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ORIGINAL ARTICLE

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AORTIC SURGERY

A new device as an open stent graft for extended aortic repair: a multicentre early experience in Japan

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Abstract

OBJECTIVES: Open stent grafting for extended aortic repair has been widely carried out around their world. We reported the effectiveness of a new device as an open stent graft for extended aortic repair.

METHODS: A new device was used as an open stent graft in this study. The graft part of the device has a woven structure made of Nitinol wire, a superelastic/shape-memory alloy. The subjects of this study were patients aged 20–84 with aneurysms ($n = 38$) or aortic dissection ($n = 22$) in the thoracic aorta, including the distal aortic arch and the proximal descending aorta. This study was a multicentre, non-blinded study. The follow-up period was 36 months.

RESULTS: Three subjects (5.0%) died during hospitalization due to multiorgan failure. Spinal cord injury (SCI) was observed in 4 subjects (6.7%): paraplegia in 1 and paraparesis in 3 subjects. The 3-year survival rate was 76.7% overall: 68.4% for the subjects diagnosed as having aortic aneurysms (the aortic aneurysm group) and 90.9% for those having aortic dissection (the aortic dissection group). For the aortic aneurysm group, thrombus formation in the aortic aneurysm was observed in 97% of the patients 6 months after operation, and in 100% 12 months after operation. Meanwhile, for the aortic dissection group, with regard to the false lumen of aortic dissection, thrombus formation was observed in 94% of the patients 6 months after operation, in 94% 12 months after operation and in 100% 24 months after operation. Expansion of the aortic aneurysm sac was observed in 2 subjects (6.1%). Among these 2 subjects, endoleak was observed in 1 subject, which was improved by additional thoracic endovascular aortic repair.

CONCLUSIONS: The safety and effectiveness of this investigational device was verified over a period up to 36 months after operation. A long-term follow-up would be necessary to further verify the effectiveness of the device in the future.

Keywords: New device • Stent graft • Aortic repair • Aneurysm • Aortic dissection

BACKGROUND

Open-style stent graft placement enables extended, one-stage treatment by simplifying the fixation of the distal side of the stent graft. This operating technique was first reported by Kato *et al.* in 1996 [1]. Since then, excellent treatment outcomes based on short- to long-term follow-ups have been reported [2, 3]. In Japan in recent times, ~300 cases of open-style stent graft placement have been carried out per year [4, 5]. Meanwhile, in Europe, E-vita OPEN PLUS, a commercialized stent graft, has become available. Many reports have reported the effectiveness of the E-vita OPEN PLUS to date. The present investigational device, the 'J Graft Open Stent Graft' (hereinafter referred to as 'this device'), was developed as a stent graft exclusively for use in open-style stent graft placement. Compared with Z stents like the E-vita OPEN, the J Graft Open Stent Graft is expected to enhance trackability to the aortic arch of the thoracic aorta due to its unique Nitinol wire-woven structure. This study was started with the aim of evaluating the safety and effectiveness of this device in Japan, on the premise that this device will obtain regulatory approval based on Japan's Pharmaceutical Affairs Law.

METHODS

A new device: open stent graft

The open stent graft used in this study consists of two parts: the graft part and the stent part. The graft part is a polyester woven graft with permeability of less than 500 ml/cm^2/min (at 120 mmHg, and in water at 37°C) and a thickness of ~450 μm. The stent part has a woven structure made of Nitinol wire, a superelastic/shape-memory alloy (Fig. 1A). The stent part is fixed to the inside of the graft to protect the stent part from directly coming in contact with the vessel wall. The stent part also has a structure such that its wire top hardly protrudes inwards when the device is bent. The delivery system consists of two elements: the resin shaft and the soft sheath (Fig. 1B). The shaft is equipped with a metal core rod that enables the bending of the tip. The soft sheath is made of a polyester-based mesh with a flexible and smooth surface. As for the stent part, the following three types of length are available: 60, 90 and 120 mm. Surgeons are able to select an optimal length for each lesion. The total length of the open stent graft is uniformly 200 mm, which is calculated by combining the length of the stent part and that of the non-stent part. The outer diameter of the stent graft ranges from 17 to 39 mm in increments of 2 mm. Referring to the preoperative measurement values obtained from computed tomography (CT) images etc., surgeons should select a stent graft with an outer diameter that is 110–120% larger than the inner diameter of the aorta where the stent graft is set to be implanted. To implant the stent graft, first, remove the string fixed to this device, and appropriately bend the distal tip including the stent part so that the configuration of the stent graft matches with that of the lesion. Then insert the stent graft into the artery to be replaced. Next, remove the cover to make the stent graft part expand, which fixes the stent graft to the target site. Similar to conventional vascular prosthesis implantation, the proximal end of the stent graft is sutured to the vessel.

