Journal of
Clinical Medicine

MDPI

Systematic Review

Unilateral vs. Bilateral Selective Cerebral Perfusion for Acute Type A Aortic Dissection with Frozen Elephant Trunk: Systematic Review and Meta-Analysis

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Abstract

Background/Objectives: Previous studies failed to demonstrate the best cerebral perfusion option during total aortic arch replacement surgery. We therefore sought to investigate clinical results of patients who received unilateral (u) versus bilateral (b) selective antegrade cerebral perfusion (SACP) during total aortic arch replacement by means of the frozen elephant trunk (FET) technique for acute type A aortic dissections (ATAADs). **Methods**: A systematic review and meta-analysis was performed by including relevant studies reporting outcomes of patients with ATAADs undergoing total arch replacement with the FET technique using either unilateral or bilateral SACP. Pubmed, ScienceDirect, SciELO, DOAJ, and Cochrane library databases were searched until May 2023. **Results**: A total of 44 papers with 5983 patients were included, 3872 for unilateral SACP and 2111 for bilateral SACP. Although patients undergoing bSACP presented a higher incidence of preoperative comorbidities compared to uSACP, there was not a significant difference in terms of mortality and major postoperative complications between the two groups. Distal body circulatory arrest time was not associated with any outcome at meta-regression, while longer SACP times in the whole population were significantly associated with higher neurological complications. Significant increased mortality was found in long uSACP. **Conclusions**: Our analysis showed that centers already apply the appropriate perfusion strategy tailored to the complexity of the patient's condition. It is therefore crucial to tailor the approach to the complexities of individual patients rather than seeking a definitive superiority between the two perfusion techniques to optimize outcomes during FET for ATAAD. Further studies are warranted to confirm these results.

Keywords: acute aortic dissection; frozen elephant trunk; selective antegrade cerebral perfusion; total arch replacement; cardiac surgery; meta-analysis

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Academic Editors: Reinhard Kopp and Anna Kabłak-Ziembicka

Received: 7 August 2025
Revised: 2 September 2025
Accepted: 9 September 2025
Published: 10 September 2025

Citation: Baudo, M.; D'Alonzo, M.; Muneretto, C.; Benussi, S.; Di Bacco, L.; Rosati, F. Unilateral vs. Bilateral Selective Cerebral Perfusion for Acute Type A Aortic Dissection with Frozen Elephant Trunk: Systematic Review and Meta-Analysis. *J. Clin. Med.* **2025**, *14*, 6392. https://doi.org/10.3390/jcm14186392

1. Introduction

Acute type A aortic dissection (ATAAD) is a critical surgical emergency with a substantial risk of mortality [1]. The primary goal of the surgical approach involves the need for the exclusion of the entry tear, located in most cases at the level of the ascending aorta or the inner curvature of the arch. However, the presence of an entry tear into the arch and the extension of the false lumen into the aortic arch and the descending thoracic aorta may necessitate more extensive interventions. Consequently, more comprehensive techniques have been introduced over the years such as total arch replacement (TAR) by means of the frozen elephant trunk (FET) procedure [2]. The device demonstrated excellent performance, particularly regarding ease of implantation, as well as false lumen exclusion and thrombosis; however, this technique was still associated with a not negligeable incidence of major neurological complications [3,4].

While some of these complications seem to be related to the device itself, such as spinal cord ischemia and injury, others seem to be a direct consequence of the cerebral perfusion strategy used during the phase of the device's positioning and the open distal anastomosis [5]. In fact, different protective cerebral perfusion strategies are available at present, with antegrade or retrograde cerebral perfusion leading to improved postoperative results when compared to deep hypothermic circulatory cerebral arrest [6]. Furthermore, selective antegrade cerebral perfusion (SACP) can be performed either unilaterally (uSACP) or bilaterally (bSACP). The comparison of these two techniques did not demonstrate a clear advantage of one over the other in previous studies [7–9], but these results were derived from comparisons involving various aortic pathologies and/or techniques. Even a recent meta-analysis on the general surgical treatment of ATAAD, which suggested a possible advantage of bSACP, included different surgical techniques [10]. Therefore, we sought to investigate clinical outcomes of patients who received uSACP versus bSACP during aortic arch replacement surgery for ATAAD by means of FET procedure.

