Hybrid type II and frozen elephant trunk in acute Stanford type A aortic dissections

Jai Sulea,*, Cher Rui Chua b,*, Caven Teob, Andrew Choonga, Faizus Sazzadb, Theo Kofidis a,b and Vitaly Sorokin a,b

aDepartment of Cardiac, Thoracic and Vascular Surgery, National University Heart Centre, National University Health System, Singapore; bDepartment of Surgery, Yong Loo Lin School of Medicine, National University of Singapore, Singapore

ABSTRACT

Objectives. Composite frozen elephant trunk is an increasingly popular solution for complex aortic pathologies. This review aims to compare outcomes of zone 0 type II hybrid (hybrid II) with the composite frozen elephant trunk (FET) technique in managing acute Stanford type A aortic dissections.

Methods. PubMed and Embase were systematically searched using PRISMA protocol. 11 relevant studies describing the outcomes of hybrid II arch repair and FET techniques in patients with type A aortic dissection were included in the meta-analysis. The study focused on early post-operative 30-day outcomes analysing mortality, stroke, spinal cord injury, renal impairment requiring dialysis, bleeding and lung infection. Results. 1305 patients were included in the analysis – 343 receiving hybrid II repair and 962 treated with the FET. Meta-analysis of proportions showed Hybrid II was associated with less early mortality [5.0 (CI 3.1–7.8) vs 8.1 (CI 6.5–10.0) %], stroke [2.3 (CI 1.1–4.6) vs 7.0 (CI 5.5–8.8) %], spinal cord injury [2.0 (CI 0.9–4.3) vs 3.8 (CI 2.8–5.3) %], renal impairment requiring dialysis [7.9 (CI 5.5–11.2) vs 11.8 (CI 9.8–14.0) %], reoperation for bleeding [3.9 (CI 1.8–8.4) vs 10.6 (CI 8.1–13.8) %] and lung infection [14.8 (CI 10.8–20.0) vs 20.7 (CI 16.9–25.1) %]. Conclusion. Hybrid II should be considered in favour of FET technique in acute Stanford type A dissection patients who are at higher risk due to age and comorbidities.

Introduction

Stanford type A aortic dissection is often extensive and associated with extremely high mortality without surgical treatment [1]. Emergent surgical repair is primarily oriented towards eliminating the origin of the intimal tear, 60% of which develop solitarily in the ascending aorta, while 30% develop in the arch [2]. However, isolated proximal repair incurs the risk of in-hospital mortality of up to 13% in DeBakey type I aortic dissections [3]. Patients are also more likely to suffer disease progression and require staged downstream procedures to treat residual aortic disease [4]. Single-stage combined ascending aorta and arch repair techniques are thus increasingly performed to manage these extensive aortic dissections at onset using either the frozen elephant trunk (FET) procedure or hybrid techniques incorporating thoracic endovascular aortic repair (TEVAR).

Nevertheless, aortic arch repair surgery is complex and associated with increased early mortality while providing lower reintervention rates compared to ascending aorta replacement alone [5]. While several studies have evaluated these techniques, most include chronic dissections, aneurysms and Stanford type B dissections and many studies evaluating hybrid techniques depict a variety of techniques including cervical arch vessel bypasses, thereby providing little evidence overall regarding outcomes of these techniques during acute management of type A aortic dissections. This study aims to provide some insight by comparing early outcomes of two standardized arch repair techniques – type II hybrid arch repair with stent landing in the ascending aortic synthetic graft corresponding to zone 0 (hybrid II) and FET procedure using a hybrid FET prosthesis – for the treatment of acute Stanford type A aortic dissections.

Materials and methods

Definitions

Acute Type A Aortic Dissection is defined as an intervention performed ≤14 days from onset of symptoms. Aortic arch zones and landing area in this study are defined by the Ishimaru classification [6]. Hybrid type refers to the classification presented by Szeto and Bavaria [7].

