The stent-graft is a device constructed from a stent and vascular graft and is inserted by means of an interventional procedure under imaging guidance. In 1986, Balko et al. reported the first stent-graft experiment, in which a Z stent covered with polyurethane was inserted into an animal aorta. In the early 1990s, Parodi et al. reported clinical introduction of the stent-graft for abdominal aortic aneurysm. In comparison to the abdominal aortic stent-graft, the thoracic stent-graft has several disadvantages, including difficulties associated with the aortic arch curvature and the relatively large caliber of the stent-graft, and the risk of central nervous system or spinal complication. However, the thoracic stent-graft is advantageous because of minimal procedural invasiveness in comparison to surgical graft replacement. In 1994, Dake et al. reported transluminal placement of an endovascular stent-graft for thoracic aortic aneurysm, and Kato et al. reported use of a stent-graft for aortic dissection and suggested that the stent-graft could be considered an alternative to surgical treatment.

Key words: arteriovenous malformations, ethanolamine oleate, sclerotherapy

STENT-GRAFT MATERIALS

The majority of thoracic aortic stent-grafts are constructed with self-expandable stents. They consist of a stainless steel or nitinol wire frame covered with vascular graft material (e.g., woven Dacron, polytetrafluoroethylene, polyester). Many types of stent-graft are already commercially available in Europe and other countries (Fig. 1). Vascular interventional radiologists and vascular surgeons could use these manufactured stent-grafts, depending on their own level of experience, their familiarity with the use of stent-grafts, and the size of available devices. However, to date, the Ministry of Health has not approved distribution of any stent-graft in Japan; the majority of stent-grafts are still constructed by physicians from a tracheal stent (or other type) and sutured with a vascular graft.

VARIETY OF STENT-GRAFT

Stent-grafts vary in terms of the delivery system, attachment of the graft to the stent, relative positioning of the stent and graft, and type of end fixation. Three common delivery systems are the after-loading, preloading, and trigger-wire system. The graft is attached to the stent, by means of a suture or bandage, in one of two ways: in a fully supported stent-graft, the entire stent is attached to the vascular graft; in a partially supported stent-graft, both ends (or the proximal end) of the stent are sutured or banded to the graft. The stent is positioned to support the graft from the inside, from the outside, or partly from the inside and partly from the outside. Fixation of the stent-graft in the aorta is accomplished by anchoring hooks or barbs on the uncovered ends of the stent; some stent-grafts are not anchored.

STENT

Tubular, tapered, and bifurcated stent-grafts are used to treat abdominal aortic aneurysm. Tubular and tapered stent-grafts are now available for the thoracic aorta. Some stent-grafts are manufactured in a curved shape in an attempt to accommodate the aortic curvature. A computer-aided design system for creating the ideal curvature is under investigation.

VASCULAR GRAFT

The vascular graft materials are selected on the basis of porosity (mL/min/cm²), i.e. the estimate leakage of blood through the vascular graft. A thin material with low porosity and a loose crimp is ideal because it can be used with a small introducer system and can accommodate the vascular curvature.
Generally, a delivery system with a small outer diameter is preferred when the diameters of the access and target arteries are small. Most of the commercially available systems use 21-24 Fr (7-8 mm) introducer sheath. The Keller-Timmermans introducer set (COOK Inc., Bloomington, IN) (Fig. 2) is one of the delivery systems made of Teflon. This system is available with an inner diameters of 18, 20, or 24 Fr and an outer diameters of 21, 23, or 27 Fr. The system is pre-shaped in a straight line or J-shaped. The dilator is tapered, and the hemostasis tube is attached at the handle side.

**INDICATIONS FOR ENDOVASCULAR TREATMENT**

Endovascular treatment can be limited by anatomical morphology. The proximal neck, which is measured as the distance between the left subclavian artery and the beginning of the aneurysm, should be longer than 20 mm for stent-grafting with proximal fixation. If the proximal neck is 40 mm or more in diameter, it will be difficult to treat by stent-grafting, and surgical repair should be considered (Table 1). Increased calcification of the proximal neck wall compromises the proximal fixation of the stent-graft. The distal neck, which is measured as the distance between the end of the aneurysm and the celiac trunk, should be more than 20 mm for stent-grafting. In a tortuous aorta, it is difficult to insert the stent-graft and fix the distal end to the vessel wall. A straight region of the aortic wall should be chosen for the stent-graft landing site, or an anatomically pre-shaped stent-graft should be used.

Stent-graft insertion is also indicated when factors are present prohibiting open surgery; such as myocardial infarction and advanced age (70 years). In patients with a high level of risk associated with open surgery, use of stent-grafts to repair aortic lesions is recommended.
PREOPERATIVE EVALUATION

Preoperative imaging is essential for minimizing the difficulties associated with endovascular stent-graft treatment. Three-dimensional image reconstruction (computed tomography (CT) and/or magnetic resonance imaging (MRI)) should be used to obtain information about vascular access, the longitudinal and transverse diameter of the aneurysm, and the anatomic relation of the aneurysm to major aortic branches.