2. Materials and Methods

2.1. Protocol and Registration

The protocol for this review is registered with the PROSPERO database of systematic reviews (ID: CRD42023465077). Because the analysis was based exclusively on previously published data and did not involve direct patient participation, institutional ethics approval and informed consent were not necessary. The datasets used and analyzed during the current study can be obtained from the corresponding author upon reasonable request.

2.2. Search Strategy

This review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework [11]. The study selection process is summarized in the flow diagram, Figure 1. A systematic literature search was performed across PubMed, ScienceDirect, SciELO, DOAJ, and the Cochrane Library up to May 2023, targeting reports of patients undergoing TAR with the FET procedure using either unilateral or bilateral SACP for ATAAD. The complete search strategy is provided in Table S1. To ensure thoroughness, reference lists of eligible papers and prior reviews were also examined (backward snowballing). Screening for eligibility was conducted independently by two investigators (M.B. and M.D.), with any discrepancies resolved through discussion and, when necessary, consultation with a third reviewer (F.R.).

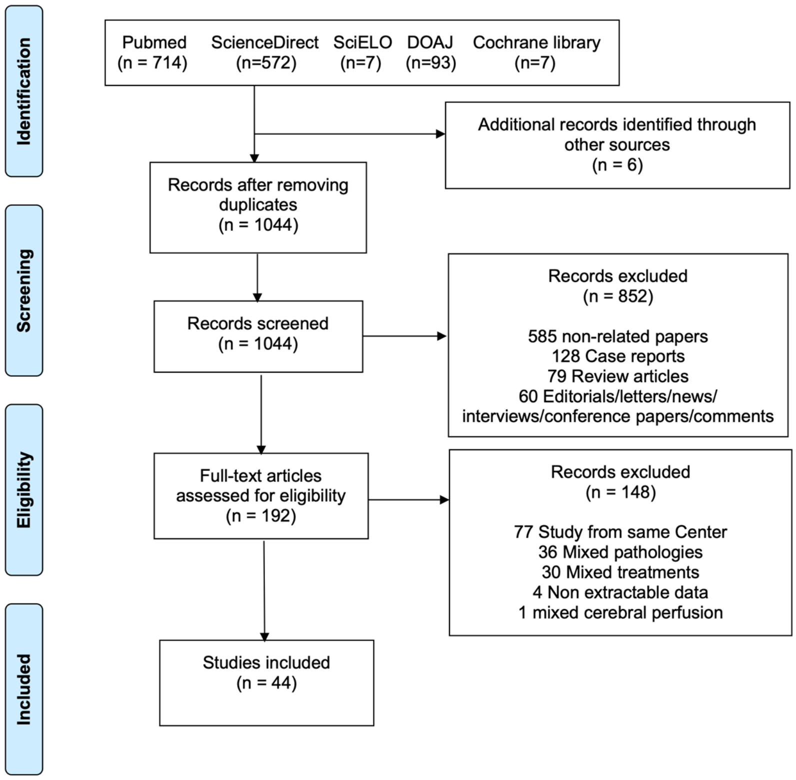

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of the included studies.

2.3. Inclusion and Exclusion Criteria

We included studies that reported outcomes of patients with ATAADs undergoing TAR with the FET technique using either unilateral or bilateral SACP. Bilateral SACP was considered when perfusion was established simultaneously in both the right and left carotid (or their parent vessels), ensuring direct antegrade blood supply to both hemispheres independently, regardless of variations or incomplete collateral circulation. This contrasts with unilateral SACP where perfusion was delivered into one cerebral vessel (commonly the right axillary or innominate artery). Adequacy of perfusion to the contralateral hemisphere depends on the integrity of the circle of Willis and collateral flow pathways. Exclusion criteria included studies involving populations with aneurysms or other non-urgent aortic conditions, as well as those employing surgical methods beyond TAR or techniques other than FET. Additionally, studies incorporating supra-aortic vessel stent branching techniques were omitted. Articles employing cerebral perfusion techniques other than unilateral or bilateral SACP were not taken into account. Papers that did not provide distinguishable data between uSACP and bSACP, or that specified that the strategy could change according to clinical worsening, were also excluded. Studies with fewer than 10 patients, along with case reports, series, reviews, abstracts, presentations, comments, and papers not in English, were also disregarded. In cases of multiple publications from the same institution, the study periods were evaluated, and the study with the largest sample size was included in the event of any time overlap.

