

## SYSTEMATIC REVIEW

# The Endo-Bentall Procedure in the Treatment of Ascending Aorta Pathologies: A Scoping Review

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## WHAT THIS PAPER ADDS

This scoping review reports the current knowledge on Endo-Bentall repair for ascending aortic pathologies, summarising case reports, anatomical feasibility studies, proof of concept models, and expert opinions. Five Endo-Bentall cases using two different stent graft platforms were identified: a balloon expandable transcatheter aortic valve implantation (TAVI) device or a self expanding TAVI device. The review highlights encouraging early results, with very low level certainty of evidence primarily due to publication bias. The review underscores the need for further research and comprehensive evaluation of such procedures (e.g., through prospective registration) to optimise device design, procedural techniques, bailout strategies, and long term outcomes.

**Objective:** The ascending aorta remains a challenging area for endovascular repair, with limited anatomical suitability of current stent grafts due to proximal landing zone constraints. This scoping review summarised, existing experiences with the Endo-Bentall procedure, evaluated its use across pathologies, identified obstacles, and proposed future advances.

**Data Sources:** PubMed, Cochrane, and Embase were systematically searched (English language, up to 30 November 2024) for studies evaluating the Endo-Bentall procedure in treating ascending aortic pathologies.

**Review Methods:** The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol extension for scoping reviews was followed, and data were reported as descriptive narratives or tables.

**Results:** Twenty studies were included, comprising case reports, anatomical feasibility analyses, reviews, expert opinions, and technical notes. Proof of concept studies in *ex vivo* ( $n = 30$ ) and *in vivo* ( $n = 20$ ) models achieved 95 – 100% technical success rates, with sustained coronary patency. Five cases were reported; indications included aortic dissection ( $n = 2$ ), aneurysm ( $n = 1$ ), and post-surgical complications ( $n = 2$ ). Balloon expandable transcatheter aortic valve implantation (TAVI) platforms were used in three cases (one used single stage and two used two stage procedures), while self expanding platforms were used in two cases (single stage). Technical success was achieved in all cases. Early follow up showed favourable outcomes in two of three balloon expandable cases and two of two self expanding cases. One patient died at 5 months (non-aortic cause). Anatomical feasibility studies for aortic dissection ( $n = 547$ ) and aortic aneurysm ( $n = 80$ ) demonstrated a median suitability rate of 68% (31 – 80%) for various device designs. The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) methodology suggested a very low certainty regarding clinical outcomes.

**Conclusion:** The Endo-Bentall procedure is an emerging endovascular approach for ascending aortic pathologies, particularly for patients at high surgical risk. Early experience suggests feasibility. However, the current literature is significantly limited by publication bias and methodological heterogeneity. Further research is required, with systematic evaluation to optimise device development, surgical technique, bailout strategies, and long term outcomes.

**Keywords:** Aortic root, Ascending aorta, Endo-Bentall, Endovascular Bentall, Endovascular valve carrying conduit

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## INTRODUCTION

The ascending aorta remains one of the last uncharted territories in endovascular therapy. The concept of treating the ascending thoracic aorta with an endoprosthesis emerged after the first in human successful case described by Dorros *et al.* in 2000.<sup>1</sup> A decade later, the first successful thoracic endovascular aortic repair (TEVAR) for type A aortic dissection (TAAD) with a dedicated stent graft for the ascending aorta was published.<sup>2</sup> Since then, surgeons have been treating the ascending aorta by endovascular means using different devices and techniques, initially with stent grafts designed for the descending aorta.<sup>3</sup> Subsequently, dedicated ascending stent grafts were developed; however, none are currently available on the market.<sup>3–5</sup> It is believed that one ongoing trial is currently investigating a dedicated stent graft for the ascending aorta.<sup>5</sup>

In a recently published European Society for Vascular Surgery (ESVS) consensus document on ascending TEVAR, a proximal landing zone of 2 cm is recommended as necessary for the treatment of chronic dissections, penetrating aortic ulcers, and pseudoaneurysms, with a lower threshold of 1 cm for acute dissections. However, in many pathologies in the ascending aorta, the repair would essentially require proximal landing involving the sinotubular junction (STJ).<sup>6</sup>

The anatomical suitability of commercially available tubular stent grafts for TAAD remains low (4 – 21%), primarily due to constraints in the proximal landing zone's diameter and length, as well as the proximity of the entry tear to the STJ and coronary ostia.<sup>7</sup> Notably, in about 40% of acute TAAD (aTAAD) cases, the primary tear occurs at the aortic root level or within 1 cm of the STJ.<sup>8</sup> To overcome these limitations, the concept of an endovascular valve carrying conduit (Endo-Bentall), initially proposed by Rylski *et al.*,<sup>9</sup> is being implemented and assessed. The term Bentall stems from the original operation performed in 1968 by Dr Bentall, where a composite graft consisting of an aortic valve prosthesis sutured into a vascular graft was constructed.<sup>10</sup> In the next step of the operation, the coronary ostia were re-implanted into the constructed valve graft prosthesis. Since then, this technique has become the standard of care for aortic root pathologies.

