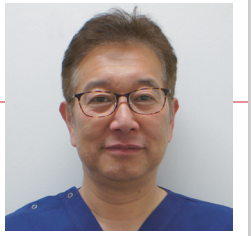
Technique and pitfalls of frozen elephant trunk insertion: Prevention of spinal cord injury



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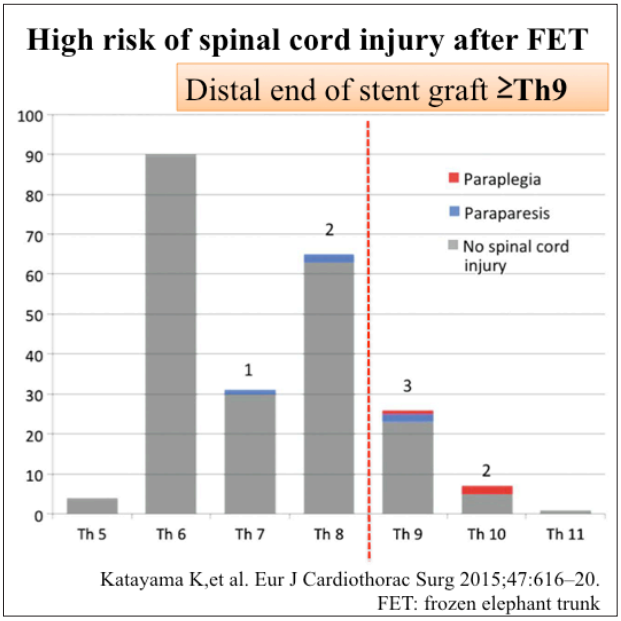
The simplicity of the frozen elephant trunk (FET) procedure has led to its increased popularity as a treatment for complex thoracic aortic pathologies. However, FET has been associated with procedure-related risks, particularly spinal cord injury and a non-negligible postoperative paraplegia/paraparesis rate. Although this devastating complication has been attributed to various mechanisms, of which spinal cord ischemia and occlusion of the thoracic intercostal arteries appear to be the most important, the exact mechanism by which spinal cord injury associates with FET intervention is not fully understood. Previous studies have cited stent graft length, thromboembolism, and spinal cord ischemia time during total circulatory arrest as responsible factors. In Japan, FROZENIX first received commercial approval in February 2014 and was implanted in 2,216 patients between July 2014 and December 2015. Among these patients, spinal cord injury occurred in 43 (1.9%), including paraparesis in 13 (0.6%) and paraplegia in 30 patients (1.3%). This incidence, which was much lower than the 6.7% reported in the premarket trial, may be attributable to the avoidance of implantation below T8 and earlier distal perfusion after delivery of the stent graft. At our center, no spinal cord injuries were observed in more than 70 consecutive patients treated with FET according to our technique, which is described in this report.

Fig. 1 **Postoperative spinal cord injury (SCI) according to the position of the distal stent graft.**