CONTACT Jai Sule roversage@gmail.com Department of Cardiac, Thoracic and Vascular Surgery, National University Heart Centre, National University Health System, 1E Kent Ridge Road, NUHS Tower Block, Level 9, Singapore 119228, Singapore. Cher Rui Chua contributed equally to this work.

Supplemental data for this article can be accessed here.

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Literature search strategy

Systematic review was conducted in accordance with current guidelines [8,9]. PubMed and Embase were searched independently by two reviewers for studies that examined outcomes of type II hybrid and FET in relation to aortic arch repair for dissection (Table S1) from inception till March 2021. References of relevant articles were also manually assessed for possible inclusion. Conflicts were resolved by consensus with a senior researcher in the team. Data extracted included data on study design, surgical technique, patient demographics, intra-operative data and post-operative outcomes. Selection process is demonstrated in the PRISMA flow chart (Figure 1). Risk of bias and methodological heterogeneity was assessed using the Newcastle-Ottawa Scale (Table S2) [10].

Eligibility criteria

Studies were included if they were full-text articles written in English that separately reported outcomes of acute type A dissection patients undergoing either hybrid II or FET repair. Publications were excluded if they comprised less than five patients undergoing total aortic arch repair, did not differentiate outcomes of acute type A dissection patients or reported other hybrid or open arch repair techniques (Table S3). In the case of studies with overlapping populations, the more recent publication was chosen where possible based on inclusion criteria.

Surgical technique

Hybrid type II

Following median sternotomy, the ascending aorta was replaced with a 4-branched graft using cardiopulmonary bypass (CPB) generally without use of hypothermic circulatory arrest (HCA). Additional concomitant procedures were performed as needed. After completing distal ascending aorta anastomosis, sequential aortic arch debranching was performed either on CPB with the cross-clamp off or off-pump. All patients received total debranching of the arch vessels including the left subclavian artery. Subsequent TEVAR was then performed with proximal landing in zone 0. The TEVAR stent graft was endovascularly deployed in a retrograde fashion from the femoral artery in most cases, or less commonly antegrade via the ascending aorta graft (Table S4).

Frozen elephant trunk

Arterial cannulation was performed via the axillary artery, innominate artery, femoral artery or directly on the ascending aorta. The ascending aorta was first replaced. Moderate or deep HCA was used for aortic arch replacement. Concomitant cardiac procedures were generally performed during cooling. Cerebral protection during HCA was achieved via selective antegrade cerebral protection (SACP). Once cooled, the aortic arch was transected distally and the stent graft inserted into the descending thoracic aorta. The arch vessels were anastomosed either individually or as an island. The various hybrid prostheses used in the enrolled studies are detailed in Table S4. The proximal anastomosis to the ascending aorta interposition graft concluded the procedure.

Outcomes measures

Primary outcomes were 30-day post-operative mortality and stroke. Secondary outcomes included spinal complications, renal impairment requiring dialysis, reoperation for bleeding and lung infection. Stroke comprised permanent neurological cerebral injury in combination with imaging confirmation and spinal cord injury comprised all reported spinal complications. Dialysis included both temporary and permanent post-operative dialysis. Endoleaks and downstream interventions were recorded as well.

Data analysis

All statistical analyses were performed using STATA v13 (Stata-Corp LP, College Station, TX, USA). In general, a random effects model was employed due to statistical heterogeneity between studies determined using I^2. Logistic regression was used to determine pooled proportions for the primary and secondary outcomes using the meta-analysis of proportions module [11]. Significance was taken at 95% confidence (p < 0.05). For graphical representation, analysis was done using the variance-stabilizing Freeman-Tukey double-arcsine transformation procedure. Continuous variables for demographic and intra-operative data were summarized with weighted pooled means. Where data were reported only in medians, interquartile range, or range, the means and standard deviations were estimated according to the recommendations by Wan et al. [12,13].