No commercialised technology has yet been developed for Endo-Bentall, although there are some patent applications. The valve carrying conduit combines a tubular stent graft with either an uncovered proximal part, fenestrations, or branches for coronary perfusion and a transcatheter aortic valve implantation (TAVI) valve, either in a single stage procedure or a multistage approach with sequential implantation of the branched and or fenestrated ascending stent graft and the valve. TAVI platforms comprise balloon expandable and self expanding valves, each offering distinct advantages based on the underlying aortic pathology and procedural approach. Balloon expandable valves have a shorter stent frame, precise deployment, stronger radial force, lower risk of paravalvular leakage, and better suitability for transapical access. In contrast, self expanding valves provide greater flexibility in the form of repositioning

capability during deployment, offer better haemodynamics, and have a reduced risk of annular injury. The anatomical valve related criteria for the Endo-Bentall device (1) an aortic annulus between 18 – 29 mm (to accommodate a prosthetic valve) and (2) coronary ostia  $\geq 10$  – 12 mm above the annulus plane.<sup>11</sup> Distally, the Endo-Bentall device would require a sealing zone either in the ascending aorta with an aortic diameter of  $< 40$  mm or potential for combination with a device allowing for arch revascularisation with branches or fenestrations and distal landing zone in the descending aorta.

This scoping review aimed to summarise current experience, identify how available technology is used in the different pathologies, assess the quality of the literature and the level of evidence, and suggest future advances.

## METHODS

### Study design

A scoping review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) extension for scoping reviews was performed.<sup>12</sup> A systematic literature search of full text English articles in PubMed, Cochrane, and Embase databases until 30 November 2024 was performed. Reference lists from all included studies were manually screened and included if suitable.

The search strategy was developed using an approach aligned with the Population, Concept, Context (PCC) framework: the population comprised patients with ascending aortic pathologies; the concept focused on the Endo-Bentall procedure involving the valve, root, and ascending aorta; and the context included studies conducted in any clinical setting (Supplementary Table S1).<sup>13</sup> Two authors (M.S. and C.F.P.) performed the search process independently, with a third senior author (K.M.) consulted to provide consensus on discrepancies. The Rayyan web based tool (Rayyan.ai) was used to facilitate systematic review management, identify duplications, and automate article screening. Full detailed search strings for the three databases are available in Supplementary Table S2.

### Data extraction and evidence synthesis

Data extraction was performed by a single reviewer, with a second reviewer verifying the extracted data. Data were reported as descriptive narratives or tables in accordance with the PRISMA guidelines for scoping reviews without any statistical analysis. The MINORS (Methodological Index for Non-Randomised Studies) quality assessment tool was used to evaluate the quality of the included literature, and the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) system was used to assess the evidence profile for outcomes in clinical studies.

Data were extracted using Microsoft Excel software (Microsoft Corp., Redmond, WA, USA). The following data were extracted: first author, publication year, study aims, methodological details, including clinical data if present (e.g., patients, baseline characteristics, type and zone of aortic disease, outcomes), and or technical data (e.g., Endo-Bentall

procedural details, designs, models, anatomical suitability, and technical and anatomical challenges).

### Data presentation

Data are presented in textual form, as well as numerically as counts ( $n$ ), percentages (%), and either mean  $\pm$  standard deviation or median with range or interquartile range.

## RESULTS

The search initially identified 125 studies. After exclusion, 20 studies were included for analysis (Fig. 1). A list of all included studies is presented in Supplementary Table S3.

Of the 20 studies that were selected, four were single centre case reports or technical notes,<sup>14–17</sup> ten were anatomical feasibility or proof of concept studies,<sup>7,9,18–25</sup> three were reviews,<sup>26–28</sup> and three were expert opinions, letters, or commentaries.<sup>29–31</sup>

The MINORS quality assessment of the literature is presented in Supplementary Table S4 and indicated an overall score of 9 – 12 for case reports and anatomical suitability studies.

### Proof of concept studies

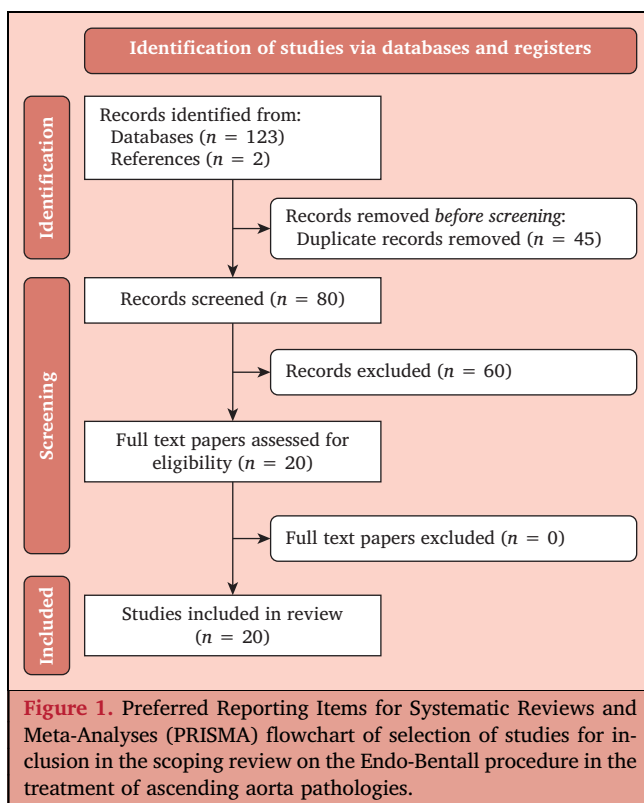
A feasibility study assessing the use of a one piece valved fenestrated stent graft with an integrated branch for the brachiocephalic trunk (BCT) was conducted in an *ex vivo* heart aortic complex with preserved supra-aortic branches from adult pigs, connected to a circulating pump with pressure sensors to simulate physiological flow. All 30 pigs had undergone computed tomography angiography (CTA),

and custom made devices (CMDs) were designed based on CTA measurements and deployed through transapical access under fluoroscopic guidance. The alignment of the stent's fenestrations with the coronary arteries and changes in coronary flow were assessed pre- and post-procedure. The technical success rate was 100% and the fenestrations were well aligned with the coronary ostia in most cases. In four cases, valve leaflets partially (nearly 20%) obstructed the left coronary artery fenestration, but this did not significantly reduce coronary flow, indicating that minor misalignment had little clinical impact.<sup>18</sup>

