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REVIEW ARTICLE

Early results and outcome predictors of the off-the-shelf t-branch endograft for endovascular repair of thoracoabdominal aortic aneurysms: a systematic review and meta-analysis

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Abstract

Objective To determine the outcomes of endovascular thoracoabdominal aortic aneurysm (TAAA) repair using t-branch stent graft.

Methods We performed a systematic search for relevant studies published after 2012 in MEDLINE, Embase, Web of Science, and Cochrane CENTRAL registry. This study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (protocol CRD42022378654). Validity and risk of bias were assessed using the National Heart, Lung, and Blood Institute Quality Assessment Tool. Both random- and fixed-effects models were used to calculate the pooled effect sizes, where appropriate. Sensitivity and subgroup analyses were performed to explore sources of heterogeneity.

Results Eleven reports from 10 retrospective observational studies, comprising 997 patients, were included. Regarding the perioperative outcomes, the overall technical success rate was 94.2% (95% confidence interval (CI) 90.1–96.6), 30-day mortality 9.0% (95% CI 5.0–13.4), spinal cord ischemia (SCI) 6.7% (95% CI 5.4–8.2), early endoleak 3.5% (95% CI 2.7–4.5), acute kidney injury (AKI) 13.8% (95% CI 8.7–21.3), permanent dialysis 2.5% (95% CI 1.2–5.4), and early reintervention 110 per 1000 person-years (95% CI 68–174). Negative regression coefficients were observed between the number of elective cases and 30-day mortality, AKI, and permanent dialysis. There was a positive regression coefficient between permanent dialysis and American Society of Anesthesiologists (ASA) class 4–5, the number of ruptured aneurysms, and Crawford class I–II–III. The overall mortality beyond the first 30 days was 138 per 1000 person-years.

Conclusion T-branch stent graft is a safe and effective option to use in endovascular TAAA repair with a good technical success rate and acceptable rate of mortality and complications.

Keywords Branched endovascular aneurysm repair · Meta-analysis · Systematic review · Thoracoabdominal aortic aneurysms · T-branch endograft

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Introduction

Thoracoabdominal and pararenal or juxta renal aortic aneurysms present a complex clinical challenge. Open surgical repair is associated with a significant risk of perioperative mortality and morbidity [1, 2]. However, the introduction of custom-made devices (CMDs) and off-the-shelf branched stent grafts has established endovascular repair as a viable alternative treatment option. This approach has demonstrated promising outcomes, including high technical success rates and low complication rates [3, 4]. Manufacturing CMDs is a time-consuming process, requiring usually 8–12 weeks, which limits the use of such devices in urgent and emergent cases [5]. Therefore, off-the-shelf branched and fenestrated devices

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are developed to overcome such limitations. The t-Branch (Cook Medical, Bloomington, IN, USA) is an off-the-shelf branched endograft manufactured based on the Zenith fenestrated and branched endovascular aneurysm repair platform, which has 4 fixed branches and is commercially available in Europe since 2012 [6]. Since then, several studies on the outcomes and safety of t-Branch, each with relatively small sample sizes, have suggested durable and feasible outcomes in both elective and urgent situations [7–10]. However, given the novelty of the t-Branch device, sufficient evidence regarding its safety and efficacy seems to be lacking. A recent meta-analysis by Konstantinou et al. comprising only 197 patients treated with t-Branch indicated relatively low complication rates and requirement for reintervention [11]. However, given the small number of patients in the last meta-analysis and the publication of more recent studies using much larger sample sizes, it seems essential to perform an updated meta-analysis to include the new emerging findings.

Methods

Study design

We conducted our review in alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [12]. The protocol for the review was registered in the International Prospective Register of Systematic Reviews (PROSPERO) (ID: CRD42022378654).

Literature search and study selection

A comprehensive search was performed across multiple electronic databases, including MEDLINE, Embase, Web of Science, and the Cochrane CENTRAL registry. The complete search strategy can be found in the Online Resource (Table S1). To ensure thoroughness, the reference lists of eligible studies, relevant citations, and related review articles were also manually screened. Gray literature and publications in languages other than English were excluded**.**

The search focused on studies published between June 2012 (the approval date for the t-Branch device) and December 2022. Only studies reporting clinical outcomes of the t-Branch device, an off-the-shelf solution for thoracoabdominal aortic aneurysms (TAAA), were included.