2.4. Data Extraction

The extraction of data was carried out using Microsoft Office 365 Excel software (Microsoft in Redmond, Washington, DC, USA). The information gathered included details about the study's timeframe, location, country, and the size of the sample. Specifics about the patients' characteristics, intraoperative data, and postoperative outcomes were also abstracted.

Given the likelihood of encountering discrepancies in reported information across cases, it was anticipated that each article might introduce unique variables not present in others. Therefore, a degree of interpretation was necessary to address missing data pertaining to certain variables. The denominators for specific variables served as indicators of their respective percentage values. In presenting this data, the denominators were based on explicit mentions of variables' presence or absence, or on reasonable inferences where applicable.

2.5. Critical Appraisal and Outcomes of Interest

The quality of included non-randomized studies was assessed through The Risk of Bias in Non-Randomized Studies of Interventions tool (ROBINS-I) [12].

The primary endpoint was hospital mortality, while secondary endpoints included postoperative cerebrovascular accidents, spinal cord ischemia, bleeding requiring surgery, and need of dialysis.

2.6. Statistical Analysis

For postoperative outcomes, pooled event rates (PERs) or means (PEMs) were calculated and were presented with a 95% confidence interval (CI). In all analyses, studies were weighted by the inverse of the variance of the estimate for that study, and between-study variance was estimated with the DerSimonian–Laird method with random effects model. Studies with zero occurrences were included in the meta-analysis, and zero cell frequencies were adjusted using a treatment arm continuity correction. Equivalence hypothesis testing was set at a two-tailed 0.05 significance level. Heterogeneity was assessed using the Cochran Q test, with I^2 values. Assessment of publication bias utilized funnel plots and Egger's regression test, where applicable.

Meta-regression was performed to further analyze the relation between the cerebral perfusion strategy with circulatory and SACP times for neurological complications and mortality. Results were expressed as odds ratio (OR), 95%CI, and *p*-value.

All analyses were carried out using R, version 4.3.1 (R Project for Statistical Computing, Vienna, Austria) and RStudio version 2023.06.0+421. The "meta" package was employed for the meta-analysis.

3. Results

3.1. Study Selection and Characteristics

The systematic review process is outlined in Figure 1. The literature search identified 1393 potentially eligible studies. Six additional articles were identified through backward snowballing. After removal of duplicates, 1044 studies were screened. Among these, 192 full-text articles were assessed for eligibility. Forty-four articles [2,13–54] met our inclusion criteria (Supplementary Material), with a total of 5983 patients, 3872 for uSACP and 2111 for bSACP. Publication year ranged from 2008 to 2023, and the sample size ranged from 10 to 1522 patients. Out of 5269 patients with stent information, most (79.7%, n = 4198) received a Cronus (MicroPort Medical, Shanghai, China), 10.5% (n = 551) a J Graft Open Stent/Frozenix (Japan Lifeline Co, Ltd., Tokyo, Japan), 6.5% (n = 343) a Thoraflex Hybrid (Terumo Aortic, Glasgow, Scotland, UK), 3.2% (n = 166) an E-Vita (Artivion, Kennesaw, GA, USA), 0.5% (n = 28) a Gianturco (Microport Medical Corp., Shanghai, China), 0.2% (n = 10) a Sutureless Integrated Stented (SIS) graft (Beijing Percutek Therapeutics Inc., Beijing, China), and 0.1% (n = 4) a Talent (Medtronic Inc., Minneapolis, MN, USA). Most procedures were carried out with separate reimplantation of epiaortic vessels and Zone 2 distal anastomosis. Details of the individual studies are shown in Tables S2 and S3. The studies included 3 propensity-matched studies and 41 observational studies. The critical appraisal of the included studies is displayed in Table S4.