Results

Study characteristics and patient demographics

Of a total of 6533 publications found till March 2021, 147 publications were reviewed in their entirety and 136 publications were excluded upon review of the full text (Figure 1). Eleven retrospective cohort studies were included in the meta-analysis, giving a total of 1305 patients [14–24]. Of these, 343 patients underwent hybrid II and 962 patients underwent FET repair. Three studies compared both techniques and were included in double-arm analysis [16–18]. These comprised 65.6% of hybrid II and 63.6% of FET procedures. There was no asymmetry seen in the funnel plots constructed based on 30-day mortality and stroke (Figures S1 and S2), and Egger’s test showed no significant publication bias (p = 0.522).

Five hybrid II and nine FET studies were included (Table 1). Patients were predominantly hypertensive males. Patients in the hybrid II group were older [mean age 58.8 (confidence interval (CI) 55.2–62.5) vs 54.0 (CI 50.0–58.0)], Lin et al. reported unusually high incidence of coronary
artery disease (CAD) [15], while the incidence of chronic obstructive pulmonary disease (COPD) was unusually high in the study by Shi et al. [18]. Not all studies reported malperfusion rates.

**Intra-operative data (Table S4)**

Mean CPB and cross-clamp times were shorter for hybrid II [145.0 (CI 120.7–169.4) vs 225.0 (CI 200.7–249.4) minutes and 71.2 (CI 57.7–84.7) vs 123.4 (CI 114.3–132.6) minutes respectively]. Moderate hypothermia was used in most studies within both groups. Mean procedure duration was comparable among studies that reported it [448.3 (CI 405.3–491.3) vs 451.3 (CI 359.9–542.7) minutes].

**Post-operative outcomes (Table 2)**

Thirty-day mortality was lower in the Hybrid II group [5.0 (CI 3.1–7.8) vs 8.1 (CI 6.5–10.0) %]. Weighted secondary outcomes of stroke and spinal cord injury were also lower for hybrid II [2.3 (CI 1.1–4.6) vs 7.0 (CI 5.5–8.8) % and 2.0 (CI 0.9–4.3) vs 3.8 (CI 2.8–5.3) % respectively], with a statistically significant between group heterogeneity evident for stroke ($p = 0.039$, Figure 2). Fewer patients in the Hybrid II group required dialysis for postoperative acute renal injury [7.9 (CI 5.5–11.2) vs 11.8 (CI 9.8–14.0)]. Forest plots for mortality, spinal cord injury and dialysis are provided in the Supplementary material (Figures S3–S5). Comparison for stroke within the double-arm studies did not reveal any significant difference (Figure S6).

Bleeding requiring reoperation and lung infection rates were also lower in the Hybrid II group [3.9 (CI 1.8–8.4) vs 10.6 (CI 8.1–13.8) % and 14.8 (CI 10.8–20.0) vs 20.7 (CI 16.9–25.1) % respectively]. Type I endoleak occurred in 1.9 (CI 0.7–4.9) % of hybrid II patients at thirty days. Mean hospital stay was similar for hybrid II and FET [18.4 (CI 13.2–23.5) vs 19.6 (CI 12.9–26.2) days] while mean intensive care unit (ICU) stay was shorter for hybrid II [4.4 (CI 3.3–5.5) vs 7.0 (CI 5.0–9.0) days].

**Follow-up**

The results show 10.5 (7.9–13.7) % of FET patients required interventions for downstream aortic disease with majority performed endovascularly. There were no reported delayed endoleaks in either group.

