Ratio of the false lumen to the true lumen is associated with long-term prognosis after surgical repair of acute type A aortic dissection

Takashi Igarashi, MD, Yoichi Sato, MD, Hirono Satokawa, MD, Shinya Takase, MD, Masumi Iwai-Takano, MD, Yuki Seto, MD, and Hitoshi Yokoyama, MD, PhD

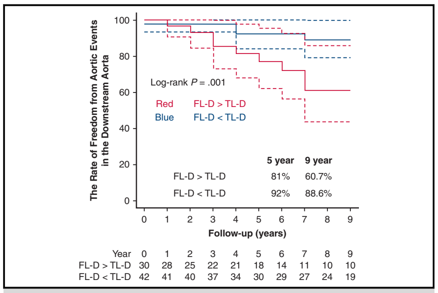
ABSTRACT

Objectives: The aim of this study was to assess potential predictors of aortic events after an emergency surgery for acute type A aortic dissection, especially paying attention to the findings of computed tomography (CT) performed immediately after the surgery.

Methods: Between January 2001 and December 2015, 72 patients, who were diagnosed as having Stanford type A acute aortic dissection with a patent false lumen in the descending thoracic aorta, survived the emergency operation, and had postoperative CT scan data, were included in this study (mean follow-up, 8.2 ± 3.8 years; range 0.8-17.4 years). From the CT scan data, the diameter of the false lumen (FL-D) and true lumen (TL-D) were measured, and the FL-D:TL-D ratio was calculated. Long-term outcomes of the FL-D > TL-D group (n = 30) and the FL-D < TL-D group (n = 42) were compared.

Results: In the late follow-up, 17 aortic events in the downstream aorta were observed. The FL-D:TL-D ratio ($P = .01$) was an adjusted risk of aortic events in multivariable analysis. The rates of freedom from aortic events at 5 and 9 years were superior in the FL-D < TL-D group than in the FL-D > TL-D group (92.0% and 88.6% vs 81% and 60.7%; log rank $P < .05$).

Conclusions: Our results suggest that the false lumen:true lumen ratio predicts long-term prognosis after surgical repair of acute type A aortic dissection. (JTCVS Open 2022;10:75-84)



The FL-D > TL-D group was inferior in the rates of freedom from aortic events.

CENTRAL MESSAGE

False lumen:true lumen ratio in postoperative computed tomography images predicts the long-term prognosis after surgical repair of acute type A aortic dissection.

PERSPECTIVE

The presence of a morphological parameter reflecting the internal pressure within the dissected aorta would help us to determine the most appropriate therapy strategy to effectively reduce internal pressure of the false lumen to improve the long-term outcomes. In postoperative follow-up, preemptive endovascular interventions such as vascular plug, stent graft, coils, and glues might be a choice.

See Commentary on page 85.

Video clip is available online.

One of the most important problem of acute type A aortic dissection (ATAAD) is postoperative dilatation of the residual false lumen in the downstream thoracic and/or abdominal aorta in the late follow-up period.[1-3] Dilatation of the aorta results in some aortic events such as secondary aortic intervention (open surgery and endovascular surgery) and aortic rupture, and leads to poor long-term outcome.[4,5]

From the Department of Cardiovascular Surgery, Fukushima Medical University, Fukushima, Japan.

Received for publication March 4, 2021; accepted for publication Feb 17, 2022; available ahead of print April 30, 2022.

Address for reprints: Takashi Igarashi, MD, Department of Cardiovascular Surgery, Fukushima Medical University, Hikarigaoka 1, Fukushima 960-1295, Japan (E-mail: igao5150@fmu.ac.jp).

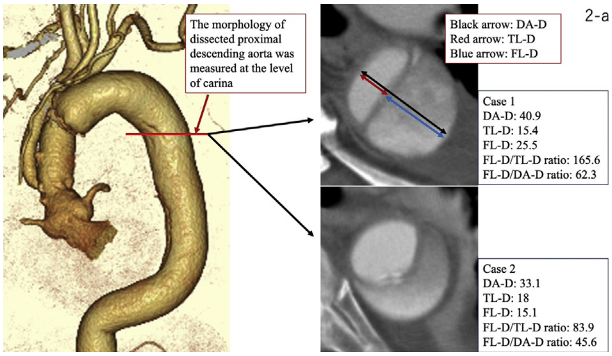
2666-2736

https://doi.org/10.1016/j.xjon.2022.02.025

Abbreviations and Acronyms

ATAAD = acute type A aortic dissection
CT = computed tomography
DA-D = diameter of the proximal descending aorta
FL-D = diameter of the false lumen
IQR = interquartile range
TL-D = diameter of the true lumen

Although previous studies have reported some predictive factors of postoperative aortic events and dilatation of the descending aorta in late follow-up,[6,7] it remains unclear an effective predictor that reflects the internal pressure within the dissected aorta. It is difficult to measure the internal pressure of the false lumen directly; therefore, a noninvasive method is required to assess the pressure from the postoperative computed tomography (CT) data. The aim of the present study was to assess the potential predictive factor of aortic events after initial emergency surgery for ATAAD from our long-term results, with special attention to the morphology of the dissected descending aorta and the findings of CT performed immediately after the surgery.



VIDEO 1. Summary of the current study on the relation between the morphology of dissected residual thoracic aorta and postoperative aortic events in late follow-up after emergent surgery for acute type A aortic dissection. In the late follow-up, we detected 17 aortic events in the downstream aorta. In the multivariable analysis, the FL-D:TL-D ratio ($P = .01$; hazard ratio, 1.009; 95% confidence interval, 1.002-1.016) was an independent predictive factor of aortic events in the downstream aorta in late follow-up. Video available at: https://www.jtcvs.org/article/S2666-2736(22)00093-6/fulltext.

METHODS

This study was a retrospective single-center study, and informed consent for the publication of this study was obtained from all patients at admission. The institutional review board of Fukushima Medical University approved this study (approval number: 2019-272; approval date February 25, 2020). Video 1 summarizes the study protocol and the key results of this study.

Patient Inclusion Criteria

One hundred sixty-three ATAAD patients underwent emergency surgical aortic repair in our hospital between January 2001 and December 2015. In the preoperative CT images, 109 patients were diagnosed as Stanford type A acute aortic dissection with a patent false lumen in the descending thoracic aorta. After the emergency operation, 90 patients survived, 74 of whom underwent a postoperative CT scan within 14 days after the operation. Two patients with Marfan syndrome were excluded. Finally, 72 patients were enrolled in this study. The patient inclusion criteria are shown in Figure 1.

