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Experimental Study of Aortic Anastomosis Using a Circular Stapling Device in the Porcine Model

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Objectives. *The aim of this study was to assess the strength (pressure resistance) and histological findings of aortic anastomoses performed using a circular stapling device.*
Materials and methods. *A circular stapling device was used for anastomosing a porcine aorta and a Dacron graft. The maximum pressure resistance of the anastomotic site of a porcine aortic specimen and a Dacron graft was examined (n=10). A porcine aorta with Dacron graft was anastomosed to a beating heart, and pressure overload was induced by adrenaline (n=5). Specimens of the anastomotic sites were harvested after 14 days and examined histologically.*
Results. *The maximum pressure resistance of the anastomotic site was 427.3±34.4 (375–511) mmHg. No anastomotic sites leaked as a result of pressure overloading at 227.6±21.1 (201–260) mmHg. Histologically, good incorporation and cell coverage were observed, and the inner surfaces of the anastomotic sites were smooth and without stenoses.*
Conclusions. *Aortic anastomosis using a circular stapling device is feasible and worthy of further investigation.*

Keywords: Animal model; Anastomosis; Aortic surgery; Surgical instruments.

Introduction

Stapling devices are routinely used in gastrointestinal surgery. It has been reported that in some situations sutures placed using a stapling device are more reliable than manual suturing.[1,2] However, experimental reports concerning automatic anastomotic devices (including stapling devices) for the aorta are extremely rare. Although there are many reports of laparoscopic abdominal aortic repair, manual suturing is used as the gold standard for these aortic anastomoses.[3–10] The properties of the aortic wall, the difficulty of handling the automatic anastomotic device within the operative field, and the inability to invert an anastomosis are enumerated as obstacles to the development of such devices for the aorta. The advent of an automatic anastomotic device for the aorta would shorten the operation and would be useful in laparoscopic surgery or in deep, narrow operative fields. We have performed a study on aortic and Dacron graft anastomoses formed by a circular stapling device (of the type used in gastrointestinal surgery), with regard to strength (pressure resistance) and histological findings.

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Materials and Methods

Stapling device

A disposable digital loading unit for circular staples (Circular Stapler Digital Loading Unit (DLU); Power Medical Interventions, Pennsylvania, USA), installed in a SurgASSIST system (Power Medical Interventions, Pennsylvania, USA), was used to anastomose the aorta and prosthesis (Fig. 1). Clinically, this DLU is used for intestinal anastomosis. Its outside diameter is 21 mm and the diameter of its cutter is 12.4 mm. The staples are made of titanium and the DLU holds 16 of them. The thickness of a staple is 0.28 mm, and its size is 4.8×4 mm (Fig. 2).

Treatment, anesthesia and euthanasia of animals

Treatment of animals was based on the Guide for the Care and Use of Laboratory Animals, prepared by the National Academy of Sciences and published by the National Institutes of Health (revised 1996) and the

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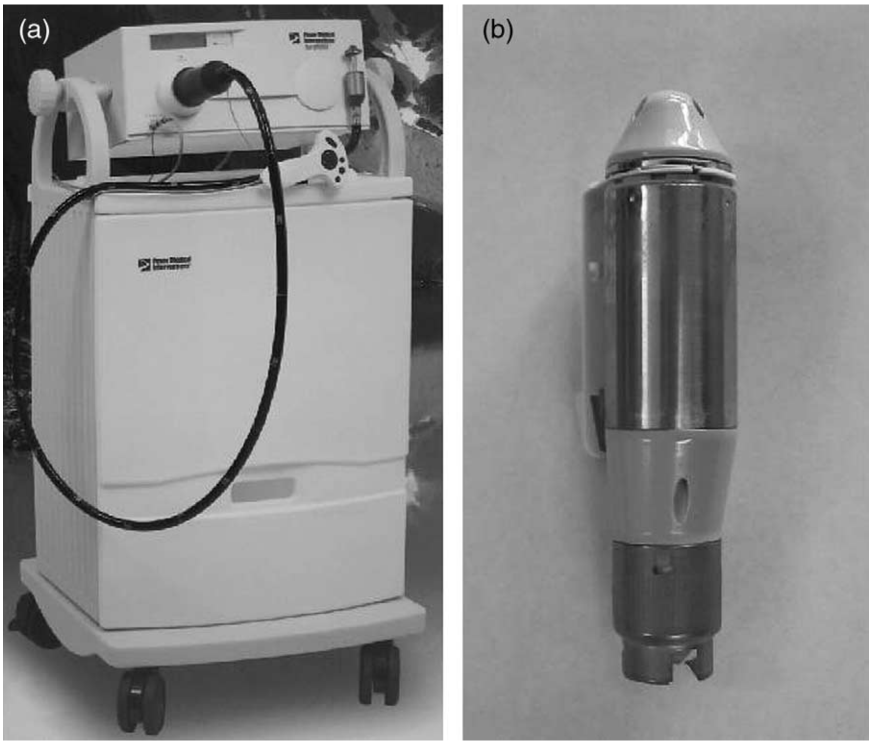