Following these *ex vivo* findings, the same group conducted an *in vivo* proof of concept study on 20 healthy pigs.<sup>19</sup> Gated CTA images were analysed, and a custom made one piece valved fenestrated stent graft was tailor made according to the cardiac and ascending aortic anatomy of the pig. Devices had three 10  $\times$  10 mm fenestrations to preserve coronary flow, a branch for the BCT for stable anchoring, and glutaraldehyde fixed bovine pericardium sutured into the stent graft to serve as an artificial aortic valve. Stent grafts were deployed through transapical access. One technical failure (5%) occurred when the endograft could not be deployed from the delivery system. Transoesophageal echocardiography (TOE), completion angiography, and instant CTA confirmed ideal positioning, preserved function, and satisfactory haemodynamic parameters in 19 cases (95%). The endografts were positioned  $9.1 \pm 2.5$  mm below the aortic annulus, with proper coaxial positioning, and all coronary arteries and BCTs were patent.<sup>19</sup>

Twelve pigs were sacrificed at the planned time, and another died due to graft infection. The mean follow up time for the remaining six pigs (30%) was  $8.1 \pm 3.6$  months. Two month follow up echocardiography showed minor aortic regurgitation in two of six pigs. Monthly CTAs confirmed that all coronary arteries and BCTs remained patent, with no graft displacement. At six months, histopathology showed normal cardiac muscle cell appearance.<sup>19</sup> Another study evaluated the biomechanical performance of a novel single stage device for treating TAAD using a generalised aorta simulation through finite element modelling. The proximal stent graft featured a diamond shaped dense stent connected to the valve by a metallic link bar.<sup>20</sup> The study compared the diamond shaped design with traditional stent designs (separated Z shaped), suggesting that the diamond shaped design would result in better biomechanical stability, reduced risks of endoleak, and improved resistance to migration. However, the increased rigidity of the device introduced higher localised stress on the vascular wall, indicating further optimisation to mitigate these effects.<sup>20</sup>

In another experimental study, a 3D model case for a coexisting ascending and arch aneurysm in a patient with previous aortic valve replacement was conducted. The study used a CMD with the Cook platform, incorporating external side branches for the coronary arteries, a tapered graft for the ascending aorta, and a balloon expandable TAVI device (20 mm, Sapien 3; Edwards Lifesciences, Irvine, CA, USA) using the rendezvous access technique. In this experiment, the graft and coronary bridging stents were successfully deployed.<sup>21</sup>



### Results of the case reports and technical notes

Five cases were included. The indications were aortic dissection ( $n = 2$ ), ascending and arch aneurysm (combination of Endo-Bentall and arch branch repair;  $n = 1$ ), and post-surgical complications, including pseudoaneurysm of the proximal anastomosis and aortic cutaneous fistula ( $n = 2$ ) (Table 1).

**Balloon expandable transcatheter aortic valve implantation platform.** Three cases, all non-TAAD, involved the use of a balloon expandable valve platform.<sup>12–14</sup> One used a single stage device, while two employed two stage devices.

The single stage balloon expandable TAVI case, representing the first reported case of an Endo-Bentall procedure, employed a CMD consisting of a Braile Inovare TAVI valve (Braile Biomedica, São José do Rio Preto, Brazil) pre-mounted on a balloon expandable platform. This valve was integrated with a self expanding aortic stent graft featuring two external/internal branches. The graft was tapered proximally to provide adequate space for coronary artery catheterisation through the graft branches, enabling the subsequent deployment of covered bridging stents. After positioning 0.014" safety guidewires in the coronary arteries through transfemoral access, the self expanding graft was deployed in the ascending aorta via transapical access. The valve was then dilated with balloon inflation within the aortic root. Extracorporeal membrane oxygenation was initiated before cannulation of the coronary arteries.<sup>14</sup>

In the two stage balloon expandable TAVI procedures, fenestrated physician modified endograft (PMEG) devices were combined with the TAVI valve. The fenestrated PMEGs consisted of two designs: (1) a Zenith TX2 Pro-Form thoracic endograft (Cook Medical, Bloomington, IN, USA) featuring three large fenestrations for accommodating the coronary ostia, with the third fenestration presumably ensuring broader anatomical compatibility; and (2) a Zenith Alpha thoracic stent graft (Cook Medical) with two coronary fenestrations and constraining sutures. Both designs incorporated a SAPIEN 3 Ultra balloon expandable transcatheter heart valve (THV; Edwards Lifesciences).<sup>15,16</sup>

The two cases had different access approaches. The rendezvous technique, which involves advancing a guidewire from the left ventricular apex (via surgical exposure) through the aortic valve and aorta, where it is snared via the common femoral artery, creating a stable through and through wire, was used in one case. In this case, the stent graft was introduced via transfemoral access and deployed across the aortic valve, followed by deployment of the TAVI valve through transapical access (hence called the rendezvous technique) (Fig. 2).<sup>15</sup> In the other case, the stent graft was introduced via the left carotid artery, advanced across the aortic valve, and rotated in a partially constrained configuration to align the fenestrations with the coronary arteries. The stent graft was then deployed while partially constrained, pinning the leaflets of the previous bioprosthetic valve open. The coronary arteries were cannulated through the fenestrations using deflectable sheaths via the right axillary artery, and stents were positioned but not deployed. Then, a TAVI valve was implanted via femoral

access, and the distal stent graft was balloon expanded to break the constraining suture. Finally, the coronary stents were deployed.<sup>16</sup> Both cases used rapid ventricular pacing and extracorporeal circulation.