**Discussion**

**Surgical technique**

FET prostheses have gained popularity by providing easier implantation through user-friendly introducers for the attached stent graft and encompassing a fabric collar for the distal anastomosis. However, FET requires experience with
Table 1. Study characteristics and demographics.

| Country | Study period | Sample size | Maximum follow-up period (months) | Gender (male) | Age (yrs), mean ± SD | Diabetes (%) | Hypertension (%) | Stroke (%) | Preoperative COPD (%) | CAD (%) | Any previous surgery (%) | Preoperative malperfusion, n (%) | TEVAR completion, n (%) | Preoperative malperfusion, n (%) |
|---------|--------------|-------------|----------------------------------|--------------|----------------------|--------------|-------------------|------------|------------------------|---------|------------------------|---------------------------------|--------------------------|------------------------|
| Chang [14] | Nov 2009-Dec 2011 China | 21 | 21 | F | 61.5 ± 6.7 | 62.2 ± 7.7 | 50.3 ± 8.0 | 6/F | 72 (72.1) | 72 (72.1) | 57.4 ± 10.3 | 72 (72.1) | 4 (4.1) | NR | NR |
| Lin [15] | Jan 2010-Jun 2016 China | 97 | 90 | F | 62.9 ± 7.1 | 61.6 ± 8.8 | 66.6 ± 10.2 | 6/F | 72 (60.0) | 72 (60.0) | 57.9 ± 10.2 | 72 (60.0) | 4 (1.1) | NR | NR |
| Liu [16] | Jan 2017-Jun 2019 China | 1 | 1 | F | 61.4 ± 7.7 | 61.2 ± 9.0 | 60.6 ± 10.2 | 7/F | 70 (70.0) | 70 (70.0) | 57.4 ± 10.3 | 70 (70.0) | 4 (3.0) | NR | NR |
| Ma [17] | Jan 2013-Dec 2015 China | 36 | 34 | F | 50.3 ± 9.0 | 50.9 ± 9.4 | 50.6 ± 11.2 | 6/F | 29 (80.6) | 29 (80.6) | 57.4 ± 10.3 | 29 (80.6) | 4 (1.1) | NR | NR |
| Shi [18] | Jan 2017-Aug 2019 China | 48.0 | 1 | 1 | F | 57.4 ± 10.3 | 57.4 ± 10.3 | 57.4 ± 10.3 | 7/F | 57.4 ± 10.3 | 57.4 ± 10.3 | 57.4 ± 10.3 | 57.4 ± 10.3 | 4 (3.0) | NR | NR |
| FET | Beckmann [19] Germany | 96 | 96 | F | 61.5 ± 6.7 | 61.5 ± 6.7 | 61.5 ± 6.7 | 6/F | 72 (72.1) | 72 (72.1) | 72 (72.1) | 72 (72.1) | 4 (4.1) | NR | NR |
| Berger [20] | Germany | 12 | 12 | F | 54.6 ± 13.2 | 54.6 ± 13.2 | 54.6 ± 13.2 | 6/F | 54.6 ± 13.2 | 54.6 ± 13.2 | 54.6 ± 13.2 | 54.6 ± 13.2 | 4 (4.1) | NR | NR |
| Chabry [21] | France | 87 | 87 | F | 61.5 ± 6.7 | 61.5 ± 6.7 | 61.5 ± 6.7 | 6/F | 72 (72.1) | 72 (72.1) | 72 (72.1) | 72 (72.1) | 4 (4.1) | NR | NR |
| Hoffman [22] | Germany | 32 | 32 | F | 61.5 ± 6.7 | 61.5 ± 6.7 | 61.5 ± 6.7 | 6/F | 72 (72.1) | 72 (72.1) | 72 (72.1) | 72 (72.1) | 4 (4.1) | NR | NR |
| Liu [16] | China | 61.2 ± 10.2 | 61.2 ± 10.2 | 61.2 ± 10.2 | 6/F | 72 (72.1) | 72 (72.1) | 72 (72.1) | NR | NR | NR | NR | NR | NR |
| Shrestha [23] | Nepal | 23 | 23 | F | 54.6 ± 13.2 | 54.6 ± 13.2 | 54.6 ± 13.2 | 6/F | 54.6 ± 13.2 | 54.6 ± 13.2 | 54.6 ± 13.2 | 54.6 ± 13.2 | 4 (4.1) | NR | NR |
| Weiss [24] | Austria | 106 | 106 | F | 61.5 ± 6.7 | 61.5 ± 6.7 | 61.5 ± 6.7 | 6/F | 72 (72.1) | 72 (72.1) | 72 (72.1) | 72 (72.1) | 4 (4.1) | NR | NR |

*Values included pathologies other than acute Stanford Type A aortic dissection.
*Values estimated from median, interquartile range, or range.