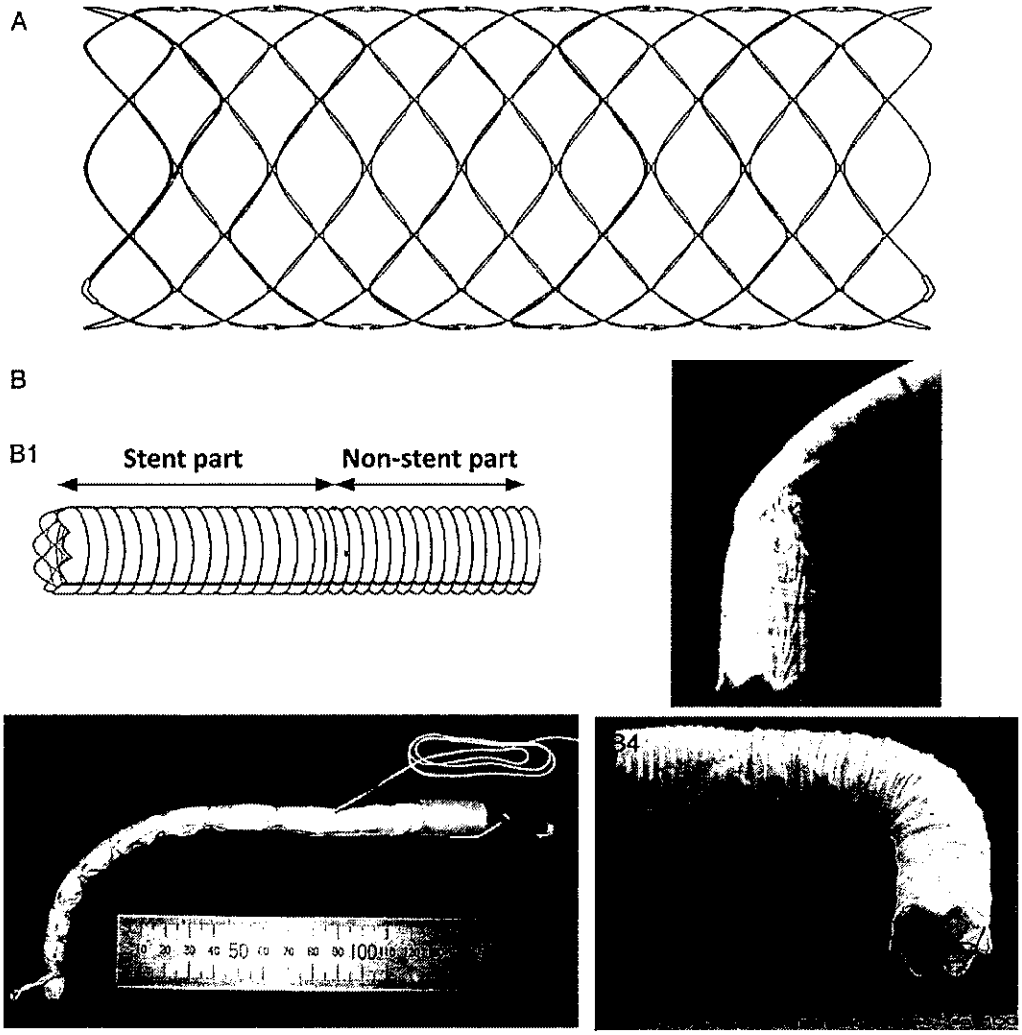

Figure 1: (A) Structure of the open stent graft used in this study. The open stent graft used in this study consists of two parts: the graft part and the stent part. The graft part is a polyester woven graft with permeability of less than 500 ml/cm^2/min (at 120 mmHg, and in water at 37°C) and a thickness of ~450 μm. The stent part has a woven structure made of Nitinol wire, a superelastic/shape-memory alloy. (B) Detailed structure of the open stent graft. The stent part is fixed to the inside of the graft to protect the stent part from directly coming in contact with the vessel wall. The stent part also has a structure such that its wire top hardly protrudes inwards when the device is bent. The delivery system consists of two elements: the resin shaft and the soft sheath. (B1) Structure of the open stent graft, (B2) before deployment, (B3) under deployment, (B4) after deployment.

Study design

The subjects of this study were patients aged 20–84 with aneurysms or aortic dissection in the thoracic aorta, including the distal aortic arch and the proximal descending aorta. In all cases, the surgeons in charge concluded that the portion the aorta in the lesion should be replaced. When enrolling the patients, we obtained written consent from all of them. This study was carried out in accordance with Japan's Pharmaceutical Affairs Law, the Good Clinical Practice (GCP) and the standard operating procedure prepared by facilities and companies that implemented this clinical trial. To secure and guarantee the reliability of the data obtained, we regularly checked the data by preparing 'Standard operating procedure for quality control of the research data and material'.

Sixty adult patients in total were enrolled at six facilities for this study. This study was a multicentre, non-blinded study. The follow-up period had initially been set at 60 months: namely, to the point of time that all the patients with the exception of those who died or withdrew from the study completed the postoperative 60-month follow-up check. However, since this device obtained regulatory approval based on the Pharmaceutical Affairs Law before the patients concerned completed the postoperative 60-month follow-up check, data obtained until 24 months after the operation were used in this study. The period of 24 months after the operation was the longest period during which all the patients who were continuing the clinical trial completed the follow-up check.