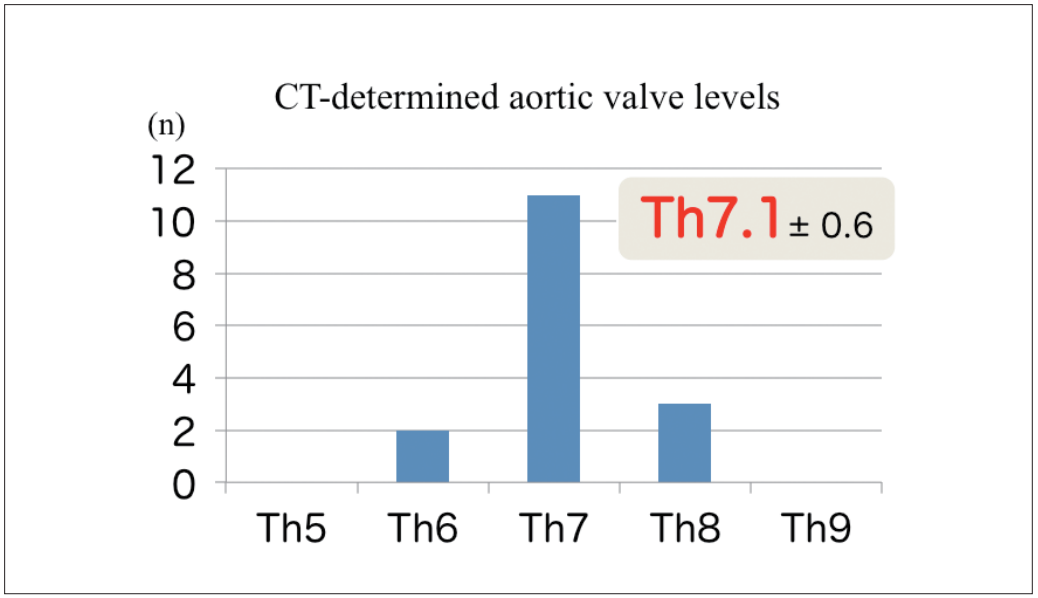
A distal stent graft position below Th9 was identified as a significant independent risk factor for SCI. The Adamkiewicz artery, which supplies blood to the spinal cord, is generally located below the Th8 level. Therefore, the distal end of the stent graft should be positioned at a more proximal level.

Key Point 1

The distal end of the stent graft should be positioned above the Th8 level!!

The Adamkiewicz artery, which supplies blood to the spinal cord, generally exists below the Th8 level; therefore, we recommend that the distal end of the stent graft should be positioned at a more proximal level (Fig. 1). For cases of aortic dissection, we recommend selecting a stent graft with a length of 6 or 9 cm after measuring the length from a benchmark near the Th7 level; this will allow stent graft implantation in the straight area of the aorta, thus reducing stress on the intima as much as possible. For this process, the aortic valve, which is located near the Th7 level, is an appropriate benchmark (Fig. 2). After this measurement, the distal end of the stent graft should be positioned using a three-step transesophageal echocardiography (TEE) method.

Fig. 2 Determination of the aortic valve level via computed tomography.



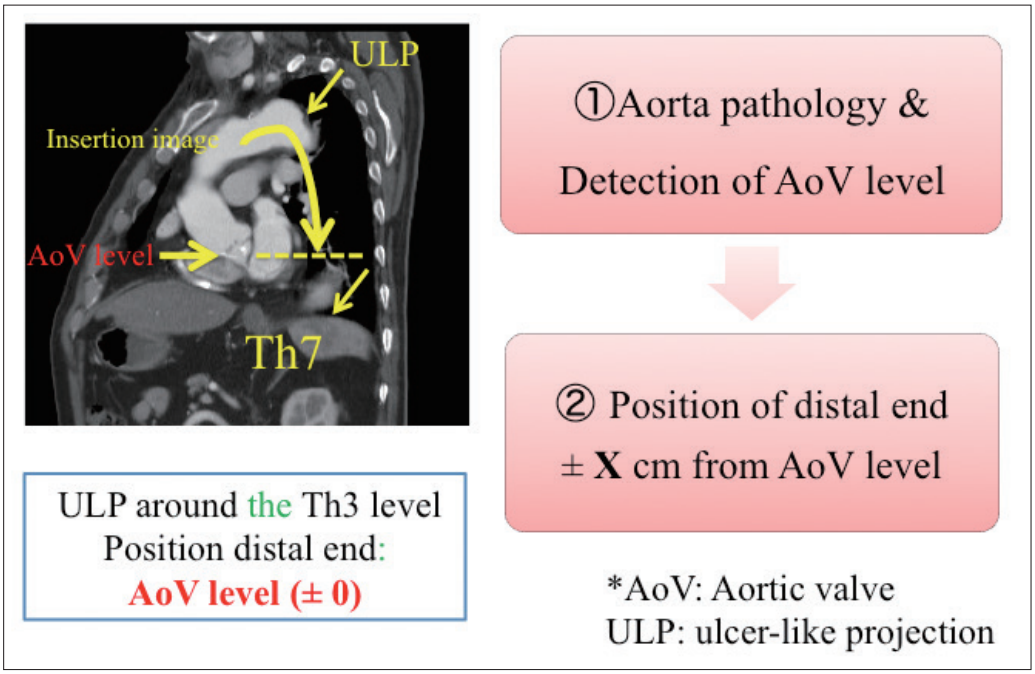
The aortic valve level, located near the Th7 level, is an appropriate benchmark.