3.2. Baseline Patients' Characteristics

The two groups showed significant differences in terms of preoperative characteristics. In particular, bSACP patients were significantly older (59.8 ± 5.4 vs. 51.6 ± 6.4, $p < 0.001$), reported more previous cerebrovascular events (8.3% vs. 4.3%, $p < 0.001$) and previous cardiac surgery (4.7% vs. 2.5%, $p = 0.003$), and suffered more from COPD (8.7% vs. 1.2%, $p < 0.001$), chronic kidney disease (13.2% vs. 3.0%, $p < 0.001$), and coronary artery disease (13.3% vs. 6.7%, $p < 0.001$), when compared to uSACP. Moreover, patients in the bSACP group had a worse clinical presentation with a higher incidence of acute neurological deficit (9.5% vs. 1.7%, $p < 0.001$), lower hemodynamic performance (18.2% vs. 3.8%, $p < 0.001$), and hemopericardium (17.8% vs. 5.2%, $p < 0.001$), when compared with the uSACP group. Baseline patients' characteristics are summarized in Table 1.

Table 1. Baseline patients' characteristics of the included studies *.

Variable	Overall (N = 5983)	Unilateral (N = 3872)	Bilateral (N = 2111)	*p*-Value
Mean age, years	57.0 ± 6.9	51.6 ± 6.4	59.8 ± 5.4	**<0.001**
Male	75.8% (4538/5983)	79.3% (3069/3872)	69.6% (1469/2111)	**<0.001**
BMI	25.8 ± 1.8	25.5 ± 1.8	26.3 ± 1.8	0.1069
Connective tissue disease	4.8% (169/3556)	4.6% (112/2432)	5.1% (57/1124)	0.6014
Diabetes	5.6% (287/5147)	5.5% (197/3613)	5.9% (90/1534)	0.5986
COPD	2.9% (118/4138)	1.2%% (40/3239)	8.7% (78/899)	**<0.001**
History of stroke	5.2% (193/3733)	4.3% (128/2954)	8.3% (65/779)	**<0.001**
Hypertension	73.9% (3891/5265)	74.9% (2793/3730)	71.5% (1098/1535)	**0.0131**
CKD	5.2% (216/4169)	3.0% (98/3277)	13.2% (118/892)	**<0.001**
CAD	7.6% (309/4045)	6.7% (236/3498)	13.3% (73/547)	**<0.001**
Previous cardiac surgery	2.9% (110/3809)	2.5% (78/3124)	4.7% (32/685)	**0.003**
Acute neurological deficit	5.4% (192/3563)	1.7% (32/1871)	9.5% (160/1692)	**<0.001**
Hemodynamic compromise	6.0% (201/3358)	3.8% (110/2859)	18.2% (91/499)	**<0.001**
Hemopericardium	7.7% (301/3933)	5.2% (166/3182)	17.8% (135/751)	**<0.001**

* The denominator is based on the data availability among the included studies. Bold values mean $p < 0.05$. BMI = body mass index; CAD = coronary artery disease; CKD = chronic kidney disease; COPD = chronic obstructive pulmonary disease; CPR = cardiopulmonary resuscitation.

3.3. Meta-Analysis

Intraoperatively, patient with uSACP underwent a significantly higher rate of root replacement surgery (PER: 30.11%, 95%CI: 23.95–37.07, vs. 12.90%, 95%CI: 7.77–20.66, $p = 0.0012$), particularly utilizing the Bentall technique (PER: 28.64%, 95%CI: 22.66–35.49, vs. 8.64%, 95%CI: 5.11–14.24, $p < 0.0001$), with respect to bSACP. The PEM for SACP time exhibited a significant discrepancy between the two groups (bSACP: 80.5 min, 95%CI: 54.7–118.5, vs. uSACP: 49.8 min, 95%CI: 39.0–63.5, $p = 0.0395$). The target temperature was significantly lower in the uSACP compared to bSACP (uSACP: 22.5 °C, 95%CI: 21.5–23.6 vs. bSACP: 26.0 °C, 95%CI: 25.1–26.9, $p < 0.001$). No other significant differences were noted, as indicated in Table 2.