The primary end-point was 'Incidence of the major adverse events, including death, in the period from the intraoperative period to the time of discharge from hospital'. The secondary end-points concerning the effectiveness of this device were as follows: thrombus formation and change in the diameters in the aneurysms or dissected lumens—both of which are evaluated preoperatively and at 6, 12 and 24 months after the operation; the mortality rate during the period of 24 months after the operation; and the incidence of major adverse events, including aortic adverse events. Thrombus formation was defined as no leak of contrast on delayed enhanced CT. Moreover, the 3-year survival rate was calculated from the Kaplan–Meier survival curves at the point where the 60 enrolled subjects completed the postoperative 36-month follow-up check. Meanwhile, since TEVAR was an operative technique that had not received approval in Japan when this study was started, patients with the precondition of using open stent graft and TEVAR together were excluded from this clinical trial. All data were analysed using the SPSS 18.0 (SPSS, Inc., Chicago, IL USA).

RESULTS

The investigational device was implanted into each of the 60 subjects enrolled in this study during the period from March 2008 to September 2010. The subjects were 44 male and 16 female patients aged 71.6 ± 8.6 on average. Thirty-eight patients were diagnosed as having aortic aneurysms (the aortic aneurysm group), while the remaining 22 patients had aortic dissection (the aortic dissection group). With regard to the 22 patients of the aortic dissection group, 6 were classified as acute type A aortic dissection, 2 chronic type A aortic dissection, 1 acute type B aortic dissection and 13 chronic type B aortic dissection. All 60 of the subjects had lesions in the area ranging from the distal aortic arch to the proximal descending aorta. In 18 subjects, extension of the lesions was observed as follows: in 6 the lesions reached the ascending aorta, in 7 the lesions reached the proximal aortic arch and in 5 the lesions reached the thoraco-abdominal aorta. Meanwhile, 12 subjects had undergone surgery in their aorta in the past. Table 1 reports preoperative concomitant diseases: 14 subjects (23.3%) had a past history of stroke, 17 (28.3%) renal dysfunction and 28 (46.7%) cardiac disorder.

Table 1: Patient characteristics

Number	60
Male	44
Female	16
Age (mean ± SD)	46–83 (71.6 ± 8.6)
Pathologies (cases)	
Atherosclerotic aneurysm	38
Aortic dissection	22
Aortic dissection (acute type A)	6
Aortic dissection (chronic type A)	2
Aortic dissection (acute type B)	1
Aortic dissection (chronic type B)	13
Aortic lesion (cases)	
Ascending	6
Proximal arch	7
Distal arch–proximal descending	60
Thoraco-abdominal	5
Previous aortic operation (cases)	12
Ascending aorta	1
Aortic arch	1
Descending aorta	1
Thoraco-abdominal aorta	2
Infrarenal abdominal aorta	7
Preoperative comorbidity (cases)	59
Peripheral atherosclerotic disease	10 (16.7%)
Hypertension	57 (95.0%)
Hyperlipidaemia	28 (46.7%)
Antiplatelet therapy	19 (31.7%)
Diabetes	13 (21.7%)
Stroke	8 (13.3%)
Heart disease	49 (81.7%)
Ischaemic heart disease	30
Valvular heart disease	4
Chronic kidney disease	17 (28.3%)
Liver dysfunction	1 (1.7%)
Intestinal ulcer	10 (16.7%)
Other abdominal diseases	18 (30.0%)
Inner diameter of the stent graft (distal edge, mm)	21.5–38.0 (29.5 ± 3.7)
Preoperative cerebrospinal fluid drainage (cases)	21 (35.0%)

In the preoperative measurement based on image diagnosis, the luminal diameter of the aorta into which the stent graft was to be installed was 29.5 mm on average. Twenty-one subjects (35.0%) underwent preoperative cerebrospinal fluid drainage (CSFD).

This device was successfully implanted into each of the 60 subjects. The following cerebroprotection methods were adopted during the extracorporeal circulation: antegrade cerebral perfusion for 38 cases, retrograde cerebral perfusion for 23 cases and hypothermic circulatory arrest for 1 case. Thirteen cases of coronary artery bypass grafting and 3 cases of cardiac valve replacement etc. were concomitantly carried out during the operation. The operation time averaged 352 ± 67 min. Extracorporeal circulation was used for 178 ± 40 min on average. The average time of circulatory arrest of the lower trunk was 40 ± 37 min, while that of cardiac ischaemia was 95 ± 39 min.

With regard to the intraoperative problems, kinking was observed in 1 subject at the non-stent graft part of the open stent graft. This

Table 2: Operative variables

Number of patients	60
Number of patients who underwent open stent grafting	60
Number of open stent grafts implanted	60
Cerebral protection during open stent grafting	
Circulatory arrest	1
Antegrade selective cerebral perfusion	38
Retrograde cerebral perfusion	23
Cardiopulmonary bypass time, (mean ± SD) (min)	178 ± 40
Open distal arrest time, (mean ± SD) (min)	40 ± 37
Heart ischaemic time, (mean ± SD) (min)	95 ± 39
Surgical time, (mean ± SD) (min)	352 ± 67
Bleeding volume, (mean ± SD) (min)	817 ± 876
Additional operation	
Aortic stent[a]	1
Concomitant operation	
Coronary arterial bypass grafting	13 (21.7%)
Valve surgery	3 (5.0%)
Myomectomy of left ventricular outflow tract	3 (5.0%)
Maze operation	1 (1.7%)
Stent graft	
External diameter of stent graft	
25 mm	3 (5.0%)
27 mm	8 (13.3%)
29 mm	5 (8.3%)
31 mm	6 (10.0%)
33 mm	13 (21.7%)[a]
35 mm	15 (25.0%)
37 mm	6 (10.0%)
39 mm	4 (6.7%)
Mean diameter (n = 60)	32.6 mm
Mean diameter (aneurysm)	33.2 mm
Mean diameter (dissection)	31.4 mm
Length of stent graft	
6 cm	8 (13.3%)[a]
Aneurysm 7 cases, dissection 1 case	
9 cm	18 (30.0%)
Aneurysm 12 cases, dissection 6 cases	
12 cm	34 (56.7%)
Aneurysm 19 cases, dissection 15 cases	
Distal landing zone	
Th5	4 (6.8%)
Th6	18 (30.5%)
Th7	15 (25.4%)
Th8	20 (33.3%)
Th9	1 (1.7%)
Th10	2 (3.4%)