Surgical Procedures

Using general anesthesia and mechanical ventilation, the patient's chest was opened via full median sternotomy. An extracorporeal circulation was established with perfusion from the subclavian artery and femoral artery, and drainage from the superior and inferior vena cava. After insertion of a left ventricular vent from the right superior pulmonary vein, systemic cooling was started and continued until the patient's bladder temperature reached 26 °C. If the false lumen was patent in the ascending aorta, we crossclamped the aorta. If the false lumen was thrombosed, we did not. In all cases, we performed distal anastomosis in an open fashion with circulatory arrest and moderate hypothermia and resected the clamped part of the aorta. During crossclamping of the ascending aorta, retrograde cardioplegia was infused to achieve cardiac arrest. Historically, for patients in early years, gelatin-resorcinol-formaldehyde glue was used for readhesion of the intima and adventitia, followed by BioGlue R (CryoLife, Inc). When the temperature reached 26 °C, circulatory arrest was achieved, and selective cerebral perfusion was established. If the primary entry was in the ascending aorta, only the ascending aorta was replaced. If the primary entry was located in the aortic arch, partial or total arch replacement was selected.

Data Acquisition and Follow-up

We reviewed the medical records of the 72 patients and obtained their preoperative characteristics, operative data, postoperative early results, and postoperative information at follow-up visits. We were able to follow-up on all 72 patients. After discharge, they underwent medical follow-ups in our hospital or outpatient clinic regularly and underwent annual CT scans. When the diameter of the dissected descending aorta reached over 55 mm in CT scan, secondary intervention was considered. The patients' conditions were assessed via medical records, direct telephone interviews, and questionnaires. The mean follow-up period was 8.2 ± 3.8 years (range, 0.8-17.4 years).

Morphological Analysis With CT

After surgery, postoperative enhanced CT was performed on all 72 patients. We used helical CT (Aquilion ONE; Canon Medical Systems) with 320 detectors that produce 0.5-mm slice axial images from the top of the aortic arch to the abdominal aorta. A thrombosed false lumen was defined when the false lumen was thrombosed throughout the thoracic descending aorta. A partially thrombosed false lumen was defined when the false lumen was thrombosed between the distal anastomosis of the graft and the proximal descending aorta at the level of the carina only. The morphology of the dissected proximal descending aorta was measured at the level of the carina in the axial view. The diameters of the proximal descending aorta (DA-D, mm), false lumen (FL-D, mm), and true lumen (TL-D, mm) were measured. DA-D was measured as a distance between an outer point and contralateral outer point of aortic wall. FL-D and TL-D were measured as a distance between an inner point and contralateral inner point of the lumen in a center line perpendicular to the intimal flap (Figure 2). The FL-D:TL-D ratio and the FL-D:DA-D ratio were calculated as percentage. In addition, considering measurement error, DA-D category

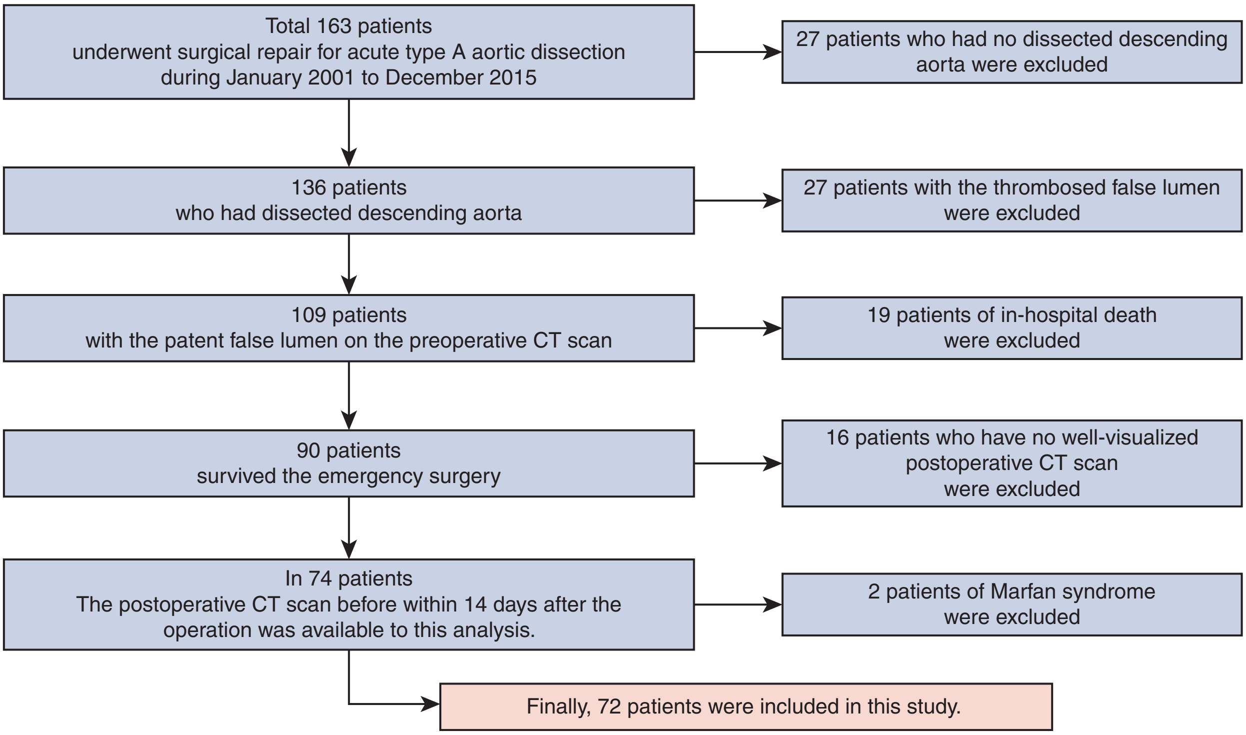


FIGURE 1. Selection process and number of patients. Between January 2001 and December 2015, 163 patients underwent emergency surgery for acute type A aortic dissection in our institute. Seventy-two patients, who were diagnosed as having Stanford type A acute aortic dissection with a patent false lumen in the descending thoracic aorta survived the emergency operation, and had postoperative computed tomography (*CT*) scan data, were included in this study. Two Marfan patients were excluded.