**Patient demographics and intra-operative data**

Patients in the hybrid II group were older and had more comorbidities. In centres that offer both procedures, elderly patients and those deemed to be higher risk may be preferentially offered hybrid II arch repair over the FET. Hybrid procedures were first offered over conventional total arch replacement to patients who are at higher risk of undergoing extensive total arch procedures [28]. Apart from the study by Ma et al. [17], the FET group showed higher incidence of pre-operative malperfusion. The presence of
Table 2. Post-operative outcomes.

| Study  | Mortality | Stroke | Spinal cord injury | Renal impairment requiring dialysis | Reoperation for bleeding | Lung infection | Endoleak (type I) | Downstream interventions, n (%) | [% endovascular] |
|--------|-----------|--------|-------------------|------------------------------------|-------------------------|---------------|------------------|---------------------------------|-----------------|
| Hybrid II |           |        |                   |                                    |                         |               |                  |                                 |                 |
| Chang [14] | 1 (4.8)  | 0 (0.0) | 0 (0.0)            | 0 (0.0)                           | 0 (0.0)                  | NR            | 1 (4.8)         | NR                             | NR              |
| Lin [15] | 8 (8.2)   | 2 (2.1) | 2 (2.1)            | 13 (13.4)                         | 6 (5.0)                 | 23 (23.7)     | 3 (3.1)        | NR                             | NR              |
| Liu [16] | 6 (6.5)   | 4 (4.3) | 4 (4.3)            | 10 (10.9)                         | NR                      | NR            | NR              | NR                             | NR              |
| Ma* [17] | 2 (5.6)   | 2 (5.6) | NR                | 3 (8.3)                           | 0 (0.0)                 | 8 (22.2)      | NR              | 1 (2.8)                        | [100.0]         |
| Shia [18] | 0 (0.0)   | 0 (0.0) | 0 (0.0)            | 1 (1.0)                           | NR                      | 3 (3.1)       | 0 (0.0)        | 6 (6.2)                        | [100.0]         |
| **Weighted average % (95% CI)** | 5.0 (3.1–7.8) | 2.3 (1.1–4.6) | 2.0 (0.9–4.3) | 7.9 (5.5–11.2) | 3.9 (1.8–8.4) | 14.8 (10.8–20.0) | 1.9 (0.7–4.9) | 5.3 (2.5–10.6) |
| FET |           |        |                   |                                    |                         |               |                  |                                 |                 |
| Beckmann [19] | 8 (8.3) | 20 (20.8) | 7 (7.3)           | 21 (21.9)                        | 15 (15.6)               | NR            | NR              | 9 (9.4)                        | [22.2]         |
| Berger* [20] | 10 (15.9)| 8 (12.7) | 5 (7.9)            | 4 (6.4)                           | 4 (6.4)                 | NR            | NR              | 8 (12.7)                       | [87.5]         |
| Chabry [21] | 18 (20.7)| 13 (14.9)| 9 (10.3)          | 19 (21.8)                        | 10 (11.5)               | NR            | NR              | 15 (17.2)                      | [100.0]        |
| Hoffman [22] | 0 (0.0) | 0 (0.0)  | 0 (0.0)            | NR                                | 4 (12.5)               | 5 (15.6)      | 0 (0.0)        | 8 (25.0)                       | [100.0]        |
| Liu [16] | 15 (5.6) | 9 (3.4)  | 13 (4.9)           | 30 (11.2)                        | NR                      | NR            | NR              | NR                             | NR              |
| Ma [17] | 19 (14.4)| 7 (5.3)  | 0 (0.0)            | 20 (15.2)                        | 4 (3.0)                 | 44 (33.3)     | NR              | 2 (1.5)                       | [100.0]        |
| Shi [18] | 0 (0.0)  | 3 (1.4)  | 0 (0.0)            | 8 (8.2)                           | NR                      | 29 (13.7)     | 0 (0.0)        | NR                             | NR              |
| Shrestha [23] | 7 (13.5)| 6 (11.5) | 2 (3.8)            | 5 (9.6)                           | 12 (23.1)               | NR            | NR              | NR                             | NR              |
| Weiss [24] | 1 (5.0)  | 1 (5.0)  | NR                | NR                                | NR                      | NR            | NR              | 3 (15.0)                       | [100.0]        |
| **Weighted average % (95% CI)** | 8.1 (6.5–10.0) | 7.0 (5.5–8.8) | 3.8 (2.8–5.3) | 11.8 (9.8–14.0) | 10.6 (8.1–13.8) | 20.7 (16.9–25.1) | NA              | 10.5 (7.9–13.7) |

