Long-term Outcomes of Intervention between Open Repair and Endovascular Aortic Repair for Descending Aortic Syndrome: A Propensity-Matched Analysis

Shin-Ah Son  
Kyungpook National University Hospital  
https://orcid.org/0000-0003-3317-6857

Hanna Jung  
Kyungpook National University Hospital

Joon Yong Cho (✉ sina0217@naver.com)  
Kyungpook National University Hospital

Research article

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Abstract

Background

The long-term complication rates of open repair and thoracic endovascular aortic repair (TEVAR) have not yet been determined. Therefore, this study aimed to compare long-term outcomes and aortic reintervention rates between open repair and TEVAR in patients with descending thoracic aortic diseases.

Methods

Between January 2002 and December 2017, 230 patients with descending thoracic aortic disease underwent surgery. Among them, 45 patients underwent open repair and 91 underwent TEVAR treatment at Kyungpook National University Hospital. The primary end points were in-hospital mortality, and short-term complications. The secondary end points were long-term mortality and reintervention rates. Based on the propensity score matching, 35 patients who underwent open repair were matched to 35 patients who underwent TEVAR (ratio = 1:1).

Results

The mean follow-up period was 70.2 ± 51.9 months. Shorter intensive care unit and hospital stay were seen in the TEVAR group than in the open repair group ($p < 0.001$ and $p < 0.001$, respectively). However, in-hospital mortality, and spinal cord ischemia were not significantly different among the two groups ($p = 0.068$ and $p = 0.211$ before matching, $p = 0.303$ and $p = 0.314$ after matching, respectively). The cumulative all-cause death and aorta-related death showed no significant difference ($p = 0.709$ and $p = 0.734$ before matching, $p = 0.888$ and $p = 0.731$ after matching, respectively). However, aortic reintervention rates were higher in the TEVAR group than in the open repair group before and after propensity score matching ($p = 0.006$ and $p = 0.013$, respectively).

Conclusion

The TEVAR group was superior in short-term recovery results but had higher reintervention rates compared to the open repair group. However, there was no significant differences between the groups in long-term survival.

Background

The treatment of descending thoracic aortic syndromes is challenging and depends on its pathologies. Since the introduction of thoracic endovascular aortic repair (TEVAR), many reports have demonstrated that it is a safe and feasible alternative to the conventional open repair [1–3]. Typically, the success of this procedure is dictated by its favorable outcomes and ease of use [4]. Although the use of TEVAR has
rapidly increased due to improved perioperative morbidity rates, significant postoperative complications associated with TEVAR, such as endoleak, stent-graft migration, retrograde type aortic dissection, new-onset dissection, and stent-graft infection, contribute to relatively poor results of TEVAR [3, 5, 6]. In early clinical results with open repair versus TEVAR covered in previous reports [3, 6, 7], there are no long-term data comparing two procedures. In particular, the durability and long-term complication rates of open repair and TEVAR have not yet been determined. In this study, the primary end points were in-hospital mortality, and short-term complications. The secondary end points were long-term mortality and reintervention rates.

The purpose of this study was to compare long-term outcomes and reintervention rates between open repair and TEVAR in patients with descending aortic syndromes. To neutralize the effects of confounding independent variables such as unbalanced numbers (45:91) and age discrepancy, a propensity matched subsample of patients was created for an adequately powered analysis.

**Methods**

**Study population**

Between January 2002 and December 2017, 512 patients were diagnosed with descending thoracic aortic syndromes including dissection, pseudoaneurysm and penetrating atherosclerotic ulcer (PAU) at Kyungpook National University. The study design flowchart is demonstrated in Fig. 1. 230 patients underwent surgery. Among them, 136 patients were included for the study. 45 patients underwent open repair, and 91 underwent TEVAR. We retrospectively reviewed the medical records and undertook telephonic clinical assessments of these patients.

**Definitions**

Acute dissections was defined when the occurrence developed in 14 days from the first symptom. Complicated aortic syndromes were defined as the presence of one or more of the following conditions: aortic maximum size > 5.5 cm; resistant hypertension despite adequate medical therapy; recurrent or refractory pain; impending rupture; rupture with end-organ malperfusion; and extension of dissection. Aortic reintervention was defined as the need for any surgical or endovascular interventions following the initial procedure during follow-up. In the TEVAR group, an endoleak was defined as radiological evidence of blood flow outside the stent-graft according to published guidelines [8].

**Operative strategies**

The treatment modality was decided collaboratively by the cardiologist and cardiac surgeons who were involved in the patients’ care; decision was based on the patients’ co-morbidities, functional status, anatomical feature of the lesion, and the appropriate of vascular access [9].