[a]Because a non-stent site of the open stent graft was kinked, aortic stenting using a Palmaz-Schatz stent was performed in 1 case.

problem was dealt with through release of the stenosis by using a Palmaz-Schatz stent during the operation. In the subject, the boundary between the stent part and the non-stent part was located in the part where the bending curve was sharp. Table 2 illustrates the size of the stent graft used in the 60 subjects. The overall average outer diameter of the stent graft used in this study was 32.6 mm (ranging from 25 to 39 mm): 33.2 mm for the aortic aneurysm group and 31.4 mm for the aortic dissection group. Open stent grafts with the stent part of the following lengths were used in this study: 6 cm for 8, 9 cm for 18 and 12 cm for 34 subjects. The positioning of the distal part of the stent graft was as follows: at the Th5 level in 4, at the Th6 level in 18, at the Th7 level in 15, at the Th8 level in 20, at the Th9 level in 1 and at the Th10 level in 2 subjects. Thus, the distal part of the stent graft was positioned at either the Th6 level or the Th7 level in more than half of the subjects (Table 2).

Table 3 presents the postoperative results obtained until the time of discharge from hospital. Three subjects (5.0%) died during hospitalization due to multiorgan failure. They died on the 27th, 32nd and 165th day after the operation, respectively. Postoperative stroke was observed in 6 subjects (10%). Spinal cord injury (SCI) was observed in 4 subjects during the period from the intraoperative period to the time of discharge from hospital: paraplegia in 1 subject and paraparesis in 3 subjects. The incidence rate of SCI caused by this device was 6.7% (4/60 subjects). Among the 4 subjects who developed SCI, with the exception of 1 subject who had no symptom of spinal cord infarction, the remaining 3 subjects had stent grafts at the Th8 level. The 3 subjects included 1 subject with paraplegia. In 2 of the 3 subjects, SCI was detected with MRI. None of the 3 subjects had undergone preoperative CSFD. One subject who developed paraplegia was a case of chronic type B aortic dissection. The subject's paraplegia was delayed-onset postoperative paraplegia that appeared 2 days after the operation. Among 2 subjects who developed paraparesis, one was a case of acute type A aortic dissection, whose paraparesis was probably caused by hypotension due to haemorrhage after implantation of the stent. Another subject was a case of arteriosclerotic thoracic aortic aneurysm. In the latter case, the open stent graft was to be positioned at the Th9 level. However, since the subject's descending aorta was a shaggy aorta, the open stent graft was shifted to 20 mm proximal and finally implanted at the Th8 level so as to avoid the plaque lesion. There is also a possibility that the debris within the shaggy aorta separated and caused the paraparesis, although the debris had not been detected on images. As symptoms of paraparesis were improved in these 2 subjects with the postoperative CSFD and rehabilitation, they left their hospitals (Table 4).

When the incidence of SCI was examined in terms of the length of stent implanted, the incidence rate of SCI for the stent graft 6 cm long was 0%, that for 9 cm was 5.5% (1/18) and that for 12 cm was 8.8% (3/34). The incidence of SCI tended to increase as the stent graft became longer. Moreover, both the time of extracorporeal circulation and that of circulatory arrest of the lower trunk were compared between subjects with SCI and those without SCI. The average time of extracorporeal circulation for subjects with SCI (n = 4) was 168.50 min, while for subjects without SCI (n = 56), it was 179.91 min. There was no significant difference (P = 0.60). Meanwhile, the average time of circulatory arrest of the lower trunk for subjects with SCI (n = 4) was 76.25 min, while for subjects without SCI (n = 56), it was 37.09 min. The average time of circulatory arrest of the lower trunk tended to be long in the subjects developing SCI (P = 0.039).

Postoperative leg ischaemia was observed in 1 subject, while postoperative recurrent laryngeal nerve palsy was observed in 3 subjects. Respiratory complication was observed in 2 subjects. Transient renal dysfunction and haematemesis were observed in 1 subject each, mediastinitis in 2 and sepsis in 4 subjects. Enterectomy for the treatment of occlusion of the superior mesenteric artery and rethoracotomy for the treatment of bleeding were carried out in 1 subject and 2 subjects, respectively. The following three aortic events were observed: one event of intraoperative kinking and two events of endoleak (Type Ib) at the distal landing site of the stent graft. The number of subjects who suffered from major complications during the postoperative period until the time of discharge from hospital totalled 27 (27/60 = 45.0%).