*Specific results were obtained through written correspondence with the studies’ corresponding authors.

bValues included pathologies other than acute Stanford type A aortic dissection, hence were not pooled.

Figure 2. Comparison of 30-day stroke. Hybrid II: $P^2 = 48.3\%$; FET: $P^2 = 85.3\%$. 
malperfusion syndromes were shown to be associated with worse post-operative outcomes [29]. As both techniques address a distal entry tear in the arch or proximal descending aorta, presence of malperfusion will not impact choice of technique. However, a distal tear will necessitate same stage stenting for the hybrid technique to prevent persistent flow into a patent false lumen.

Higher CPB and cross-clamp duration may contribute to the overall risk of the FET procedure. Increased cooling and need for circulatory arrest are also likely to increase transfusion requirements for the FET, and their associated risks. Blood product transfusions were shown to be higher in the FET group [17]. CPB duration, ischemia time and need for circulatory arrest may also explain the need for longer ICU recovery after FET.

**Early post-operative outcomes**

**Mortality**

While higher mortality in the FET group may represent the underlying population, it emphasizes that FET indications should be clearly defined for emergent type A dissection repairs. Overall mortality for the hybrid II group was lower in this comparison despite TEVAR being performed single-staged. A recent two-centre review showed that FET produced lower mortality rates in patients with chronic aortic dissections, with malperfusion syndrome a significant risk factor in patients with acute aortic dissection [30]. In this review, mortality was even higher among patients with thoracic aneurysm. Results from the E-Vita open registry showed overall 30-day mortality to be 11% even in high-volume centres, but encompassed a mix of arch pathologies [31].

Studies that reported higher mortality rates in the FET group also reported more concomitant aortic root replacement procedures [17,23]. This may additionally reflect the complexity of the dissection coupled with a more aggressive approach towards treating more complicated dissections. While malperfusion syndromes are generally associated with greater mortality, it is not the only contributor. Two studies reported relatively low mortality despite having the highest incidence of malperfusion syndromes [19,22]. Age, CPB and HCA duration, and minimal body temperature were significantly associated with mortality in the EPI-Flex French registry study for Thoraflex (Terumo Aortic) FET, with only HCA > 50min being significant on multivariate analysis [21]. When both types of procedures were analysed, pre-operative CAD, leucocytosis, CPB and total procedure times were significant risk factors for stroke on multivariate analysis [32].

Interestingly, the studies by Hoffman et al. and Shi et al. reported zero mortality [18,22]. In the series by Hoffman et al., stent grafts were sized according to the total size of the descending aorta at the level of the left atrium resulting in larger stent graft size used [22]. For the cohort followed up in the study by Shi et al., we understand that several complex patients were transferred to other tertiary centres post-operatively where follow-up was not clearly stated [18]. Nevertheless, patient selection may contribute to lower FET mortality rates reported in some studies.