(category 1 = 25-29 mm, category 2 = 30-34 mm, category 3 = 35-39 mm, category 4 = 40-44 mm, category 5 = 45-49 mm), FL-D category (category 1 = 0-4 mm, category 2 = 5-9 mm, category 3 = 10-14 mm, category 4 = 15-19 mm, category 5 = 20-24 mm, category 6 = 25-29 mm, category 7 = 30-34 mm), and TL-D category (category 1 = 5-9 mm, category 2 = 10-14 mm, category 3 = 15-19 mm, category 4 = 20-24 mm, category 5 = 25-29 mm, category 6 = 30-34 mm, category 7 = 35-39 mm) were defined as another scale. From the same CT scan data, the number of visceral arteries originating from the false lumen, conditions of dissected supra-arch vessels, and the presence of intimal tear in the thoracic descending and abdominal aorta were evaluated (Figure 2).

Statistical Analysis

Statistical analysis was performed using Statistical Package for Social Sciences, version 25 (SPSS Inc) and R version 4.1.0 (The R Foundation for Statistical Computing). Preoperative characteristics, operative data, and postoperative early results were analyzed. Data are expressed as median with interquartile range (IQR; 25th- 75th percentile) for continuous variables. Categorical variables are expressed as numbers and percentages. In univariable analyses, continuous and categorical variables were compared using the Student *t* test, χ^2, or Fisher exact test as appropriate (Fisher exact test was used only when 1 of the 4 cells of a 2 × 2 table had <5 observations.). In multivariable analyses, Cox proportional hazard regression analysis was used to identify risk factors for postoperative aortic events in the downstream aorta in the late follow-up, and variables with P values < .05 in the univariable analyses were included. As the result, DA-D and FL-D:TL-D ratio were included in the final Cox model without other categorical variables. Survival curves were estimated using the Kaplan–Meier method, and comparisons between 2 groups was performed using the log rank method. All tests were 2-sided.

RESULTS

Patient Characteristics

The preoperative patient characteristics are summarized in Table 1. The median age was 64 (IQR, 75-75) years. Thirty-five patients were female (49%), and the primary entry was located in the ascending aorta in 48 patients (67%). Preoperative shock state in 5 patients (7%), cardiac tamponade in 9 (13%), rupture in 2 (3%), and organ malperfusion in 20 (28%) were observed. Postoperative aortic events were also observed in 17 patients in the late follow-up.

Operative Data and Early Results

The perioperative data and early results are summarized in Table 2. Ascending aorta replacement was performed in 44 cases (61%), partial arch replacement in 11 cases (15%), and total arch replacement in 17 cases (24%). Resection of primary tear was achieved in 64 cases (89%). As a concomitant procedure, coronary artery bypass grafting was performed in 4 cases (6%). The median operation time, extracorporeal circulation time, aortic cross-clamping time, and circulatory arrest time were 443 (IQR, 393-553), 216 (IQR, 191-249), 137 (IQR, 118-151), and 55 (IQR, 49-62) minutes, respectively. The median period of stay in the intensive care unit and the hospital stay were 4 (IQR, 2-5) and 26 (IQR, 19-34) days, respectively.

