Aortic remodeling, reintervention, and survival after zone 0 arch repair with frozen elephant trunks for acute type A aortic dissection: Midterm results

Takuya Wada, MD, Hiroshi Yamamoto, MD, PhD, Daichi Takagi, MD, PhD, Takayuki Kadohama, MD, PhD, Gembu Yamaura, MD, PhD, Kentaro Kiryu, MD, PhD, and Itaru Igarashi, MD

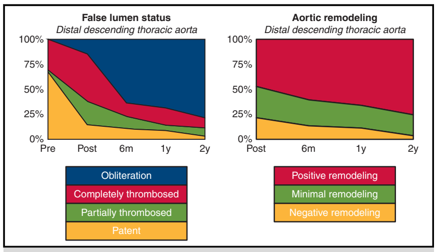
ABSTRACT

Objectives: To investigate the midterm results after zone 0 arch repair with frozen elephant trunks for acute type A aortic dissection.

Methods: Between October 2014 and April 2021, 196 patients underwent zone 0 arch repair with frozen elephant trunks for acute type A aortic dissection. The true lumen area, aortic lumen area, and false lumen status were assessed at four aortic levels, the proximal and distal descending thoracic aorta (level A and level B, respectively), celiac artery branching (level C), and terminal aorta (level D). Aortic remodeling (postoperative area as a percentage of the preoperative area) was classified into 3 groups, positive (true lumen area ≥120% with aortic lumen <120% or true lumen area ≥80% with aortic lumen <80%), minimal (80% ≤ true lumen area and aortic lumen area <120%), and negative remodeling (all other changes).

Results: In-hospital mortality was 13 (6.6%) patients. The overall survival rate was 85.1% at 5 years. The freedom from distal aortic reintervention was 89.9% at 5 years. The prevalence of completely thrombosed or obliterated false lumen at 2 years was 96.8% at level A, 88.4% at level B, 47.2% at level C, and 27.6% at level D. The prevalence of positive aortic remodeling at 2 years was 84.7% at level A, 75.0% at level B, 29.2% at level C, and 16.7% at level D.

Conclusions: Zone 0 arch repair with frozen elephant trunks for acute type A aortic dissection can avoid invasive aortic arch resection and facilitate aortic remodeling of the descending thoracic aorta. The FET effect on aortic remodeling is limited at the aortic level below the FET stent end. (JTCVS Techniques 2022;14:29-38)



Zone 0 arch repair with FET for ATAAD promotes aortic remodeling of the descending aorta.

CENTRAL MESSAGE

Zone 0 arch repair with FET for acute type A aortic dissection is less invasive and has satisfactory early and midterm results. FETs promote aortic remodeling of dissection in the descending aorta.

PERSPECTIVE

Zone 0 arch repair with FET for acute type A aortic dissection is less invasive and has satisfactory early and midterm results, reducing the risk of reintervention in the downstream aorta. Aortic remodeling is limited at the aortic level below the FET stent end. Therefore, careful inspections using periodic CT examinations are required to detect distal aortic events during the follow-up period.

From the Department of Cardiovascular Surgery, Akita University Graduate School of Medicine, Akita, Japan.

Poster exhibited at the 2022 AATS Aortic Symposium Workshop Boston, May 13-14, 2022.

Received for publication May 24, 2022; accepted for publication May 24, 2022; available ahead of print May 31, 2022.

Address for reprints: Hiroshi Yamamoto, MD, PhD, Department of Cardiovascular Surgery, Akita University Graduate School of Medicine, Hondo 1-1-1, Akita, Akita 010-8543, Japan (E-mail: h-yama@cvs.med.akita-u.ac.jp).

2666-2507

https://doi.org/10.1016/j.xjtc.2022.05.013

Abbreviations and Acronyms

AL	= aortic lumen
ATAAD	= acute type A aortic dissection
CPB	= cardiopulmonary bypass
CT	= computed tomography
dSINE	= distal stent graft-induced new entry
FET	= frozen elephant trunk
FL	= false lumen
TAR	= total arch replacement
TEVAR	= thoracic endovascular aortic repair
TL	= true lumen
Z-0-FET	= zone 0 arch repair with frozen elephant trunk

▶ Video clip is available online.

The frozen elephant trunk (FET) technique has been increasingly used for acute type A aortic dissection (ATAAD). This technique may facilitate true lumen (TL) expansion combined with false lumen (FL) thrombosis and shrinkage, which has been termed aortic remodeling.[1-3] Aortic remodeling of the downstream dissecting aorta with the thrombosed is crucial for better long-term results because the patent residual FL has been shown to be a significant predictor of late aortic reinterventions.[4] In addition, FET can not only reduce the incidence of distal aortic malperfusion and late aneurysm formation of the downstream aorta but also offer an ideal landing zone for distal aortic endovascular reintervention.[5]

Since 2014, we have employed the zone 0 arch repair strategy using FETs (Z-0-FET) in surgery for ATAAD.[6] This technique is less invasive than conventional total arch replacements (TARs) in that it eliminates the need for aortic arch incision or resection and reduces technical difficulties by the proximalization of distal anastomosis to the aortic zone 0. However, in terms of surgery using commercially available FETs for ATAADs, there is a small number of the published data on the long-term effects on aortic remodeling, FET-specific complications such as distal stent graft-induced new entry (dSINE), late aneurysm formation in the downstream aorta, and late aortic reinterventions. The aim of this study was to investigate the midterm results of aortic remodeling, surgical outcomes, complications, and reinterventions after Z-0-FET for ATAADs.

METHODS

Study Population and Definitions

This study was approved by the institutional review board and ethics committee of the Akita University (No. 2757 on October 20, 2021). The need for individual patient consent was waived.

Between October 2014 and April 2021, 196 patients with ATAAD (excluding DeBakey type II) underwent total arch repair based on Z-0-FET[6] at Akita University Hospital. The patients with an ascending aorta <50 mm in diameter and completely thrombosed FL were medically treated. Perioperative information for each patient, including age, sex, comorbidities, preoperative status associated with ATAAD, shock, pericardial effusion, cardiopulmonary arrest, consciousness disturbance, malperfusion, aortic insufficiency, the European System for Cardiac Operative Risk Evaluation II score,[7] the Japanese System for Cardiac Operative Risk Evaluation,[8] intraoperative data (cardiopulmonary bypass [CPB] time, aortic crossclamp time, circulatory arrest time, and selective cerebral perfusion time), in-hospital mortality and morbidities were retrospectively analyzed. Additionally, postoperative midterm follow-up information for each patient, including cumulative mortality, aortic remodeling (presence or absence of complete FL thrombosis, TL area, and aortic lumen [AL] area), distal aortic events, and reintervention, were retrospectively analyzed.