Three independent reviewers (SA, RR, and MSG) applied predefined Population, Intervention, Comparator, Outcomes, Study design (PICOS) criteria to screen for relevant studies. The target population included patients diagnosed with TAAA based on computed tomography (CT) angiography. The intervention of interest was endovascular repair using the t-Branch device (Cook Medical, Bloomington, Ind). No comparator group was defined, as the analysis was single-arm in nature.

Studies had to report at least one of the outcomes pertaining to either perioperative or medium-term outcomes. Perioperative outcomes (within the 30-days postoperative period) included technical success, 30-days mortality, spinal cord ischemia (SCI) (transient or permanent), stroke, acute kidney injury (AKI), and endoleak. Early outcomes were defined as 1-year survival, target visceral vessel (TVV) patency, reintervention rate, and endoleak during the early follow-up.

Exclusion criteria included case reports, studies with fewer than 15 patients, editorials, letters, and review articles. If multiple publications presented data from the same patient cohort, the most recent or largest study was used. For partially overlapping studies, corresponding authors were contacted to clarify and obtain exclusive data. If authors were unreachable, preference was given to studies with larger sample sizes and more robust designs.

Data extraction and quality assessment

Two reviewers (ZF and SA) independently extracted data from the included studies. Any disagreements were resolved through consensus. Extracted data included:

- Publication details: study name, year of publication, and country.
- Study design and follow-up: duration of follow-up and study type.
- Baseline patient characteristics: number of participants, mean age, sex, American Society of Anesthesiologists (ASA) classification, Crawford classification, history of previous aortic surgery, symptomatic status, presence of ruptured aneurysms, and maximum aneurysm diameter.
- Procedural details: type of procedure (elective or emergent), staging of procedures, use of cerebrospinal fluid drainage (CSFD), proximal thoracic extensions, planned TVVs, and types of bridging stents (balloon-expandable (BE) vs. self-expandable (SE)).
- Outcomes: perioperative and medium-term clinical outcomes.

The quality and risk of bias of the included studies were evaluated using the National Heart, Lung, and Blood Institute (NHLBI) Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies [13]. A third reviewer (SH) resolved any discrepancies.

Analysis strategy

All statistical analyses were performed using Comprehensive Meta-Analysis software (version 3.0). Continuous variables were summarized as means with standard deviations (SD), and categorical variables were reported as proportions for pooling. Heterogeneity among studies was quantified using the chi-squared Q-statistic and I^2 values, where I^2 thresholds of 25%, 50%, and 75% reflected low, moderate, and high heterogeneity, respectively [14].

To address heterogeneity, a random-effects model was applied when significant heterogeneity was present ($P < 0.05$), even after sensitivity and subgroup analyses. Otherwise, a fixed-effects model was used. Sensitivity analysis involved sequentially excluding individual studies to assess the robustness of pooled outcomes. If omitting a study resulted in a > 20% change in the effect size, that study was excluded to minimize bias.

Univariate meta-regression was performed to explore potential associations between baseline characteristics (e.g., patient demographics or procedural details) and clinical outcomes. Publication bias was evaluated using Egger's test, and corrections were applied through Duval and Tweedie's trim-and-fill method [15–17]. P-value < 0.05 was considered statistically significant across all analyses.

In cases where individual studies reported patient-level data or median values with ranges, conversions were applied to derive consistent effect size measures. Notably, results from overlapping populations, such as Kölbel et al. [18] and Spanos et al. [19], were combined and analyzed as a single dataset to avoid duplication.