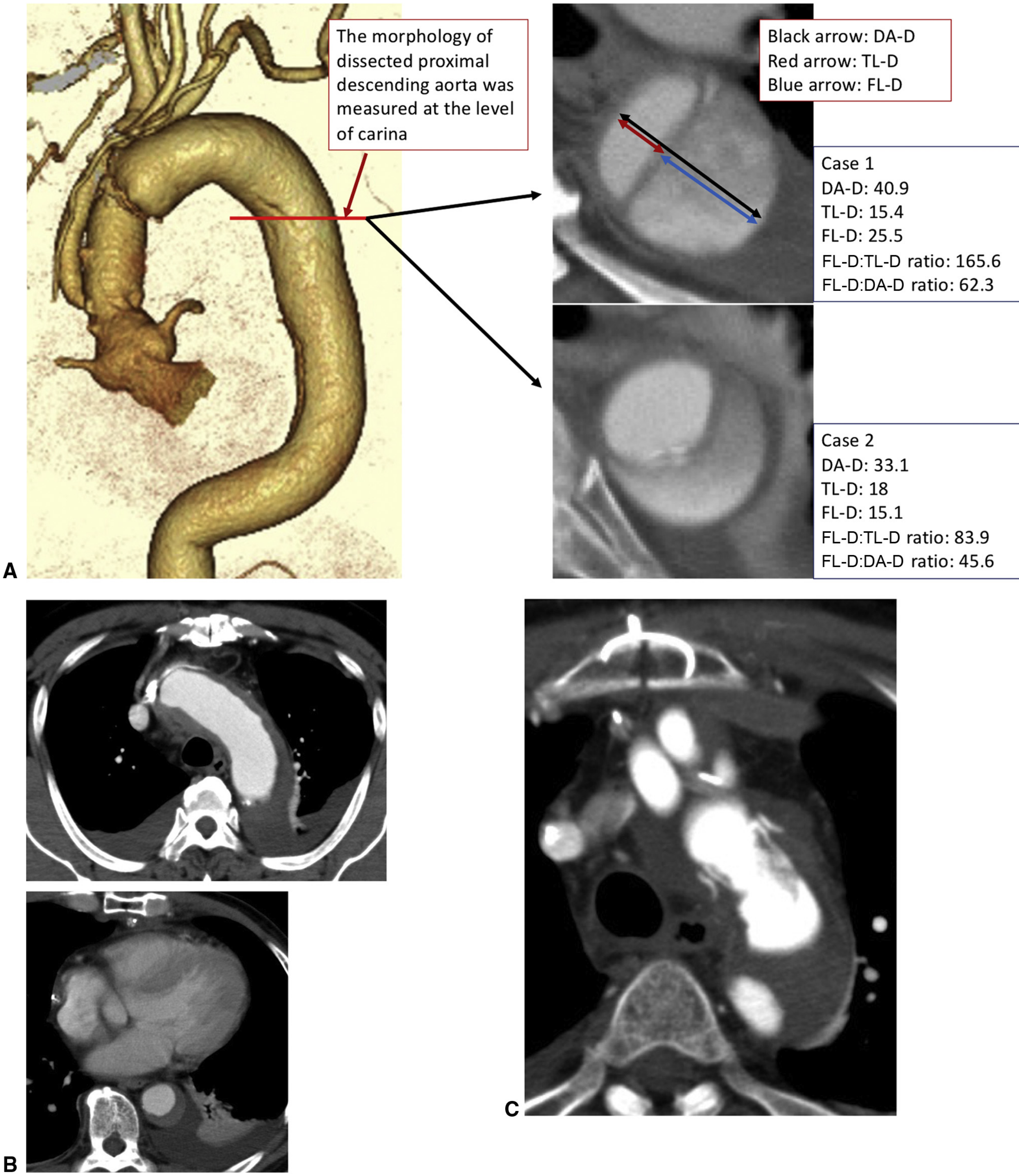


FIGURE 2. Definitions of morphological parameters of the dissected descending aorta. In the axial view, the diameters of the proximal descending aorta (*DA-D*, *black arrow*), false lumen (*FL-D*, *blue arrow*) and true lumen (*TL-D*, *red arrow*) were measured. The FL-D:TL-D ratio and the FL-D:DA-D ratio were calculated (A, case 1 and 2). Thrombosed false lumen was defined when the false lumen was thrombosed throughout the thoracic descending aorta (B). Partial thrombosis was defined when the false lumen was thrombosed between the distal anastomosis of the graft and the proximal descending aorta only (C).

TABLE 1. Preoperative patient characteristics

Variable	Total (n = 72)	Aortic event group (n = 17)	Control group (n = 55)	*P* value
Age, y	64 (57-75)	75 (67-82)	68 (58-75)	.963
Octogenarian	5 (7)	1 (6)	4 (7)	.663
Female sex	35 (49)	8 (47)	27 (49)	.884
Height, cm	159 (150-166)	160 (150-170)	162 (154-166)	.608
Weight, kg	57 (47-72)	64 (58-69)	61 (53-77)	.608
Body mass index	23.5 (20.6-25.8)	24.8 (23.9-25.8)	24.1 (22.0-27.5)	.573
Hypertension	48 (67)	14 (82)	34 (62)	.116
Dyslipidemia	8 (11)	1 (6)	7 (13)	.390
Diabetes mellitus	5 (7)	1 (6)	4 (7)	.663
Smoking	13 (18)	4 (24)	9 (16)	.364
COPD	2 (3)	1 (6)	1 (2)	.419
CVA	4 (6)	1 (6)	3 (6)	.668
CAD	5 (7)	1 (6)	4 (7)	.663
Creatinine, mg/dL	0.84 (0.65-1.09)	0.91 (0.84-0.98)	0.97 (0.75-1.22)	.874
eGFR	56 (48-76)	54 (49-59)	55 (39-76)	.925
Pre-cardiac surgery	1 (1)	0	1 (2)	.764
Pre-AAA surgery	3 (4)	1 (6)	2 (4)	.560
Primary tear in ascending aorta	48 (67)	11 (65)	37 (67)	.844
Preoperative shock state	5 (7)	2 (12)	3 (6)	.337
Cardiac tamponade	9 (13)	2 (12)	7 (13)	.642
Rupture	2 (3)	0	2 (4)	.581
Malperfusion	20 (28)	4 (24)	16 (29)	.455

Data are presented as median (interquartile range) or n (%) except where otherwise noted. *COPD*, Chronic obstructive pulmonary disease; *CVA*, cerebrovascular accident; *CAD*, coronary artery disease; *eGFR*, estimated glomerular filtration rate; *AAA*, abdominal aortic aneurysm.

Findings of Postoperative CT Imaging

The findings of postoperative CT scan are summarized in Table 3. The patent false lumen of the descending aorta was observed in 54 cases (75%), and partially thrombosed false lumen in the proximal descending aorta was observed in 35 cases (49%). The number of visceral arteries originating from the false lumen was 1 (IQR, 0-2). The presence of intimal tear in the descending aorta and abdominal aorta

TABLE 2. Perioperative data and early results

Variable	Total (n = 72)	Aortic event group (n = 17)	Control group (n = 55)	*P* value
Procedure				
Ascending aorta replacement	44 (61)	9 (53)	35 (64)	.429
Partial arch replacement	11 (15)	2 (12)	9 (16)	.490
Total arch replacement	17 (24)	6 (35)	11 (20)	.165
Resection of primary tear	64 (89)	15 (88)	49 (89)	.610
Concomitant procedure				
CABG	4 (6)	1 (6)	3 (6)	.668
Operation time, min	443 (393-553)	376 (344-407)	407 (391-469)	.235
ECC time, minutes	216 (191-249)	195 (193-197)	194 (175-215)	.320
ECC time > 4 h	22 (31)	7 (41)	15 (27)	.277
AoX time, minutes	137 (118-151)	110 (103-117)	123 (111-136)	.251
Circulatory arrest time, min	55 (49-62)	48 (43-52)	54 (48-60)	.240
Early results				
ICU stay, d	4 (2-5)	4 (3-4)	3 (2-5)	.692
Hospital stay, d	26 (19-34)	21 (18-24)	26 (16-37)	.879

Data are presented as median (interquartile range) or n (%) except where otherwise noted. *CABG*, Coronary artery bypass grafting; *ECC*, extracorporeal circulation; *AoX*, aorta cross-clamping; *ICU*, intensive care unit.

TABLE 3. Postoperative computed tomography findings

Variable	Total (n = 72)	Aortic event group (n = 17)	Control group (n = 55)	*P* value
Patent false lumen of the descending aorta	54 (75)	13 (77)	41 (75)	.575
Partially thrombosed false lumen in the proximal descending aorta	35 (49)	8 (47)	27 (49)	.884
Number of visceral arteries originating from false lumen	1 (0-2)	1 (0-1)	1 (0-3)	.576
DA-D, mm	35.3 (33-37.8)	36.6 (33.3-39.8)	35.5 (32.2-39.5)	.039
DA-D category	3 (2-3)	3 (2-3)	3 (2-3)	.079
FL-D, mm	17.2 (12.8-19.4)	18.9 (7-30.4)	17.5 (15.3-19)	.009
FL-D category	4 (3-4)	5 (2-7)	4 (4-4)	.014
TL-D, mm	18.6 (15.5-22.7)	17.7 (9.4-26)	17 (14-22)	.260
TL-D category	3 (3-4)	3 (1-5)	3 (2-4)	.384
FL-D:TL-D ratio	95 (58-124)	176 (28-323)	97 (86-136)	.028
FL-D/DA-D ratio	49 (37-55)	49 (22-76)	49 (46-58)	.028
FL-D > TL-D	30 (42)	12 (71)	18 (33)	.006
Reentry in the BCA	12 (17)	1 (6)	11 (20)	.161
Reentry in the LCCA	4 (6)	0	4 (7)	.332
Reentry in the LSCA	8 (11)	4 (24)	4 (7)	.083
Presence of intimal tear in the descending aorta	22 (31)	7 (41)	15 (27)	.277
Presence of intimal tear in the abdominal aorta	18 (25)	5 (29)	13 (24)	.425