AAD was defined as dissection treated surgically no later than 14 days after onset. Hemodynamic shock was defined as having a preoperative blood pressure <70 mm Hg. Malperfusion was defined as ischemic signs or symptoms caused by cessation of blood flow to end-organ systems, such as the central nervous system, myocardium, visceral organs, or extremities. Permanent neurologic dysfunction was defined as new-onset brain damage persisting in the postoperative period.

Surgical Procedures

The surgical technique of Z-0-FET has been previously described in detail,[6] which is characterized by FET deployment, ascending aortic replacement, and arch vessel reconstruction. In all patients, a FET was deployed from the zone 0 aorta into the descending aorta regardless of the entry tear location. Under general anesthesia, CPB was initiated for systemic perfusion via a straight prosthetic graft anastomosed to the left axillary artery and bicaval venous drainage cannulae. After repair of the proximal aortic stump under cardioplegic arrest, circulatory arrest with selective cerebral perfusion was instituted at a rectal temperature <25 °C. A commercially available FET graft (J Graft FROZENIX; Japan Lifeline Co, Ltd), a straight vascular prosthesis with a distal stented part, was deployed from the trimmed distal aortic end (aortic zone 0) toward the descending aorta and anastomosed to a 4-branched arch graft (J Graft SHIELD; Japan Lifeline Co, Ltd) together with the distal aortic wall, which was followed by resumption of distal perfusion and systemic warming. The arch graft was anastomosed to the repaired proximal aortic stump, the myocardium was reperfused, then the left carotid and innominate arteries were reconstructed. After the cessation of CPB, the perfusion side branch of the arch graft was anastomosed to the straight graft for left axillary artery perfusion drawn to the anterior mediastinum via the left thoracic cavity.

The FET used in our hospital, J Graft FROZENIX, is a straight vascular prosthesis with 2 parts (nonstented part and stented part); the stented part has 10 kinds of diameters (2-mm increments from 21 to 39 mm) and 4 kinds of lengths (60, 90, 120, and 150 mm). The length of the nonstented part varies depending on the aortic distal anastomosis site. The FET stent diameter was determined by preoperative enhanced computed tomography (CT) (90%-100% of descending aortic diameter at the level of the main pulmonary arteries). The FET stent length has been fixed to 150 mm since November 2019. Before then, there was no criteria for determining the stent length to be used, the shortest (60 mm) stent was used in the beginning because of an anxiety about the spinal cord injury caused by longer stents, and later the longer ones were used on a step-by-step basis. A FET graft was deployed so that the proximal stent end (indicated by a blue marker on the FROZENIX graft) of the FET graft with a stent of 150 mm was positioned at the origin of the innominate artery since November 2019, and it was deployed so that the distal stent end of the FET graft with a stent <150 mm was positioned just proximal to the level of the aortic valve using transesophageal echocardiography between October 2014 and November 2019.[9]

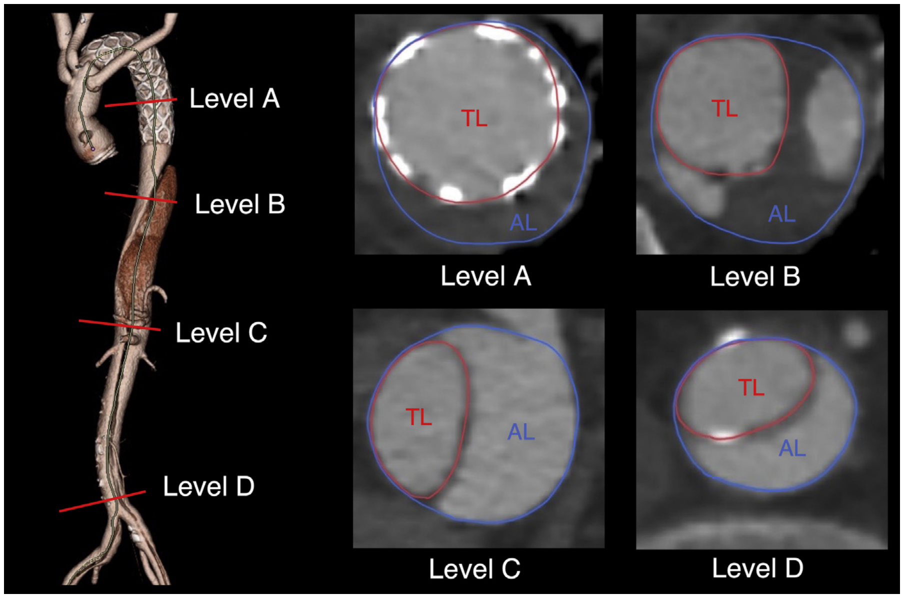


FIGURE 1. Aortic remodeling assessments of the downstream aorta on contrast-enhanced computed tomography findings. The false lumen status was assessed at 4 levels of the downstream aorta (proximal descending thoracic aorta at the level of pulmonary artery bifurcation [level A], distal descending thoracic aorta at the 9th thoracic vertebral level [level B], abdominal aorta at the level of celiac artery branching [level C], and terminal aorta [level D]). *TL*, True lumen; *AL*, aortic lumen.

Aortic Remodeling Assessments of the Downstream Aorta

FL status, AL area, TL area, and TL area to AL area ratio (TLR) were evaluated to assess aortic remodeling of the downstream aorta on the preoperative, postoperative, and follow-up (6 months, 1 year, and 2 years) contrast-enhanced CT findings. The FL status was classified into 4 types (patent, partially thrombosed, completely thrombosed, or obliteration [disappeared FL]) and assessed at 4 levels of the downstream aorta (proximal descending thoracic aorta at the level of pulmonary artery bifurcation [level A], distal descending thoracic aorta at the ninth thoracic vertebral level [level B], abdominal aorta at the level of celiac artery branching [level C], and terminal aorta [level D]). At each level, the AL and TL areas were measured by using ImageJ Fiji (an open-source software focused on biological image analysis)[10] on the image of the cross-section perpendicular to a centerline of the aorta by a 3-dimensional centerline analysis (Figure 1) using the image analysis system (SYNAPSE VINCENT; Fuji Film Co, Ltd). The TLR was calculated by dividing the TL area by the AL area and expressed as a percentage. Aortic remodeling was classified into 3 types according to the postoperative area expressed as a percentage of the preoperative area in terms of AL area or TL area, as shown in Figure 2 (positive remodeling [red segments], minimal remodeling [green segment], and negative remodeling [yellow segments]).