THREE-STEP METHOD FOR POSITIONING THE DISTAL END OF A STENT GRAFT

*The distal end of the stent graft is located by measuring the distance from the aortic valve level.

Step 1: Decisions regarding stent graft position and size (Fig. 3)
The size and position of the stent graft are determined using preoperative computed tomography scan data. The distance between the aortic valve and the intended distal end position of the stent graft is also measured at this time.

Fig. 3 Step 1: Decisions regarding stent graft position and size

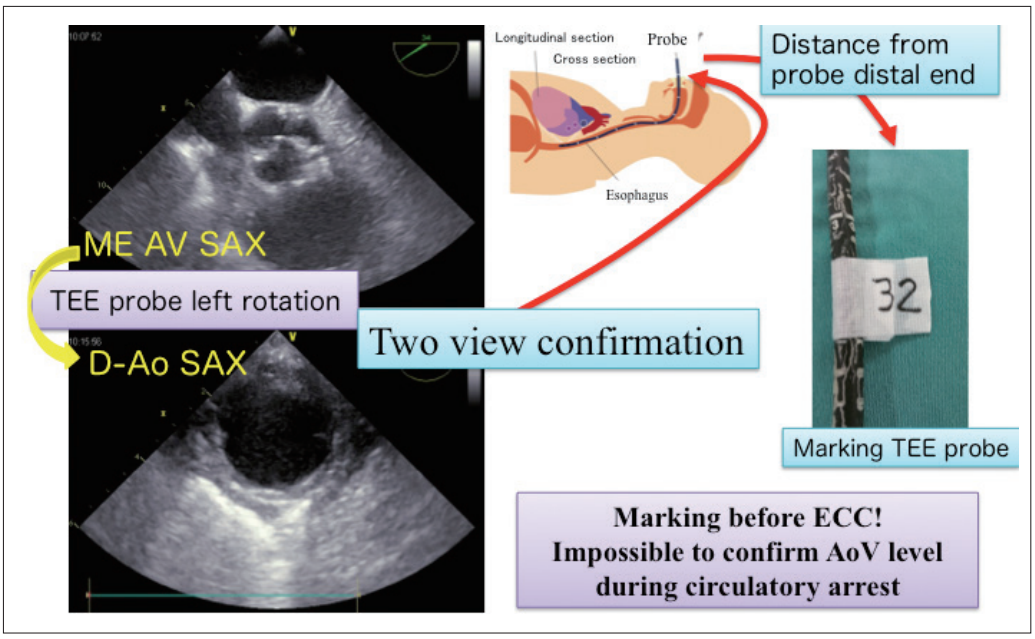


The stent graft size and position are determined via preoperative computed tomography. The distance between the aortic valve and the scheduled distal end position of the stent graft are also measured at this time.

Step 2: Marking the TEE probe at the aortic valve level (Fig. 4)
After visualizing the aortic valve at the center of the ME AV SAX view using TEE, the probe is rotated a half-turn (DAo SAX view of TEE) such that the descending aorta at the aortic valve level is visible at the center. The TEE probe is marked on the lips because we are unable to confirm the location of the descending aorta at the aortic valve level during circulatory arrest.