**Open aortic repair**
Open aortic repair was generally performed via left thoracotomy or median sternotomy. All procedures employed with sequential clamping to minimize ischemic times. In case of left atrial-left femoral artery partial bypass (LHB), blood was drained from the left atrium via the inferior pulmonary vein and returned through the femoral artery. In case of circulatory arrest, bypass was initiated via the femoral artery and vein or the ascending aorta and right atrium.

**TEVAR**

Preoperative CT scans were reviewed for the preoperative assessment of access routes for the feasibility of TEVAR and to measure the bilateral vertebral artery for assessing the subclavian steal syndrome with a policy of selective subclavian artery revascularization. All TEVAR procedures were performed via the transfemoral approach under general anesthesia. Perioperative anticoagulation with heparin was prescribed at a dose of 3000–5000 units. The proximal landing zones in the aortic arch were classified as 0 to 4 according to Ishimaru’s classification [10].

**Statistical analysis**

When comparing continuous variables, the Student’s t-test and Wilcoxon test were used for parametric and nonparametric data, respectively, and are presented with the mean ± standard deviation (SD) or as median and interquartile range (IQR). Categorical variables were reported as absolute numbers or percentages and the Fisher’s exact test or Chi-square test was used for comparison. The Kaplan-Meier method was used to estimate survival. For statistical analyses, p-values < 0.05 were deemed significant. Univariate and multivariate logistic regression models were utilized to determine independent risk factors. Hazard ratios (HRs) are presented with 95% confidence intervals (CIs).

To reduce the effect of selection bias and potential confounding in this retrospective cohort study, estimated propensity scores were used to match two groups. This was computed for each patient using a logistic regression model including the following variables: age, proximal maximal aortic size, aortic pathology, and proximal aortic tear site. The propensity score model was well-calibrated (Hosmer-Lemeshow goodness-of-fit test; p = 0.784) with good discrimination (c-statistic = 0.712). To neutralize the effects of confounding variables, 35 patients in the open repair group were matched to 35 patients who underwent TEVAR using propensity score matching (PSM). The data were analyzed using SAS/STAT software, v. 9.4 (SAS Institute Inc., NC, USA) and SPSS 25 (IBM, Armonk, NY, USA).

**Results**

**Baseline characteristics of patients**

Baseline characteristics of patients who underwent open repair and TEVAR are shown in Table 1. The mean follow-up duration was 70.2 ± 51.9 months (range, 0.0–212.0 months). The median ages of the patients were 56.0 (range, 43.0–64.0) years, and 65.0 (range, 57.0–72.0) years for the open repair and TEVAR groups, respectively, which was significantly different between the two groups (p < 0.001).
Moreover, connective tissue diseases were observed at a significantly higher rate in the open repair group than in the TEVAR group (p < 0.001). After PSM, the baseline characteristics of the patients in each group exhibited no significant difference.
Table 1
Baseline characteristics of patients