Data are presented as median (interquartile range) or n (%) except where otherwise noted. *DA-D*, Diameter of the proximal descending aorta; *FL-D*, false lumen diameter; *TL-D*, true lumen diameter; *BCA*, brachiocephalic artery; *LCCA*, left common carotid artery; *LSCA*, left subclavian artery.

was observed in 22 (31%) and 18 cases (25%), respectively. The DA-D was 35.3 (IQR, 33-37.8) mm, the FL-D was 17.2 (IQR, 12.8-19.4) mm, and the TL-D was 18.6 (IQR, 15.5-22.7) mm. The DA-D category, the FL-D category and the TL-D category were 3 (IQR, 2-3), 4 (IQR, 3-4), and 3 (IQR, 3-4), respectively. The FL-D:TL-D ratio was 95% (IQR, 58%-124%) and the FL-D/DA-D ratio was 49% (IQR, 37%-55%). In 30 cases (42%), the FL-D was greater than the TL-D. Reentry in the brachiocephalic artery, the left common carotid artery, and the left subclavian artery were observed in 12 cases (17%), 4 cases (6%), and 8 cases (11%), respectively. Between the aortic event group and the control group, there were differences in the DA-D (36.6 [IQR, 33.3-39.8] mm vs 35.5 [IQR, 32.2-39.5] mm; $P < .05$), the FL-D (18.9 [IQR, 7-30.4] mm vs 17.5 [IQR, 15.3-19] mm; $P < .05$), the FL-D category (5 vs 4; $P < .05$), the FL-D:TL-D ratio (176 [IQR, 28-323] vs 97 [IQR, 86-136]; $P < .05$), FL-D/DA-D ratio (49 [IQR, 22-76] vs 49 [IQR, 46-58]; $P < .05$), and FL-D > TL-D (12 cases [71%] vs 18 cases [33%]; $P < .05$).

The Predictive Factor of Aortic Events in the Downstream Aorta in Late Follow-up

In the late follow-up, we detected 17 aortic events in the downstream aorta (5 cases of ruptured thoracic aneurysm, 4 cases of redo aortic arch repair, 4 cases of thoracic endovascular aortic repair, 1 case of replacement of the thoracoabdominal aorta, 1 case of descending aorta replacement, 1 case of new acute type B aortic dissection, and 1 case of sudden death). In the multivariable analysis, the FL-D:TL-D ratio ($P < .05$; hazard ratio. 1.009; 95% confidence interval, 1.002-1.016) was an adjusted risk of aortic events in the downstream aorta in late follow-up (Table 4).

Long-Term Outcomes

The overall survival rates at 5 and 10 years were 88% and 67.5%, respectively. The rates of freedom from aortic death at 5 and 10 years were 98.3% and 88.9%, respectively. The rates of freedom from aortic events in the downstream aorta at 5 and 10 years were 87.7% and 71.3%, respectively (Figure 3).

Subgroup Analysis of the Relation Between the False Lumen Patency and Long-Term Outcome

We compared 2 groups with patent false lumen (n = 54) and thrombosed false lumen (n = 18) (Figure 4). The rates of freedom from aortic events in the downstream aorta at 5 and 7 years were 87.7% and 77.1% in the group with patent

TABLE 4. Predictive factors of aortic events in the downstream aorta in late follow-up

Variable	Multivariable analysis: *P* value	Multivariable analysis: Hazard ratio (95% CI)
Diameter of the proximal descending aorta	.053	1.117 (0.999-1.249)
False lumen diameter: true lumen diameter ratio	.01	1.009 (1.002-1.016)

CI, Confidence interval.

false lumen, respectively, and 87.7% in the group with thrombosed false lumen, respectively.

Subgroup Analysis of the Relation Between the Morphology of False Lumen and Long-Term Outcome

We compared 2 groups, with (n = 30) and without (n = 42) FL-D > TL-D (Figure 4). The rates of freedom from aortic events in the downstream aorta at 5 and 9 years were 81% and 60.7% in the FL-D > TL-D group, respectively, and 92% and 88.6% in the FL-D < TL-D group, respectively. The rates of freedom from aortic death at 5 and 9 years were 96% and 86.1% in the FL-D > TL-D group, respectively, and 100% and 96.6% in the FL-D < TL-D group, respectively. Figure 5 shows the measurement of morphologic parameters of dissected aorta and the main results of the current study.

DISCUSSION

In this study, we found that the FL-D:TL-D ratio was an adjusted risk of postoperative aortic events in the downstream aorta. Previous studies have reported predictive factors of postoperative aortic events and dilatation of the descending aorta in late follow-up.[6,7] The most basic predictive factor was the presence of a patent false lumen.[4,8-10] In addition, the presence of a large intimal tear in the proximal descending aorta,[5] location of the intimal tear,[5,11,12] maximum diameter of the thoracic