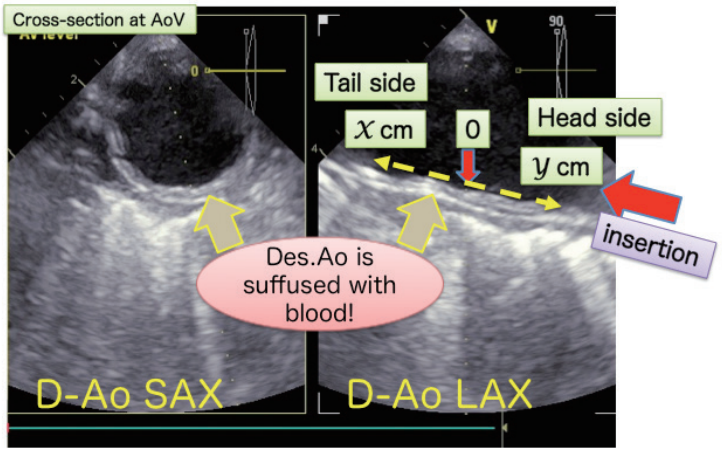
Step3: TEE guidance of stent graft placement (Fig. 5)
Upon its introduction into the aorta, FROZENIX is detected by TEE as a strongly echogenic line accompanied by an acoustic shadow in which the stent graft is packed. If FROZENIX is directed to the aortic wall or intimal flap, where it might cause damage, reshaping and reinsertion are attempted. Initially, TEE is located at the aortic valve level (marking in mouth corner), with FROZENIX visible at the

Fig. 4 **Step 2: Marking the TEE probe at the aortic valve level**



After visualizing the aortic valve at the center in the ME AV SAX view of TEE, the probe is rotated a half-turn (DAo SAX view of TEE) such that the descending aorta at the aortic valve level is visible at the center. The TEE probe in the corner of the mouth is marked at this position because we are unable to confirm the descending aorta at the aortic valve level during a circulatory arrest.

Fig. 5 **Step 3: TEE guidance of stent graft placement**

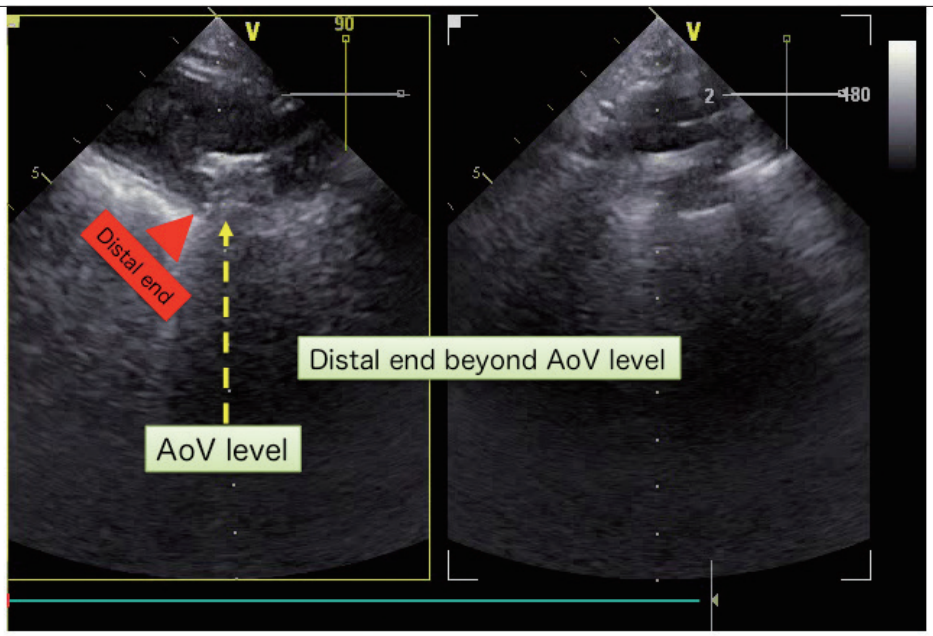


AoV: aortic valve level

TEE is initially used to locate the aortic valve level (marking in mouth corner), with FROZENIX visualized at the center. The distance from the aortic valve is defined as the difference in TEE probe depths between these two levels. FROZENIX is deployed at the planned distance from the aortic valve level under TEE guidance.

center (Fig. 6). The distance from the aortic valve is defined as the difference in TEE probe depths between these two levels. FROZENIX is subsequently deployed at the planned distance from the aortic valve level under TEE guidance (Fig. 7). Inflation via a Foley balloon catheter is generally avoided to prevent intimal injury; in addition, despite the initially small diameter of FROZENIX, dilation occurs gradually after distal perfusion.