FIGURE 4
WIRE TECHNIQUE
A) PULL THROUGH WIRE TECHNIQUE (A GUIDE-WIRE WHICH INSERTED FROM THE FEMORAL IS CAUGHT AND PASSED THROUGH THE BRACHIAL ARTERY), IS USEFUL TO SUPPORT THE DELIVERY SYSTEM INSERTION WHEN THE APPROACH VESSEL PRESENT SEVERE TORTUOUS.

Contrast-enhanced CT

Three-dimensional CT images are obtained with, for example, parameters such as 120 kV, 200 mA, 2.5-mm thickness, 2.5-mm reconstruction, and table speed of 0.875, 0.5 sec/scan, 300 mgI/ml, 3.0 ml/sec. When guidance from a pre-operative image is necessary to reach the ascending aorta, electrocardiogram gate acquisition should be employed. If the operator is familiar with the contrast navigation method, the region of interest should be placed at the descending thoracic aorta. A test injection of 5-10 ml, given under the same conditions that will be present during the actual procedure, is time consuming but increases the chances of a successful procedure, espe-
cially in patients with complicated blood flow dynamics (e.g., large aneurysm, retrograde dissection).

The two landing zones (proximal and distal stent-graft end) have to be chosen with care. Multi-planar reconstruction images on contrast-enhanced CT are helpful for determining the existence of wall calcification and mural thrombus, and to differentiate the aneurysm from the vessel’s inner lumen. These are also useful for measuring the vessel length and diameter. Volume-rendered images facilitate understanding of the relation between the lesion and other branches (especially the left subclavian artery), but image quality is more influenced by the operator in volume-rendered than in other types of images, and thus the volume-rendered image should not be used for measurement without comparison to another type of image. To evaluate the whole vessel tract, contrast-enhanced CT image should be obtained from the aortic arch (occasionally from the carotid bifurcation) to the femoral artery. Multi-detector row CT is useful for increasing the patient’s comfort by decreasing the duration of breath holding.

**MR imaging**

A combination of T1- and T2-weighted MRI is useful for evaluating the thrombus organization. Blood flow affects the signal intensity, and it is sometimes difficult to differentiate it from thrombus. Electrocardiographic-gated cine MRI depicts the blood flow in high intensity; thus it
can be differentiated from the vascular lumen and thrombus. Dynamic enhanced MR Angiography (e.g., spoiled GRASS) is useful for detecting the lumen with a small amount of contrast material (0.1 - 0.2 mmol/kg). This modality is recommended for patients with renal insufficiency or at risk of an adverse reaction to iodine contrast media.

PROCEDURES

The procedures are generally performed in an operating room with complete angiographic capabilities, and imaging is performed with a portable digital C-arm unit. The guidelines are relatively strict, but stent-graft procedures can also be performed in an angiography suite under the condition that the angiography suite is thoroughly sterilized and prepared to support possible surgical conversion.

In principle, general anesthesia is used for insertion of the thoracic aorta stent-graft.

Ancillary procedures such as a carotid-to-subclavian bypass to lengthen the proximal landing site may be performed before stent-graft insertion. Right carotid-to-left carotid and carotid-to-subclavian bypasses are occasionally necessary to prevent occlusion of the left carotid and subclavian arteries by the stent-graft (Fig.3).

Brachial artery access is necessary for frequent contrast injections through a catheter. Initial aortography is performed from the left anterior oblique position to confirm the length of vessel requiring stent-graft repair and to confirm the branch level. Patients are given intravenous hepa-
rin (5000 units) just after the placement of introducer system. Activated clotting times are checked throughout the procedure, and systemic anticoagulation is maintained.

The stent-graft delivery system is inserted into the access artery. The delivery system is advanced to the proximal landing site by a route that is determined according to whether the origin of the left subclavian artery is to be covered. When the access route (e.g., iliac artery, abdominal artery) is severely tortuous, a stiff wire (e.g., Amplatz extra stiff (COOK Inc., Bloomington, IN)) should be used to support the system as it passes through the region.

The pull-through wire method (a guide wire inserted from a femoral approach site is caught by the snare from the brachial artery and passed through the femoral to the brachial artery (Fig. 4a)) with constant wire tension also helps to support the system insertion12 (Fig. 5, 6).

Before the stent-graft deployment, the whole system should be placed a little bit proximally, as a tab (Fig. 5a, 6a). For precise proximal placement, anesthetic hypotension (at least 80 mmHg) or asystole is useful to prevent the stent-graft from drifting in a distal direction13,14.

The stent-graft is deployed when the blood pressure reaches 80 mmHg (or during the asystolic period) to ensure attachment at the proximal and distal landing zones. The effect of temporary vena caval occlusion is under investigation15.

On occasion, a second prosthesis is needed for additional length depending on the extent of disease in the descending aorta. Post-deployment balloon dilatation is performed to ensure not only full graft expansion, including any overlap zones, but also complete contact with the aortic wall.

