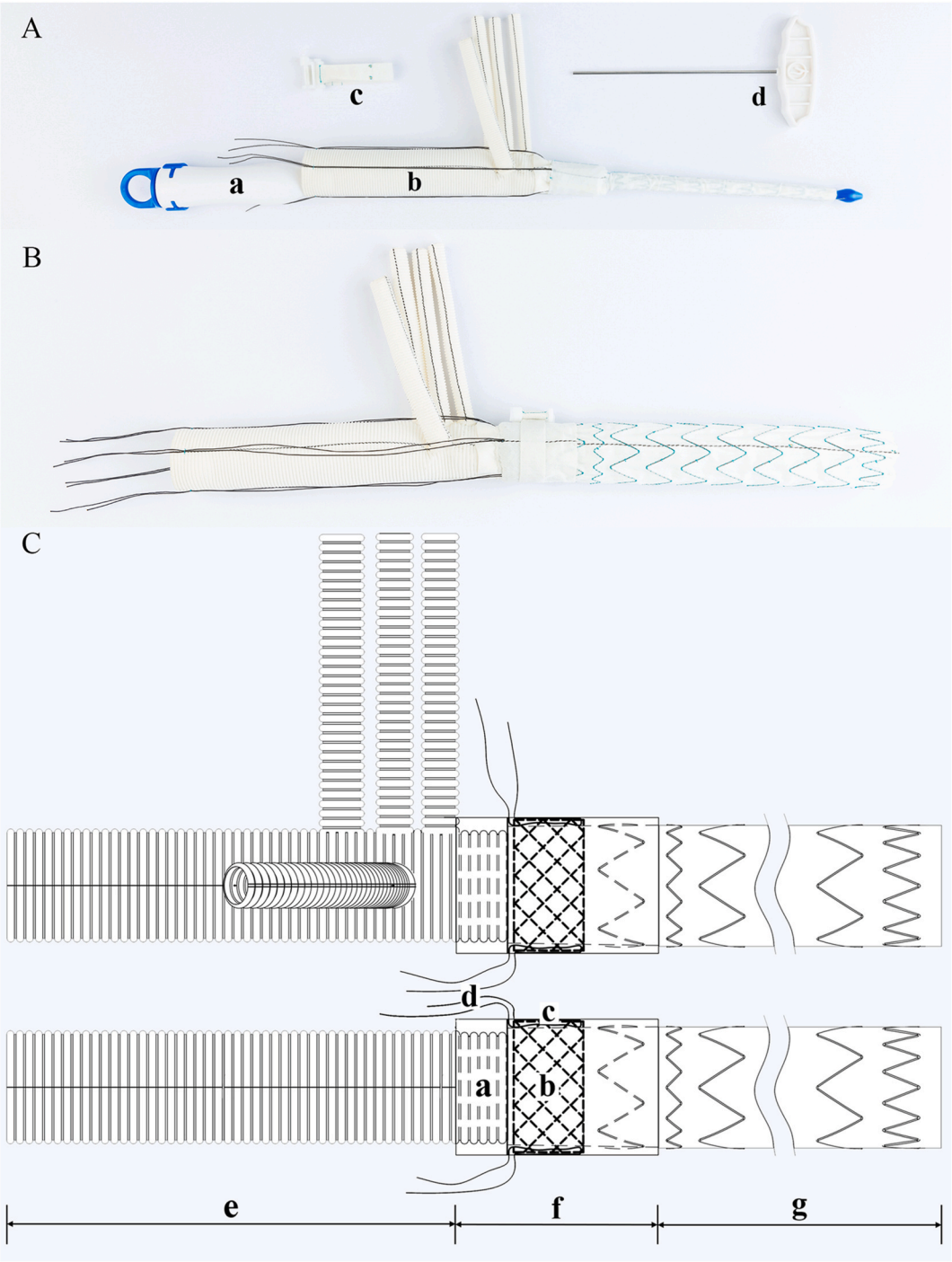

Fig. 1. Sutureless Integrated Stented (SIS) graft prosthesis. A. Real product image of the SIS graft prosthesis before release: a, Delivery system; b, Vascular graft; c, Sutureless belt; d, Wrench. **B.** Real product image of the SIS graft prosthesis after release. **C.** Design drawing of the SIS graft prosthesis for clinical use (above) and experimental use (below): a, Terylene vascular graft with screw threads; b, Sutureless elastic support annulus; c, Terylene without screw threads; d, Restraint sutures; e, Terylene vascular graft region; f, Sutureless region; g, Stented-graft region.

lesions with graft prosthesis because of the complex anatomical structure of the aortic arch. However, both hypothermia circulatory arrest (HCA) and cerebral perfusion strategies are required for the arch surgery, which makes it one of the most challenging cardiovascular surgeries [4]. In the early years, the postoperative mortality rate was as high as 26 %. With the improvement of surgical techniques, the overall postoperative mortality rate has decreased, while it has still remained higher than 10 % [5,6].