Results

The systematic search process is demonstrated as the PRISMA flow diagram in Fig. 1. The complete search strategy and list of excluded studies upon full-text scrutiny, along with the exclusion reasons, are outlined in Online Resource (Table S1 and Table S2). A total of 11 retrospective observational studies, comprising 997 patients, met the eligibility criteria to be synthesized into the meta-analysis [2, 5, 9, 10, 18–24]. The weighted mean follow-up was 2.33 months. Treated patients included 706 (70.8%) males, and the weighted mean age was calculated as 70.339 (95% confidence interval (CI): 69.95–70.73) years. Pooled mean aneurysm diameter was 68.125 (95% CI: 67.32–68.93) mm. According to the NHLBI Quality Assessment Tool, 9 studies were considered low risk bias, while 1 was reported to have a high risk of bias. The detailed quality assessment is shown in Online Resource (Table S3). Table 1 and Table 2 summarize the characteristics of included studies and the patients and procedural baseline characteristics, respectively. The pooled estimates were not substantially deviated by any single study, as revealed by the sensitivity analyses.

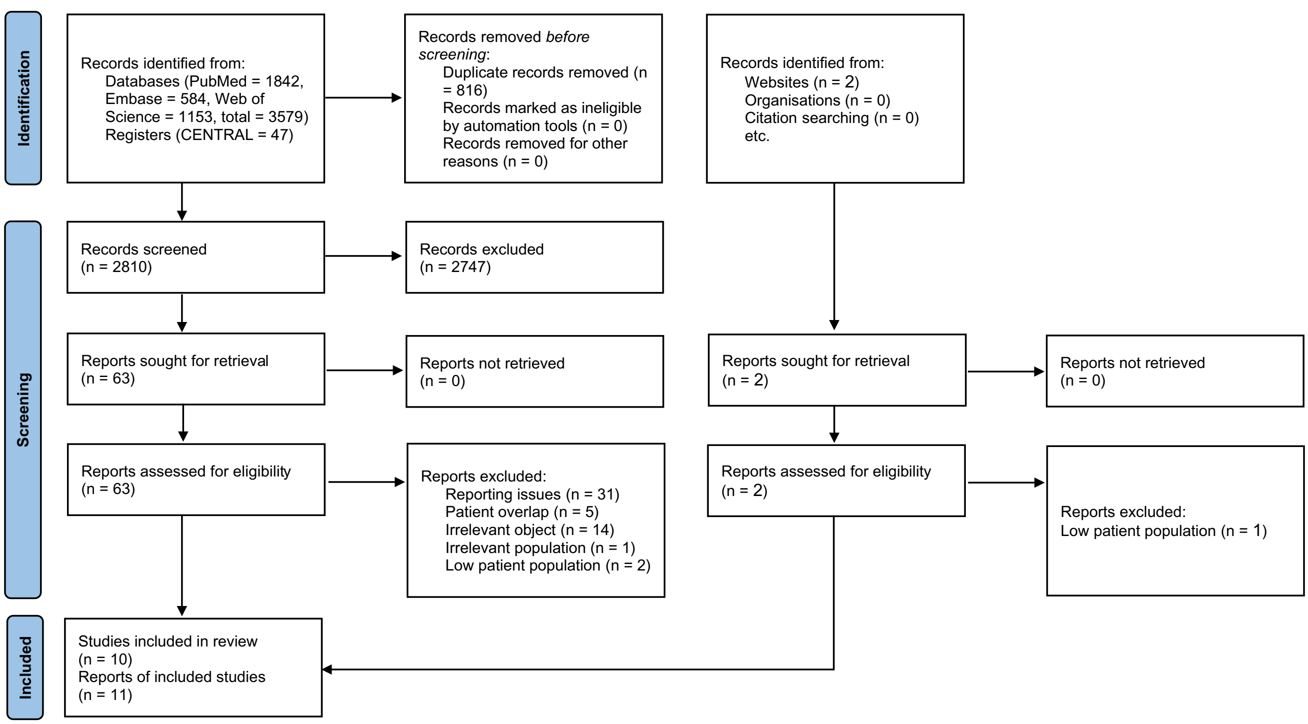

Fig. 1 The Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram, demonstrating the systematic search process