In both two stage PMEG procedures, intra-operative complications were encountered and managed. In the first case, on releasing the Pro-Form fixation, the proximal end of the PMEG device migrated into the sinuses of Valsalva and was pushed into the ascending aorta. The through and through wire was repositioned outside the first PMEG, and a second modified PMEG was successfully deployed.<sup>15</sup> In the second case, the patient developed haemodynamic instability after removal of the cardiopulmonary bypass. TOE showed severe right ventricular dysfunction due to right coronary artery malperfusion caused by detachment of the patent right coronary artery stent from the aortic endograft, which was solved by implantation of a bridging Viabahn VBX stent graft (Gore, Flagstaff, AZ, USA).<sup>16</sup>

Technical success, defined as adequate seal and exclusion of the pathology, with correct endograft deployment on completion angiography and the absence of coronary ischaemia, unintentional occlusion of coronaries or arch vessels, new aortic valve insufficiency or retrograde dissection, and 24 hour death,<sup>32</sup> was eventually achieved in all three cases.

Early follow up CTA ( $n = 2$ , < 30 days;  $n = 1$ , 4 months) showed favourable outcomes in two of three cases. One case presented with a contained proximal type Ia endoleak (into the first migrated PMEG) but without perfusion of the 10 cm thoracic aortic aneurysm (TAA) sac. All had sustained coronary perfusion. Follow up duration ranged 5 days to 9 months. There were no reported deaths.

**Self expandable transcatheter aortic valve implantation platform.** A self expandable TAVI valve was used in two cases of TAADs (Fig. 3). Both were treated with a one stage device encompassing a PMEG tapered TEVAR device (Zenith TX2; Cook) with two proximal fenestrations for the coronary ostia, sutured circumferentially to a self expandable TAVI device (Evolut PRO; Medtronic, Minneapolis, MN, USA). The back table modification time ranged 40 – 50 minutes. Deployment was performed via femoral access, with and without cardiopulmonary bypass support. Both these cases were from the same unit and used the same technique. One case was combined with an endovascular arch repair distal to the Endo-Bentall.

Technical success was achieved in both cases without intra-operative complications. Early follow up CTA ( $n = 1$ , < 30 days;  $n = 1$ , 3 months) showed complete thrombosis of the false lumen, without endoleaks, and sustained coronary perfusion. One patient died after five months due to non-aortic related complications.<sup>17</sup>

**Coronary perfusion during Endo-Bentall.** In the five cases above, coronary perfusion was maintained via branches (two of ten) or fenestrations (eight of ten). In one case, perfusion also relied on stent graft diameter reducing ties, allowing flow to persist as an endoleak aside the stent graft during cannulation and stenting of the coronaries.

**Table 1.** Overview of published case reports on Endo-Bentall procedures, including data on patient characteristics and intervention details.

Author, year	Patient	Indication	Device design and implanted grafts	Coronary stenting	Access for the Endo-Bentall	Extra-corporeal circulation	CO reduction	TS*	Complications
Gaia, 2020 <sup>14</sup>	64 y/o woman	Pseudoaneurysm in the suture line of the ascending aorta (s/p with fistula to the skin and AI) with previous SAVR (Magna 23 mm aortic xenograft). Failed percutaneous closure attempts of the fistula, and failing aortic valve	One stage CMD: modified balloon expandable transcatheter prosthesis (22 mm Braile Inovare, Braile Biomedica, Brazil) proximally, connected to a tapered (34 – 40 mm) self expandable aortic stent with external/internal coronary branches (30 F)	Fluency stent and Ventus BX stent	Transapical	ECMO	RVP	Yes	In the LCA, the Fluency stent positioning was unsuccessful, thus switching to Ventus BX stent
Gandet, 2022 <sup>15</sup>	86 y/o woman	10 cm symptomatic distal arch and descending aneurysm, with a 5.5 cm dilatation of the ascending aorta	Two stage device: 100 mm PMEG, with three large proximal fenestrations for the coronary ostia, followed by TAVI and arch repair using an inner branch device: (1) Zenith TX2 Pro-Form thoracic endograft (40 × 152 mm) (2) SAPIEN 3 Ultra balloon expandable transcatheter heart valve (23 mm)	No	Rendezvous access, transapical to transfemoral (through and through)	ECMO	RVP	Yes	Migration of the proximal end of the PMEG into the sinuses of Valsalva. The wire was repositioned and a second modified PMEG was successfully deployed
Ghoreishi, 2023 <sup>17</sup>	63 y/o woman	aTAAD with a tear at non-coronary cusp and severe AI	One stage device: modified ascending tapered graft sutured circumferentially with TAVI and two proximal fenestrations for the coronary ostia: (1) PMEG ascending Cook device (2) Evolut PRO self expandable TAVI	None	Transfemoral	No	RVP	Yes	—