Fig. 1. Stapling device used in this study. (a) SurgASSIST system (Power Medical Interventions, Pennsylvania, USA). (b) Circular stapler digital loading unit (Power Medical Interventions, Pennsylvania, USA).

guideline for the Care and use of Laboratory Animals in Takaramachi Campus of Kanazawa University. The protocols in this study were approved by the animal experimentation committee of the Kanazawa University.

Pigs were sedated using an intramuscular injection of 5% ketamine hydrochloride (6 mg/kg body mass) and intravenous pancuronium bromide (3 mg/kg body mass) before intubation. Anesthesia was maintained using 1% halothane. Euthanasia was effected by administering KCl (40 mequiv), intravenously, under general anesthesia.

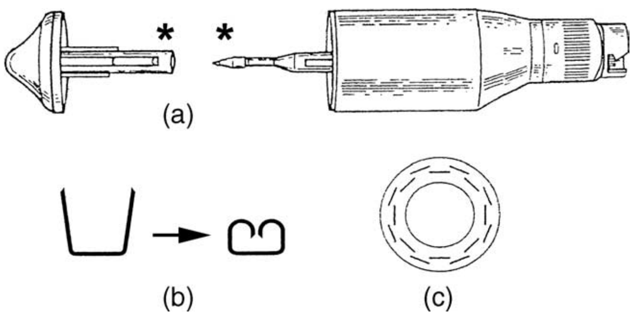


Fig. 2. (a) The DLU is composed of two parts, an anvil and a cartridge. These unite in a connected part, '*', and come together. (b) Staplers form 'B' character type after fire. (c) One cartridge has 16 staplers.

Experimental protocol

Evaluation of maximum pressure resistance in the anastomotic site

A descending aortic specimen from a pig of about 100 kg was anastomosed end-to-end with a 22-mm diameter Dacron graft using the DLU. Then, the opposite ends of the aorta and the Dacron graft were closed by ligation and forceps. This closed system was filled with heparinized porcine blood (1000 U/l), and external pressure was manually applied while monitoring the interior pressure of the system ($n=10$) (Fig. 3).