Table 1 Baseline characteristics of included studies

Author	Year	Country	Study design	No. of patients	Mean age ± SD (yr.)	Mean follow-up (mo.)	Crawford type of aneurysm (n)	Outcomes	Quality
Bertoglio et al. [20]	2018	Italy	Retrospective observational	18	74.55 ± 8.04	1	Type II (6) Type III (7) Type IV (5)	**Perioperative:** Technical success, 30-day mortality Stroke, SCI, AKI	Good
Bisdas et al. [10]	2014	Germany	Retrospective observational	22	70 ± 8	6	Type I (0) Type II (9) Type III (12) Type IV (1)	**Perioperative:** Technical success 30-day mortality, SCI **Intermediate-term:** Mortality, Reintervention	Good
Bosiers et al. [21]	2021	Germany Sweden	Retrospective observational	80	71 ± 7.4	12	Type I (5) Type II (30) Type III (14) Type IV (28)	**Perioperative:** Technical success, 30-day mortality Stroke, SCI, AKI Primary patency Endoleak **Intermediate-term:** Mortality, Stroke, SCI, AKI Reintervention, Endoleak	Good
Ferrer et al. [5]	2022	Italy	Retrospective observational	48	73 ± 8	18	Type I (3) Type II (9) Type III (7) Type IV (15)	**Perioperative:** Technical success, 30-day mortality Stroke, SCI, AKI Primary patency Endoleak **Intermediate-term:** Mortality, Stroke, AKI, Endoleak Reintervention, Primary patency	Good

Table 1 (continued)

Author	Year	Country	Study design	No. of patients	Mean age ± SD (yr.)	Mean follow-up (mo.)	Crawford type of aneurysm (n)	Outcomes	Quality
Gallitto et al. [2]	2022	Italy	Retrospective observational	65	73 ± 7	18	Type I–II–III (54) Type IV (11)	**Perioperative:** Technical success, 30-day mortality SCI, AKI, Endoleak **Intermediate-term:** Mortality, Reintervention	Fair
Mirza et al. [22]	2020	USA	Retrospective observational	24	72 ± 10	13.71	Type I–II–III (21)	**Perioperative:** Technical success, 30-day mortality Stroke, SCI, AKI **Intermediate-term:** Mortality, Reintervention	Good
Silingardi et al. [9]	2018	Italy	Retrospective observational	73	72 ± 7	18.55	Type I (5) Type II (28) Type III (24) Type IV (16)	**Perioperative:** Technical success 30-day mortality Stroke, SCI, AKI Reintervention Primary patency, Endoleak **Intermediate-term:** Mortality, Reintervention Primary patency, Endoleak	Good
Kölbel et al. and Spanos et al. [18, 19]	2021 & 2022	Germany Greece Poland	Retrospective observational	542	70.5 ± 8.5	1	Type I (31) Type II (73) Type III (118) Type IV (233) Type V (32)	**Perioperative:** Technical success, 30-day mortality Stroke, SCI, AKI, Reintervention Primary patency, Endoleak **Intermediate-term:** Primary patency	Good

Table 1 (continued)

Author	Year	Country	Study design	No. of patients	Mean age ± SD (yr.)	Mean follow-up (mo.)	Crawford type of aneurysm (n)	Outcomes	Quality
Tenorio et al. [23]	2022	Germany Poland Italy UK US	Retrospective observational	100	70.64 ± 6.76	6.4	Type I (8) Type II (28) Type III (29) Type IV (26) Type V (2)	**Perioperative:** Technical success, 30-day mortality Stroke, SCI, AKI **Intermediate-term:** Mortality, Endoleak, Reintervention Primary patency	Good
Ulsaker et al. [24]	2022	Norway	Retrospective observational	28	69.09 ± 1.69	2.26	Type I (3) Type II (8) Type III (8) Type IV (9)	**Perioperative:** Technical success 30-day mortality, SCI Reintervention **Intermediate-term:** Mortality, SCI, Primary patency	Good

SD, standard deviation; *SCI*, spinal cord ischemia; *AKI*, acute kidney injury

Perioperative outcomes

The overall technical success rate was 94.2% (95% CI 90.1–96.6, $I^2=58.951\%$, 10 studies; Fig. 2). Univariate meta-regression showed a negative regression coefficient with Crawford class I–II–III and ASA class 4–5, with lower success rate in patients with Crawford class I–II–III ($R^2=0.75$, $P=0.035$) and ASA class 4–5 ($R^2=0.69$, $P=0.067$) (Online Resource, Table S4). Regression for aneurysmal diameter, number of ruptured cases, number of elective cases, previous aortic surgery, and SE stent graft to BE stent graft ratio (SE/BE) was not significant.