RESULTS

According to recently published data, from the European Collaborators on Stent-graft Techniques for Thoracic Aortic Aneurysm and Dissection Repair (EUROSTAR) and the United Kingdom Thoracic Endograft registries, primary technical success was obtained in 217 of 249 patients (87.1%) with degenerative aneurysm and in 116 of 131 (88.6%) with aortic dissection16.

Since 2000, 75 patients with a descending thoracic aortic lesion have been treated by stent-graft placement at Sapporo Medical University. The technical success rate for stent-graft deployment was 100%. The patients were 59 men and 16 women, and their age ranged from 17 to 86 years (mean 67.7 years).

Forty-five patients were more than 70 years of age. A single stent-graft was used in 69.3% (1.33 ±0.55 (mean standard deviation (SD)) of patients. Average stent-graft dimensions were 34.9 mm in diameter (range 22 mm to 40 mm) and 122 mm in length (range 50 mm to 255 mm).

COMPLICATIONS

One of the most important and frequent complications related to stent-graft insertion is endoleak. Endoleak is classified as one of four types according to the mechanism of leakage to the aneurysmal sac (or false lumen). Type I endoleak (Fig. 7a, 8) is caused by caliber mismatch (or warp) between the proximal (or distal) native vessel and the stent-graft. Additional balloon inflation is helpful for supporting full expansion of the stent-graft. If substantial endoleak remains after the balloon inflation, an additional stent-graft and/or embolic procedure should be used to decrease the leakage. Type II endoleak (Fig. 7b) is caused by backflow into the aneurysm from the left subclavian artery. Additional treatment with left subclavian embolization or with carotid-to-subclavian bypass surgery should resolve this type of endoleak. Type III endoleak (Fig. 7c) is leakage from a gap between two stent-grafts caused by factors such as caliber mismatch or warping. Additional stent-graft insertion to cover the gap is effective in resolving this leakage. Type IV endoleak (Fig. 7d) is the penetration of blood through the porous graft material. Preoperative graft selection is the key to avoiding this type of leakage, and most commercially available stent-grafts prevent this problem.

### Table 1

**Definition of term**

- Delivery success
  - Success of precise insertion and deployment of stent-graft
- Technical success
  - Delivery success without type I endoleak
- Initial success
  - Technical success without deleterious accident
- Early success
  - No leak, no migration, or no accident within 30 days
- Mid-term success
  - No leak, no migration, no accident, or no aneurysmal dilatation within 2 years
- Long-term success
  - No leak, no migration, no accident, or no aneurysmal dilatation more than 2 years

### Table 2

**Anatomical indication**

- **Proximal landing zone**
  - More than 20mm
- **Proximal caliber size**
  - Within 40mm
At present, the complication rate varies according to the patients’ conditions. Of the 443 patients in the EUROSTAR and United Kingdom registries, 41 (9.3%) died within 30 days, with mortality rates after elective procedures of 5.3% for degenerative aneurysm and 6.5% for aortic dissection. In cases of degenerative aneurysm, the mortality rate was greater (28%; P) after emergency repair than after elective procedures. In cases of aortic dissection, 12% of patients underwent emergency repair and a similar percentage underwent elective procedures.

Direct comparison between open surgery and stent-graft procedures may not be justified, but the 30-day mortality rate reported for stent-graft procedures is lower than that for open surgery, which can be as high as 67%.16. Nienaber et al.17 reported no death or paraplegia, stroke, embolization, or infection in the stent-graft group, but a 12-month mortality rate of 33%, a serious morbidity rate of 42%, and significantly longer stays in the intensive care unit and hospital in comparison to surgical repair (P<0.001).

In other studies, paraplegia from spinal artery occlusion occurred after stent-graft insertion in 1.7% to 3.2% of patients, rates which compare favorably with the reported 6.5% to 8% in patients who underwent thoracoabdominal surgical repair.18,19 In all of these patients, repair of an abdominal aortic aneurysm was performed either before or simultaneously with stent-graft deployment. The interruption of a significant number of intercostal vessels with use of a thoracic aorta stent-graft, combined with interruption of multiple lumbar arteries during the abdominal aortic aneurysm repair, was the likely cause of paraplegia in these patients.

Spinal complications presumably result from coverage of the artery of Adamkiewicz and spinal collaterals during the stent-graft procedure. Non-invasive, preoperative detection of the artery of Adamkiewicz as a means of decreasing the occurrence of spinal complications is currently under investigation.20-22 Use of a retrievable stent-graft with evoked spinal cord potential monitoring to prevent spinal cord ischemia is also under investigation.22

SUMMARY


Početkom 1990. Parodi je referisao kliničku primenu stent grafa u lečenju aneurizme abdominalne aorte. U porijeklu sa abdominalnim stent graftovima, torakalni imaju dosta sličnosti ali se i razlikuju po kalibru, mestu insercije, blizini arkusa aorte kao i mogućnosti nastajanja komplikacija od strane nervnog sistema.

U odnosu na hirurški stent –graft insertovan pod kontrolom radioškopije predstavlja napredni metod lečenja u grupi minimalno invanzivnih tretmana.

Ključne reči: aorta, stent, graft

REFERENCES