**Stroke**

As this is a meta-analysis of proportions, it is not possible to ascertain a significant p-value, and the results suggest a trend favouring hybrid II that needs to be confirmed with further randomized studies. The higher incidence of stroke in the FET group is likely contributed by the need for sustained HCA and prolonged CPB time. A recent meta-analysis for all-cause FET use reported a pooled stroke rate of 7.6% [33], while a study comparing hybrid debranching procedures reported stroke rate of 2.5% among patients undergoing hybrid type II arch repair [34]. Lower stroke incidence in the hybrid group may also be a result of being able to perform the procedure without HCA. A recent meta-analysis showed poorer stroke outcomes for the use of deep HCA with no difference comparing SACP to retrograde cerebral perfusion (RCP) [35]. However, this was not evident in the studies that used deep HCA in this analysis [18,22]. The more recent FET studies utilized moderate HCA likely for the other benefits of limiting cooling. Multivariate analysis in the study by Liu et al. revealed that composite adverse events and stroke correlated more with comorbidities and malperfusion syndromes [16].

**Spinal cord injury**

In both groups, most studies reported no permanent paraplegia. However, overall spinal cord injury rates varied and appeared higher in the FET group. Spinal cord injury after TEVAR is multifactorial and coverage of the intercostal and lumbar arteries alone is associated with relatively low rates [36]. However, it may be aggravated by HCA. Recent results from the E-Vita registry reported spinal cord ischemia rates of 7% [31]. In the review by Moulakakis et al. of all hybrid arch debranching, irreversible spinal cord injury occurred in 3.6% of patients in the hybrid repair group [37].

In most studies, a spinal drain for preventive cerebrospinal fluid (CSF) drainage was not inserted in the acute setting, and its routine use was only reported in studies in Hannover, where it was generally inserted immediately post-operatively in the intensive care unit [19,23]. This may be due to unavailability of routine cerebrospinal fluid drainage in the emergent setting and fear of possible bleeding complication from the lumbar puncture. The EPI-Flex Registry study, in which CSF drainage was sparsely used, cautioned the need for adequate spinal protection and emphasized using short FET stents, systematically reimplanting the left subclavian artery to facilitate alternative conduct of CPB through the left subclavian and performing routine CSF drainage even for emergency cases [21].

**Renal impairment requiring dialysis**

The higher postoperative dialysis rates in the FET group suggest that the risk of renal impairment due to contrast nephropathy from image-guided TEVAR insertion is likely
less than that arising from prolonged CPB and ischemia duration. As the definitions of acute renal impairment varied among studies that reported it, dialysis was used as a more consistent comparison. Review of TEVAR procedures in general reported renal impairment rates of 3–13%, but also a delayed risk of up to 17.7% at 6 months [38,39].

The newer FET studies reported consistently higher dialysis rates of about twenty percent despite the use of newer graft prostheses [19,21]. In the study by Beckmann et al., this may correspond to the high incidence of malperfusion syndromes and a more aggressive approach to treatment, and most patients only needed dialysis temporarily. FET implantation is advantageous in expanding the descending aortic true lumen earlier in the repair and helps in restoring visceral and lower body perfusion [40]. Acute renal disease and stroke were shown to be highly significant predictors of early mortality when analysing both these procedures for acute dissection repair [32].

**Other secondary outcomes**

Elevated reoperation rates for bleeding in the FET group are likely contributed by longer CPB times and higher level of surgical complexity. A study on bleeding incidence in type A dissections showed dissection symptom duration, hypertension, organ malperfusion, Debakey type 1 dissections, elevated creatinine, and CPB and cross-clamp times as predictors of massive bleeding post-operatively among other factors leading to this complication [41].