The pooled 30-day mortality rate was 9.0% ($P=0.03$, 95% CI 5.0–13.4, $I^2=52.24\%$, 10 studies; Fig. 3). Univariate meta-regression for the number of elective procedures showed a negative regression coefficient. Regression for ASA class 4–5, Crawford class I–II–III, number of ruptured cases, aneurysmal diameter, previous aortic surgery, and SE/BE ratio was not significant.

The overall stroke rate was 2.7% (95% CI 1.8–4.0, $I^2=0.00\%$, 7 studies; Online Resource Figure S1). The data for stroke rate and number of studies were not sufficient to perform meta-regression. The results for the other perioperative outcomes are presented in Online Resource (Table S5 and Figure S2). In summary, the pooled rate for SCI was 6.7% (95% CI 5.4–8.2, $I^2=49.75\%$, 10 studies), for early endoleak 3.5% (95% CI 2.7–4.5, $I^2=90.66\%$, 8 studies), for AKI 13.8% (95% CI 8.7–21.3, $I^2=73.40\%$, 7 studies), for permanent dialysis 2.5% (95% CI 1.2–5.4, $I^2=57.15\%$, 7 studies), and for early reintervention 110 per 1000 person-years (95% CI 68–174, $I^2=68.22\%$, 7 studies). Further subgroup analysis revealed that the rate of permanent SCI was even lower with a rate of 4.04% (95% CI: 2.87–5.66; $I^2=0.00\%$). The high heterogeneity regarding the

Table 2 Baseline characteristics of patients and procedures of the included studies

Variable	No. of studies	No. of patients
Patient characteristics		
Gender (female/male)	11	291/706
Crawford class		
Type I	9	55
Type II	9	191
Type III	9	219
Type IV	11	347
Type V	11	34
Asymptomatic patients	10	637
Symptomatic patients	10	250
Ruptured aneurysms	9	111
Previous aortic surgery	6	334
ASA score		
Class 1	6	12
Class 2	6	116
Class 3	6	513
Class 4	7	156
Class 5	7	12
Procedural characteristics		
Emergency		
Elective	9	612
Urgent or emergent	9	349
CSF drain		
Prophylactic	10	300
Therapeutic	9	26
Staged repair	5	77
Use of thoracic extension(s)	4	147
Number of TVVs		
Total	11	3806
Planned	11	3696
Successful	11	3631
Type of bridging stents		
Balloon-expandable	6	1157
Self-expandable	6	1683

No., number; *ASA*, American Society of Anesthesiologists; *CSF*, cerebrospinal fluid; *TVV*, target visceral vessel

early endoleak rate could also be treated using within studies subgroup analysis based on types of endoleak (Online Resource, Figure S2). Meta-regression showed no association between SCI rate and prophylactic CSFD, ASA class 4–5, Crawford class I–II–III, number of elective cases, or aneurysmal diameter. In addition, there was no association between early endoleak and Crawford class I–II–III, number of elective cases, SE/BE ratio, or aneurysmal diameter. AKI had a strong negative regression coefficient with the number of elective procedures. We could not find a significant regression coefficient between AKI and ASA class 4–5 (insufficient data), Crawford class I–II–III, aneurysmal diameter, or number of ruptured aneurysms. We identified a strong negative regression coefficient between permanent dialysis and the number of elective cases, and it also showed a positive regression coefficient with ASA class 4–5 (coefficient 3.71, R^2 1.00), number of ruptured aneurysms (coefficient 5.78, R^2 1.00), and Crawford class I–II–III (coefficient 5.23, R^2 1.00). Regarding early endoleak, we found a positive regression coefficient with the SE/BE ratio (coefficient 0.393, R^2 1.00) and aneurysmal diameter (coefficient 0.130, R^2 0.68). We identified no significant regression coefficients linking early endoleak to the proportion of elective/ruptured cases or Crawford class I–III.

Furthermore, we evaluated the publication bias regarding the technical success rate and early mortality. Although the funnel plot was not symmetric for either outcome, the Egger test *P*-value was significant only for the 30-day mortality rate (Online Resource Figure S3 and S4). Using the trim-and-fill method, the adjusted rate of 30-day mortality was estimated to be 12% (95% CI 7.9–17.9).