| Characteristics                  | Overall series |          |          | After matching |          |          |          |
|----------------------------------|----------------|----------|----------|----------------|----------|----------|----------|
|                                  | Open repair    | TEVAR    | p-value  | Open repair    | TEVAR    | p-value  |
|                                  | N = 45         | N = 91   |          | N = 35         | N = 35   |          |
| Age (years)                      | 56.0 (43.0–64.0)| 65.0 (57.0–72.0) | < 0.001 | 60.0 (49.0–69.0) | 59.0 (51.0–68.0) | 0.967    |
| Men                              | 31 (30.1)      | 72 (69.9) | 0.279    | 25 (71.4)      | 30 (85.7) | 0.145    |
| Height (cm)                      | 167 ± 10.0     | 166 ± 9.0 | 0.623    | 164.8 ± 10.1   | 168.3 ± 7.6 | 0.112    |
| Weight (kg)                      | 66.1 ± 13.2    | 64.9 ± 11.0 | 0.584   | 65.7 ± 12.9    | 68.9 ± 12.4 | 0.283    |
| Initial SBP (mmHg)               | 133.5 ± 34.2   | 141.3 ± 29.3 | 0.208   | 135.7 ± 37.3   | 145.5 ± 27.1 | 0.215    |
| Hypertension                     | 30 (66.7)      | 66 (72.5) | 0.480    | 26 (74.3)      | 25 (71.4) | 0.788    |
| Diabetes                         | 5 (11.1)       | 12 (13.2) | 0.731    | 5 (14.3)       | 1 (2.9)  | 0.088    |
| Current smoking                  | 20 (44.4)      | 36 (39.6) | 0.586    | 16 (45.7)      | 16 (45.7) | 1.000    |
| Obesity                          | 2 (4.4)        | 3 (3.3)   | 0.738    | 2 (5.7)        | 2 (5.7)  | 1.000    |
| CAOD                             | 4 (8.9)        | 10 (11.0) | 0.705    | 3 (8.6)        | 6 (17.1) | 0.284    |
| PAOD                             | 4 (18.2)       | 18 (81.8) | 0.105    | 4 (11.4)       | 5 (14.3) | 0.721    |
| COPD                             | 2 (4.4)        | 4 (4.4)   | 0.990    | 2 (5.7)        | 2 (5.7)  | 1.000    |
| Cerebrovascular accident         | 1 (2.2)        | 11 (12.1) | 0.056    | 1 (2.9)        | 4 (11.4) | 0.164    |
| Acute kidney injury              | 2 (4.4)        | 5 (5.5)   | 0.794    | 2 (5.7)        | 1 (2.9)  | 0.555    |
| Chronic renal failure            | 4 (8.9)        | 7 (7.7)   | 0.810    | 2 (5.7)        | 3 (8.6)  | 0.643    |
| Previous cardiac operation       | 10 (22.2)      | 18 (19.8) | 0.740    | 3 (8.6)        | 6 (17.1) | 0.284    |
| Connective tissue disease        | 8 (17.8)       | 1 (1.1)   | < 0.001  | 2 (5.7)        | 0 (0.0)  | 0.151    |
| Preoperative status              |                |          |          |                |          |          |
| Shock                            | 7 (15.6)       | 5 (5.5)   | 0.052    | 5 (14.3)       | 3 (8.6)  | 0.654    |
| Hemoptysis                       | 6 (13.3)       | 11 (12.1) | 0.836    | 4 (11.4)       | 4 (11.4) | 1.000    |
| Persistent pain                  | 37 (82.2)      | 73 (80.2) | 0.780    | 30 (85.7)      | 27 (77.1) | 0.356    |
| Neurologic deficit               | 3 (6.7)        | 3 (3.3)   | 0.368    | 2 (5.7)        | 0 (0.0)  | 0.151    |
| Characteristics | Overall series | After matching | p-value | Overall series | After matching | p-value |
|----------------|---------------|---------------|---------|---------------|---------------|---------|
|                | Open repair   | TEVAR         |         | Open repair   | TEVAR         |         |
|                | N = 45        | N = 91        |         | N = 35        | N = 35        |         |

Values are presented as the median (interquartile range), mean ± standard deviation or number of patients (%)

TEVAR: thoracic endovascular aortic repair; SBP: systemic blood pressure; CAOD: coronary artery occlusive disease; PAOD: peripheral artery occlusive disease; COPD: chronic obstructive pulmonary disease.

Descending thoracic aortic diseases details of patients are shown in Table 2. No variables showed significant difference between the groups, before and after PSM, respectively.
Table 2
Descending thoracic aortic diseases details of patients

| Characteristics                      | Overall series |               | After matching |               |               |          |
|--------------------------------------|----------------|---------------|----------------|---------------|---------------|----------|
|                                      |                | Open repair   | TEVAR p-value  | Open repair   | TEVAR p-value |          |
|                                      |                | N = 45        | N = 91         | N = 35        | N = 35        |          |
| Acute                                |                |               | 0.154          |               | 0.112         |          |
| Rupture                              |                | 15 (33.3)     | 20 (22.0)      | 13 (37.1)     | 7 (20.0)      | 0.081    |
| Preoperative diagnosis               |                |               | 0.021          |               | 0.081         |          |
| Dissection                           |                | 10 (22.2)     | 27 (29.7)      | 8 (22.9)      | 10 (28.6)     | 0.584    |
| PAU                                  |                | 2 (4.4)       | 1 (1.1)        | 2 (5.7)       | 0 (0.0)       | 0.151    |
| Pseudoaneurysm                       |                | 33 (73.3)     | 63 (69.2)      | 25 (71.4)     | 25 (71.4)     | 1.000    |
| Arch involvement                     |                | 12 (26.7)     | 14 (15.4)      | 9 (25.7)      | 4 (11.4)      | 0.124    |
| Maximal aortic size (mm)             |                | 54.9 ± 4.7    | 51.5 ± 4.5     | 52.8 ± 4.8    | 51.8 ± 3.7    | 0.985    |
| Aortic tear site                     |                |               | 0.471          |               | 0.445         |          |
| Arch                                 |                | 5 (11.1)      | 4 (4.4)        | 4 (11.4)      | 1 (2.9)       | 0.164    |
| Isthmus                              |                | 8 (17.8)      | 34 (37.4)      | 6 (17.1)      | 12 (34.3)     | 0.101    |
| Descending                           |                | 32 (71.1)     | 53 (58.2)      | 25 (71.4)     | 22 (62.9)     | 0.445    |
| Malperfusion                         |                | 5 (11.1)      | 3 (3.3)        | 3 (8.6)       | 0 (0.0)       | 0.077    |
| CSF drainage                         |                | 14 (31.1)     | 17 (18.7)      | 8 (22.9)      | 7 (20.0)      | 0.771    |
| Emergency                            |                | 17 (37.8)     | 28 (30.8)      | 16 (45.7)     | 9 (25.7)      | 0.081    |

Values are presented as mean ± standard deviation or number of patients (%)

TEVAR: thoracic endovascular aortic repair; PAU: penetrating atherosclerotic ulcer; CSF: cerebrospinal fluid.