Total arch replacement (TAR) combined with frozen elephant trunk (FET) implantation is a widely used strategy in TAAD cases involving the aortic arch, accompanying by various prosthetic products that are utilized globally [7,8]. However, the further reduction of circulatory arrest time has been limited by the complexity of surgical procedures, resulting in a persistently high incidence of postoperative mortality and complications [9,10]. Therefore, to streamline surgical procedures, a novel prosthesis called Sutureless Integrated Stented (SIS) graft prosthesis was developed. In comparison to the existing CRONUS graft (MicroPort, Shanghai, China) used in China since 2003, the SIS graft prosthesis combines a 4-branched vascular graft with a stented graft, and it employs a sutureless approach for anastomosing the descending aorta. This innovative design enables a shorter anastomosis time, which effectively reduces complications associated with prolonged HCA time. This study represents a preclinical animal experiment aimed at assessing the safety and effectiveness of the SIS graft prosthesis *in vivo*. The findings may provide valuable evidence to finalize the design and pave the way for the future clinical trials.

2. Material and methods

2.1Ethical statement

This study was approved by the Ethics Committee of Fuwai Hospital, Chinese Academy of Medical Sciences (Beijing, China; Approval No. 0086-2-26-HX(Z)), and it was performed in accordance with the ethical rules published by the National Institutes of Health (NIH, Publication No. 88-23, revised in 1996).

This was a prospective animal study with 1 pilot group. A total of 10 healthy male Small-Tailed Han sheep (Jin Yu Tong Feng Trading Co., Ltd., Beijing, China; Approval No. SYXK (Jing) 2017-0015), aging about 24 months old, with a mean weight of 68.8 (range, 63–78) kg were utilized in this study. Each animal was quarantined preoperatively. Fasting was required for 72 h before the surgery and water was forbidden on the morning of the surgery.

2.2. Sutureless integrated stented (SIS) graft prosthesis

The SIS graft prosthesis (Beijing Percutek Therapeutics Co., Ltd., Beijing, China) consists of a vascular graft and a sutureless belt. The vascular graft integrates a 4-branched vascular graft, a sutureless elastic support annulus, and a FET (Fig. 1A and B). From the proximal end to the distal end, it can be divided into three regions: the terylene vascular graft region, sutureless region, and stented-graft region. The 4-branched vascular graft is specifically designed for clinical use, while the straight type vascular graft is suggested for experimental purposes (Fig. 1C). The sutureless region is multilayered, which comprises a layer of terylene with screw threads, a sutureless elastic support annulus, and a layer of terylene without screw threads from the inner layer to the outer layer. The sutureless elastic support annulus and stented graft, composed of nitinol, are compacted and attached to the delivery system, which are able to self-expand after being released in the descending aorta. Four 5-0 polypropylene sutures are evenly preset along the circumferential direction. After pulling and tying these restraint sutures, the annulus is compressed in the axial direction to obtain a radial supporting force. Another four polypropylene sutures can be applied to the proximal end of the descending aorta and tied with restraint sutures to avoid migration of the vascular graft. After that, the sutureless belt can be wrapped around the adventitia of the aorta on the area corresponding to the sutureless region. The wrench is used to adjust the diameter of the belt by turning a ratchet, so that the graft can be tightly attached to the autologous aortic wall without suture anastomosis of the vascular graft, FET, and descending aorta. A maximum turning force is preset to prevent excessive fastening and necrosis of the aortic wall. When the turning force reaches the maximum value, the ratchet just slips. Technically, the SIS graft prosthesis can shorten the circulatory arrest time, avoid deep

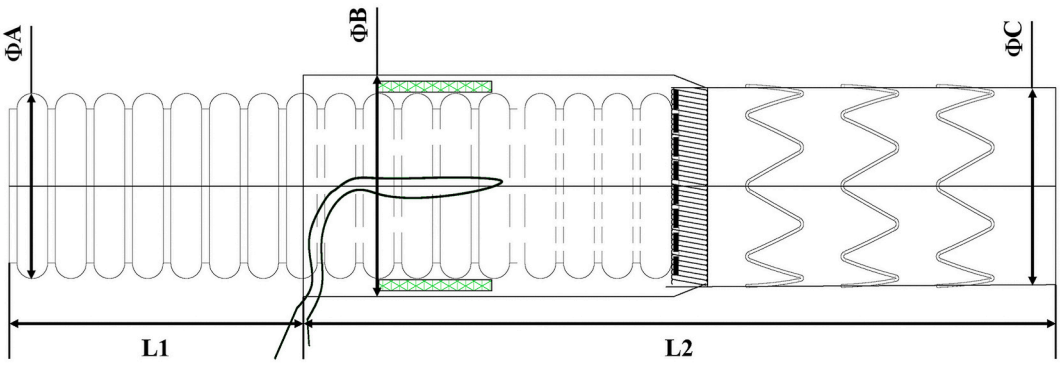

Fig. 2. Straight type of the Sutureless Integrated Stented graft prosthesis for animal experiment. ΦA = 16 mm; ΦB = 20 mm; ΦC = 20 mm; L1≥40 mm; L2 = 60 mm.

hypothermia, and simplify surgical procedures.

2.3. Surgical technique

Based on the principles of animal experiment (Replacement, Reduction, and Refinement) [11], it was attempted to directly cross clamp the aorta under normal temperature without using cardiopulmonary bypass (CPB) on the premise of ensuring the purpose. Straight type SIS graft prosthesis was utilized in the experiment, which was downsized to match the sheep's descending aorta (Fig. 2).