Early outcomes

Data from seven studies including 412 patients were pooled regarding early follow-up outcomes [2, 5, 9, 10, 21–23]. The included studies exhibited substantial heterogeneity in early follow-up duration (range: 1–72 months), with a pooled reintervention rate of 8 per 1000 person-years (95% CI 3–13, $I^2 = 81.67\%$). Sensitivity analysis indicated that the study by one of the studies [23] deviated from the pooled effect substantially. Hence, we ran the analysis excluding this study, which achieved a reintervention rate of 9 per 1000 person-years (95% CI 6–12) with a reduced heterogeneity ($I^2 = 47.18$, $P = 0.092$). Meta-regression identified ASA class 4–5 as the only factor significantly associated with an increased reintervention rate during early follow-up ($R^2 = 0.75$, $P = 0.005$).

The overall mortality beyond the first 30 days was 138 per 1000 person-years ($P < 0.001$, 95% CI: 89–186; $I^2 = 94.19\%$). Meta-regression demonstrated a significant association between early follow-up mortality and ASA class 4–5 ($R^2 = 0.74$, $P = 0.004$). No significant associations were found with the ratio of ruptured aneurysms, elective procedures, Crawford class, or aneurysm diameter.

Discussion

T-branch off-the-shelf stent graft was introduced in 2012 for endovascular repair of TAAAs. In this comprehensive meta-analysis, we evaluated the outcomes of this new device. We analyzed the data from 10 studies, including

Study name	Statistics for each study			Weight
	Event rate and 95% CI	Z-Value	P-Value	
Bertoglio et al. (2018)[20]	0.974 (0.690 - 0.998)	2.519	0.012	4.15
Bisdas et al. (2014)[10]	0.978 (0.732 - 0.999)	2.662	0.008	2.35
Bosiers et al. (2021)[21]	0.994 (0.906 – 1.000)	3.555	0.000	4.07
Ferrer et al. (2022)[5]	0.958 (0.848 – 0.989)	4.346	0.000	12.39
Gallitto et al. (2022)[2]	0.861 (0.754 – 0.926)	5.086	0.000	17.67
Mirza et al. (2020)[22]	0.980 (0.749 – 0.999)	2.724	0.006	2.35
Silingardi et al. (2018)[9]	0.917 (0.828 – 0.962)	5.662	0.000	9.58
Kolbel et al. & Spanos et al. (2021 & 2022)[18,19]	0.970 (0.952 – 0.981)	13.805	0.000	24.08
Tenorio et al. (2022)[23]	0.920 (0.848 – 0.959)	6.626	0.000	16.26
Ulsaker et al. (2022)[24]	0.890 (0.712 – 0.964)	3.462	0.001	7.10
Random effects (Q value = 21.925, I^2 = 58.951%, P = 0.009)	**0.942 (0.901 – 0.966)**	**9.623**	**0.000**	

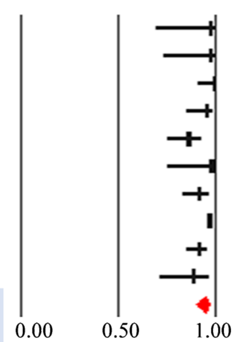

Fig. 2 Technical success rate. Event rate, rate of successful t-branch implantation in patients; CI, confidence interval

Study name	Statistics for each study			Weight
	Event rate and 95% CI	Z-Value	P-Value	
Bertoglio et al. (2018)[20]	0.055 (0.008 - 0.306)	-2.751	0.006	4.15
Bisdas et al. (2014)[10]	0.022 (0.001 - 0.268)	-2.662	0.008	2.35
Bosiers et al. (2021)[21]	0.012 (0.002 – 0.086)	-4.214	0.000	4.07
Ferrer et al. (2022)[5]	0.104 (0.044 – 0.227)	-4.555	0.000	12.39
Gallitto et al. (2022)[2]	0.200 (0.120 – 0.315)	-4.471	0.000	17.67
Mirza et al. (2020)[22]	0.020 (0.001 – 0.251)	-2.724	0.006	2.35
Silingardi et al. (2018)[9]	0.041 (0.013 – 0.120)	-5.341	0.000	9.58
Kolbel et al. & Spanos et al. (2021 & 2022)[18,19]	0.127 (0.102 – 0.158)	-14.944	0.000	24.08
Tenorio et al. (2022)[23]	0.090 (0.047 – 0.164)	-6.621	0.000	16.26
Ulsaker et al. (2022)[24]	0.071 (0.018 – 0.244)	-3.495	0.000	7.10
Random effects (Q value = 18.847, df = 9, I^2 = 52.240%, P = 0.027)	**0.090 (0.059 – 0.134)**	**-10.075**	**0.000**	