*Continued*

**Table 1-continued**

Author, year	Patient	Indication	Device design and implanted grafts	Coronary stenting	Access for the Endo-Bentall	Extra-corporeal circulation	CO reduction	TS*	Complications
	85 y/o woman	Ascending aortic aneurysm (6.3 cm) with multiple dissection flaps, a tear in left coronary cusp	One stage device: modified ascending graft (tapered) sutured circumferentially with TAVI and two proximal fenestrations for the coronary arteries: (1) PMEG ascending Cook device (2) Evolut PRO self expandable TAVI	Two CSs (Viabahn 5 × 19 mm and iCAST 6 × 19 mm) into the LCA; one CS (iCAST 6.0 × 19 mm) in the RCA	Transfemoral	No	RVP	Yes	—
Leshnower, 2023 <sup>16</sup>	72 y/o man	SAVR with a 29 mm bioprosthetic valve for severe AI 4 years earlier. Fistula from the non-coronary sinus of Valsalva to the LA was symptomatic (severe volume overload and cardiogenic shock)	Two stage device: proximal PMEG with two fenestrations for the coronaries and multiple constraining sutures, followed by TAVI: (1) Zenith Alpha thoracic stent graft (42 × 94 mm) (2) SAPIEN 3 balloon expandable transcatheter aortic valve (3) Conformable TAG Thoracic Endoprosthesis (45 × 100 mm)	2× balloon expandable CSs (Viabahn VBX)	Left common carotid artery and TAVI through right axillary artery	CPB circuit	—	Yes	Haemodynamic instability after removal of the CPB. TOE showed severe RV dysfunction due to RCA malperfusion caused by detachment of the patent RCA stent from the aortic endograft. Implantation of a VBX 7 × 39 mm

CO = cardiac output; TS = technical success; y/o = years old; s/p = status post-; AI = aortic insufficiency; SAVR = surgical aortic valve replacement; CMD = custom made device; ECMO = extracorporeal membrane oxygenation; RVP = rapid ventricular pacing; LCA = left coronary artery; PMEG = physician modified endograft; TAVI = transcatheter aortic valve implantation; aTAAD = acute type A aortic dissection; CS = covered stent; RCA = right coronary artery; LA = left atrium; CPB = cardiopulmonary bypass; TOE = transoesophageal echocardiography; RV= right ventricle.

\* TS was defined as adequate seal and exclusion of the pathology, correct endograft deployment at the completion angiography, and the absence of coronary ischaemia, unintentional occlusion of coronaries or arch vessels, new aortic valve insufficiency or retrograde dissection, and 24 hour death.

Six coronary arteries were stented: four with balloon expandable stent grafts, one with self expanding stent, and one with overlapping self expanding and balloon expandable stents. In the two unstented cases, one involved an aTAAD, while the other had an aneurysmal ascending aorta. The latter demonstrated a contained proximal type Ia endoleak.

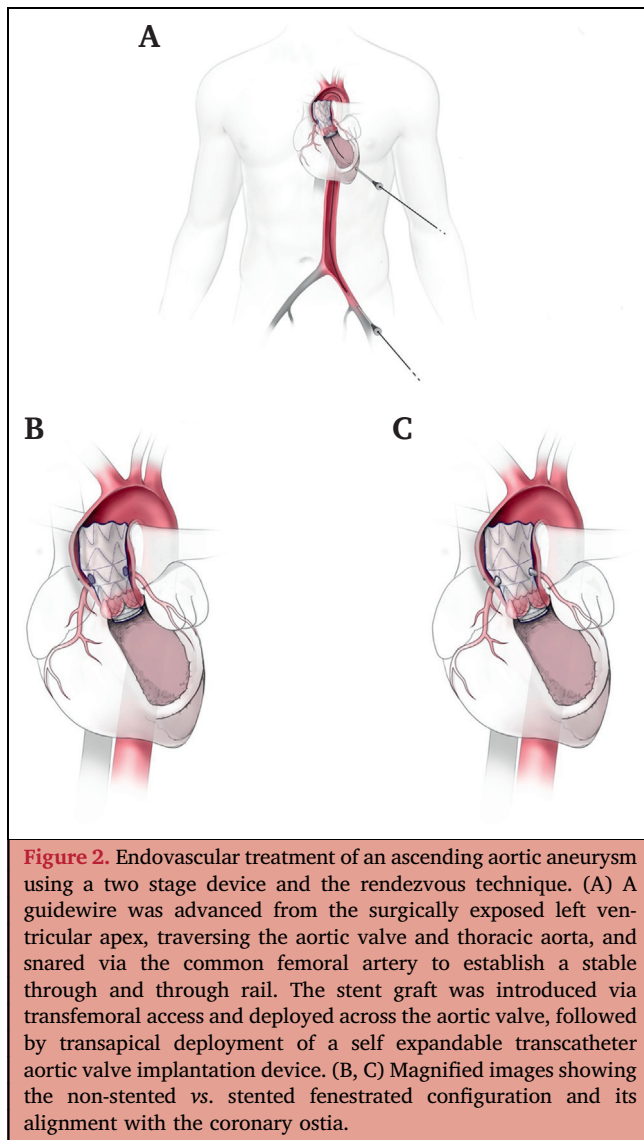
#### Evaluation of evidence profile for outcomes in clinical studies

The GRADE evaluation of evidence for the outcomes of technical success and overall survival in the clinical studies

suggested very low certainty. This was primarily due to serious risk of selection and publication bias in the available clinical literature, as well as the lack of long term data regarding overall survival ([Supplementary Table S5](#)).