All animals were operated by the same surgeon. The main surgical procedures are illustrated in Fig. 3. Anesthesia was induced intramuscularly by ketamine (10 mg/kg), midazolam (1 mg/kg), and Sumianxin II (combinations of xylazole, ethylene-diamine tetraacetie acid, dihydroetorphine hydrochloride, and haloperidol, 1 mg/kg). Isoflurane (2 %, inhalational) and fentanyl (2 μg/kg/h, intravenously) were administered to maintain anesthesia. For neuromuscular blockage, succinylcholine (0.7 mg/kg/h) was given intravenously. Anesthetized animals were moved to the operating table (Amax9000, Mwdiland) for endotracheal intubation. Mechanical ventilation (Savina, Drager) was administered, and blood pressure, nasopharyngeal temperature, O_2 saturation, respiratory parameters, and electrocardiography (MP60/MP70; Philips, Amsterdam, Netherlands) were permanently monitored. Besides, 5 % glucose saline and plasma substitute were intravenously administered for fluid infusion. Animals were placed in the right decubital position with the 3rd intercostal thoracotomy after sterilization. The descending aorta was exposed and dissociated for 8–10 cm, and 4 polypropylene sutures (5-0) with gaskets were evenly preset along the circumferential direction at the expected aortic incision where the stented graft was implanted. Systemic heparinization (4 mg/kg) was performed when blood pressure was reduced to 60–80 mmHg by nicardipine (10 μg/kg/min, intravenously). Activated clotting time of whole blood was monitored and maintained over 300 s (Hemochron, ITC Medical Inc., New York, NY, USA). The descending aorta was cross clamped proximally and distally about 8 cm apart, and 1/3 perimeter of the aorta wall was resected in the middle. Next, the distal clamp was removed, and the sutureless region and stented-graft region were deployed into the descending aorta. After withdrawing the delivery system, four restraint sutures were securely tightened and tied in situ, and were then tied with the corresponding 4 polypropylene sutures preset on the aortic wall before. After that, the other 2/3 perimeter of the aorta wall was fully resected and the autologous aorta was trimmed into an appropriate length for proximal anastomosis with continuous suture of a 5-0 polypropylene suture. Perfusion to the lower part of the body was restarted after the completion of proximal anastomosis. The sutureless belt was then wrapped around the adventitia of the aorta on the area corresponding to the sutureless elastic support annulus, which was then fastened by turning the ratchet clockwise with the wrench

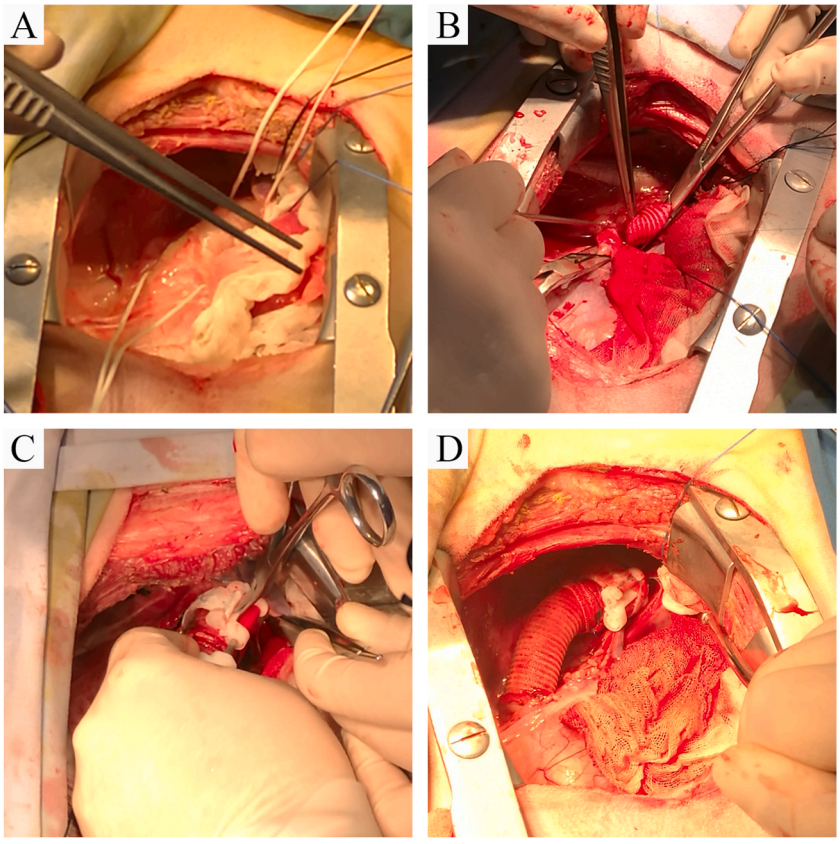

Fig. 3. Photos of the surgical procedures. A. Dissociation of the descending aorta for 8–10 cm; **B**. Anastomosis of the proximal descending aorta and terylene vascular graft; **C**. Adjustment of the sutureless belt by the wrench; **D**. The whole view of the prosthesis before chest closure.

until the ratchet was slipped. After the vascular graft, proximal anastomosis segment and the sutureless region were confirmed to be without hemorrhage, and dopamine (10 μg/kg/min) was administered intravenously to raise blood pressure back to 120 mmHg. The incision was anastomosed after protamine (3 mg/kg, intravenously) neutralized hemostasis. Immediately after the surgery, the use of the device was quantitatively scored by the surgeon on a scale of 1–10. For better understanding, the video simulating the deployment of SIS graft prosthesis in a patient with TAAD was attached in the supplementary material. The animals were followed up for 26 weeks, and they were then sacrificed by intravenous injection of 10 % potassium chloride solution after anesthesia. The sample size and the follow-up time met the requirements of <Cardiovascular implants—Tubular vascular prostheses (YY 0500–2004)> (at least 6 animals for 20 weeks) and <Cardiovascular implants—Endovascular devices—Part 1: Endovascular prostheses (YY/T 0663.1–2014)> (at least 6 animals for 26 weeks) (National Medical Products Administration, NMPA, China).