As for the results in the chronic stage, 7 subjects died during the period from the time of discharge from hospital to the 24th month after the operation. However, no death was related to the stent graft. The follow-up period averaged 1011 ± 388 days. Although 4

other subjects died in the period after the postoperative period of 24 months, no death was related to the aortic events. The 3-year overall survival rate was 76.7% (46/60): 68.4% (26/38) for the aortic aneurysm group and 90.9% (20/22) for the aortic dissection group (Fig. 2). Five cases of secondary operation were carried out for the abdominal aortic aneurysm within the postoperative period of 24 months. Thoracic aortic events were also observed in 7 subjects within the postoperative period of 24 months. Additional TEVAR was carried out for those 7 subjects as elective surgery due to the following causes: Type Ib endoleak in 3 subjects, residual dissection in 1 subject and descending aorta enlargement in 3 subjects. Postoperative progress was favourable in all 7 of the subjects. Three other subjects underwent additional TEVAR because of the descending aorta enlargement without endoleak, and 2 other subjects underwent operations for the treatment of abdominal aortic aneurysms (Table 3).

Table 3: Postoperative variables

Early mortality (cases)	3 (5.0%)
Operative death	1 (1.7%)
In-hospital death	3 (5.0%)
Early morbidities (cases)	
Major adverse event	28 (46.6%)
Stroke	6 (10.0%)
Spinal cord injury	3 (5.0%)
Paraplegia	1 (1.7%)
Paraparesis	2 (3.3%)
Lower limb ischaemia	2 (3.3%)
Recurrent nerve paralysis	3 (5.0%)
Cardiac event (LOS, PMI)	0
Respiratory complication	2 (3.3%)
Liver dysfunction	0
Renal dysfunction	1 (1.7%)
Re-exploration for bleeding	2 (3.3%)
SMA thrombosis	1 (1.7%)
Haematemesis	1 (1.7%)
Mediastinitis	2 (3.3%)
Sepsis	4 (6.7%)
Aortic event after open stent grafting	2 (3.3%)
Kinking stenosis	1 (1.7%)
Distal endoleak	1 (1.7%)
Follow-up period (mean ± SD) (days)	1011 ± 388
Late mortality (cases)	7
Stroke	2
MNMS due to AAA op	1
Cancer	2
Panperitonitis	1
Aortic event (cases)	12
Endovascular stent graft on the descending aorta	7
Type Ib distal endoleak	3
Residual entry	1
Dilatation of the descending aorta without endoleak	3
Abdominal aorta	5

The stent graft was evaluated at 6, 12 and 24 months after the operation, by means of CT (Fig. 3). In the aortic aneurysm group, thrombus formation in the aortic aneurysm was observed in 97% (34/35) at 6 months after operation, and in 100% (33/33) at 12 months after operation. Meanwhile, in the aortic dissection group, with regard to the false lumen of aortic dissection, thrombus formation was observed in 94% (16/17) at 6 months after operation, in 94% (17/18) at 12 months after operation and in 100% (18/18) at 24 months after operation. The quantitative and qualitative change in the diameter of aneurysms and that of dissected lumens are presented in Table 5. The average diameter of the aortic aneurysms at 6 months after operation was significantly smaller than that before operation, which became smaller at 12 months after operation and remained small at 24 months after operation ($P \leq 0.05$). The average diameter of the false lumens of aortic dissection was also significantly smaller than that before operation, which became smaller at 12 months after operation and remained small at 24 months after operation ($P \leq 0.05$) (Table 5). Meanwhile, the true lumen of aortic dissection became larger, although there were no significant differences among measured values. The aortic aneurysm sac shrinkage was observed in 74.3% (26/35) at 6 months after operation, in 90.9% (30/33) at 12 months after operation and in 86.2% (25/29) at 24 months after operation. Expansion of the aortic aneurysm sac was observed in 2 subjects (6.1%). Among these 2 subjects, endoleak was observed in 1, which was improved by additional TEVAR. Although the diameters of aneurysms of the 2 subjects transiently increased after operations, thereafter the diameters gradually decreased. The aortic aneurysms of the 2 subjects continued shrinking during the postoperative period from 12 to 24 months to reach the same size as that before operation. The size of the aortic aneurysms of those 2 subjects remained unchanged during the postoperative period from 24 to 36 months. Meanwhile, the shrinkage of the false lumen of aortic dissection was observed in 70.6% (12/17) at 6 months after operation, in 83.3% (15/18) at 12 months after operation and in 57.9% (11/19) at 24 months after operation (Table 5). Expansion of the false lumen was observed in 1 subject (5.6%), who was a case of chronic aortic dissection. In this subject, blood flow entry was newly observed in both the distal descending aorta and the abdominal aorta at the distal end of the stent. After additional TEVAR, the false lumen gradually shrank.