Operative details are showed in Table 3. In the open repair group, circulatory arrest perfusion was performed most frequently (60.0%), and thoracotomy was the most common approach (60.0%). In the TEVAR group, zone 3 TEVAR was performed most frequently (40.7%).
| Open repair | (N = 45) |
|-------------|----------|
| **Perfusion method** |  |
| Left atrium- Femoral artery partial bypass | 15 (33.3) |
| Partial Shunt * | 3 (6.67) |
| Circulatory arrest | 27 (60.0) |
| Femoral artery-Femoral vein | 9 (20.0) |
| Aorta-Right atrium | 18 (40.0) |
| **Operative Approach** |  |
| Median sternotomy | 10 (22.2) |
| Median sternotomy + Thoracotomy | 8 (17.7) |
| Thoracotomy | 27 (60.0) |
| Cardiopulmonary bypass time (min) | 191.1 ± 104.3 |
| Cross clamp time (min) | 60.5 ± 49.9 |
| Circulatory arrest time (min) | 25.5 ± 31.4 |
| **TEVAR** | (N = 91) |
| Number of devices | 1.2 ± 0.4 |
| Proximal stent size (mm) | 35.1 ± 4.7 |
| Stent Length (mm) | 140.2 ± 28.2 |
| Zone 0 | 6 (6.6) |
| Total debranching bypass with TEVAR |  |
| Zone 1 | 1 (1.1) |
| BCA to LCCA and LCCA to LSCA bypass |  |
| Zone 2 | 25 (27.5) |
| LCCA to LSCA bypass in 5 patients |  |
| Zone 3 | 37 (40.7) |
| Zone 4 | 22 (24.2) |
Postoperative outcomes and complications

Postoperative outcomes and complications are shown in Table 4. The patients in the open repair group significantly required more operative time, needed longer ventilator care, stayed longer in the intensive care unit, and had longer periods of hospitalization than those in the TEVAR group (all \( p < 0.001 \), respectively), before and after PSM, respectively.
### Table 4
Postoperative outcomes and complications

| Characteristics          | Overall series |              |              | After matching |              |              |              |
|--------------------------|----------------|--------------|--------------|----------------|--------------|--------------|--------------|
|                          | Open repair N=45 | TEVAR N=91   | p-value      | Open repair N=35 | TEVAR N=35 | p-value      |
| **Outcomes**             |                |              |              |                |              |              |              |
| Operative time           | 420.6 ± 182.9  | 149.3 ± 92.9 | < 0.001      | 386.7 ± 124.5  | 150.9 ± 88.7 | < 0.001      |
| Postop Hospital stay (day)| 41.5 ± 42.7    | 18.3 ± 16.0  | < 0.001      | 34.2 ± 26.5    | 15.1 ± 8.6   | < 0.001      |
| Total ICU stay (day)     | 19.6 ± 31.2    | 5.7 ± 14.0   | < 0.001      | 17.7 ± 24.6    | 3.7 ± 5.4    | 0.002        |
| Total ventilator care (min)| 145.7 ± 334.1  | 33.6 ± 158.2 | 0.009        | 111.9 ± 225.4  | 11.9 ± 48.6  | 0.008        |
| Reintubation             | 7 (15.6)       | 4 (4.4)      | 0.025        | 5 (14.3)       | 1 (2.9)      | 0.088        |
| **Complications**        |                |              |              |                |              |              |              |
| Acute kidney injury      | 19 (42.2)      | 18 (19.8)    | 0.006        | 15 (42.9)      | 6 (17.1)     | 0.019        |
| Dialysis                 | 6 (13.3)       | 6 (6.6)      | 0.192        | 3 (8.6)        | 1 (2.9)      | 0.303        |
| Hematologic complications| 1 (2.2)        | 2 (2.2)      | 0.993        | 1 (2.9)        | 0 (0.0)      | 0.314        |
| Bleeding                 | 9 (20.0)       | 3 (3.3)      | 0.001        | 6 (17.1)       | 2 (5.7)      | 0.133        |
| Spinal cord injury       | 2 (4.4)        | 1 (1.1)      | 0.211        | 1 (2.9)        | 0 (0.0)      | 0.314        |
| Stroke                   | 3 (6.7)        | 1 (1.1)      | 0.071        | 2 (5.7)        | 0 (0.0)      | 0.151        |
| Pulmonary complications   | 9 (20.0)       | 7 (7.7)      | 0.036        | 7 (20.0)       | 2 (5.7)      | 0.074        |
| Wound complications      | 12 (26.7)      | 6 (6.6)      | 0.001        | 9 (25.7)       | 3 (8.6)      | 0.057        |
| In-hospital mortality    | 5 (11.1)       | 3 (3.3)      | 0.068        | 3 (8.6)        | 1 (2.9)      | 0.303        |
| 30-day mortality         | 5 (11.1)       | 4 (4.4)      | 0.138        | 3 (8.6)        | 2 (5.7)      | 0.643        |