2.4. Postoperative procedure

During the follow-up, penicillin (4.8 U/d) was injected intramuscularly for 1 week after the surgery, and aspirin (100 mg/d) was taken orally until the endpoint.

Aortic digital subtraction angiography (DSA) was performed at 4, 14, and 26 weeks postoperatively to assess the location, integrity, and patency of the prostheses. Weight changes, postoperative medication, and all adverse events (including death, infections, anastomotic hemorrhage, intra-prosthesis embolism, endoleak of stent graft, coagulopathy, paralysis, respiratory insufficiency and anuria, etc.) were recorded. For death cases, post-mortem examinations were immediately performed. The animals were sacrificed after 26 weeks for histological analysis.

2.5. Histological analysis

After sacrificing, the prostheses, together with at least 5 cm of the autologous aortic tissues at both proximal and distal end, were removed and fixed in 10 % neutral buffered formalin. The statuses of the specimens (including with or without pseudoaneurysm and the integrity, shape, patency, and endothelialization of the prostheses, etc.) were recorded.

The gross specimens were sampled in 5 sites: the proximal anastomosis segment, terylene vascular graft region, sutureless region, stented-graft region, and distal autologous aorta (Supplemental Fig. 1). The tissues were rinsed with phosphate-buffered saline solution, dehydrated with alcohol, invested in resin or paraffin, and were then made into slices and stained with hematoxylin-eosin (H-E) after solidification. Histological analysis, including inflammations, foreign body reactions, and intimal fibrosis, was scored quantitatively by observation through the optical microscopy, and scoring rubric is shown in Supplemental Table 1. The histological analysis was carried out by PharmaLegacy Laboratories Co., Ltd. (Shanghai, China).

2.6. Definitions and statistical analysis

In this study, the circulatory arrest time was defined as the interval from cross-clamp of the descending aorta to completion of the proximal anastomosis. The immediate success of the surgery was defined as the prosthesis was in normal shape without kink and leakage before chest closure. The cross-sectional area (CSA) of the sutureless region was determined by multiplying the semi-major axis by the semi-minor axis of the sutureless belt and then multiplying the result by π. The results were expressed as mean $\pm$ standard deviation.

3. Results

3.1. Procedural results

The SIS graft prostheses were implanted in 10 Small-Tailed Han sheep with 100 % immediate success rate of the surgery. The intraoperative data are summarized in Supplemental Table 2. The mean proximal anastomosis time, circulatory arrest time, and surgical time were 5.30 ± 1.42, 7.55 ± 1.43, and 68.90 ± 8.42 min, respectively. As the surgical instruments did not work well during the surgery of #3 sheep, the proximal anastomosis was difficult, which was resulted in the excessive hemorrhage of about 1500 mL. Supplemental Table 3 shows the specific scores of the device, and the overall mean score was 9.65 ± 0.99. The delivery system was pushed and withdrawn conveniently, which could precisely send the stented-graft to the expected position and release it smoothly. The vascular graft region was easy for suture, and there was no blood leakage in the proximal anastomosis segment and the sutureless region. The size of the sutureless belt was easy to adjust and was convenient to cooperate with the sutureless elastic support annulus and wrench. Three animals died during follow-up. Besides, sheep #3 died 2 days after surgery due to excessive intraoperative hemorrhage and insufficient blood replenishment; sheep #8 died 19 days after surgery due to pulmonary adhesion and pneumonia; sheep #9 died 58 days after surgery due to sepsis caused by pneumonia. The other 7 animals were recovered well and survived to the endpoint (26 weeks). Furthermore, sheep #1, #2, and #4 lost more than 10 % of their weight, which could be related to the surgical trauma and feeding conditions (15.1 %, 10.3 %, and 27.7 %, respectively).

3.2. Angiographic results

The representative images of Aortic DSA, performed at 4, 14, and 26 weeks, are shown in Fig. 4. The position of the sutureless

region remained stable. The prostheses' structure was all intact with no leakage at the proximal and distal anastomotic segments. Moreover, sheep #1, #2, #4, and #5 showed varying degrees of filling defects, which refers to the presence of space-occupying in the lumen of the prosthesis, resulting in a partial defect of the contrast agent, at the junction of the vascular graft region and sutureless region; sheep #7 exhibited a filling defect at the junction of the sutureless region and stented-graft region.

3.3. Histological results

All the prostheses were intact and in a normal shape without pseudoaneurysm formation. Furthermore, 8 animals had endothelialization in the prostheses, except for sheep #3 and #8 due to their early death. After transecting the specimens in the 5 sites, no mural thrombus was found on the intima. The internal dimension of the sutureless region was the smallest with a mean reduction rate in CSA by 26.4 % (range, 1.3–39.1 %) (Supplemental Table 4).