DISCUSSION

The stent part of the open stent graft used in this study has a woven structure made of Nitinol wire, a superelastic/shape-memory alloy. This stent part is fixed to the inside of the graft. We consider this

Table 4: Spinal cord injury

	Spinal cord injury	Pathology	Distal level of stent graft (thoracic vertebral)	CSFD	Comment	Onset after operation	Prognosis
1	Paraplegia	Chronic type B	Th8	No	Global thrombosis of the false lumen	2 days	No change
2	Paraparesis	Acute type A	Th8	No	Hypotension because of bleeding	1 day	Improving
3	Paraparesis	Atherosclerotic aneurysm	Th8	No	Prolonged ischaemic time of lower body	1 day	Improving
4	Paraparesis	Atherosclerotic aneurysm	Th6	Yes	Unknown	1 day	Improving

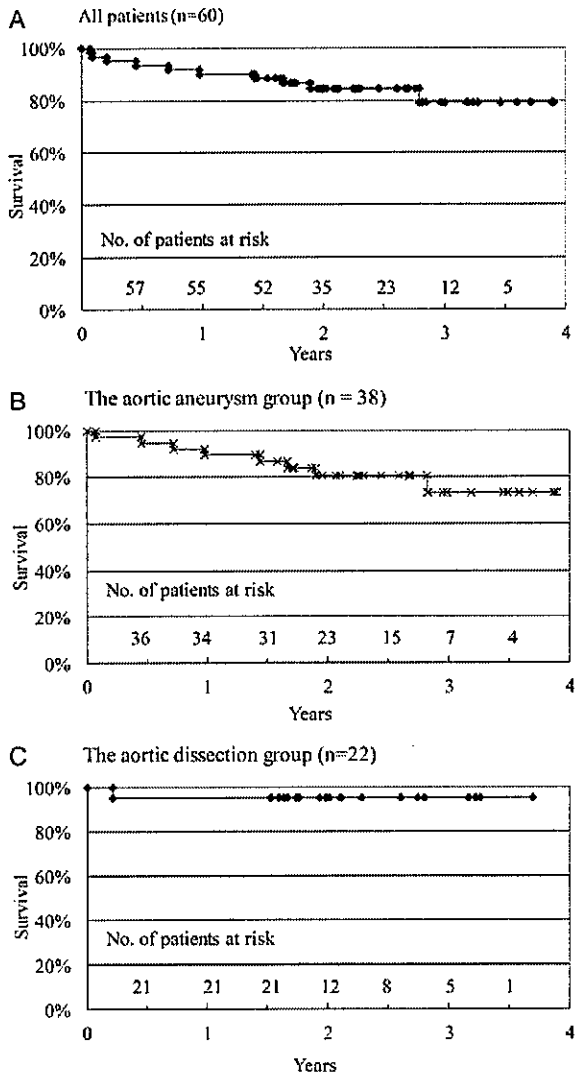

Figure 2: Survival curve. (A) Survival curve for all patients ($n = 60$), (B) survival curve for the aortic aneurysm group ($n = 38$), (C) survival curve for the aortic dissection group ($n = 22$).

structure of the stent part to be helpful in reducing the risk of damage to the intima when this device is compared with E-vita OPEN. This stent also has a structure such that its wire top hardly protrudes inwards when the device is bent. Furthermore, this stent maintains high trackability even when deployed into a lesion with a complex cross section that is frequently observed in chronic aortic dissection. Therefore, this stent has the ability to reduce the effect on the blood flow and secure the vessel lumen. The delivery system is equipped with a soft sheath that is wrapped by polyester-based mesh with a flexible and smooth surface, not with a hard sheath like that used in conventional self-made devices. The soft sheath reduces the risk of intimal damage when the device is being deployed. Compared with the devices prepared following the Z stent graft, the open stent graft used in this study showed favourable trackability to the curved aortic arch. This is expected to become a useful device in the open-style stent graft placement for cases of acute aortic dissection.

With regard to safety evaluation, which is a major subject of this study, the mortality rate during the 30-day period after operation was 1.7% (1/59), while that during hospitalization was 5.1% (3/59). Since the mortality rate after open-style stent graft placement is 4.7% according to other studies [6–10], the results obtained from this investigational device compare favourably with those from all other types of devices. All 3 of the subjects who died during hospitalization were aortic aneurysm cases. Meanwhile, no patients with aortic dissection died during this study. The open stent graft may make the blocking of blood flow easy because suturing at the deep part is unnecessary. As for mortality in the cases of aortic dissection, this study showed favourable results compared with a multicentre experience using E-Vita OPEN, which reported a mortality rate of 12% [11]. Moreover, since securing an operational field for suturing is unnecessary in this operating technique, the burden on lungs can be reduced. As a result, the incidence of adverse events such as postoperative pneumonia is expected to be reduced.

Concerning the problems related to this device, kinking of the device was observed in one of the 60 subjects enrolled in this study. The kinking was observed at the boundary between the stent part and the non-stent part of the open stent graft. Thus, the kinking was presumably caused by the positioning of the non-stent part of the open stent graft: specifically, the non-stent part was positioned at the flexure of the aorta. As mentioned previously, this open stent graft has favourable trackability to the aortic arch. Furthermore, the following three types of graft length are available in this open stent graft: 6, 9 and 12 cm. To protect the stent graft from kinking, the stent part should be positioned in a manner that sufficiently covers the aortic arch by selecting the optimal graft length according to the length of the lesion. In addition, the following operation scenario should be designed to prevent kinking: the non-stent part with the length that is being kept as short as possible must be anastomosed to the proximal vessel.