While not all studies reported lung infection, incidence was substantial in both groups averaging at 15–20%, and higher in the FET group. Operative times, urgent surgery and red cell transfusions have been shown to increase the risk of post-operative respiratory infections in cardiac surgery [42,43]. Given the longer operative times and need for transfusions, the FET group may be more susceptible to post-operative lung infections.

Type I endoleaks are a drawback of the hybrid approach and a cause for reinterventions, but were relatively low at 1.9%. Early type I endoleaks may resolve spontaneously, or may be managed endovascularly with additional stent graft placement or embolization procedures [44]. They are often associated with excessive oversizing of the stent graft in hybrid II arch repair [45]. Type Ia endoleaks are related to the proximal end of the stent graft, and are contributed by the curvature of the aorta. They depend on the length and course of the dacron grafts in the ascending aorta and proximal arch, and any graft kinks/angulations or too short an interposition may preclude proximal landing in zone 0. The use of hybrid FET grafts eliminates this. However, newer TEVAR stent grafts are designed to minimize the effect of aortic curvature. Interestingly, there were no type Ib endoleaks reported, which are associated with dilatation of the distal aorta over time, and suggest that adequate proximal aortic repair may sufficiently support distal remodelling.

Need for further downstream interventions varied between studies depending also on duration of follow-up. These were mostly performed endovascularly and likely due to aneurysmal complications or underlying concomitant aortic disease rather than ischemia. In the study by Beckmann et al., none of the patients required further measures in the downstream aorta to relieve ischemia following FET implantation [19]. However, FET by itself does not obviate the need for intervention distal to the stented prosthesis when other pathologies prevail.

**Future directions**

Development of newer devices may further ease definitive treatment of this complex disease. The Relay (Terumo Aortic/Bolton Medical, Barcelona, Spain) stent offers better conformability and accuracy navigating the arch facilitated by an additional bar along the stent graft body and flexibility of the delivery device, and newer branched options provide useful alternatives to total arch debranching for patients with high surgical risk or difficult arch anatomy [46]. Such branched stent grafts may also enable total endovascular aortic arch repair [47,48].

In the initial results of the multicentre Dissected Aorta Repair Through Stent Implantation (DARTS) trial, implantation of the novel single-stage Ascyrus Medical Dissection Stent (AMDS; Ascyrus Medical, Boca Raton, FL) where entry tears are limited to the proximal ascending aorta showed favourable results, with 7.7% 30-day mortality reported even in the malperfusion cohort, but mid to long-term results are needed to rule out complications arising from the bare metal stent [49].

Newer trifurcated FET prostheses such as the EVITA Open Neo (Cryolife/Jotec, Kennesaw, GA, USA/Hechingen, Germany) also facilitate siting of the distal anastomosis more proximally towards zone 0. A more proximal anastomosis may simplify the FET procedure especially in the acute setting of Debakey I dissections and shorten HCA time [50]. The shorter coverage of the descending aorta may also help mitigate spinal complications.

**Limitations**

All included studies are observational, and most were single arm. There was heterogeneity in sample size, country of origin, surgical technique including choice of technique, type of prostheses, concomitant procedures, and not all studies reported the secondary outcomes, all of which may lead to selection bias. Duration from time of onset of symptoms to surgery may vary in different centres or countries and was not reported in the included studies. Publication bias using funnel plots may not be reliable in a meta-analysis of proportions [51]. Lastly, this study does not discuss intricacies of graft sizing, imaging assessments and aortic remodelling. The authors acknowledge the real-life variability within both approaches and the uniformity between the chosen studies oversimplifies this comparison.

**Conclusion**

The FET and hybrid type II repairs are currently established procedures providing comparable early results. Both
procedures require considerable expertise in aortic arch surgery, but operative times and results may not differ significantly from high volume centres, and specialized aortic teams may be more relevant [21]. Patient selection should be prioritized and the hybrid approach should be favoured in older patients with more comorbidities.

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