Representative images of the slices at No. 1–5 sites and the pathological scores of the 7 animals, surviving for 26 weeks, are presented in Fig. 5 and Supplemental Table 1. The medial wall of the prosthesis was covered by the neointima with endothelioid cells. Mural thrombus, intimal hyperplasia, and vascular rupture were not found in the slices. There was no plasmacyte aggregation, and the overall mean scores of lymphocytes, giant cells, multinucleated giant cells, and degree of intimal fibrosis were 0.15 ± 0.21, 0.69 ± 0.45, 0.57 ± 0.38, and 0.05 ± 0.12, respectively, which indicated that the inflammation, foreign body reactions, and intimal fibrosis were mild. Besides, no tissue necrosis was identified in the sutureless region under the pressure of the belt.

4. Discussion

Since 2003, the TAR + FET strategy has been implemented in China as a surgical approach for cases of TAAD involving the aortic arch. Although the procedures are more extensive, it can reduce the reoperation rate and significantly improve patients' quality of life [12,13]. However, compared with common cardiac surgery, such as coronary artery bypass grafting and valve replacement, TAR + FET surgery is significantly more challenging due to the necessity of employing HCA. This HCA strategy, while essential for the procedure, contributes to the increased incidence of postoperative complications and mortality associated with TAR + FET surgery [9,

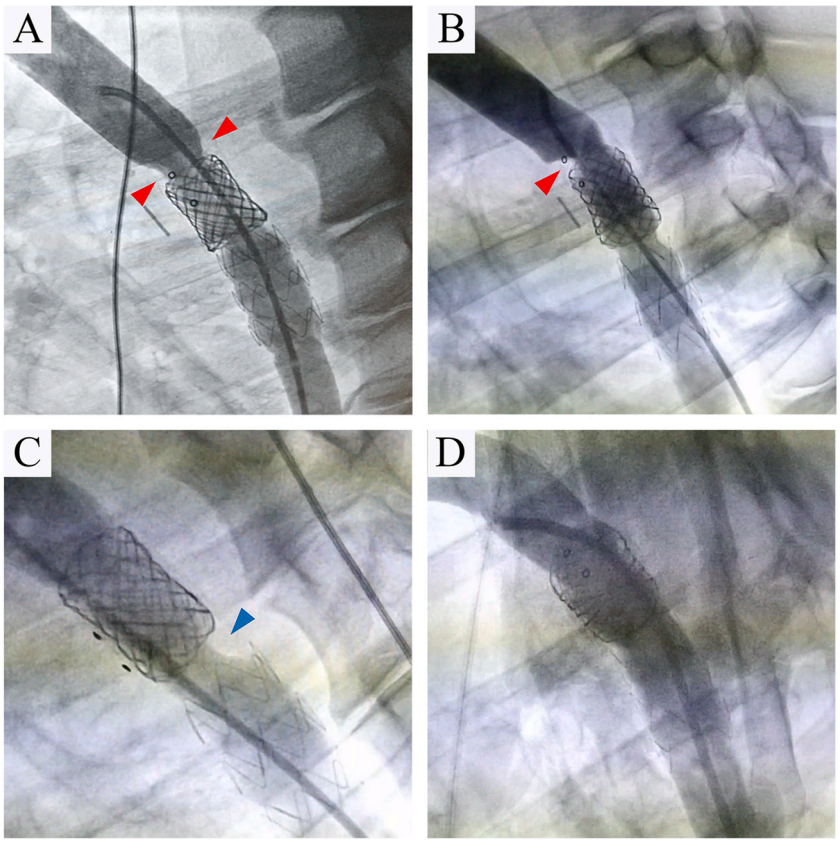

Fig. 4. Results of the aortic digital subtraction angiography (DSA). Aortic DSA was performed in 7 animals for 3 times and 1 animal for once (n = 22) with representative images of the results at 26 weeks. Red arrowheads indicate filling defects at the junction of the vascular graft region and sutureless region; Blue arrowheads indicate a filling defect at the junction of the sutureless region and stented-graft region. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