Values are presented as mean ± standard deviation or number of patients (%)

TEVAR: thoracic endovascular aortic repair; Postop: postoperative; ICU: intensive care unit.

Acute kidney injury (AKI) was significantly higher in the open repair group than those in the TEVAR group, before and after PSM, respectively. Bleeding, pulmonary and wound complications were significantly
more observed in the open repair group; however, there was no statistical difference after PSM. There was no statistical difference in-hospital mortality and 30-day mortality between the two groups, before and after PSM, respectively. In-hospital mortality was observed in five patients in the open repair group (11.1%), of whom four and one died of acute aorta-related complications and hospital-acquired pneumonia, respectively. In the TEVAR group, among three patients (3.3%), two patients died of delayed rupture after stent insertion and one patient died of aspiration pneumonia.

Reintervention

Reintervention data associated with specific treatments are depicted in Table 5. In the open repair group, five patients (11.1%) required reinterventions; and four patients experienced new onset aortic expansion. Among these patients, secondary open repair surgery was performed in three patients, and TEVAR was performed in one patient. In the TEVAR group, 22 patients (48.9%) required reintervention; twelve patients had endoleaks and four patient developed fistula, such as aortobronchial fistula (ABF) or aortoesophageal fistula (AEF).

Table 5
Aortic reintervention details

| Cause of Reintervention | Open repair (N = 5, 11.1%) | TEVAR (N = 22, 48.9%) |
|-------------------------|----------------------------|----------------------|
| New onset dissection/expansion | Aorta replacement:3 | Aorta replacement:2 |
|                         | TEVAR:1                   | TEVAR:1              |
| Fistula formation       | Aorta replacement and lobectomy:1 | Aorta replacement and lobectomy:4 |
|                         |                           | Aorta replacement and esophagotomy:1 |
|                         |                           | TEVAR:1              |
| Endoleak                | TEVAR:12                  | LSCA plug obliteration:1 |
| Infection               | Aorta replacement:1       |                      |
| TEVAR: thoracic endovascular aortic repair; LSCA: left subclavian artery.