In this study, this device was used for various lesions, as follows: aortic aneurysms located in the area ranging from the distal aortic arch to the proximal descending aorta, and aortic dissection of either type A or type B, and either acute or chronic. In every lesion, this device provided favourable effects. When the prognosis of the aorta was observed in terms of thrombus formation, the prognosis was favourable because the rate of thrombus formation was 100% in the aortic aneurysms and 94% in the false lumens of aortic dissection. In the open-style stent graft placement, unlike TEVAR, the Type Ia endoleak can surely be prevented since the proximal side of the stent graft is directly anastomosed to the vessel. In this study, the Type Ib endoleak was observed in 2 subjects. Among these 2 subjects, one underwent additional TEVAR. Especially when an open stent graft is implanted into the aneurysm with an expanded aorta, there is a high possibility that after the blood pressure has returned to normal, the distal part of the stent graft will migrate to the proximal side from the position where it is implanted during the circulation arrest. To prevent these problems, the following two options should be deliberated upon when the open stent graft is implanted in the aneurysm largely projecting to the outer curvature: positioning the open stent graft at the level about one vertebral length more distal, considering the effect of migration, or carrying out additional TEVAR as a two-stage operation after the circulatory dynamics have stabilized so as to prevent paraplegia. Meanwhile, when this device is implanted in the narrowed true lumen of aortic dissection, the incidence of migration and that of Type Ib endoleak are low. Instead, the risk of intimal damage in the distal end due to stent grafting is high. However, this device was developed with a design to reduce the risk of intimal damage by adopting a woven structure made of flexible wire and a structure such that the stent is

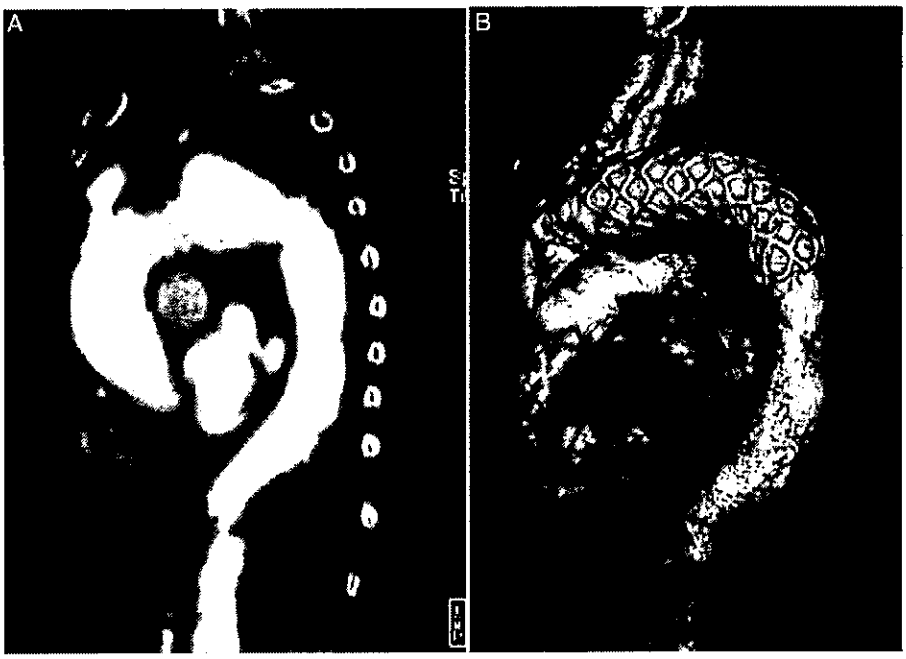

Figure 3: Preoperative CT image and postoperative CT image. The stent graft was evaluated 6, 12 and 24 months after the operation, by means of CT. Compared with the Z stent graft, the open stent graft shows favourable trackability to the curved aortic arch. (A) Preoperative, (B) postoperative.

fixed to the inside of the graft to prevent it from directly coming in contact with the vessel wall. In practice, no tear was newly detected at the distal end of the stent graft during this study.