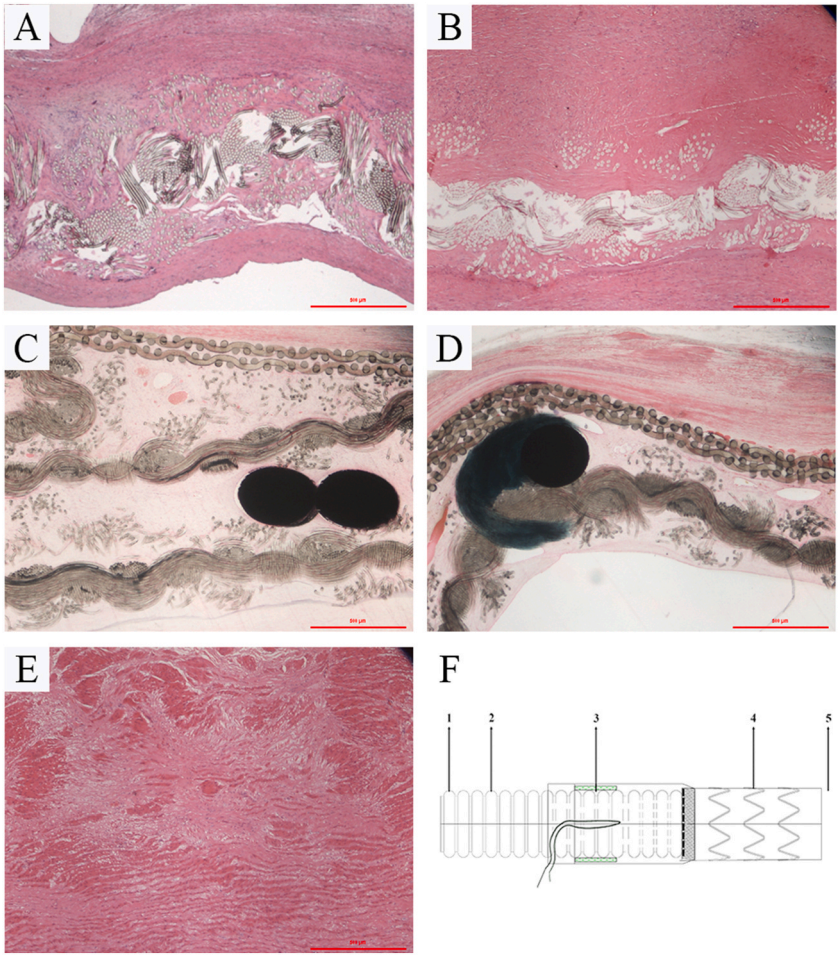

Fig. 5. Histological results. Histologic analysis (H-E stain × 40) was performed in 7 animals surviving to the end point at 5 sites (n = 35) with representative images of the results. **A-D** panels represent 1–4 sites of sampling, respectively.

10]. Both ischemia and hypoxia resulting from circulatory arrest, along with the pathophysiological changes induced by hypothermia, have been identified as risk factors contributing to a poor prognosis. These factors can lead to damage to vital organs and have a significant impact on patient outcomes [14,15]. Mousavizadeh et al. demonstrated that increasing HCA time was a significant predictor of postoperative stroke and spinal cord injury [9]. Some studies showed that moderate hypothermia had a shorter CPB time than deep hypothermia, leading to a shorter postoperative hospital stay with lower incidence rates of pulmonary infection, gastrointestinal hemorrhage, and kidney injury [16,17]. To our best knowledge, suture anastomosis of the descending aorta, which remarkably prolongs the HCA and CPB time, is necessary for all commercial FET devices around the world, including CRONUS graft (MicroPort, Shanghai, China), Thoraflex™ Hybrid Plexus prosthesis (Terumo Aortic, Inchinnan, Scotland, UK), and E-vita open plus hybrid prosthesis (Jotec, Hechingen, Germany) [18–20]. Therefore, in order to further raise the circulatory arrest temperature and shorten HCA time, the SIS graft prosthesis was developed for sutureless anastomosis of the descending aorta, and it is expected to control the circulatory arrest time within 10 min.

Sheep were utilized in this preclinical experiment, while the CPB and HCA techniques are very traumatic to animals with high surgical risks, which requires more professional facilities and CPB teams. Moreover, the cardiac rebeating technology in sheep is still in its early stages of development, making it susceptible to complications such as ventricular fibrillation. This factor significantly increases the uncertainty associated with surgical procedures [21]. It is difficult to evaluate the relationships between the adverse events and devices if the animals die or become paraplegic intraoperatively, which may interfere with the experimental conclusions. Hence, in the present study, it was attempted to operate on the descending aorta to avoid using those complex techniques. Besides, the actual circulatory arrest time in the experiment was 5.77–10.00 min (Supplemental Table 2), which was no more than 10 min and included both distal and proximal anastomosis time. In contrast to the experimental approach, the circulation can be restarted after only completing the distal anastomosis in clinical surgery, which allows for the potential reduction of circulatory arrest time. Therefore, the surgical strategy employed in the present experiment serves the purpose of the study by simulating the clinical scenario and facilitating the achievement of study objectives. It is worth mentioning that when the SIS graft prosthesis is being implanted into a dissected aortic

arch in actual clinical surgery, the aortic arch will be transected before the opening of the left subclavian artery, and the false lumen will be closed by the expansion of the sutureless elastic support annulus, together with the wrap of the sutureless belt (see the video in supplementary material).