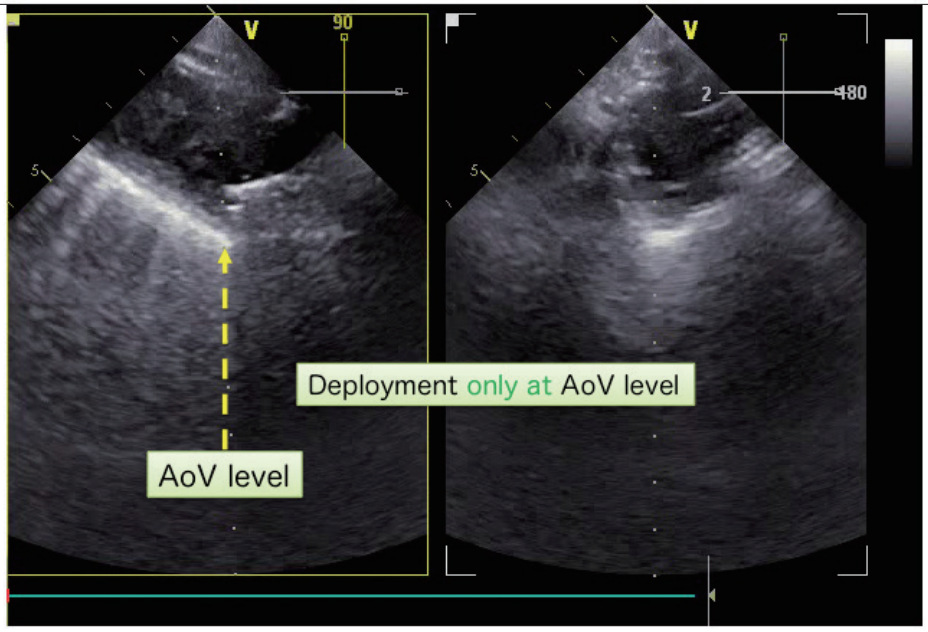
Fig. 6 TEE image obtained while positioning the distal end of FROZENIX



*AoV level: Descending aorta at aortic valve level

Upon introduction into the aorta, FROZENIX is depicted on TEE as a strongly echogenic line accompanied by an acoustic shadow, with the stent graft packed inside.

Fig. 7 TEE view during deployment



*AoV level: Descending aorta at aortic valve level

FROZENIX was deployed at the planned distance from the aortic valve level under TEE guidance.

Key Point 2

Selective left subclavian artery (LSA) perfusion and distal body circulatory arrest within 60 min

Leontyev et al. reported a body core temperature of ≥28 °C to be an independent predictor of paraplegia for patients in whom distal body arrest exceeds 40 min. In accordance with these findings, we recommend moderate hypothermia during FET procedures, especially if a prolonged lower body arrest time is expected or if additional risk factors are present. A prolonged lower body arrest time may increase the risk of spinal cord injury, especially under conditions of mild hypothermia. Accordingly, additional antegrade perfusion of the LSA is crucial for increasing the blood supply to the spinal cord. We describe two types of antegrade LSA perfusion:

Type 1: Retrograde cerebral perfusion is performed when the bladder temperature falls to 25 °C before a circulatory arrest. After the aortic arch is opened, balloon catheters are inserted into the brachiocephalic artery, left common carotid artery, and left subclavian artery. After retrograde cerebral perfusion is stopped, selective antegrade perfusion is initiated at a rate of 800 ml/min and FET is deployed (Fig. 8).

Type 2: After perfusion (200 ml/min) via an 8-mm graft anastomosed to LSA, the proximal LSA is ligated and FET is implanted to the proximal LSA. This procedure may reduce the risk of recurrent laryngeal nerve damage (Fig. 9).