Table 2. Meta-analysis of the intraoperative data.

Outcome	**Group**	**Studies**	**Total Pts**	**Estimate [95%CI]**	**Heterogeneity: I^2, p-Value**	**Egger's**	**Group Difference**
Root replacement	Bilateral Unilateral	26 13	1917 3697	12.90% [7.77–20.66] 30.11% [23.95–37.07]	91.0%, $p < 0.0001$ 91.5%, $p < 0.0001$	$p = 0.0012$ $p = 0.2448$	$\mathbf{p = 0.0012}$
VSRR	Bilateral Unilateral	20 12	1393 2541	5.73% [2.94–10.88] 2.09% [0.82–5.26]	84.5%, $p < 0.0001$ 80.5%, $p < 0.0001$	$p < 0.0001$ $p = 0.5701$	$p = 0.0833$
Bentall	Bilateral Unilateral	20 11	1393 2508	8.64% [5.11–14.24] 28.64% [22.66–35.49]	78.9%, $p < 0.0001$ 85.5%, $p < 0.0001$	$p = 0.0009$ $p = 0.0165$	$\mathbf{p < 0.0001}$
Wheat	Bilateral Unilateral	21 11	1608 2508	1.36% [0.82–2.25] 1.03% [0.36–2.92]	0.0%, $p = 0.9661$ 60.2%, $p = 0.0051$	$p = 0.0405$ $p = 0.0028$	$p = 0.6375$
Root repair	Bilateral Unilateral	23 12	1497 2541	0.00% [0.00–0.00] 1.76% [0.34–8.51]	0.0%, $p = 0.9964$ 87.8%, $p < 0.0001$	$p < 0.0001$ $p = 0.1098$	$p = 0.5901$
AV repair	Bilateral Unilateral	25 12	1778 2175	1.70% [0.66–4.35] 2.73% [1.06–6.87]	84.0%, $p < 0.0001$ 80.0%, $p < 0.0001$	$p < 0.0001$ $p = 0.0008$	$p = 0.4877$
AV replacement	Bilateral Unilateral	26 12	1917 2175	5.20% [2.85–9.30] 1.41% [0.42–4.58]	81.6%, $p < 0.0001$ 80.0%, $p < 0.0001$	$p = 0.0023$ $p = 0.0039$	$p = 0.0534$
CABG	Bilateral Unilateral	26 13	1917 3697	7.64% [5.35–10.78] 9.57% [4.84–18.02]	64.8%, $p < 0.0001$ 97.0%, $p < 0.0001$	$p = 0.0027$ $p = 0.3827$	$p = 0.5575$
CPB time	Bilateral Unilateral	29 14	2111 2716	218.3 min [204.5–233.0] 217.1 min [205.0–229.9]	99.0%, $p < 0.0001$ 98.2%, $p < 0.0001$	$p = 0.0643$ $p = 0.4348$	$p = 0.9015$
CXC time	Bilateral Unilateral	27 14	2081 2716	125.0 min [116.1–134.5] 122.4 min [112.7–132.9]	98.4%, $p < 0.0001$ 98.4%, $p < 0.0001$	$p = 0.0937$ $p = 0.4867$	$p = 0.7091$
CA time	Bilateral Unilateral	27 11	1965 2129	38.9 min [32.2–47.0] 30.7 min [24.9–37.9]	99.8%, $p < 0.0001$ 99.7%, $p < 0.0001$	$p = 0.5360$ $p = 0.8003$	$p = 0.1019$
SACP time	Bilateral Unilateral	19 9	1270 1994	80.5 min [54.7–118.5] 49.8 min [39.0–63.5]	99.9%, $p < 0.0001$ 99.6%, $p < 0.0001$	$p = 0.0305$ -	$\mathbf{p = 0.0395}$
Target temperature	Bilateral Unilateral	27 14	1984 3828	26.0 °C [25.1–26.9] 22.5 °C [21.5–23.6]	99.8%, $p < 0.001$ 99.9%, $p < 0.001$	$p = 0.5198$ $p = 0.0375$	$\mathbf{p < 0.001}$
Stent length	Bilateral Unilateral	18 5	852 200	9.99 cm [9.15–10.90] 10.25 cm [9.00–11.68]	100%, $p < 0.0001$ 100%, $p < 0.0001$	$p = 0.9145$ -	$p = 0.7431$