The diameter of the descending aorta of Small-Tailed Han sheep is 16–20 mm. There were no commercial FET devices matching the size of the sheep's descending aorta, thus, we did not set up a control group. The immediate success rate of the surgery was 100 %, and 3 animals died during follow-up with no relationship with the devices. The aortic DSA results showed that 5 animals had filling defects, all of which had no influence on the patency of the prostheses inside the animals. After sampling, quantitative analysis of the sutureless region was carried out. The initial diameter of the sutureless elastic support annulus was 20 mm, and it was then compressed by the sutureless belt to 12.5–15.9 mm under different wrenching forces. Compared with the 16 mm vascular graft, the diameter was reduced by 0.1–3.5 mm, with a reduction of CSA by 1.3–39.1 %. Within the range, no rupture, vascular necrosis or thrombosis was found in the sutureless region after gross and histological inspection, which ensured the effectiveness of the sutureless structure under different wrenching forces from different surgeons. Besides, the animals did not present with any visceral, extremity, or spinal cord malperfusion during the follow-up. According to the physical characteristics of nitinol, under the same radial supporting force, the larger the diameter of sutureless elastic support annulus, the lower the reduction rate of CSA. The diameter of our prosthesis in clinical surgery is significantly larger than that in animal experiments. Therefore, we predicted that when the diameters of the annulus used in clinic were 30–36 mm, the expected diameters after implantation were no less than 22.5–28.5 mm, and the reduction rate of CSA was no more than 25 %, which was significantly reduced compared with the animal experiments and would not significantly affect the long-term patency of the prostheses. Besides, it is difficult to experience thrombotic restenosis in the large-diameter vascular graft (>6 mm) because of the fast blood flow [22]. Furthermore, the prosthesis is collagen-coated, which is one of the most important components of the extracellular matrix and it can effectively induce the endothelialization process, so as to prevent thrombosis due to the lack of biocompatibility and the prosthesis patent [23]. Intact endothelial cells (ECs) can not only secrete several anticoagulation factors, such as tissue factor pathway inhibitor, prostacyclin, and nitric oxide, but also provide an attachment surface for antithrombin III and protein S [24]. Pratt et al. confirmed that collagen I/III significantly improved the attachment and growth of human ECs on polystyrene and polyethylene terephthalate materials [25]. Inflammation and fibrosis are common intrinsic responses of the host in a graft-versus-host reaction, which may potentially lead to implantation failure. These processes are mainly driven by macrophages and fibroblasts [26]. When exposed to abnormal shear stress, the inflammatory reaction of ECs would increase, along with extracellular matrix remodeling and cellular migration, which might eventually cause apoptosis, vascular stiffening, and thrombosis [27]. In the present study, the results of histological analysis confirmed that the prostheses were all endothelialized without mural thrombus, and the inflammation, foreign body reactions, and intimal fibrosis were mild, which indicated that our vascular prosthesis had a promising biocompatibility, and the radial supporting forces of the prosthesis were appropriate with no significant changes in the shear stress.

The present study had some limitations. Firstly, it is important to note that the size of the SIS graft prosthesis used in our animal experiment differed from the one used in clinical settings. Additionally, no conventional aortic surgery strategies were utilized, making it difficult to fully replicate the conditions of clinical surgery. However, despite these limitations, this animal study adequately served its purpose of evaluating the safety and effectiveness of the SIS graft prosthesis. Secondly, it is noteworthy that no control group was involved in this study. This was primarily due to the fact that it was a feasibility study and also because there was a lack of commercially available FET devices in corresponding sizes at the time.

In conclusion, the SIS graft prosthesis was feasible and effective *in vivo*, and the safety of the device used in animal experiment was acceptable with the convenient delivery system. Using the SIS graft prosthesis in TAAD surgery was expected to simplify the procedures and shorten the circulatory arrest time to improve surgical outcomes. Further large-scale clinical trials are required to deeply assess the clinical effectiveness and safety of the prosthesis.

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Data availability statement

The data are not publicly available, but are available from the corresponding author on reasonable request.

Ethics declarations

This study was reviewed and approved by the Ethics Committee of Fuwai Hospital, Chinese Academy of Medical Sciences (Beijing, China), with the approval number: No. 0086-2-26-HX(Z).

CRediT authorship contribution statement

Lu Dai: Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Chenyu Zhou:** Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Liang Zhang:** Investigation, Validation. **Juntao Qiu:** Investigation, Methodology. **Shen Liu:** Conceptualization, Investigation. **Jiawei Qiu:** Investigation. **Rui Zhao:** Formal analysis. **Enzehua Xie:** Validation. **Jian Song:** Validation. **Cuntao Yu:** Conceptualization, Investigation, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Cuntao Yu reports financial support was provided by Capital Health Development and Scientific Research Foundation. Cuntao Yu reports financial support was provided by High-Level Hospital Construction Project of Fuwai Hospital.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30323.