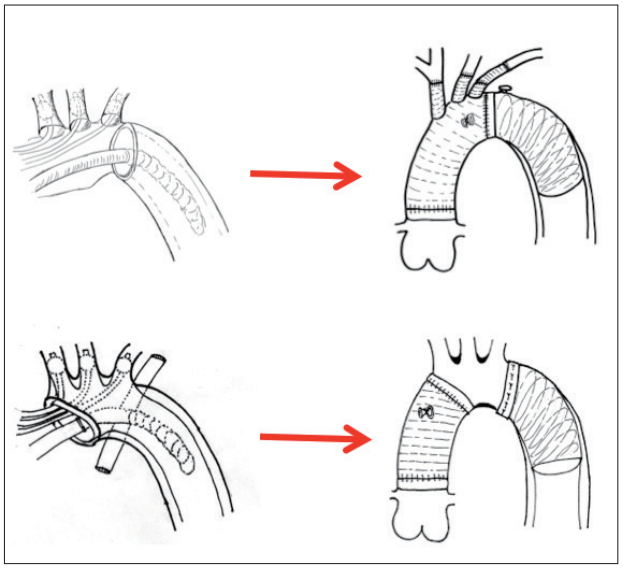
After the stent graft is inserted and deployed, the prosthesis is sutured to the proximal end of the descending thoracic aorta. Anastomosis should be performed to ensure a high level of accuracy, as the arch can be difficult to reach once it has been replaced. For this procedure, we use a 3-0 Prolene suture and a strong needle, although the suture line could also be reinforced with Teflon felt. Distal perfusion (500 ml/min) is then initiated via the femoral artery, with an occlusion balloon catheter placed into the stent graft. Our experience has led us to define a distal body circulatory arrest time with LCA perfusion of <60 min as acceptable. Therefore, we recommend additional distal perfusion if the distal body circulatory arrest exceeds 60 min.

Key Point 3

Mean blood pressure should be maintained at ≥70mmHg.

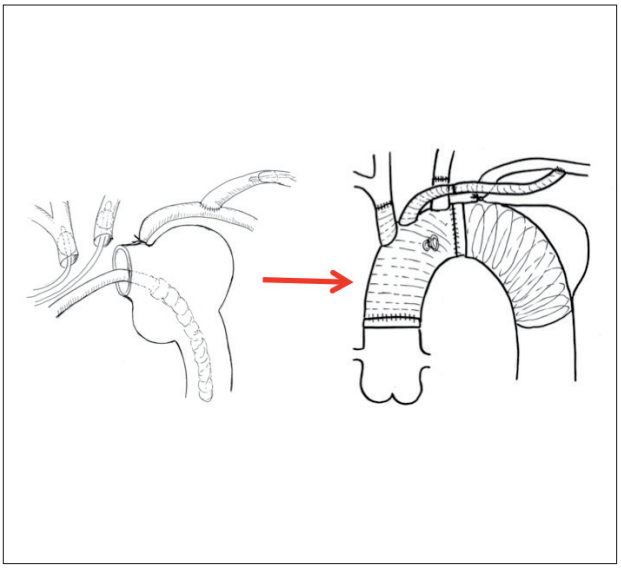
To ensure adequate spinal cord perfusion pressure, stable hemodynamics, with a mean arterial pressure of ≥70 mmHg, should be sought after stent graft deployment together with a central venous pressure (CVP) of <10 mmHg, if possible. Although an increased mean arterial pressure may render hemostasis more difficult, hemostasis should not be achieved by reducing the blood pressure. Therefore, diligent surgical techniques and adequate administration of coagulation products are important.

Fig. 8 **Type 1 left subclavian artery perfusion**



After opening the aortic arch, balloon catheters are inserted into the brachiocephalic artery, left common carotid artery, and left subclavian artery. Selective antegrade cerebral perfusion is then initiated at a rate of 800 ml/min.

Fig. 9 **Type 2 left subclavian artery (LSA) perfusion**



After perfusion via an 8-mm graft anastomosed to the LSA, the proximal LSA is ligated and the FET is implanted into the aorta proximal to the LSA in an attempt to reduce the risk of recurrent laryngeal nerve damage.

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2021-07-00-01

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