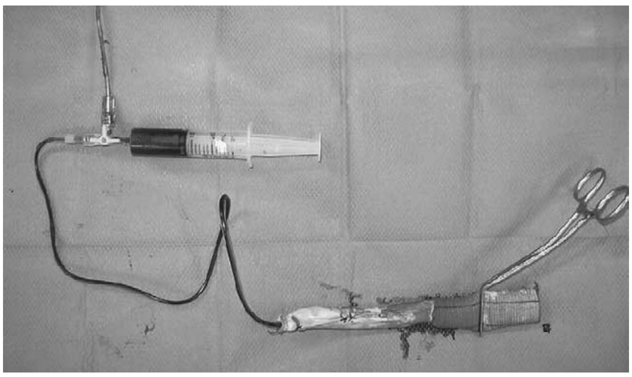
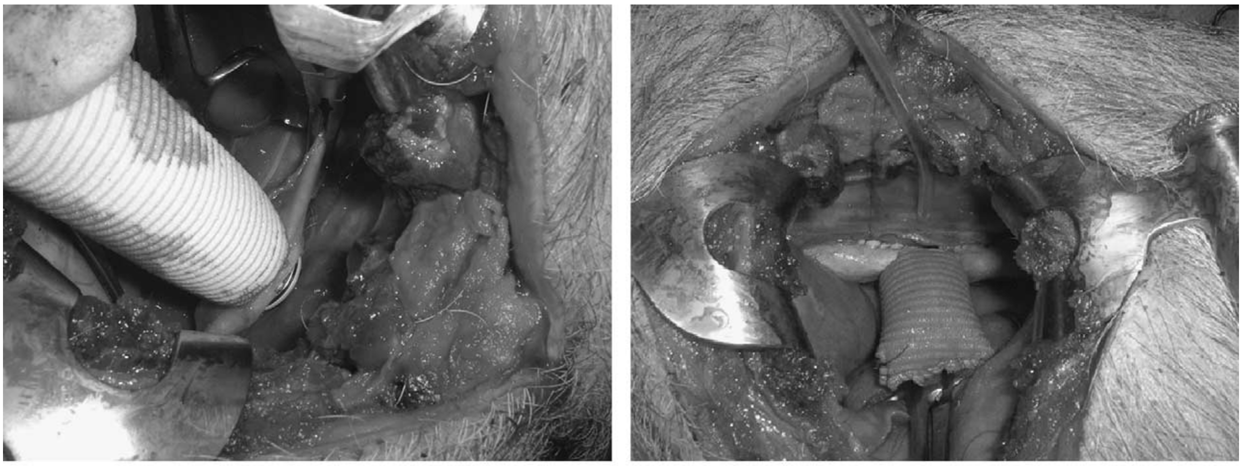


Fig. 3. Closed circuit for the evaluation of maximum pressure resistance in the anastomotic site, a porcine descending aortic specimen and a Dacron graft.



(a) (b)

Fig. 4. The porcine descending aorta and the Dacron graft were anastomosed end-to-side on a beating heart. (a) The anvil was inserted into a slit of the aorta. (b) An anastomosis was completed.

The maximum pressure resistance was defined as the pressure at which leakage commenced from the anastomotic site.

Evaluation of anastomosis on a beating heart with pressure overload

Five pigs (female, approximately 30 kg) were used. The animal was positioned in the right lateral recumbent position under general anesthesia and a left thoracotomy was performed. The descending aorta was dissected and encircled with vessel tapes; it was clamped proximally and distally after intravenous administration of heparin sodium (300 U/kg). The descending aortic wall was cut in a sagittal direction to allow entry of the stapler. An anvil was inserted there and fired. The descending aorta and the Dacron graft were anastomosed end-to-side. Following this, the cut aortic wall behind the anastomotic site were sutured with 4–0 prolene. After the aorta was unclamped, the opposite end of the Dacron graft was sutured with 4–0 prolene (Fig. 4). Adrenaline (2 mg/kg body mass) was administered via intramuscular injection, for induction of pressure overload. Systemic blood pressure was monitored in the left common carotid artery.

Histological examination

Specimens of the anastomotic sites of pigs used in protocol 2 were harvested after 14 days. After the specimen was fixed with 10% formaldehyde solution, resin-embedded sections were made.

Results

Evaluation of maximum pressure resistance in the anastomotic site

Ten end-to-end anastomoses between the descending aorta and the Dacron graft were successfully performed, all with a smooth firing action and no misfires. The maximum pressure resistance of the anastomotic site was 427.3 ± 34.4 (375–511) mmHg, with a median of 423 mmHg (Table 1).

Evaluation of anastomosis on a beating heart with pressure overload

On beating hearts, the anastomoses were performed completely without stress in a narrow, deep operative field. The mean systolic blood pressure achieved using adrenaline was 227.6 ± 21.1 (201–260) mmHg, with a median of 227 mmHg (Table 2). No hemorrhage occurred in any of the anastomotic sites. Paraplegia developed in all pigs because of spinal ischemia secondary to dissection and encircling of the descending aorta.