Follow-up and Reinterventions of the Downstream Aorta

The postoperative patients were followed up by physical and chest radiographic examinations every 6 months at our patient clinic or with local cardiologists after discharge. Follow-up CT was performed at 3 weeks (before discharge) and 6 months, 1 year postoperatively, and yearly thereafter. Indications for distal aortic reinterventions during the follow-up period include postoperative distal malperfusion, persistent pain, dSINE, AL or FL enlargement of the downstream aorta (AL ≥60 mm), and TL severe stenosis without ischemic symptoms.

Statistical Analyses

Categoric variables are summarized as numbers and percent frequencies. Continuous variables are summarized as means ± SD of the means and were compared with the Student *t* test (unpaired). Postoperative survival, distal aortic reintervention-free curves, and dSINE-free curves were constructed by analyzing data using the Kaplan-Meier method. All statistical analyses were performed using R version 4.0.3 (R Foundation for Statistical Computing).

RESULTS

Patient Demographic Characteristics and Preoperative Data

Preoperative clinical presentation and aortic characteristics related to aortic dissection details are shown in Table 1.

Postoperative lumen area		AL area (% of the preoperative value)		
		< 80%	80% - 120%	120% ≤
TL area (% of the preoperative value)	120% ≤	Positive	Positive	Negative
	80% - 120%	Positive	Minimal	Negative
	< 80%	NA	Negative	Negative

FIGURE 2. Aortic remodeling classification, including 3 types (positive remodeling [*red segments*], minimal remodeling [*green segment*], and negative remodeling [*yellow segments*]) according to the postoperative area expressed as a percentage of the preoperative area in terms of aortic lumen (*AL*) area or true lumen (*TL*) area. *NA*, Not applicable (no patient).

TABLE 1. Patient demographic characteristics, preoperative comorbidities, and aortic characteristics (N = 196)

Variable	Result
Male gender	100 (51.0)
Mean age (y)	66.0 (12.6)
Preoperative comorbidities	
Hypertension	80 (40.8)
PCI	5 (2.6)
Cerebrovascular accident	21 (10.7)
Malignant tumor	16 (8.2)
Diabetes mellitus	10 (5.1)
COPD	8 (4.1)
Chronic atrial fibrillation	10 (5.1)
Chronic kidney disease	8 (4.1)
Salvage from CPA	2 (1.0)
Consciousness disorder	30 (15.3)
Hemodynamic shock	36 (18.5)
Cardiac tamponade	24 (12.3)
Spinal cord ischemia	4 (2.1)
Malperfusion	
Cardiac	9 (4.6)
Cerebral	16 (8.2)
Mesenteric	7 (3.6)
Lower limb	18 (9.2)
Moderate to severe AI	42 (21.4)
Mean EuroSCORE 2	6.26 (6.85)
Mean Japan Score, mortality	12.45 (9.53)
Sites of primary tear	
Ascending aorta	106 (54.1)
Aortic arch	40 (20.4)
Proximal descending aorta	19 (9.7)
Unknown	31 (15.8)
Distal end of dissection	
Aortic arch, proximal descending aorta	28 (14.4)
Proximal descending, distal descending aorta	5 (2.6)
Distal descending aorta, celiac artery branch	26 (13.3)
Celiac artery branch, terminal aorta	33 (16.9)
Distal to terminal aorta	103 (52.8)
False lumen status	
Patent	151 (77.0)
Thrombosed	18 (9.2)
Presence of ULP	27 (13.8)

Values are presented as n (%) or mean (SD). *PCI*, Percutaneous coronary intervention; *COPD*, chronic obstructive pulmonary disease; *CPA*, cardiopulmonary arrest; *AI*, aortic insufficiency; *EuroSCORE 2*, European System for Cardiac Operative Risk Evaluation; *ULP*, ulcer-like projection.

The study cohort comprised 196 patients (100 men and 96 women) aged 66.0 ± 12.6 years. The primary tear was in the ascending aorta in more than half of the enrolled patients. The aortic dissection ranged from the ascending aorta to the descending aorta or iliac arteries, the distal end of which varies from patient to patient. The distal end of dissection extended to the iliac arteries in more than half of patients. The FL was patent in more than 70% of patients.

Intraoperative Data

The operative data and size distribution of the FET graft used (ie, stent diameter and length) are shown in Table 2. The most concomitant procedure was aortic valve replacement, followed by aortic root replacement and coronary artery bypass grafting. The most-used stent length and diameter of FET were 120 mm and 27 mm, respectively.

Early Postoperative Data

The 30-day mortality was 7 (3.6%) patients, and the in-hospital mortality was 13 (6.6%) patients (Table 2). The causes of deaths were myocardial infarction in 4 patients, mesenteric ischemia in 2 patients, multiple organ failure in 2 patients, stroke in 1 patient, pneumonia in 1 patient, sepsis in 1 patient, left ventricular rupture in 1 patient, and bleeding in 1 patient. The most postoperative complication was new-onset permanent neurologic dysfunction. The new-onset paraplegia developed in 1 patient (0.5%).

Midterm Postoperative Results

During the follow-up period (median, 32 months; range, 1-80 months), the overall survival rate was 90.8%, 87.6%, and 85.1% at 1, 3, and 5 years, respectively (Figure 3, *A*), the freedom from distal aortic reintervention was 94.6%, 91.1%, and 89.9% at 1, 3, and 5 years, respectively (Figure 3, *B*), and the freedom from dSINE was 99.0%, 96.5%, and 96.5% at 1, 3, and 5 years, respectively (Figure 3, *C*). Six patients (3.1%) experienced dSINEs, and the time from Z-0-FET to onset of dSINE was 19.6 ± 13.6 months (range, 2-45 months). The thoracic endovascular aortic repair (TEVAR) was performed for dSINE in 5 patients (2.6%), TL severe stenosis without ischemic symptoms in 5 patients (2.6%), aortic dilatation in 2 patients (1.0%), residual major tears in the descending aorta in 2 patients (1.0%), persistent pain in 1 patient (0.5%), and visceral malperfusion in 1 patient (0.5%). All the distal aortic reinterventions were successfully treated with TEVARs without any major complications. No patients required reinterventions through a left thoracotomy during the follow-up period.