References

[1] L.Z. Sun, J.M. Zhu, L.J. Huang, J. Zheng, C.N. Li, Y.P. Ge, Chinese expert consensus of standardized diagnosis and treatment for aortic dissection, Chin J Thorac Cardiovasc Surg 33 (2017) 641–654.
[2] L. Xia, J.H. Li, K. Zhao, H.Y. Wu, Incidence and in-hospital mortality of acute aortic dissection in China: analysis of China Health Insurance Research (CHIRA) Data 2011, J Geriatr Cardiol 12 (2015) 502–506.
[3] R. Erbel, V. Aboyans, C. Boileau, et al., ESC Guidelines on the diagnosis and treatment of aortic diseases: document covering acute and chronic aortic diseases of the thoracic and abdominal aorta of the adult. The Task Force for the Diagnosis and Treatment of Aortic Diseases of the European Society of Cardiology (ESC), Eur. Heart J. 35 (2014) 2873–2926, 2014.
[4] M. Thomas, Z. Li, D.J. Cook, K.L. Greason, T.M. Sundt, Contemporary results of open aortic arch surgery, J. Thorac. Cardiovasc. Surg. 144 (2012) 838–844.
[5] M. Gemelli, E. Di Tommaso, R. Natali, et al., Validation of the German registry for acute aortic dissection type A score in predicting 30-day mortality after type A aortic dissection surgery, Eur. J. Cardio. Thorac. Surg. 63 (2023).
[6] Y. Zhu, B. Lingala, M. Baiocchi, et al., Type A aortic dissection-experience over 5 decades: JACC historical breakthroughs in perspective, J. Am. Coll. Cardiol. 76 (2020) 1703–1713.
[7] Z.G. Liu, L.Z. Sun, Q. Chang, et al., Should the "elephant trunk" be skeletonized? Total arch replacement combined with stented elephant trunk implantation for Stanford type A aortic dissection, J. Thorac. Cardiovasc. Surg. 131 (2006) 107–113.
[8] D.H. Tian, B. Wan, M. Di Eusanio, D. Black, T.D. Yan, A systematic review and meta-analysis on the safety and efficacy of the frozen elephant trunk technique in aortic arch surgery, Ann. Cardiothorac. Surg. 2 (2013) 581–591.
[9] M. Mousavizadeh, M. Daliri, H.A. Aljadayel, et al., Hypothermic circulatory arrest time affects neurological outcomes of frozen elephant trunk for acute type A aortic dissection: a systematic review and meta-analysis, J. Card. Surg. 36 (2021) 3337–3351.
[10] H. Sato, N. Kawaharada, J. Fukada, et al., Estimation model for hypothermic circulatory arrest time to predict risk in total arch replacement, Ann. Thorac. Surg. 113 (2022) 256–263.
[11] P. Flecknell, Replacement, reduction and refinement, ALTEX 19 (2002) 73–78.
[12] Y.J. Ok, S.R. Kang, H.J. Kim, J.B. Kim, S.J. Choo, Comparative outcomes of total arch versus hemiarch repair in acute DeBakey type I aortic dissection: the impact of 21 years of experience, Eur. J. Cardio. Thorac. Surg. 60 (2021) 967–975.
[13] Y. Ikeno, K. Yokawa, Y. Koda, et al., The fate of the downstream aorta after open aortic repair for acute DeBakey type I aortic dissection: total arch replacement with elephant trunk technique versus non-total arch replacement, Eur. J. Cardio. Thorac. Surg. 55 (2019) 966–974.
[14] K.H. Polderman, Mechanisms of action, physiological effects, and complications of hypothermia, Crit. Care Med. 37 (2009) S186–S202.
[15] M. Erecinska, M. Thoresen, I.A. Silver, Effects of hypothermia on energy metabolism in Mammalian central nervous system, J. Cerebr. Blood Flow Metabol. 23 (2003) 513–530.
[16] Y. Du, Z. Fang, Y. Sun, et al., Moderate and deep hypothermic circulatory arrest have comparable effects on severe systemic inflammatory response syndrome after total aortic arch replacement in patients with type A aortic dissection, Front Surg 8 (2021) 758854.
[17] H. Zhou, G. Wang, L. Yang, et al., Acute kidney injury after total arch replacement combined with frozen elephant trunk implantation: incidence, risk factors, and outcome, J. Cardiothorac. Vasc. Anesth. 32 (2018) 2210–2217.
[18] M. Shrestha, E. Beckmann, H. Krueger, et al., The elephant trunk is freezing: the Hannover experience, J. Thorac. Cardiovasc. Surg. 149 (2015) 1286–1293.
[19] M. Bashir, H. Abo Aljadayel, M. Mousavizadeh, et al., Correlation of coagulopathy and frozen elephant trunk use in aortic arch surgery: a systematic review and meta-analysis, J. Card. Surg. 36 (2021) 4699–4714.
[20] C. Detter, T.J. Demal, L. Bax, et al., Simplified frozen elephant trunk technique for combined open and endovascular treatment of extensive aortic diseases, Eur. J. Cardio. Thorac. Surg. 56 (2019) 738–745.
[21] L. DiVincenti, R. Westcott, C. Lee, Sheep (Ovis aries) as a model for cardiovascular surgery and management before, during, and after cardiopulmonary bypass, JAALAS : JAALAS 53 (2014) 439–448.
[22] C. Spadaccio, A. Rainer, R. Barbato, M. Trombetta, M. Chello, B. Meyns, The long-term follow-up of large-diameter Dacron® vascular grafts in surgical practice: a review, J. Cardiovasc. Surg. 60 (2019) 501–513.
[23] N.M. Coelho, V. Llopis-Hernandez, M. Salmeron-Sanchez, G. Altankov, Dynamic reorganization and enzymatic remodeling of type IV collagen at cell-biomaterial interface, Adv Protein Chem Struct Biol 105 (2016) 81–104.
[24] T. Liu, S. Liu, K. Zhang, J. Chen, N. Huang, Endothelialization of implanted cardiovascular biomaterial surfaces: the development from in vitro to in vivo, J. Biomed. Mater. Res. 102 (2014) 3754–3772.
[25] K.J. Pratt, B.E. Jarrell, S.K. Williams, R.A. Carabasi, M.A. Rupnick, F.A. Hubbard, Kinetics of endothelial cell-surface attachment forces, J. Vasc. Surg. 7 (1988) 591–599.
[26] C.E. Witherel, D. Abebayehu, T.H. Barker, K.L. Spiller, Macrophage and fibroblast interactions in biomaterial-mediated fibrosis, Adv. Healthcare Mater. 8 (2019) e1801451.
[27] T.A. Russo, A.M.M. Banuth, H.B. Nader, J.L. Dreyfuss, Altered shear stress on endothelial cells leads to remodeling of extracellular matrix and induction of angiogenesis, PLoS One 15 (2020) e0241040.