Table 1. Maximum pressure resistance in the anastomotic site

	$n = 10$									
	1	2	3	4	5	6	7	8	9	10
Pressure (mmHg)	412	432	441	421	422	407	428	511	375	424

The anastomosis of a porcine descending aortic specimen and a Dacron graft; median, 423 mmHg; average, 427.3 ± 34.4 mmHg.

Table 2. Pressure overload during evaluation of anastomosis on the beating heart

	$n=5$				
	1	2	3	4	5
Pressure* (mmHg)	229/132	201/149	260/138	221/151	227/155

Median (systolic), 227 mmHg; average (systolic), 227.6.3±21.
2 mmHg.
* Adrenaline 2 mg.

Histological examination

Specimens of anastomotic sites harvested after 14 days showed good incorporation and a full endothelial coverage (Fig. 5). The anastomotic site was not stenotic and with no increase in elastic fibers. The anastomotic site had findings of infection outside the Dacron graft because no antibiotic had been used. However, there were no macroscopic thrombi inside the anastomotic site (Fig. 6).

Discussion

There have been reports concerning automatic anastomotic devices for blood vessels since 1894; Zeebregts has reviewed these in detail.[11] Automatic anastomotic devices are under active development for myocardial revascularization, and their clinical use is also advanced.[12–19] Nevertheless, an aortic anastomotic device has not yet been developed and made available for clinical use.

Anastomosis of the vessel by inverted suture has the disadvantage of stenosis and thrombosis at the anastomotic site. Another difficulty arises because the intima of the aorta—a large, elastic artery—is turned over so as to expose an annular segment. These considerations have limited the use of an automatic anastomotic device for the aorta. Recently, however, a device for coronary anastomotic stapling by inverted suture has been developed.[20] A report by Stephane on aortic anastomosis using a circular stapling device suggested the histological safety of aortic inverted anastomosis.[21] Although specimens of the anastomotic site in this study were harvested during the acute to sub-acute term, the inverted anastomotic site was histologically confirmed to be in a satisfactory condition. As the aorta has larger diameter than the coronary artery, an inverted anastomosis is likely to be acceptable.

An anastomosis using the stapling device is completed rapidly, strong and able to be used in narrow operating fields. There are some issues concerning the future use of a circular stapling device to perform aortic anastomoses. When a circular DLU was pulled out from an anastomotic site after firing, resistance was felt. There was no actual difficulty in extracting the DLU in this study, but the resistance created some unease. This resistance is due to the anastomotic site being smaller than the anvil and

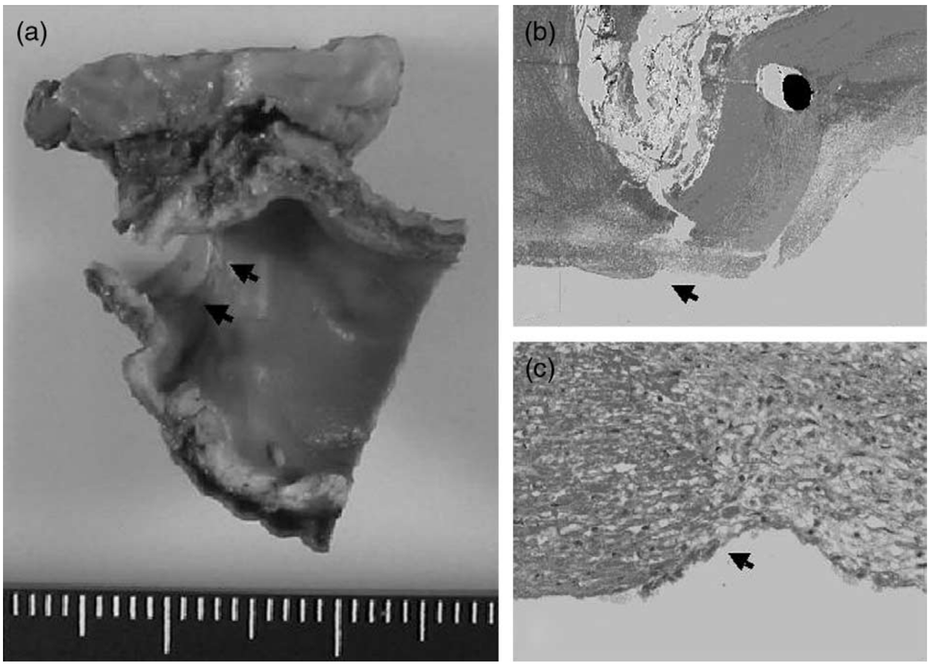


Fig. 5. Histological examination of the anastomotic site (black arrow) harvested after 14 days. Macroscopic view (a), microscopic view, H&E stain, original magnification 4× (b), 40× (c).