Aortic Remodeling Assessments

Figure 4, *A*, shows the time-dependent prevalence changes in the 4 FL statuses (patent, partially thrombosed, completely thrombosed, and obliteration [disappeared FL]) each aortic level at the preoperative period and during the follow-up period. The patients with no dissection were

TABLE 2. Intraoperative and early postoperative data (N = 196)

Variable	Result
Intraoperative data	
CPB time (min)	214.2 (74.4)
CA time (min)	49.0 (14.3)
Aortic crossclamp time (min)	130.6 (51.4)
SCP time (min)	99.7 (34.3)
Concomitant procedures	
AVR	18 (9.2)
David procedure	1 (0.5)
Bentall procedure	10 (5.1)
CABG	10 (5.1)
Peripheral arterial bypass	5 (2.6)
EIA-SMA bypass	1 (0.5)
FET stent length (mm)	
60	47 (24.0)
90	19 (9.7)
120	90 (45.9)
150	40 (20.4)
FET stent diameter (mm)	
23	9 (4.6)
25	33 (16.8)
27	66 (33.7)
29	42 (21.4)
31	26 (13.3)
33	11 (5.6)
35	7 (3.6)
37	2 (1.0)
Early postoperative data	
30-d mortality	7 (3.6)
In-hospital deaths	13 (6.6)
Complications	
Tracheostomy	5 (2.6)
Dialysis	6 (3.1)
New-onset PND	11 (5.6)
New-onset paraplegia	1 (0.5)
Vocal cord paralysis	3 (1.5)

Values are presented as mean (SD) or n (%). *CPB*, Cardiopulmonary bypass; *CA*, circulatory arrest; *SCP*, selective cerebral perfusion; *AVR*, aortic valve replacement; *CABG*, coronary artery bypass grafting; *EIA-SMA*, external iliac artery-superior mesenteric artery; *FET*, frozen elephant trunk; *PND*, permanent neurological dysfunction.

excluded at each aortic level. The prevalence of patent or partial thrombosed FL (before surgery and at 2 years) was 67.6% and 3.2%, respectively, at level A; 69.3% and 11.6%, respectively, at level B; 80.4% and 52.8%, respectively, at level C; 88.8% and 72.4%, respectively, at level D. The prevalence of completely thrombosed or obliterated FL (before surgery and at 2 years) was 32.4% and 96.8%, respectively, at level A; 30.7% and 88.4%, respectively, at level B; 19.6% and 47.2%, respectively, at level C; 11.2% and 27.6%, respectively, at level D. The completely thrombosed FL was observed at the aortic arch level in all patients (data not shown).

Figure 4, *B*, shows the time-dependent prevalence changes of positive, minimal, and negative aortic remodeling at each aortic level during the postoperative follow-up period. The prevalence of positive aortic remodeling (before discharge and at 2 years) was 72.1% and 84.7%, respectively, at level A; 47.0% and 75.0%, respectively, at level B; 29.0% and 29.2%, respectively, at level C; 21.3% and 16.7%, respectively, at level D. The prevalence of negative aortic remodeling (before discharge and at 2 years) was 7.7% and 1.4%, respectively, at level A; 21.9% and 4.2%, respectively, at level B; 17.5% and 37.5%, respectively, at level C; 13.1% and 34.7%, respectively, at level D.

The postoperative time-dependent changes of the TL area, AL areas, and TLR are shown in Table 3. The measurement of TL and AL arears was available in all 196 patients preoperatively, but 182 patients (92.8%) before discharge, 149 patients (76.0%) at 6 months, 109 patients (55.6%) at 1 year, and 71 patients (36.2%) at 2 years. The TL areas and TLRs were significantly increased throughout the follow-up period at level A, level B, and level C, whereas they tended to be increased, but not significantly, at level D. The AL area was significantly decreased at level A throughout the follow-up period.

DISCUSSION

Aortic repairs using FETs have recently grown in number in patients with ATAAD because their efficacy has been reported worldwide.[11,12] This trend is rationalized on the ground that less surgical invasiveness and better distal aortic remodeling may be expected in aortic repairs using FETs. It is safe to say that total arch replacements, requiring aortic arch resection, are more invasive compared with ascending aortic or hemiarch replacements[13-15] although there are controversies regarding the early postoperative results.[16] Our technique, Z-0-FET,[6] is a straight-forward strategy regardless of the entry tear locations unlike the tear-oriented surgery, which is characterized by FET deployment from the aortic zone 0, eliminating the need for dissecting the periaortic tissues and resecting the wall of the aortic arch and being less invasive than conventional total arch replacement or FET deployment from the aortic zone 3. Plus, distal anastomosis proximalization enables surgeons to view closely and maneuver in the shallow operative field, providing a significant advantage of safety and simplicity of the anastomotic procedures or additional stitches for hemostate.

The effect of FET in the initial surgery for ATAAD has been known to facilitate aortic remodeling by obstructing as many tears as possible to decrease the FL pressure, increasing the TL pressure of the downstream aorta, and preventing blood leakage into the FL from the suture line of the distal anastomosis.[4,6,17] These aortic remodeling mechanisms of FET may influence the fate of aortic