As for the characteristics of this study, among the 60 subjects who underwent open-style stent graft placement, 22 were diagnosed as having aortic dissection (Type A: 8 subjects; Type B: 14 subjects). No subjects of the aortic dissection group died during hospitalization in the early stage after operation. In particular, this study had attached importance to the postoperative results for the Type A aortic dissection. As the results showed, no major adverse events such as death and paraplegia were observed. In addition, thrombus formation in the false lumen was observed in all the subjects, which showed favourable aortic remodelling. When this stent graft is used in the operation for acute type A aortic dissection cases, most of which need emergency operation, postoperative results from the early stage to the late stage would be improved for the following reasons: a stent graft of optimum size can be selected from the stent graft line-up of various sizes; and the risk of intimal damage can be reduced owing to the stent part having a woven structure made of Nitinol wire, a superelastic/shape-memory alloy—which has favourable trackability to curved structures—and a delivery system with a soft sheath wrapped by polyesther-based mesh. The controversial problems in the open-style stent graft placement for acute aortic dissection are the diameter of the stent graft to be used and how far the stent graft is inserted. The length of the stent graft is inevitably determined by the position of the distal end. In the E-Vita OPEN PLUS marketed in Europe, the shortest stent graft is 13 cm in length. Therefore, E-Vita OPEN PLUS is probably implanted into more distal parts than this investigational device can be. Hoffman *et al.* [12] reported that they have no cases developing paraplegia after implanting the stent graft into the level from Th10 to Th12. However, the Adamkiewicz artery that supplies blood to the spinal cord exists below the Th8 level in general [13]. Therefore, we consider that the distal end of the stent graft should be positioned at a more proximal level than Th8. In this study, the investigational stent graft was implanted at a level more proximal than the Th8 level in all 22 subjects of the aortic dissection group. For the cases of aortic dissection, we recommend selecting any one of the stent grafts with a length of 6 or 9 cm, after measuring the length by setting a benchmark around the Th6 level so as to make possible the stent graft implantation in the straight part of the aorta, with the aim of reducing the stress on the intima as much as possible. As for the optimal diameter of the stent graft used for the cases of acute aortic dissection, selecting a stent graft with the same diameter as that of the original aorta before dissection occurred would be ideal, considering the aortic remodelling. If a stent graft is selected by referring to the diameter of the narrowed true lumen, a stent graft with a diameter much smaller than the outer diameter of aorta would be implanted. In this situation, the implanted stent graft would be expanded into an elliptic shape and a new tear would highly likely be generated on the side of the minor axis having a large radius of curvature. When a stent graft with the same diameter as the outer diameter of aorta is selected, which enables the stent graft to be implanted with its round shape, the wall tension on the intima would become low. On the basis of the preoperative CT measurement, Hoffman *et al.* [12] selected a stent graft with a diameter corresponding to the outer diameter calculated from the sum of the diameter of true lumen and that of false lumen of the descending aorta measured at the level of the left atrium. When acute dissection occurred, the tunica adventitia of the aorta would be expanded because blood flows into the false lumen, which may make the aorta to expand to some degree. However, how far the diameter of the aorta would enlarge after dissection occurred compared with before operation is uncertain, which is a topic for future discussion. At the very least, satisfactory aortic remodelling of the descending aorta would be achieved throughout the long-term follow-up period when an optimally sized stent graft is implanted.

The major problem in open stent grafts is believed to be the appearance of paraplegia. Another paper reported that the

Table 5: Fate of aneurysm or false lumen (changes of diameter and size)

Diameter				
Atherosclerotic aneurysm				
Interval after surgery (months)	Number	Diameter of aneurysm (mm)		*P*
		Preop	Postop	
6	35	57.8 ± 10.1	51.4 ± 9.1	0.00005
12	33	57.7 ± 10.1	47.7 ± 9.7	0.00008
24	29	55.5 ± 12.9	50.6 ± 11.5	0.0009
Aortic dissection (false lumen)				
Interval after surgery (months)	Number	Diameter of false lumen (mm)		*P*
		Preop	Postop	
6	19	18.0 ± 15.8	15.1 ± 16.6	0.2
12	19	16.5 ± 14.1	11.3 ± 15.0	0.01
24	19	19.1 ± 15.2	12.3 ± 17.0	0.01
Aortic dissection (true lumen)				
Interval after surgery (months)	Number	Diameter of true lumen (mm)		*P*
		Preop	Postop	
6	19	27.1 ± 11.4	29.7 ± 5.4	0.2
12	19	26.5 ± 11.7	30.1 ± 5.1	0.09
24	19	25.8 ± 11.3	30.1 ± 4.2	0.10
Size				
Atherosclerotic aneurysm				
Interval after surgery (months)	Number	Change of aneurysm size		
		Shrinkage	No change	Dilation
6	35	74.3% (26/35)	17.1% (6/35)	8.6% (3/35)
12	33	90.9% (30/33)	3.0% (1/33)	6.1% (2/33)
24	29	86.2% (25/29)	10.3% (3/29)	3.4% (1/29)
Aortic dissection (false lumen size)				
Interval after surgery (months)	Number	Change of false lumen size		
		Shrinkage	No change	Dilation
6	19	70.6% (12/17)	17.6% (3/17)	11.8% (2/17)
12	19	83.3% (15/18)	11.1% (2/18)	5.6% (1/18)
24	19	57.9% (11/19)	26.3% (5/19)	15.8% (3/19)

incidence rate of SCI is 8.2% on average, ranging from 0 to 25% [14]. The collateral network is thought to be affected in the cases of SCI in the operations for the aorta these days [15]. Also, in this study, SCI was observed in subjects with the intraoperative findings suggesting hypoperfusion of the entire collateral network due to the following causes: intraoperative circulatory arrest for a long time, hypotension caused by haemorrhage and massive thrombus formation in the false lumen following the blood flow block caused by this open-style stent graft placement. Furthermore, paraplegia in this study was probably caused by an extensive occlusion of the intercostal artery due to thrombus formation in the false lumen after the stent grafting. SCI after frozen elephant trunk is reported to be caused by a combination of factors [16].

In particular, it is thought that surgeons should position the distal side of the open stent graft at the Th8 level or more proximal to prevent SCI, because the incidence of SCI becomes high when the open stent graft is implanted at the Th9 level or more distally. As for this device, three types of length are available: 60, 90 and 120 mm. Taking into account the pathology and anatomy of each patient, the surgeon is allowed to select an optimal length and to determine the adequate distal landing zone. Thus, this device is expected to reduce the occurrence of SCI.

Limitations

This study was a domestic multicentre study using a commercialized device as the investigational device. The safety and effectiveness of this investigational device was evaluated over a period until the 36th month after operation. A long-term follow-up would be necessary to further verify the effectiveness of the device in the future.

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