Bold means $p < 0.05$. AV = aortic valve; CA = circulatory arrest; CABG = coronary artery disease; CI = confidence interval; CPB = cardiopulmonary bypass; CXC = cross-clamp; pts = patients; SACP = selective antegrade cerebral perfusion; VSRR = valve sparing root replacement.

There was no significant difference in mortality and postoperative complications between the unilateral and bilateral SACP groups, Table 3.

Table 3. Meta-analysis of the postoperative outcomes.

Outcome	**Group**	**No. of Studies**	**No. Total Pts**	**Estimate [95%CI]**	**Heterogeneity: I^2, p-Value**	**Egger's**	**Group Difference**
Bleeding requiring surgical revision	Bilateral Unilateral	19 11	1132 2501	7.92% [5.14–12.02] 4.64% [2.55–8.30]	68.3%, $p < 0.0001$ 76.0%, $p < 0.0001$	$p = 0.0009$ $p = 0.1630$	$p = 0.1494$
Dialysis	Bilateral Unilateral	15 9	1112 1955	12.85% [8.59–18.78] 12.82% [9.22–17.55]	78.7%, $p < 0.0001$ 57.1%, $p = 0.0168$	$p = 0.3028$ -	$p = 0.9939$
CVA	Bilateral Unilateral	22 10	1389 2057	9.30% [6.93–12.38] 6.37% [3.85–10.35]	56.5%, $p = 0.0006$ 59.3%, $p = 0.0084$	$p = 0.1377$ $p = 0.3358$	$p = 0.1932$
SCI	Bilateral Unilateral	25 11	1782 2136	2.75% [1.77–4.26] 4.34% [2.78–6.72]	37.9%, $p = 0.0296$ 37.6%, $p = 0.0987$	$p = 0.0017$ $p = 0.7471$	$p = 0.1525$
Hospital mortality	Bilateral Unilateral	27 15	1868 3872	9.09% [7.42–11.10] 7.87% [6.26–9.84]	31.4%, $p = 0.0619$ 55.0%, $p = 0.0053$	$p = 0.0840$ $p = 0.8609$	$p = 0.3483$

CI = confidence interval; CVA = cerebrovascular accident; ICU = intensive care unit; pts = patients; SCI = spinal cord injury.

3.4. Meta-Regression

Distal body circulatory arrest was not associated with any outcome at meta-regression. On the other hand, longer SACP times in the total population were significantly associated with higher neurological complications, and longer SACP times in the uSACP were significantly associated with higher mortality (Table 4).

Table 4. Meta-regression of circulatory arrest and SACP times on mortality and neurological complications.

	Circulatory Arrest Time		SACP Time	
Outcome	**OR (95%CI)**	***p*-Value**	**OR (95%CI)**	***p*-Value**
		Neurological complications		
Total population	1.01 (0.99–1.02)	0.3265	1.01 (1.00–1.02)	**0.0157**
uSACP	0.99 (0.90–1.08)	0.7942	1.01 (0.99–1.03)	0.0738
bSACP	1.01 (0.99–1.03)	0.2615	1.01 (0.99–1.02)	0.0928
		Mortality		
Total population	1.00 (0.99–1.01)	0.5210	1.00 (0.99–1.01)	0.2315
uSACP	1.02 (0.99–1.05)	0.1491	1.01 (1.00–1.02)	**0.0473**
bSACP	1.00 (0.99–1.01)	0.9577	0.99 (0.99–1.01)	0.9067

Bold means $p < 0.05$. CI = confidence interval; OR = odds ratio.