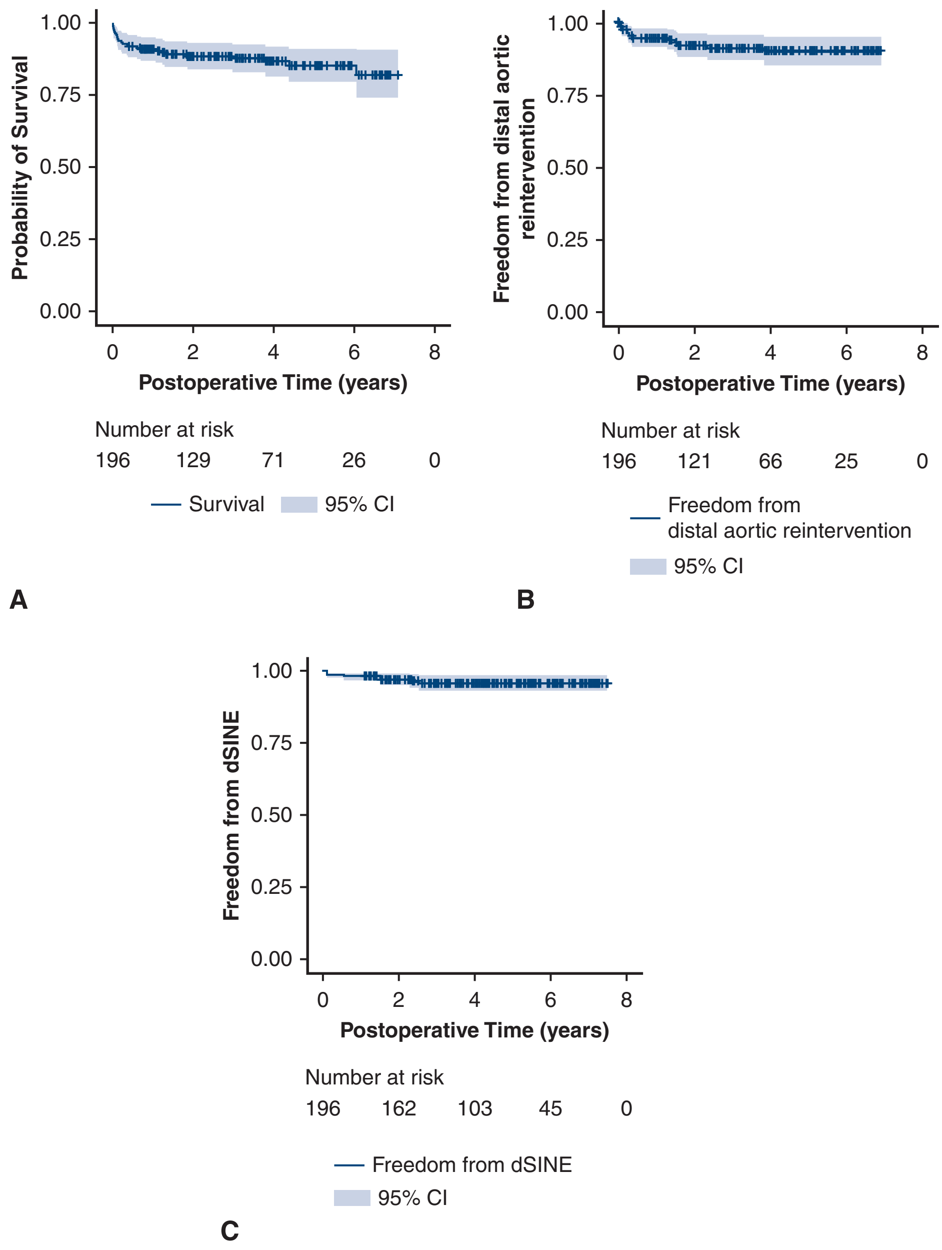


FIGURE 3. Kaplan-Meier curves for total arch repair using the "zone 0 arch repair" strategy for acute type A aortic dissection. A, Survival. B, Freedom from distal aortic reintervention. C, Freedom from distal stent-induced new entry. *CI*, Confidence interval; *dSINE*, distal stent-induced new entry.

dissection (ie, shrinkage, minimal change, or dilatation of the FL) for a long time and the influence may vary depending on the aortic level. Compared with ascending aortic replacement, TAR without FET has reported to have a less incidence of aortic arch reinterventions[18] and TAR with FET has reported to have a less incidence of descending aortic reinterventions,[19] suggesting that FET deployment may contribute to a shift of the level of aortic events in a more distal direction. In the present study, we evaluated the aortic remodeling effect of FET by analyzing the TL and AL areas, TLR, and FL status (presence or absence of thrombosis or obliteration) at 4 different levels of the aorta on the CT images during the 8-year follow-up period. Throughout the follow-up period, no residual FL blood flow was observed in the entire aortic arch. The prevalence of the thrombosed FL at 2 years (Figure 4, *A*) was more than 80% at the levels of the proximal descending aorta in which the FET stent is positioned (level A) and distal descending aorta slightly peripheral to the FET distal stent end (level B), whereas it was <40% at the celiac artery level (level C) and terminal aortic level (level D). Similarly, the prevalence of positive aortic remodeling at 2 years (Figure 4, *B*)