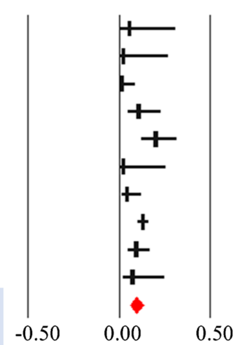

Fig. 3 Thirty-day mortality rate forest plot. Event rate, death rate within 30 days of operation; CI, confidence interval

997 patients. Most studies were performed retrospectively on prospectively collected data from patients. We were unable to identify trials or prospective studies that met our inclusion criteria. Furthermore, there was a certain amount of heterogeneity among the studies regarding patient population and the definition of some endpoints. Therefore, the results found should be cautiously interpreted. As our study focused solely on the t-branch stent graft, we are unable to make direct comparisons between this device and alternative techniques or devices. The outcomes and rates referenced for other approaches in the following sections are derived from previously published studies to provide contextual insight.

In comparison to a previous meta-analysis with a similar objective [11], we evaluated 5 times greater number of patients (997/197). We did not include all the studies included in the previous review. Some studies included in their review were updated by the time of conducting the current study; therefore, we included the new reports. In addition, some studies in their review had fewer than 15 patients treated with t-branch; therefore, we excluded these studies. Regarding data analysis, in contrast to the previous review, we had enough data for meta-regression analysis to determine the effect of moderators on the majority of outcomes.

Perioperative outcomes Our study demonstrated a technical success rate of 94.2%, which aligns with rates reported for both off-the-shelf and customized endografts. For instance, this result is comparable to prior reports of multibranched endografts (92.75%) [11] and physician-modified stent grafts (PMSG) (91.4%) [25]. Another review [26] reported a success rate of 98.7% using chimney grafts for abdominal aortic aneurysm repair. However, in that review, the proportion of urgent/emergent surgeries was significantly lower than in the current study. The unadjusted 30-day mortality rate of 9.0% in our analysis (12.0% after adjusting for publication bias using the trim-and-fill method) is similar to the 8.9% reported by another study [4] for open surgical repair of TAAAs. The difference with the 6.18% rate reported in the review [25] for PMSG was also non-significant. We also found that the number of elective procedures shows a negative regression coefficient with the 30-day mortality rate. The low stroke rate of 2.7% is consistent with the previous review [11] which reported a low rate of 4%, and is also similar to the 3.9% stroke rate after open TAAA repair [4].

The occurrence of SCI has been a concern in endovascular treatment of TAAAs, especially using t-branch stent grafts, due to the larger extent of the healthy aorta and the number of intercostal arteries sacrificed during the implantation, as compared to open repair [20]. The overall SCI rate in our study showed an acceptable rate of 6.7% for any type of SCI, and 4.0% for permanent SCI. This is significantly lower than the 13% in-hospital SCI rate after endovascular repair of TAAAs and is comparable to the 7% rate reported for open repair [4]. We could not identify a correlation between the prophylactic use of CSFD and SCI rate. So, our results regarding SCI rate are consistent with what is reported by another study [27], which reported a permanent SCI rate of 6% that was not correlated with the overall usage of CSFD.