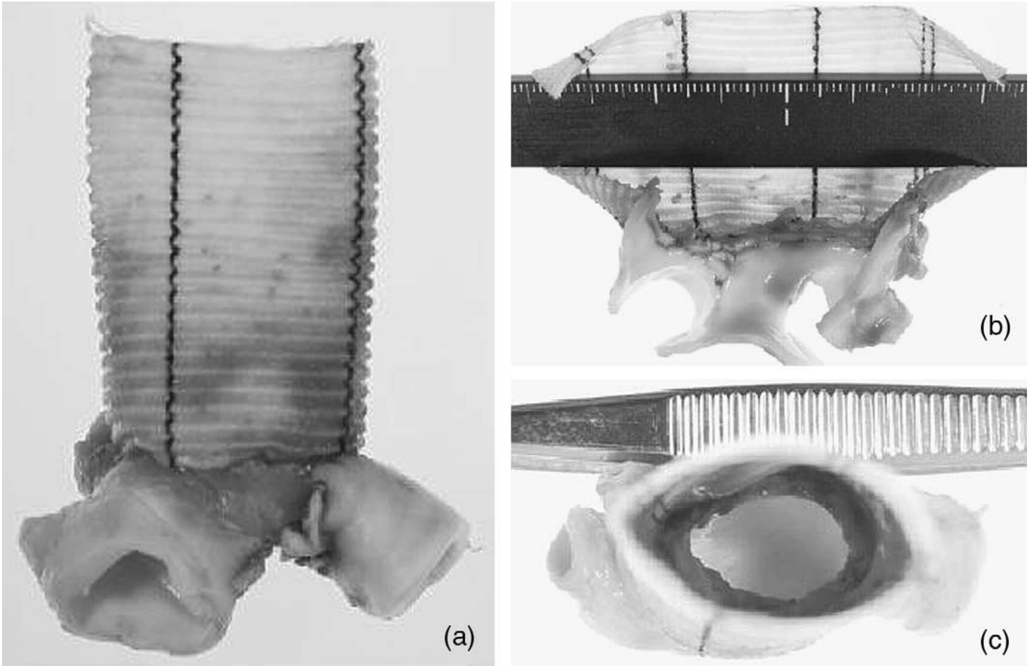


Fig. 6. Anastomotic site of porcine aorta and Dacron graft, created using the SurgASSIST system with circular stapler DLU. (a) External form. (b) Suture line. (c) Internal view.

lacking the flexibility of the Dacron graft. There has been a report that removal after anastomosis was made easier with an improved, thinner anvil; thus, the shape of the anvil may need to be improved for use in the aorta. Furthermore, in the current circular stapling device, the setting for the binding interval between the anvil and the staple housing, not to mention the size of the staples themselves, are appropriate for the stomach and intestines. Therefore, the optimal settings for the aorta remain to be determined. Finally, for anastomosis of the aorta and artificial graft, the development of an artificial graft that is matched to the system of the circular stapler (for example, blind opposite end or curved shape) will enhance the efficacy of the device. The minimum size of the DLU used in this study was 21 mm. The diameter of the aortas of the pigs used in this study was about 15 mm, therefore, we chose to use an end-to-side anastomosis.

This study showed that the strength of an aortic anastomotic site using a circular stapling device is enough to use clinically. An inverted anastomotic site was covered with endothelium smoothly. Furthermore, it was showed that the automatic anastomotic device with a flexible shaft was useful in small and narrow operative fields. The development of an automatic anastomotic device for aortic surgery is likely to be important.

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