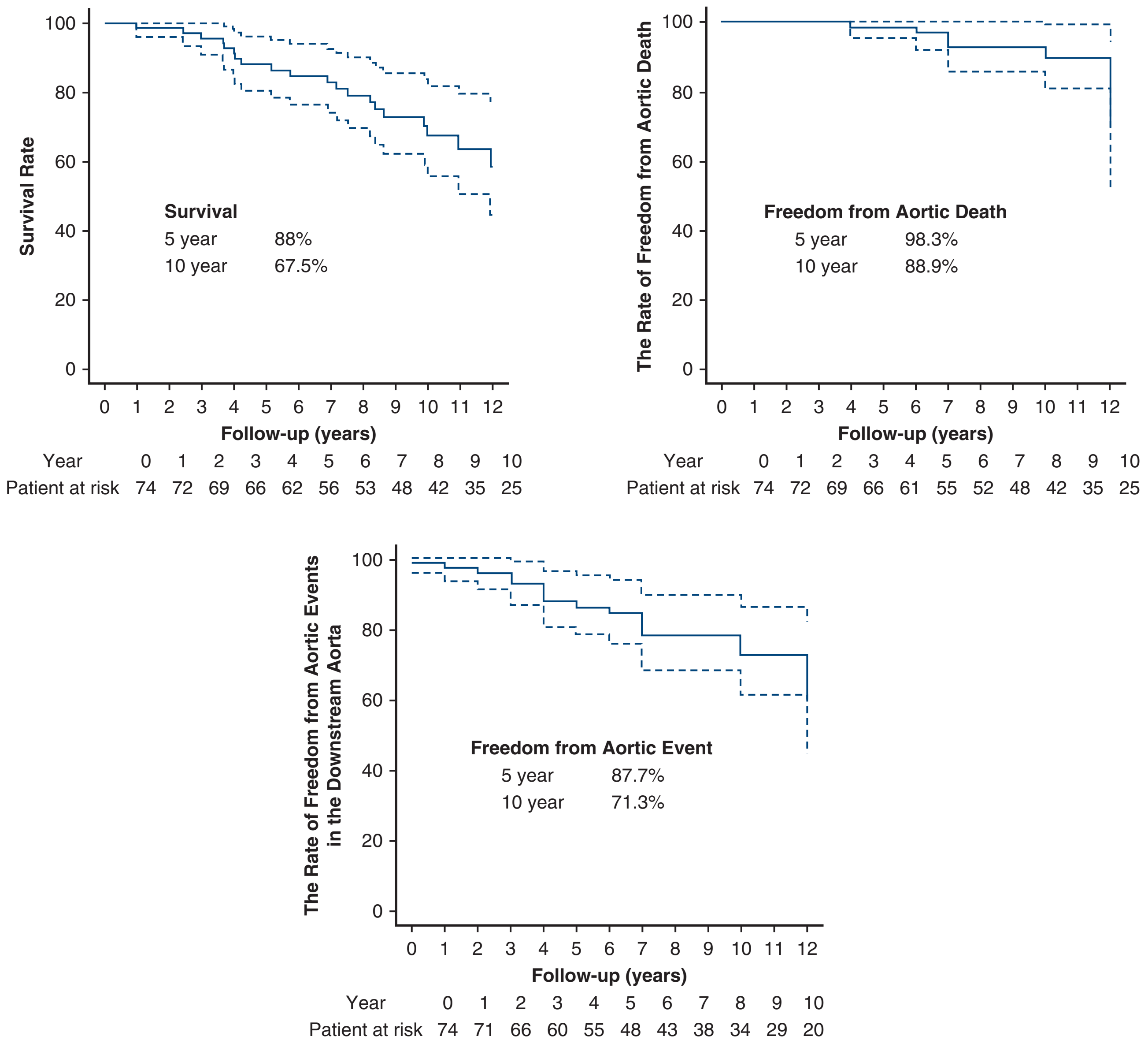


FIGURE 3. Kaplan–Meier curves of actuarial survival (*upper*), freedom from aortic death (*middle*), and aortic events in the downstream aorta (*lower*) with number of patients at risk and 95% confidence intervals.

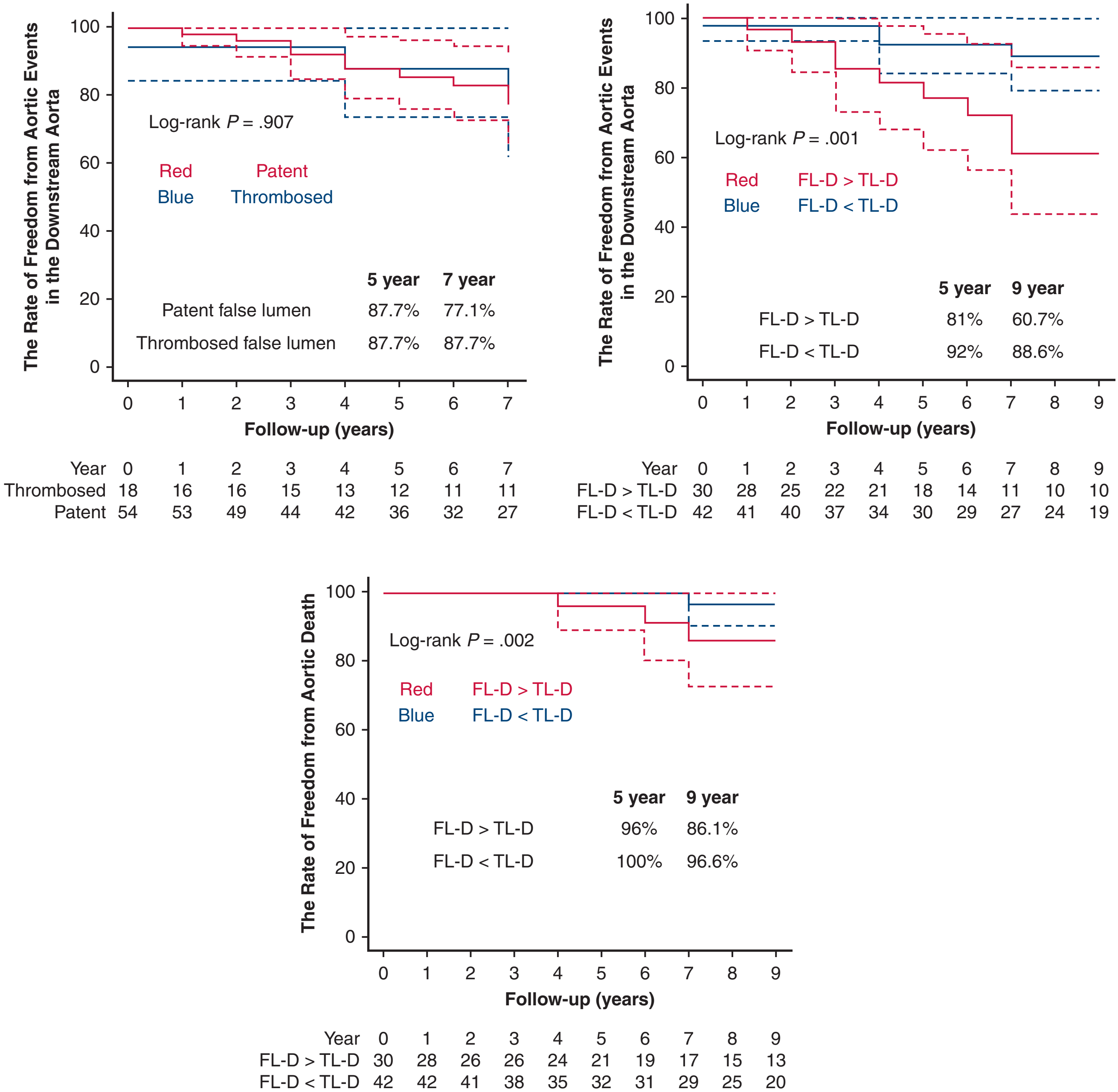
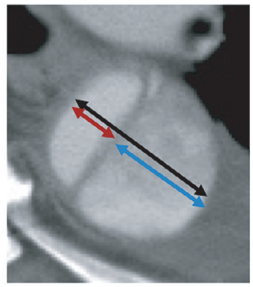