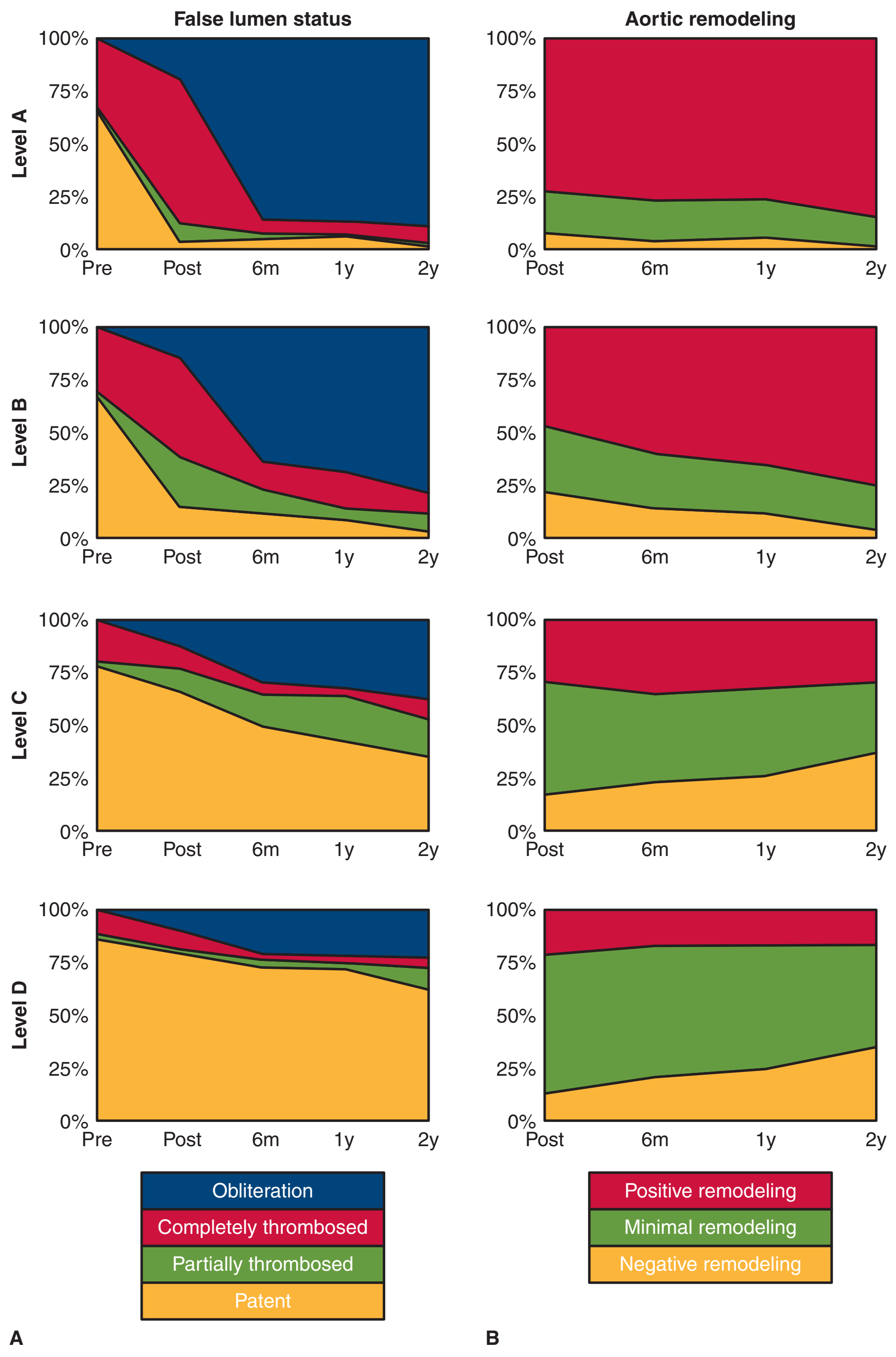


FIGURE 4. The time-dependent prevalence changes of false lumen status (A) and aortic remodeling (B) at 4 aortic levels during the follow-up period. Level A shows the proximal descending thoracic aorta. Level B shows the distal descending thoracic aorta. Level C shows level of celiac artery branching. Level D shows the terminal aorta.

was more than 70% at level A and level B, whereas it was <40% at level C and level D. Therefore, regular postoperative follow-up CT examinations would be required for a lifetime to detect late sequelae of FL enlargement at distal levels of the downstream aorta.

The mechanism of late insufficient aortic remodeling at the distal levels may be associated with the fact that in patients with the dissection extending into the abdominal aortic or iliac artery region, the number of reentry tears was substantially greater in the abdominal aorta or iliac

TABLE 3. Time-dependent changes of true lumen (TL) area, aortic lumen (AL) area, and TL area/AL area ratio (TLR)

Variable	Preoperative (n = 196)	Postoperative (n = 182)	6 mo (n = 149)	1 y (n = 109)	2 y (n = 71)	*P* value*
Level A						
TL area (mm^2)	364.2 (208.5)	508.9 (155.0)	586.9 (146.4)	601.9 (159.9)	645.5 (150.4)	<.001
AL area (mm^2)	776.9 (186.3)	743.9 (237.2)	646.7 (181.0)	670.6 (201.8)	688.6 (214.8)	<.001
TLR (%)	50.1 (34.4)	73.1 (23.1)	93.9 (18.4)	93.5 (19.5)	96.3 (12.8)	<.001
Level B						
TL area (mm^2)	350.2 (228.8)	449.2 (203.7)	526.9 (193.8)	536.6 (190.7)	573.9 (198.0)	<.001
AL area (mm^2)	739.5 (201.9)	772.2 (260.6)	699.3 (258.1)	685.6 (266.2)	665.4 (260.5)	.06
TLR (%)	48.7 (28.8)	63.5 (29.3)	82.7 (29.1)	85.8 (27.0)	90.9 (21.8)	<.001
Level C						
TL area (mm^2)	309.2 (189.0)	342.6 (174.0)	365.6 (147.5)	376.2 (142.3)	400.7 (130.3)	<.001
AL area (mm^2)	586.0 (208.5)	603.8 (259.0)	600.1 (189.0)	610.3 (200.5)	628.0 (221.0)	.31
TLR (%)	56.1 (31.5)	62.5 (32.1)	68.5 (33.0)	70.2 (33.0)	73.3 (31.6)	<.001
Level D						
TL area (mm^2)	206.4 (138.4)	218.0 (130.1)	220.7 (114.9)	215.8 (104.2)	229.97 (117.09)	.50
AL area (mm^2)	321.7 (126.1)	324.3 (131.5)	323.5 (127.8)	332.2 (146.0)	360.41 (166.20)	.52
TLR (%)	67.2 (33.7)	71.0 (30.4)	74.1 (31.4)	73.5 (32.1)	72.50 (32.23)	.09

Values are presented as mean (SD). *Preoperative versus 1 year.

arteries than in the lower thoracic aorta.[20] Insufficient remodeling in the downstream aorta may be due to the remaining residual FL blood flow below the distal-end level of the FET because a tear-obstructing effect of FET cannot extend down to the reentry tears formed; for example, at the origins of the visceral arteries or the iliac arteries. Similarly, negative remodeling at the level of the abdominal aorta compared to the descending thoracic aorta has been reported in patients after TEVAR for type B aortic dissection.[21]

Postoperative dSINE is among the late complications specific to FETs.[22] The mechanism of dSINEs has been reported to be caused by stent-diameter oversizing[23-25]