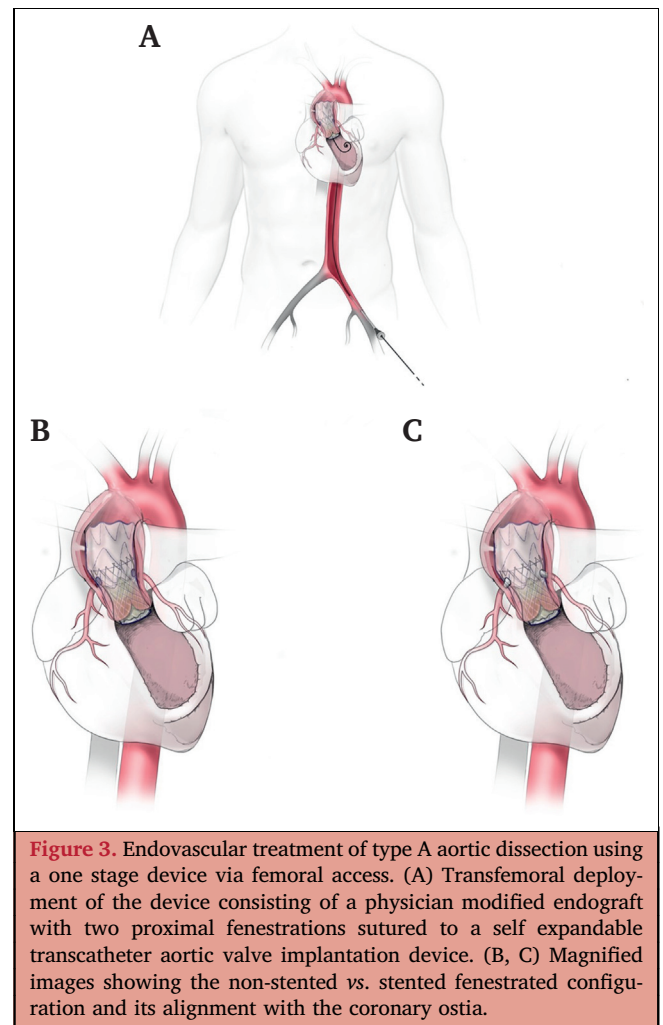
#### Results of anatomical suitability studies

There are no formal instructions for use (IFU) available for the devices used in the Endo-Bentall procedure. Consequently, the authors of the papers on anatomical feasibility for Endo-Bentall have all defined their own anatomical criteria based on the IFU for commercially available TAVI



and tubular stent grafts, considering the pitfalls of the complex geometry and physiology of the aortic root.<sup>33</sup>

The anatomy of 547 patients with aTAAD was analysed over four studies for different Endo-Bentall designs (Tables 2 and 3). Rong *et al.* proposed anatomical criteria for a modular branched balloon expandable valve carrying conduit that includes a stent graft with two inner branches, a proximal tapered connecting segment, and a balloon expandable TAVI device, all deployed through transapical access, subsequently with the inner branches stented via transfemoral access.<sup>22</sup> For this device, it was postulated that the aortic annulus diameter should range 16 – 28 mm to accommodate the currently available balloon expandable aortic valves in clinical practice. A minimum stent graft diameter of 30 mm at the STJ was proposed, corresponding to an STJ diameter > 28.6 mm with 5% oversizing, accommodating the aortic valve and two inner branches. Similarly, the maximum diameter of the stent graft was proposed to be 48 mm (aortic diameter at STJ and BCT diameter < 45.7 mm). A minimum 10 mm diameter difference between the aortic annulus and



STJ was deemed to be required to accommodate the stent's inner branches, and the maximum diameter difference between the STJ and BCT should not exceed 12 mm to ensure proper tapering of the stent graft. Additionally, the presence of coronary artery bypass grafts was contraindicated. This study concluded that 66.4% of patients were eligible for this modular Endo-Bentall stent graft system. Of these, 95% could be treated using four stent graft lengths, although tapered grafts were required in most cases, with 24.8% treatable with straight grafts.<sup>22</sup>

Kern *et al.* evaluated two endovascular designs for TAAD: fenestrated and branched balloon expandable valve carrying conduit.<sup>7</sup> Both required an annulus diameter < 30 mm and a minimal 10 mm distance from the aortic annulus to the proximal coronary artery. The fenestrated design required a 10 mm landing zone proximal to the STJ, while the branched design solely anchored in the annulus. Feasibility was 31% for the fenestrated design and 80% for the branched design.<sup>7</sup>

Vallée *et al.* evaluated a modular approach combining fenestrated and branched endografts with balloon expandable valves.<sup>23</sup> The fenestrated Endo-Bentall targeted tears > 10 mm distal to the STJ, while the branched Endo-Bentall addressed tears within 10 mm of the STJ. Another criterion