Acute renal failure remains a significant complication following endovascular repair of aortic aneurysms and may substantially influence perioperative and long-term outcomes [28, 29]. In this study, we identified an AKI rate of 13.8%, comparable to the 18.7% reported in the earlier review [11]. We observed a negative regression coefficient between AKI incidence and the number of elective procedures performed. However, significant heterogeneity among studies persisted, likely reflecting inconsistencies in AKI diagnostic criteria. To mitigate this variability, we analyzed the incidence of renal injury requiring permanent dialysis, which occurred in 2.5% of cases. This rate aligns with the 4.0% incidence of dialysis-dependent AKI after open repair [4] but remains lower than the 6.9% reported following branched TAAA repair [29]. Multivariate analysis demonstrated that elective procedure (negative association), ASA class 4–5, ruptured cases, and Crawford class I–II–III (positive associations) influenced this outcome.

Reintervention due to complications such as TVV stenosis and endoleak also warrants attention after endovascular TAAA repair [30]. Our analysis found an early reintervention rate of 11% for t-branch stent grafts, with marked heterogeneity across studies. We further identified an association between higher SE/BE ratios and elevated early reintervention rates. These results exceed the 7.2% reintervention rate documented for custom-made branched/fenestrated stent grafts [31].

Early outcomes The average follow-up time in this review was 2.33 months, compared to 15 months in the earlier analysis [11]. This difference is due to a study included in the current review [18, 19], which accounted for roughly half of the total patients. Early outcomes were reported in one paper [18], while late outcomes were reported in another [19]. Since the late outcomes paper [19] did not specify the average follow-up duration, we used the early outcomes data [18], which had a 1-month follow-up. This significantly reduced the overall weighted follow-up time.

To clarify the range of follow-up durations across studies: individual studies reported follow-ups ranging from 1 to 24 months. In the study by Spanos et al. [19], some patients were followed for up to 72 months.

During this follow-up period, the late reintervention rate was 8 per 1000 person-years, with a high level of heterogeneity between the studies. The overall early mortality rate was 138 per 1000 person-years. Early mortality was higher in patients with ASA class 4–5, consistent with previous findings [32]. Emerging evidence suggests that postoperative complications, particularly cardiopulmonary events, and pre-existing chronic kidney disease are associated with reduced survival [33, 34].

Limitations The main limitation of our study was the small number of studies reporting the outcomes of the t-branch stent graft, which is a relatively new device. Although we included more patients than in the previous meta-analysis, the majority of new patients came from a single study, which can limit the generalizability of our results. Furthermore, the weighted mean follow-up duration across studies was very short (2.33 months), limiting our ability to assess long-term outcomes. Another factor affecting the quality of our results was the methodology of the included studies, which were mostly retrospective observational studies conducted on prospectively collected data. We were unable to identify any trials or prospective studies that met our inclusion criteria. Importantly, our analysis relied solely on aggregated study-level data rather than individual patient-level data, which restricts the depth of subgroup exploration and adjustment for confounding factors.

Another issue was the considerable heterogeneity between studies regarding patient populations and reporting standards for some endpoints (with I^2 exceeding 50% for multiple outcomes and reaching > 90% for early endoleak rates), reducing the precision and generalizability of pooled estimates. Subgroup analyses to explore sources of heterogeneity were only feasible for a limited number of outcomes (e.g., early endoleak, SCI) due to insufficient stratified data; key outcomes like 30-day mortality and AKI lacked the necessary data for such analyses. Another concern was the publication bias observed regarding the 30-day mortality rate. Although we used the trim-and-fill method to calculate an adjusted value, this cannot fully address the potential bias. Additionally, the meta-regression analyses should be interpreted cautiously due to the limited number of studies available for specific covariates, which reduces statistical power and increases susceptibility to variability in study-level reporting.

Conclusion

The t-branch stent graft demonstrates good early outcomes in endovascular TAAA repair, with a high technical success rate and acceptable mortality and complication rates. However, more prospective trials and direct comparative studies with other techniques and devices are needed to validate these findings and assess long-term performance.

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Data availability Please contact the corresponding author to access the data used in this study.

Declarations

Ethical approval Approval was obtained from the Ethics Committee of Isfahan University of Medical Sciences (ID: IR.MUI.MED.REC.1401.394).

Informed consent Not applicable. As this study is a review based solely on previously published data, no new data were collected from human or animal participants.

Statement of human and animal rights Not applicable. As this study is a review based solely on previously published data, no new data were collected from human or animal participants.

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