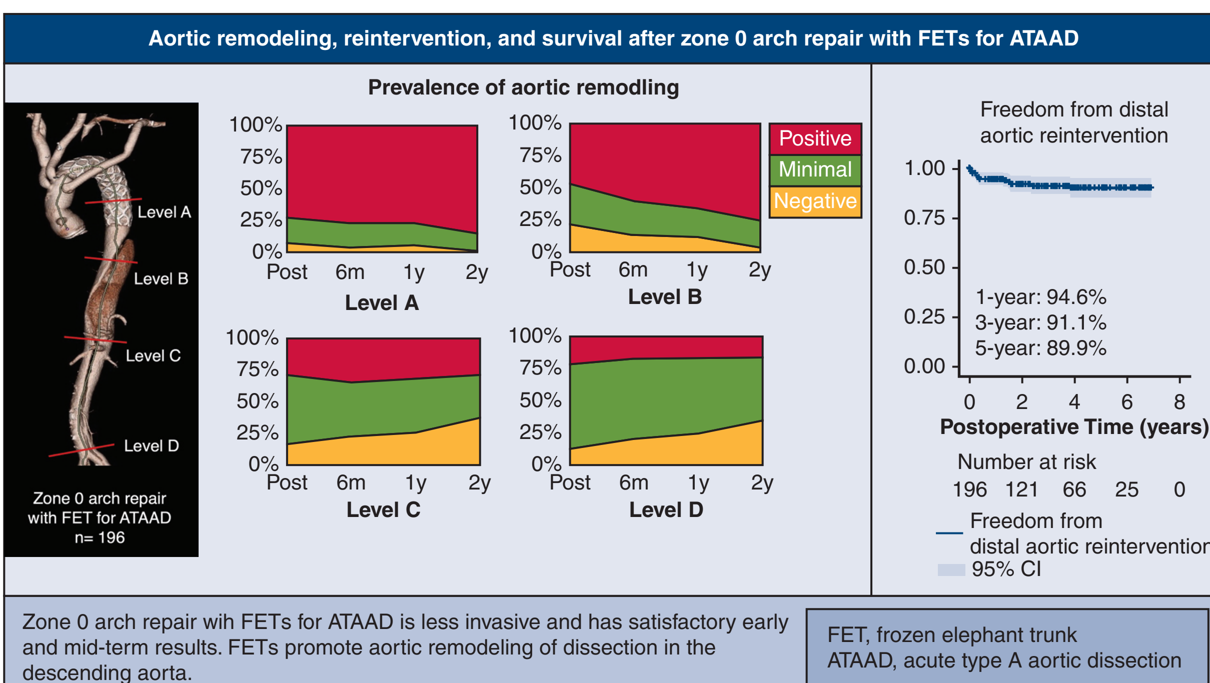
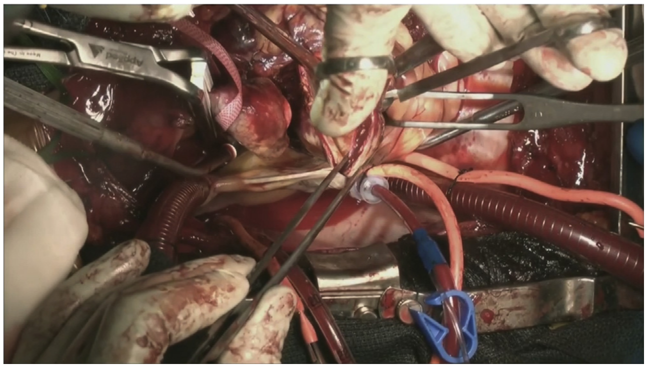


FIGURE 5. Summary of the study. The zone 0 arch repair strategy for acute type A aortic dissection (*ATAAD*), less invasive aortic arch repair with a frozen elephant trunk (*FET*) deployed from the aortic zone 0, can make distal aortic anastomosis easier. This technique postoperatively facilitates aortic remodeling of the downstream aorta and may reduce the risk of distal aortic reinterventions. However, false lumen thrombosis and subsequent aortic remodeling are limited at more distal aortic levels (level C and level D). Freedom from distal aortic reintervention was 90.8% and 85.1% at 1 year and 5 years, respectively. *CI*, Confidence interval.



VIDEO 1. A short video describing the early and midterm results after total arch repair with a frozen elephant trunk deployed from the aortic zone 0 (ie, the zone 0 arch repair strategy). Video available at: https://www.jtcvs.org/article/S2666-2507(22)00343-1/fulltext.

or spring back force.[26] In addition, we previously proposed another mechanism called "aortic remodeling mismatch" by reporting 1 case of a dSINE (ie, flap perforation) at the FET stent end caused by the flap-aortic long axis angulation, a flap shift toward the inside of the TL below the stent end along with FL enlargement, which was due to a substantial difference in the extent of aortic remodeling between the stented part and nonstented part of the FET.[27] In the present study, we observed that the extent of aortic remodeling between the proximal (stented) part and distal (nonstented) part of the descending aorta varied from patient to patient. Six patients with dSINEs (3.1%) were observed (aortic remodeling mismatch in 3 and spring-back force in 3), and 5 TEVARs (2.6%) were performed for the dSINEs. From those observations, we are speculating that after surgery for ATAADs, aortic remodeling mismatch, or spring-back force rather than stent-diameter oversizing might be an important cause of dSINEs. Oversize-induced dSINEs are considered relatively rare after FET deployment for ATAADs, because the FET diameters used are prone to be smaller than the aortic diameters in the FET landing zone.

The onset of dSINEs is difficult to be predicted because most of the patients experiencing dSINEs are asymptomatic and coincidentally diagnosed at CT examinations. Periodic CT follow-up is important postoperatively to prevent or detect dSINEs. Reinterventions using TEVAR may be safe to perform because the stented part of the FET provides an adequate landing zone for TEVAR, thereby significantly reducing risks of performing invasive open surgery.[5,28] In the present study, all patients who underwent TEVAR had uneventful postoperative courses without any major complications.

Limitations

The limitation of this study is the single-center, retrospective design. The follow-up period was not long enough to evaluate the long-term results (median, 32 months; range, 1-80 months). The number of patients whose postoperative aortic remodeling was assessed is less than that of the patients who survived at the time of the assessment during the follow-up period because the patients who could not have contrast-enhanced CT examination due to renal dysfunction, patient's wishes, or relocation were excluded.

CONCLUSIONS

Z-0-FET for ATAADs can eliminate the need for invasive aortic arch resection and make distal anastomosis easier, resulting in satisfactory early and midterm results that may facilitate aortic remodeling of the downstream aorta and reduce the risk of distal aortic reinterventions. However, FL thrombosis and subsequent aortic remodeling are limited at distal aortic levels (ie, lower thoracic and abdominal aorta). Therefore, careful inspections using periodic CT examinations are required to detect distal aortic events during the follow-up period (Figure 5, Video 1).