**Table 2. Overview of studies on the anatomical feasibility of Endo-Bentall procedure in different patient cohorts.**

Study	Patient cohort – n	Male – n (%)	Ethnicity	Inclusion criteria	Exclusion criteria	Imaging techniques	Device	Suitability
Rylski, 2014 <sup>9</sup>	51	35 (69)	Caucasian*	Severe aortic stenosis and ascending aortic diameter >45 mm and increased surgical risk profile	Bicuspid aortic valves	Aquarius iNtuition workstation (TeraRecon, Inc., Foster City, CA, USA). A centreline was created from the aortic valve annulus to the left subclavian artery	Tubular stent graft with a proximal uncovered portion, integrated with a TAVI valve via clips or single sutures	–
Kreibich, 2019 <sup>24</sup>	167	122 (73.1)	Caucasian*	aTAAD	An entry within the aortic root or within the 10 mm LZ	Multiplanar CT reconstruction, 3D software, manual correction of centreline	Balloon expandable valve, connected to an uncovered portion of a stent graft, with a distal stent graft	68%
Kern, 2023 <sup>7</sup>	112	–	Caucasian*	TAAD	–	Syngovia (Siemens), multiplanar reformatting, and 3D reconstructions	Balloon expandable valve carrying conduits with fenestrations or branches for the coronary arteries	Fenestrated: 31% Branched: 80%
Rong, 2023 <sup>22</sup>	152	102 (67.1)	East Asia*	aTAAD	Connective tissue disease or previous aortic valve replacement	Aquarius iNtuition workstation, centreline method	A stent graft with two inner branches, a proximal tapered connecting segment, and a balloon expandable valve	66.4%
Aldag, 2025 <sup>25</sup>	29	13 (45)	Caucasian*	Aortic annulus diameter 18–29 mm, ≥8 mm iliac artery diameter without severe calcification/tortuosity and ≥10 mm distance between aortic annulus and coronary ostium. Absence of mechanical aortic valve or coronary grafts in ascending aorta. Coronary arteries ≥3 mm in diameter and ≥10 mm in length	Mechanical aortic valve. Coronary anomalies, ostial stents, or severe calcification. Inadequate distal landing zones (<20 mm in length or >38 mm in diameter)	Aquarius iNtuition workstation	A stent graft for aortic repair with branches for coronary arteries. A separate aortic valve prosthesis compatible with TAVI	75.9%
Vallée, 2024 <sup>23</sup>	116	–	Caucasian*	aTAAD	Anatomical coronary related exclusion factors such as coronary height <10 mm and coronary length <5 mm for bridging stents	Multiplanar CT reconstruction, Aquarius iNtuition workstation	Fenestrated Endo-Bentall (targets entry tears in the aortic root or zone 0.1, while branched Endo-Bentall addresses distal entry tears. A TAVI component (Edwards Sapiens 3/Medtronic Corevalve Evolut)	63.7% (eligibility increased to 73.3% with extended criteria) <sup>†</sup>

TAVI = transcatheter aortic valve implantation; aTAAD = acute type A aortic dissection; LZ = landing zone; CT = computed tomography; TAAD = type A aortic dissection.

\* Based on the country where the study was conducted, considering it was an inaccurate assumption.

<sup>†</sup> Extended criteria: accommodating larger aortic annuli by adding 2 mm for endograft fabric thickness (e.g., Edwards Sapiens 3 suited for annuli up to 33.7 mm). It also included borderline dimensions typically excluded under standard criteria.

was a left main coronary length > 5 mm for the branched design. CTA evaluation showed 63.8% eligibility, increasing to 73.3% with extended anatomical criteria (defined as possible overexpansion of TAVI devices to aortic annulus up to 33.7 mm).<sup>23</sup>

Kreibich *et al.* suggested a different design consisting of a stent graft with a proximal uncovered part connected to the transcatheter aortic valve.<sup>24</sup> The study excluded cases with entry tears within the aortic root or the landing zone. The anatomical requirements included aortic annulus diameter

**Table 3. Anatomical key measurements in the cohorts studied in the six studies on anatomical suitability for Endo-Bentall.**

Study	Aortic annulus diameter – mm	STJ diameter – mm	Ascending aorta diameter at BCT offspring – mm	Predissection* STJ Diameter – mm	Ascending aorta Predissection* diameter at BCT offspring – mm	Distance from annulus to STJ – mm	Distance annulus– LCA – mm	Distance annulus– RCA – mm	Distance from STJ to BCT – mm	Distance from annulus to entry tear – mm	Entry tear in aortic root – n (%)
Rylski, 2014 <sup>9</sup>	28.7 ± 3.6	35.5 ± 4.6	42.0 ± 4.2	–	–	17.0 ± 4.5	13.5 ± 3.2 <sup>*</sup>	13.9 ± 3.9 <sup>†</sup>	119.0 ± 15.0 <sup>‡</sup> 56.0 ± 9.8 <sup>§</sup> 84.5 ± 11.1 <sup>‡</sup>	–	–
Kreibich, 2019 <sup>24</sup>	25.0 (22.6, 27.1)	40.8 (34.6, 45.8)	42.8 (37.9, 45.4)	35.1 (29.8, 39.4)	36.0 (31.8, 38.1)	28.0 (24.1, 30.0)	17.0 (4.0, 19.1) <sup>†</sup>	22.0 (19.0, 24.1) <sup>†</sup>	89.1 (80.0, 101.2) <sup>‡</sup>	65.2 (48.0, 98.1) <sup>‡</sup>	Excluded from study
Kern, 2023 <sup>7</sup>	26.36 ± 3.71	42.29 ± 9.08	46.7 ± 11.96	–	–	23.51 ± 5.12	13.84 ± 3.71 <sup>†,  </sup>	–	47.8 ± 58.01 <sup>‡</sup>	66	–
Rong, 2023 <sup>22</sup>	24.1 (22.7, 26.0)	40.8 (34.6, 45.8)	43.5 (40.2, 47.2)	37.7 (33.8, 40.7)	37.3 (34.5, 40.5)	28.4 (26.0, 34.0)	12.7 (9.5, 15.4) <sup>†</sup>	16.7 (14.9, 19.8) <sup>†</sup>	80 (73.5, 91.0) <sup>‡</sup>	49.5 (23.7, 78.7)	64 (42.1)
Aldag, 2025 <sup>25</sup>	25 (22.6, 27.1)	36.3 (32.6, 40.0)	–	–	–	–	13	–	117 (107.8, 126.3) <sup>‡,¶</sup>	–	–
Vallée, 2024 <sup>23</sup>	26.7 ± 3.7	43.3 ± 7.8	48.3 ± 7.1	–	–	24.5 ± 5.4	16.4 ± 6.4	18 ± 6.2	84.4 ± 13.3	45.9 ± 30.6	10 (9)

Data are presented as mean ± standard deviation or median (interquartile range) unless otherwise stated. STJ = sinotubular junction; BCT = brachiocephalic trunk; LCA = left coronary artery; RCA = right coronary artery.