FIGURE 4. Subgroup analysis in long-term outcome. A, Kaplan–Meier curves of freedom from aortic events between the groups with patent false lumen and thrombosed false lumen with number of patients at risk and 95% confidence intervals. B, Kaplan–Meier curves of freedom from aortic events between the FL-D > TL-D group and FL-D < TL-D group with number of patients at risk and 95% confidence intervals. C, Kaplan–Meier curves of freedom from aortic death between the FL-D > TL-D group and FL-D < TL-D group with number of patients at risk and 95% confidence intervals. *FL-D*, False lumen diameter; *TL-D*, true lumen diameter.

descending aorta on the postoperative CT scan,[5,10,13] presence of a patent false lumen of dissected supra-arch vessels,[14] presence of visceral arteries or intercostal arteries originating from the false lumen,[15] and Marfan syndrome[5] were also reported as predictive factors. Most of these previous studies suggest that the presence of the channel of blood supply causes the patent false lumen, which then results in the dilatation of the false lumen and descending aorta. If higher internal pressure of the false lumen is maintained, the dilatation of the descending aorta will occur with high probability. However, because hemodynamics into the false lumen are diverse depending on the number, location, and size of the channels of blood supply, it is difficult to assess internal pressure conditions of the

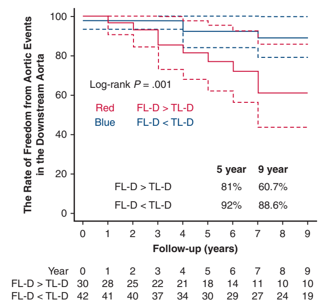
False Lumen / True Lumen Ratio Predicts the Long-term Prognosis After Surgical Repair of Acute Type A Aortic Dissection

Methods



Black arrow: DA-D
Red arrow: TL-D
Blue arrow: FL-D

Results



- The rates of freedom from the aortic events at 5 and 9 years were superior in the FL-D < TL-D group than the FL-D > TL-D group.
- The FL-D:TL-D ratio was an independent predictor of the aortic events

Variables	Multivariable Analysis		
	P value	Hazard ratio	95% CI
FL-D:TL-D ratio	.01	1.009	1.002–1.016

Implications

FL-D:TL-D ratio predicts long-term prognosis after surgical repair of acute type A aortic dissection.

FIGURE 5. Data of 72 patients, who were diagnosed as having Stanford type A acute aortic dissection with a patent false lumen in the descending thoracic aorta, survived the emergency operation, and had postoperative CT scan data, were analyzed. The diameters of the false lumen (*FL-D*) and true lumen (*TL-D*) were measured, and the FL-D:TL-D ratio was calculated. Long-term outcomes for the FL-D > TL-D group (n = 30) and the FL-D < TL-D group (n = 42) were compared. In the late follow-up, 17 aortic events in the downstream aorta were observed. The FL-D:TL-D ratio was an independent predictor of aortic events in multivariable analysis. The rates of freedom from aortic events at 5 and 9 years were superior in the FL-D < TL-D group than in the FL-D > TL-D group. Our results suggest that the false lumen:true lumen ratio predicts long-term prognosis after surgical repair of acute type A aortic dissection. *DA-D*, Diameter of the proximal descending aorta; *CI*, confidence interval.

false lumen according to any of the anatomical conditions. When the internal pressure of the false lumen becomes higher, the false lumen will dilate naturally. We therefore hypothesized that the diameters of the true and false lumen reflect changes in the internal pressure of the dissected descending aorta just after the initial operation because the dissected intimal flap is soft and flexible.

Immer and colleagues[16] reported that a large false lumen with an area of the true lumen < 30% 6 months after surgery is the strongest predictor for secondary dilatation of the diseased downstream aorta. This finding is consistent with the results of the current study. Matsushita and colleagues[17] also reported an initial aortic diameter of >40 mm and FL-D > TL-D were predictors of major adverse events after uncomplicated acute type B aortic dissection. Song and colleagues[18] reported that a >22 mm false lumen diameter of the upper descending thoracic aorta on initial CT images predicted a late aneurysm with a sensitivity of 100% and a specificity of 76% in the patients with acute aortic dissection, and patients with initial upper descending thoracic aorta false lumen diameter >22 mm showed higher event rates (aneurysm or death) than others.

In the present study, we measured the FL-D and the TL-D and calculated an FL-D:TL-D ratio from the CT data performed immediately after surgery. As a result, the FL-D:TL-D ratio was an adjusted risk of aortic events in the late follow-up. We believe that the measurement of these parameters is a very simple and effective method to predict aortic events.

Although the progress of endovascular aortic repair has brought about the reduction of invasiveness in secondary surgery and improved the outcomes, it remains unclear regarding an appropriate indication, timing, and combination of therapy techniques after the initial surgery for ATAAD. To improve the long-term outcomes, a strategy to effectively reduce internal pressure of the false lumen is required. In postoperative follow-up, preemptive endovascular interventions such as vascular plug, stent graft, coils, and glues might be a choice if the blood flow from the intimal tear to the false lumen is severe.[19-21] From this standpoint, the presence of a morphological parameter reflecting the internal pressure would help us to determine the most appropriate therapy strategy.

This study has some limitations. First, it is a retrospective single-center study. There are some statistical limitations because of the very small sample size. We observed only 17 cases of aortic events in late follow-up. The data in the Kaplan–Meier methods were unadjusted. Our multivariable stepwise regression model limits interpretability of this study. Not only residual confounding, but measurement error and sampling error could greatly influence results in a small population. Second, we could not remove the confounding of heterogeneity of cases and procedures. Third, we did not assess the influence of the flexibility and pliability of the intimal flap or aortic wall on the measured morphological parameters. Fourth, the relationship between the tortuosity of the aorta and the dilatation of the false lumen was not examined. Fifth, some debate exists about use of a center line measurement to determine the true transverse diameter as well as either double oblique versus orthogonal measurements. These approaches might adjust for any overestimation in measurement. Finally, we selected clinical outcomes such as survival and aortic events as the end points in this study. Therefore, the actual degree of aortic dilatation was not examined.