4. Discussion

This meta-analysis showed the following: (1) institutions that utilized bSACP would perform a TAR+FET in patients with more comorbidities than institutions using uSACP, possibly because the institutions utilizing uSACP, in a scenario of higher comorbidities, performed a less extensive operation; (2) the most concerning complications (SCI, CVA, postoperative bleeding, dialysis, and hospital mortality) remained relevant regardless of the cerebral perfusion approach applied; (3) longer SACP times, but not longer distal body circulatory arrest times, were associated with worse outcomes.

The current analysis highlighted a hospital mortality ranging from 8% to 9%, along with a postoperative incidence of SCI at 3–4% and CVA at 6–9%. Nevertheless, it remains a demanding and intricate procedure, particularly in the urgent setting of ATAAD [55,56]. This complexity is reflected in the mortality and the most concerning neurological complications rates. These findings align with a recent meta-analysis that specifically addressed these complications [5]. In line with prior reviews focusing on perfusion strategies across different aortic arch conditions and techniques, our study also revealed no notable distinctions between uSACP and bSACP [7–9], thus suggesting FET procedures during ATAAD remain an intricate procedure with a high incidence of mortality and neurological complications. A recent meta-analysis analyzing ATAAD outcomes, including heterogeneous surgical interventions, indicated that uSACP may offer particular benefits in the context of TAR [10]. However, this finding was based on a subgroup analysis that was likely influenced by a selection of studies not specifically designed to address the question in this subset of patients. To our knowledge, we are the first in confirming this relation in the context of TAR with FET for ATAAD.

The comprehensive analysis of critical postoperative outcomes following FET procedures for ATAAD confirmed a very intuitive association. Bilateral perfusion strategies were generally performed in more comorbid patients. Longer SACP times were also required, suggesting surgical teams expected a more challenging intervention in this specific subset of patients. However, postoperative results showed a surprisingly degree of similarity between the two groups. A possible explanation is that institutions employing bSACP may have tended to perform TAR+FET in patients with greater comorbidity burdens and/or more extensive procedures, whereas those using uSACP might have opted for less extensive procedures in similarly high-risk patients, possibly highlighting a different expertise and/or preference. Overall, institutions adopted only a single cerebral perfusion strategy. In other words, this intriguing finding emphasizes the appropriate perfusion strategy should be tailored to the complexity of the patient's procedure. In this regard, a comprehensive understanding of advantages and disadvantages associated with each method allowed for a technical customization, thus yielding similar surgical results and optimal outcomes for each individual case [57]. For the majority of patients without significant pathologies or less extensive procedures, uSACP seemed to offer adequate safety, while bSACP was better employed for the more comorbid patients with the worst clinical presentation from a neurological point of view and/or more complex procedures [58].

The reported target body temperature differed between unilateral and bilateral SACP. In unilateral perfusion, surgeons often employ deeper systemic hypothermia to safeguard the contralateral hemisphere in case intracranial collaterals are inadequate. Conversely, bilateral perfusion allows direct supply to both hemispheres, making higher target temperatures feasible and thereby shortening cooling and rewarming times, which can reduce the overall duration of cardiopulmonary bypasses. Nevertheless, not all centers apply warmer temperatures with bilateral perfusion, as temperature management is frequently determined by the anticipated duration of circulatory arrest and surgical complexity rather than perfusion strategy alone. Temporal trends must also be taken into account, since more recent practice has progressively shifted toward warmer moderate hypothermic circulatory arrest [59], even in unilateral perfusion [60]. Importantly, a recent meta-analysis demonstrated that both randomized and propensity-matched data consistently associated deep hypothermic circulatory arrest with a higher incidence of stroke compared with moderate or mild hypothermia ($p = 0.0029$ and $p = 0.019$, respectively) during aortic arch procedures [61]. The analysis did not find a clear advantage of lower temperatures for either SCP technique.