In the overall series, freedom from aortic reintervention at 1, 5, and 10 years in the open repair group was 97.1% ± 0.1%, 94.2% ± 0.1%, and 87.1% ± 0.0%, respectively. The corresponding rates in the TEVAR group were 93.2% ± 0.1%, 68.4% ± 0.1%, and 62.2% ± 0.0%. After PSM, the freedom from aortic reintervention at 1, 5, and 10 years in the open group was 100% ± 0.0%, 96.4% ± 0.1%, and 92.2% ± 0.1%, respectively. In the TEVAR group, the corresponding values were 91.0% ± 0.1%, 78.1% ± 0.1%, and 66.8% ± 0.1%. Freedom from aortic reintervention (Fig. 2) was lower in the TEVAR group than the open repair group before and after PSM (p = 0.006 and p = 0.013).
A multivariable Cox proportional hazard model is shown in Table 6.
| Variable                | Overall series |                                      | After matching |                                      |                                      |                                      |
|-------------------------|----------------|---------------------------------------|----------------|---------------------------------------|---------------------------------------|---------------------------------------|
|                         | Univariate     | Multivariate                          | Univariate     | Multivariate                          | Univariate                           | Multivariate                        |
|                         | HR (95% CI)    | HR (95% CI)                           | HR (95% CI)    | HR (95% CI)                           | HR (95% CI)                           | HR (95% CI)                         |
|                         | p-value        | p-value                               | p-value        | p-value                               | p-value                               | p-value                               |
| Male                    | 2.0 (0.6–5.8)  | 0.191                                 | 0.2 (0.0–2.2)  | 0.230                                 |                                      |                                      |
| Hemoptysis              | 2.8 (1.3–6.9)  | 0.026                                 | 3.8 (1.2–11.3) | 0.016                                 | 8.5 (2.4–29.3)                        | 0.001                                 | 6.8 (1.3–34.7)                      | 0.021                               |
| Hoarseness              | 2.2 (0.8–9.0)  | 0.102                                 |                |                                       | 1.6 (0.2–13.2)                       | 0.619                                 |                                      |                                      |
| Hypertension            | 0.2 (0.5–2.9)  | 0.595                                 |                |                                       | 4.4 (0.5–34.9)                       | 0.151                                 | 7.9 (0.8–73.1)                      | 0.048                               |
| Diabetes                | 2.0 (0.7–5.4)  | 0.148                                 |                |                                       | 1.3 (0.2–10.7)                       | 0.766                                 |                                      |                                      |
| CAOD                    | 2.5 (0.9–6.7)  | 0.059                                 |                |                                       | 2.2 (0.5–10.6)                       | 0.210                                 |                                      |                                      |
| PAOD                    | 1.7 (0.7–4.4)  | 0.210                                 |                |                                       | 1.9 (0.4–8.9)                        | 0.400                                 |                                      |                                      |
| COPD                    | 3.4 (1.0–11.4) | 0.046                                 |                |                                       | 4.4 (0.9–21.2)                       | 0.063                                 |                                      |                                      |
| Cerebrovascular accident| 2.2 (0.7–6.4)  | 0.144                                 |                |                                       | 1.7 (0.2–14.2)                       | 0.579                                 |                                      |                                      |
| Acute kidney injury     | 1.1 (0.1–7.4)  | 0.994                                 |                |                                       | 5.1 (0.6–41.2)                       | 0.124                                 |                                      |                                      |
| Previous cardiac        | 1.1 (0.6–3.4)  | 0.388                                 |                |                                       | 3.2 (0.8–12.4)                       | 0.082                                 | 6.81 (1.3–34.9)                     | 0.021                               |

HR: hazard ratio; CI: confidence interval; CAOD: coronary artery occlusive disease; PAOD: peripheral artery occlusive disease; COPD: chronic obstructive pulmonary disease.
Change of aorta size after the repair

Figure 3 shows the changes in the aorta size after the repair. During the following 5 years, the maximal aortic diameter was reduced in the open repair group compared to that in the TEVAR group before and after PSM ($p = 0.004$ and $p = 0.05$). The maximal aortic diameter decreased from 55.4 ± 18.2 mm to 40.07 ± 11.0 mm in the open repair group as we expect. Meanwhile the maximal aortic diameter increased from 52.0 ± 14.7 mm to 56.8 ± 19.1 mm in the TEVAR group.

Survival

In the open repair group, overall mortality was 42.2% (19/45), and aorta-related mortality was 17.8% (8/45) during follow-up. Aorta-unrelated death secondary to cancer occurred in three patients and three patients died of pneumonia. Late deaths secondary to unknown causes occurred in four patients. In the TEVAR group, overall mortality was 35.2% (32/91), and aorta-related mortality was 12.1% (11/91) during follow-up. Aorta-unrelated death secondary to cancer occurred in three patients and two patients died of pneumonia. Late deaths secondary to unknown causes occurred in 10 patients.

The cumulative survival of all-cause death was not statistically different, either before or after PSM, Additionally, the cumulative survival rates from aorta-related deaths were also not significantly different, before and after PSM, respectively (Fig. 4A,B).

A multivariable Cox proportional hazard model identified that age > 80 years, systolic blood pressure < 90 mmHg, diabetes, preoperative chronic renal failure, and aortic arch involvement were predictive factors in the in overall series; after PSM analysis, age > 80 years, and aortic arch involvement (p = 0.024 and p = 0.048, respectively) were independent predictors of aorta-related mortality (Table 7).
Table 7
Cox proportional hazard regression analysis for aorta-related mortality