CONCLUSIONS

We found that the FL-D:TL-D ratio and FL-D > TL-D were adjusted risks of aortic events in the downstream aorta. In long-term outcome, the rate of freedom from aortic events in the downstream aorta was inferior in the FL-D > TL-D group compared with the FL-D < TL-D group. These results suggest that the morphology of the false lumen predicts the long-term prognosis after surgical repair of ATAAD.

Conflict of Interest Statement

The authors reported no conflicts of interest.

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

The Biostatistical Consulting Service at Clinical Research Center, Fukushima Medical University, and in particular Dr Noriko Tanaka, helped with the interpretation of the results from statistical analysis in this study.

References

1. Heinemann M, Laas J, Karck M, Borst HG. Thoracic aortic aneurysms after acute type A aortic dissection: necessity for follow-up. *Ann Thorac Surg*. 1990;49:580-4.
2. Olsson C, Hillebrant CG, Liska J, Lockowandt U, Eriksson P, Franco-Cereceda A. Mortality and reoperations in survivors operated on for acute type A aortic dissection and implications for catheter-based or hybrid interventions. *J Vasc Surg*. 2013;58:333-9.
3. Omura A, Miyahara S, Yamanaka K, Sakamoto T, Matsumori M, Okada K, et al. Early and late outcomes of repaired acute DeBakey type I aortic dissection after graft replacement. *J Thorac Cardiovasc Surg*. 2016;151:341-8.
4. Fattouch K, Sampognaro R, Navarra E, Caruso M, Pisano C, Coppola G, et al. Long-term results after repair of type A acute aortic dissection according to false lumen patency. *Ann Thorac Surg*. 2009;88:1244-50.
5. Evangelista A, Salas A, Ribera A, Ferreira-Gonzalez I, Cuellar H, Pineda V, et al. Long-term outcome of aortic dissection with patent false lumen: predictive roles of entry tear size and location. *Circulation*. 2012;125:3133-41.
6. Tsai TT, Schlicht MS, Khanafer K, Bull JL, Valassis DT, Williams DM, et al. Tear size and location impacts false lumen pressure in an ex vivo model of chronic type B aortic dissection. *J Vasc Surg*. 2008;47:844-51.
7. Rylski B, Hahn N, Beyersdorf F, Kondov S, Wolkewitz M, Blanke P, et al. Fate of the dissected aortic arch after ascending replacement in type A aortic dissection. *Eur J Cardiothorac Surg*. 2017;51:1127-34.
8. Akutsu K, Nejima J, Kiuchi K, Sasaki K, Ochi M, Tanaka K, et al. Effects of the patent false lumen on the long-term outcome of type B acute aortic dissection. *Eur J Cardiothorac Surg*. 2004;26:359-66.
9. Tanaka A, Sakakibara M, Ishii H, Hayashida R, Jinno Y, Okumura S, et al. Influence of the false lumen status on clinical outcomes in patients with acute type B aortic dissection. *J Vasc Surg*. 2014;59:321-6.
10. Zierer A, Voeller RK, Hill KE, Kouchoukos N, Damiano RJ, Moon MR. Aortic enlargement and late reoperation after repair of acute type A aortic dissection. *Ann Thorac Surg*. 2007;84:479-87.
11. Clough RE, Waltham M, Giese D, Taylor PR, Schaeffter T. A new imaging method for assessment of aortic dissection using four-dimensional phase contrast magnetic resonance imaging. *J Vasc Surg*. 2012;55:914-23.
12. Girish A, Padala M, Kalra K, Mclver BV, Veeraswamy RK, Chen EP, et al. The impact of intimal tear location and partial false lumen thrombosis in acute type B aortic dissection. *Ann Thorac Surg*. 2016;102:1925-32.
13. Halstead JC, Meier M, Etz C, Spielvogel D, Bodian C, Wurm M, et al. The fate of the distal aorta after repair of acute type A aortic dissection. *J Thorac Cardiovasc Surg*. 2007;133:127-35.
14. Heo W, Song SW, Lee KH, Lee SY, Kim TH, Baek MY, et al. Surgery for acute type 1 aortic dissection without resection of supra-aortic entry sites leads to unfavourable aortic remodeling. *Eur J Cardiothorac Surg*. 2018;54:34-41.
15. Ge YY, Guo W, Cheshire N, Liu XP, Jia X, Xiong J, et al. Preoperative thoracic false lumen branches relate to aortic remodeling after thoracic endovascular aortic repair for DeBakey IIIb aortic dissection. *J Vasc Surg*. 2017;65:659-68.
16. Immer FF, Krähenbühl E, Hagen U, Stalder M, Berdat PA, Eckstein FS, et al. Large area of the false lumen favors secondary dilatation of the aorta after acute type A aortic dissection. *Circulation*. 2005;112:I249-52.
17. Matsushita A, Hattori T, Tsunoda Y, Sato Y, Mihara W. Impact of initial aortic diameter and false-lumen area ratio on type B aortic dissection prognosis. *Interact Cardiovasc Thorac Surg*. 2018;26:176-82.
18. Song JM, Kim SD, Kim JH, Kim MJ, Kang DH, Seo JB, et al. Long-term predictors of descending aorta aneurysmal change in patients with aortic dissection. *J Am Coll Cardiol*. 2007;50:799-804.
19. Kim TH, Song SW, Lee KH, Baek MY, Yoo KJ. Effects of false lumen procedures on aorta remodeling of chronic DeBakey IIIb aneurysm. *Ann Thorac Surg*. 2016;102:1941-7.
20. Ishii H, Nakamura K, Nakamura E, Furukawa K, Ochiai K. Successful embolization therapy through reentry tear in the right subclavian artery for treating patent false lumen in the aortic arch formed after type A dissection repair. *Ann Vasc Dis*. 2017;10:261-4.
21. Kim TH, Lee JH, Shim WH. Embolization of persistent false lumen through reentry tear in a patient who underwent hemiarch replacement operation due to type A dissection. *Ann Thorac Surg*. 2015;99:e43-5.

Key Words: aortic dissection, patent false lumen, postoperative aortic event, morphology of dissected thoracic aorta, preemptive therapy