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires authors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

References

1. Kato M, Kuratani T, Kaneko M, Kyo S, Ohnishi K. The results of total arch graft implantation with open stent-graft placement for type A aortic dissection. *J Thorac Cardiovasc Surg*. 2002;124:531-40.
2. Katayama A, Uchida N, Katayama K, Arakawa M, Sueda T. The frozen elephant trunk technique for acute type A aortic dissection: results from 15 years of experience. *Eur J Cardiothorac Surg*. 2015;47:355-60.
3. Dohle DS, Tsagakis K, Janosi RA, Benedik J, Kühl H, Penkova L, et al. Aortic remodelling in aortic dissection after frozen elephant trunk. *Eur J Cardiothorac Surg*. 2016;49:111-7.
4. Kimura N, Itoh S, Yuri K, Adachi K, Matsumoto H, Yamaguchi A, et al. Reoperation for enlargement of the distal aorta after initial surgery for acute type A aortic dissection. *J Thorac Cardiovasc Surg*. 2015;149:91-8.
5. Haensig M, Schmidt A, Staab H, Steiner S, Scheinert D, Branzan D. Endovascular repair of the thoracic or thoracoabdominal aorta following the frozen elephant trunk procedure. *Ann Thorac Surg*. 2020;109:695-701.
6. Yamamoto H, Kadohama T, Yamaura G, Tanaka F, Takagi D, Kiryu K, et al. Total arch repair with frozen elephant trunk using the "zone 0 arch repair" strategy for type A acute aortic dissection. *J Thorac Cardiovasc Surg*. 2020;159:36-45.
7. Nashef SA, Roques F, Sharples LD, Nilsson J, Smith C, Goldstone AR, et al. EuroSCORE II. *Eur J Cardiothorac Surg*. 2012;41:734-44.
8. Motomura N, Miyata H, Tsukihara H, Takamoto S. Risk model of thoracic aortic surgery in 4707 cases from a nationwide single-race population through a web-based data entry system: the first report of 30-day and 30-day operative outcome risk models for thoracic aortic surgery. *Circulation*. 2008;118:153-9.
9. Takagi D, Yamamoto H, Kadohama T, Kiryu K, Wada T, Igarashi I. Optimal stent length and distal positioning of frozen elephant trunks deployed from the aortic zone 0 for type A acute aortic dissection. *J Thorac Cardiovasc Surg*. March 12, 2022 [Epub ahead of Print]. https://doi.org/10.1016/j.jtcvs.2022.03.007
10. Schindelin J, Arganda-Carreras I, Frise E, Kaynig V, Longair M, Pietzsch T, et al. Fiji: an open-source platform for biological-image analysis. *Nat Methods*. 2012;9:676-82.

11. Di Bartolomeo R, Pantaleo A, Berretta P, Murana G, Castrovinci S, Cefarelli M, et al. Frozen elephant trunk surgery in acute aortic dissection. *J Thorac Cardiovasc Surg*. 2015;149:105-9.
12. Ogino H, Okita Y, Uchida N, Kato M, Miyamoto S, Matsuda H, et al. Comparative study of Japanese frozen elephant trunk device for open aortic arch repairs. *J Thorac Cardiovasc Surg*. April 1, 2021 [Epub ahead of print]. https://doi.org/10.1016/j.jtcvs.2021.03.079
13. Kim JB, Chung CH, Moon DH, Ha GJ, Lee TY, Jung SH, et al. Total arch repair versus hemiarch repair in the management of acute DeBakey type I aortic dissection. *Eur J Cardiothorac Surg*. 2011;40:881-7.
14. Rylski B, Beyersdorf F, Kari FA, Schlosser J, Blanke P, Siepe M. Acute type A aortic dissection extending beyond ascending aorta: limited or extensive distal repair. *J Thorac Cardiovasc Surg*. 2014;148:949-54.
15. Lio A, Nicolò F, Bovio E, Serrao A, Zeitani J, Scafuri A, et al. Total arch versus hemiarch replacement for type A acute aortic dissection: a single-center experience. *Tex Heart Inst J*. 2016;43:488-95.
16. Li B, Ma WG, Liu YM, Sun LZ. Is extended arch replacement justified for acute type A aortic dissection? *Interact Cardiovasc Thorac Surg*. 2015;20:120-6.
17. Zhang J, Ma W, Chen J, Zhu D, Zhang Y, Kong Y, et al. Distal remodeling after operations for extensive acute aortic dissection. *Ann Thorac Surg*. 2021;112:83-90.
18. Uchida K, Minami T, Cho T, Yasuda S, Kasama K, Suzuki S, et al. Results of ascending aortic and arch replacement for type A aortic dissection. *J Thorac Cardiovasc Surg*. 2021;162:1025-31.
19. Uchida N, Shibamura H, Katayama A, Shimada N, Sutoh M, Ishihara H. Operative strategy for acute type a aortic dissection: ascending aortic or hemiarch versus total arch replacement with frozen elephant trunk. *Ann Thorac Surg*. 2009;87:773-7.
20. Hirst AE Jr, Johns VJ, Kime SW Jr. Dissecting aneurysm of the aorta: a review of 505 cases. *Med (Baltim)*. 1958;37:217-79.
21. Huptas S, Mehta RH, Kühl H, Tsagakis K, Reinsch N, Kahlert P, et al. Aortic remodeling in type B aortic dissection: effects of endovascular stent-graft repair and medical treatment on true and false lumen volumes. *J Endovasc Ther*. 2009;16:28-38.
22. Kreibich M, Bünte D, Berger T, Vötsch A, Rylski B, Krombholz-Reindl P, et al. Distal stent graft-induced new entries after the frozen elephant trunk procedure. *Ann Thorac Surg*. 2020;110:1271-9.
23. Czerny M, Eggebrecht H, Rousseau H, Mouroz PR, Janosi RA, Lescan M, et al. Distal stent graft-induced new entry after TEVAR or FET: insights into a new disease from EuREC. *Ann Thorac Surg*. 2020;110:1494-500.
24. Pantaleo A, Jafrancesco G, Buia F, Leone A, Lovato L, Russo V, et al. Distal stent graft-Induced new entry: an emerging complication of endovascular treatment in aortic dissection. *Ann Thorac Surg*. 2016;102:527-32.
25. Jang H, Kim MD, Kim GM, Won JY, Ko YG, Choi D, et al. Risk factors for stent graft-induced new entry after thoracic endovascular aortic repair for Stanford type B aortic dissection. *J Vasc Surg*. 2017;65:676-85.
26. Dong Z, Fu W, Wang Y, Wang C, Yan Z, Guo D, et al. Stent graft-induced new entry after endovascular repair for Stanford type B aortic dissection. *J Vasc Surg*. 2010;52:1450-7.
27. Wada T, Yamamoto H, Kadohama T, Takagi D. Aortic remodeling mismatch: a potential risk factor of late distal stent graft-induced new entry after frozen elephant trunk deployment. *J Thorac Cardiovasc Surg Tech*. 2021;8:46-8.
28. Kreibich M, Berger T, Rylski B, Chen Z, Beyersdorf F, Siepe M, et al. Aortic reinterventions after the frozen elephant trunk procedure. *J Thorac Cardiovasc Surg*. 2020;159:392-9.

Key Words: acute type A aortic dissection, zone 0 arch repair, frozen elephant trunk, aortic remodeling, distal stent-induced new entry