| Variable                        | Overall series | After matching |
|---------------------------------|----------------|----------------|
|                                 | Univariate     | Multivariate   | Univariate     | Multivariate   |
|                                 | HR (95% CI)    | p-value        | HR (95% CI)    | p-value        | HR (95% CI)    | p-value        |
| Age > 80 years                  | 5.9 (1.3–25.9) | 0.018          | 16.7 (2.7–104.3) | 0.002          | 9.9 (1.2–83.4) | 0.031          | 24.0 (1.5–378.1) | 0.024 |
| SBP < 90 mmHg                   | 2.9 (0.9–8.9)  | 0.058          | 6.0 (1.6–22.4)  | 0.008          | 2.6 (0.5–13.3) | 0.241          |
| Hemoptysis                      | 2.5 (0.9–7.0)  | 0.077          | 5.2 (1.2–22.0)  | 0.023          |
| Dissection                      | 0.7 (0.3–1.4)  | 0.356          | 0.4 (0.0–3.3)   | 0.392          |
| Pseudoaneurysm                  | 1.4 (0.7–2.6)  | 0.333          | 2.8 (0.3–23.2)  | 0.329          |
| Arch involvement                | 3.5 (1.4–8.7)  | 0.007          | 5.4 (1.8–16.1)  | 0.002          | 5.1 (1.3–20.9) | 0.022          | 14.5 (1.0–211.5) | 0.048 |
| Maximal aortic size > 50 mm     | 3.1 (0.9–10.8) | 0.068          | 3.8 (0.5–31.9)  | 0.200          |
| Malperfusion                    | 2.3 (0.5–10.1) | 0.210          | 5.2 (0.6–43.9)  | 0.128          |
| Chronic renal failure           | 7.0 (2.4–20.3) | 0.000          | 5.7 (1.2–26.8)  | 0.027          | 8.4 (1.5–46.7) | 0.015          |
| eGFR                            | 1.2 (1.1–1.3)  | 0.001          | 1.1 (0.9–1.5)   | 0.211          |
| Diabetes                        | 2.8 (1.0–7.8)  | 0.047          | 3.1 (0.9–10.7)  | 0.049          | 4.2 (0.8–20.9) | 0.080          |
| COPD                            | 2.7 (0.6–11.9) | 0.178          | 0.1 (0.0–34.8)  | 0.654          |
## Discussion

Since the report on the first successful open repair of a descending thoracic aortic aneurysm with a prosthetic graft in 1953 by De Bakey and Cooley [11], an open surgical repair for treating descending thoracic aortic disease has been the gold standard for 50 years [11–14]. Despite remarkably improved operative techniques and maximized organ protection, open repair of the descending thoracic aorta is still associated with high complications, including intraoperative and postoperative death, hemorrhage, stroke, and paraplegia [9, 15].

Dake et al. [12] proposed an alternate method of TEVAR which sought to provide better clinical outcomes in patients who were deemed to be at high risk for open repair or were typically considered nonsurgical candidates. Therefore, TEVAR has shown significantly improved early quality of life versus open repair and a general trend toward better short-term perioperative survival and freedom from major complications [1, 3, 4, 16]. However, TEVAR has anatomic restrictions such as severe thoracic aortic tortuosity, short landing and sealing zones, and extensive mural thrombus. These are the limiting factors, although a seemingly infinite variety of debranching and bypass procedures can be applied to extend either the proximal or distal sealing zones [6, 17]. Furthermore, significant complications related to stent-grafts were always implied [3, 5, 15].

Patients who underwent TEVAR have a tendency to have a worse prognosis and older age, with multiple comorbidities, than patients who underwent open repair. Due to the relative lack of data supporting the long-term reliability of TEVAR, open repair procedure has been preferentially offered to younger patients [4, 18]. Therefore, to neutralize the effects of age difference which could potentially unmask a mortality benefit, PSM was performed between the two groups to perform an adequately powered analysis.

In present study, operative time, postoperative length of stay, and procedure-related complications showed better results with TEVAR before and after PSM. Not surprisingly, TEVAR was considering as the procedure involved no aortic cross-clamping, ischemic time, or thoracotomy [4]. In open repair cases, some disadvantages of deep hypothermia, including coagulopathy which caused difficulty in controlling bleeding, retraction injury to a heparinized lung, cold injury to the lung, and a profound inflammatory response from the bypass circuit [19]. For the in-hospital mortality of the open repair group, in present study, one patient died of pneumonia. AKI is another important complication and regarded as a marker of increased early or late morbidity and mortality after open repair or TEVAR [20]. Patients who underwent TEVAR were older and tended to receive larger amounts of contrast agent, which was not safe considering the risk of AKI. In the present study, postoperative AKI was higher in the open repair group (42.2%), and dialysis was performed in 13.3% of patients. Eighteen patients who underwent TEVAR
(19.8%) had an AKI with six requiring dialysis. Before and after PSM, AKI was higher in the open repair group; however, there was no statistical difference in dialysis between the two groups.

Although a short-term hospital outcome is more favorable for TEVAR, aorta-related complications are more frequent for TEVAR. Five patients (11.1%) in the open repair group underwent reintervention, and the most common cause of reintervention was new-onset aortic dissection or expansion. In the case of TEVAR, the most common cause of reintervention was endoleaks. Twenty-two (48.9%) patients who underwent reintervention showed no in-hospital mortality in the TEVAR; however, seven patients showed late mortality, one patient died of ABF and one patient died of sepsis due to stent-graft infection. Ascending aortic replacement was performed in one patient with retrograde aortic dissection, four patients with ABF underwent aorta replacement and lobectomy, and one patient with AEF underwent aorta replacement and esophagotomy, and showed late mortality. Additionally, eight patients who were initially offered TEVAR, later crossed over to open repair due to difficult anatomy or other reasons.