In adjunct, while preoperative CT angiography can potentially identify high-risk patients [62], the vast majority of surgical centers primarily rely as intraoperative monitoring techniques on transcranial Doppler or near-infrared spectroscopy (NIRS) [63,64]. Conversion from unilateral to bilateral SACP is considered when unilateral cerebral oxygen saturation declines. Patients with a non-patent circle of Willis receiving (uSACP) have not demonstrated an increased incidence of neurological deficits [64], and several factors may contribute to this. A watershed infarct in the opposite cerebral hemisphere might present with varying clinical manifestations and may not always be promptly diagnosed, or collateral cerebral vessels may offer some contralateral perfusion in these patients [8].

There was contradictory evidence regarding the connection between unilateral and SACP and the duration of distal body circulatory arrest [7,8]. In the present analysis, no significant distinction was noted between the two perfusion strategies in this regard. However, a notable difference was identified concerning the cerebral perfusion time. This relation was confirmed at meta-regression, where longer cerebral perfusion, but not distal body circulatory arrest times, were associated with worse outcomes.

Strengths and Limitations

While numerous comparable studies have explored variations in selective antegrade cerebral perfusion strategies during aortic arch surgery, our research investigated such outcomes for FET in ATAAD exclusively. This approach ensures that different techniques and aortic pathologies are not intermingled in our analysis.

The current meta-analysis is subject to certain limitations, though. Data was obtained mainly from retrospective studies, thus adding all related biases into the analysis. Moreover, due to the diversity in temperature measurement methods (rectal or nasopharyngeal) and cannulation strategies across the studies, we were unable to assess the correlation between these two parameters to the overall risk of neurological injury. Moreover, other missing parameters, like cerebral blood flow and mean perfusion pressure, could have impacted the outcomes.

Because all but one included study evaluated either unilateral or bilateral SACP exclusively within individual centers, observed differences between strategies may be confounded by center-specific expertise and practice patterns, limiting causal inferences about the effect of the SACP strategy itself.

5. Conclusions

Our analysis revealed consistent postoperative outcomes between uSACP and bSACP, despite significant different baseline patients' features. This emphasizes the importance of tailoring the approach to the complexity of individual patient's procedures, while a definitive superiority of bSACP over uSACP may be difficult to define. Of note, longer cerebral perfusion times, rather than distal body circulatory arrest durations, were associated with adverse postoperative outcomes. These findings collectively highlight the significance of considering the cerebral perfusion strategy according to the patient's associated comorbidities to optimize outcomes during FET for ATAAD. Further studies, possibly randomized, are warranted to confirm these results.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jcm14186392/s1, Table S1: Search strategy, Table S2: Outline of the included studies, Table S3: Distal anastomosis zone (Ishimaru) and epiaortic vessel management, Table S4: Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I) with traffic lights.

Author Contributions: Conceptualization, M.B., L.D.B. and F.R.; methodology, M.B., L.D.B. and F.R.; software, M.B.; validation, M.B., C.M. and S.B.; formal analysis, M.B.; investigation, M.B., M.D., L.D.B. and F.R.; resources, C.M. and S.B.; data curation, M.B. and M.D.; writing—original draft preparation, M.B., L.D.B. and F.R.; writing—review and editing, all authors; visualization, M.B. and M.D.; supervision, C.M., S.B., L.D.B. and F.R.; project administration, M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Since our study entails the examination of pre-existing data and does not encompass the participation of individual patients, research ethics board approval was not required.

Informed Consent Statement: Since our study entails the examination of pre-existing data and does not encompass the participation of individual patients, patient consent was not required.

Data Availability Statement: The datasets generated or analyzed during this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: Claudio Muneretto reports a relationship with Corcym SRL that includes: consulting or advisory roles. Stefano Benussi reports a relationship with AtriCure Inc. that includes: consulting or advisory roles. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results. The other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Abbreviations

The following abbreviations are used in this manuscript:

ATAAD	Acute type A aortic dissection
CI	Confidence interval
CVA	Cerebrovascular accident
FET	Frozen elephant trunk
OR	Odds ratio
SACP	Selective antegrade cerebral perfusion
SCI	Spinal cord injury
TAR	Total arch replacement

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