In the open repair cases, high-volume centers reported mortality and neurological morbidity rates ranging from 5.4–7.2% for mortality, 2.1–6.2% for permanent stroke, 5.7% for permanent paraparesis, and 0.8–2.3% for permanent paralysis, respectively [21, 22]. In the TEVAR cases, the perioperative results for the three stent-graft trials showed 1.9–2.1% for mortality, 2.4–4% for stroke, 4.4–7.2% for permanent paraparesis, and 1.3–3% for permanent paralysis, respectively [1, 2, 23]. In the present study, the open repair group showed 63.8% of overall 10-year survival rate, 84.3% of aorta-related 10-year survival rate, 6.7% of stroke, and 4.4% of SCI (after PSM, 65.4%, 88.5%, 5.7%, and 2.9%, respectively). In TEVAR, overall 10-year survival rate was 56.5%, aorta-related 10-year survival rate 81.3%, 1.1% stroke, and 1.1% SCI (after PSM, 64.2%, 88.7%, 0.0%, 0.0%, respectively). Although mortality was higher than previous large-scale studies, it was difficult to compare our results because previous reports did not have long-term follow-up data.

Moreover, although long-term survival of the two groups had no significant difference, more reinterventions occurred in the TEVAR group; the costs of additional graft modules to treat endoleaks and of follow-up computed tomography increase hospital cost, attributing to the disadvantage of TEVAR. In addition, TEVAR has less procedure-related complications than that of open repair; patients had more adverse events, such as re-dissection, fistula formation and stent-graft infection should be considered in the choice of approach.

Some authors have proposed that TEVAR does not change the natural history of the disease, and although less invasive, may be inferior to open therapies [24]. In our present study, maximal aortic size decreased more in the open repair group than in the TEVAR group, but not dramatically. This supports the report that it does not alter natural history of aortic pathologies, and, emphasizes the importance of long-term follow up. For this reason, in patients requiring TEVAR, the establishment of a precise TEVAR indication will reduce the requirement for further reintervention; better results are expected with improvements in debranching skills and stent-graft development.
Our study has several limitations. First, it was a single-center retrospective study that included a small number of patients, with a possible selection bias that might have affected our results. Second, the difference of follow-up duration and frequency can affect the survival rate of both groups. We performed PSM attempts to reduce the bias due to confounding variables. However, since TEVAR was introduced in 2007, it has a relatively short follow-up duration, whereas more frequent follow-up to monitor stent-grafts is expected to affect the results. Finally, the functional status of patient information influenced treatment strategy; there was no data interpretation, and studies on cost analysis, which is an increasingly important consideration for treatment strategy, have not been conducted.

Conclusions

In conclusion, our study showed that a long-term comparison between the open repair and TEVAR group demonstrated similar results in patients with descending aortic syndromes. However, patients who underwent TEVAR showed superior short-term recovery results and a higher reintervention rate than the open repair group. Larger multicenter population studies that consider quality of life could support our present study results.

Declarations

Ethics approval and consent to participate

The institutional review board (IRB) of Kyungpook National University Hospital approved this retrospective study and waived the requirement for individual patient consent (IRB approval No. 2019-10-051).

Consent for publication

Not applicable

Availability of data and materials

All data generated or analysed during this study are included in this published article and its supplementary information files.

Competing interests

The authors declare that they have no conflict of interest.

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Authors' contributions
SS collected the case data and drafted the original manuscript. JC and HJ operated and treated the patients and critically reviewed the manuscript. All authors read and approved the final manuscript.

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We certify that this research is our own work and all sources of information used in this research have been fully acknowledged.

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**Figures**

2002 January - 2017 December
512 patients
Descending thoracic aorta diseases

Exclusion
- Medical treatment (N=253)
- Refuse operation (N=29)

230 patients
Underwent repair

Exclusion
- Traumatic injury (N=89)
- Hybrid aortic surgery (N=4)
- Congenital aortic disease (N=1)

Inclusion
136 patients

Open repair
45 patients

TEVAR
91 patients

1 : 1 Propensity score matching
35 patients from each group

Figure 1
Study design flowchart

Figure 2

Freedom from aortic reintervention before propensity matching and after propensity matching

Figure 3

Changes in aortic diameters over time before propensity matching and after propensity matching
Figure 4

Cumulative survival of all-cause death and aorta-related death