\* Predissection diameters were estimated using the method of Rylski et al.<sup>33</sup>

† Centreline.

‡ Greater curvature.

§ Smaller curvature.

|| Proximal coronary artery.

¶ Distance from annulus to BCT.

between 23 – 31 mm, 10 mm landing zones starting at the STJ and ending just proximal to BCT, and a 5% oversizing for the stent graft. Eligibility reached 68%, with tapered grafts needed due to significant diameter differences in the proximal and distal ascending aorta.<sup>24</sup>

Two studies examined the anatomical suitability of an Endo-Bentall device for treating ascending aortic aneurysms. Rylski *et al.* proposed a tubular stent graft with a proximal uncovered portion, allowing coronary perfusion and integration with a TAVI valve.<sup>9</sup> These components are connected using clips or single sutures, with a single stage implantation via transapical access. The study population comprised patients with severe aortic stenosis screened for TAVI with an ascending aortic diameter ≥ 45 mm. The device requires suitable landing zones: aortic annulus < 30 mm, proximal diameter < 45 mm (for self expandable valve), and distal ascending diameter < 42 mm, allowing for graft implantation sized between 30 – 46 mm and achieving 10% oversizing, and a minimum safe distance of 10 mm between the annulus and coronary ostia is also required. This device was deemed suitable for 78% of patients with an annular range of up to 30 mm.<sup>9</sup>

Aldag *et al.* proposed a double component device incorporating a branched stent graft and a balloon expandable valve.<sup>25</sup> Anatomical criteria included an annulus diameter of 18 – 29 mm, ≥ 10 mm distance between the annulus and coronary ostia,

and absence of mechanical aortic valve, coronary bypass grafts originating from the ascending aorta, or left ventricular thrombus. For the distal landing zone, a ≥ 20 mm distal landing zone is required, and a diameter of ≤ 38 mm unless extension into the arch is performed. Coronary artery criteria include diameter ≥ 3 mm and ≥ 10 mm in length, in addition to being free from anomalies, aneurysms, dissections, previous ostial stents, ostial stenosis, or severe calcification, and no dissection of the ascending aorta. Of the 29 consecutive patients with ascending aortic aneurysm, 75.9% were found to be anatomically suitable candidates for this device.<sup>25</sup>

## DISCUSSION

This review summarises the current published experience with the Endo-Bentall procedure, which remains limited due to its focus on early feasibility studies and case reports. Significant limitations remain, such as the scarcity of published data, heterogeneous off label device combinations instead of a dedicated design, and lack of long term outcomes. Therefore, the use of this new technique is not recommended in routine clinical practice and should be limited to studies approved by research ethics committees<sup>34</sup> or highly selected cases (e.g., compassionate use) within experienced centres.

Securing an adequate landing zone is critical in endovascular aortic repair, as the aortic root is a highly dynamic structure with

alterations in shape and is decidedly mobile during the cardiac cycle. The ascending aorta presents numerous challenges due to its short length, variable wall elasticity, high pressure flow, elevated wall shear stress, turbulence, extensive motion, and rotational forces. Additionally, its proximity to critical structures, including the STJ, aortic valve, coronary ostia, and arch vessels, further complicates endovascular intervention.<sup>3,6</sup>

The valve carrying conduit extends the proximal landing zone to include the aortic annulus and STJ, with the coronary ostia as a major complicating factor, potentially increasing the number of patients eligible for endovascular treatment.<sup>7</sup> The concept of Endo-Bentall is evolving, with several devices and approaches being developed and implemented. However, the real world experience of the Endo-Bentall procedure is limited to a few published case reports.<sup>14–17</sup> Additional cases are being performed and presented at scientific meetings. There may also be failed attempts and programmes not shared with the public. While the concept is promising, its broader applicability remains uncertain due to several key limitations. Positive publication bias may over represent successful outcomes, while selection bias stemming from the inclusion of highly selected patients and optimised imaging protocols limits generalisability to real world conditions. As an example, the high rate of eligibility of patients for Endo-Bentall identified in anatomical feasibility studies of aortic dissection and aneurysm may not translate into clinical practice owing to device availability, operator training, and patient variability. Moreover, there is a lack of long term durability data beyond the early post-operative period.

Based on the case reports that were identified in the current literature, two concepts have emerged. The first involves using a balloon expandable valve in combination with a tubular graft across the left ventricular outflow tract, as either a one or two stage device. In this approach, the device crosses the native aortic valve during implantation, leading to severe aortic regurgitation, necessitating cardiopulmonary bypass to unload the heart and compensate for the temporary circulatory collapse.<sup>14–16</sup> The second concept is a physician constructed self expandable valve conduit. The TAVI valve's proximal pericardium cuff secures the tubular graft to the valve frame without interfering with leaflet function. A single stage deployment via retrograde access limits the risk of aortic insufficiency during deployment, minimising the need for bypass support.<sup>17</sup>

Another proposed concept in the anatomical suitability studies involves a tubular stent graft with a proximal uncovered portion integrated with a TAVI valve.<sup>9,24</sup> However, when evaluated in TAAD, patients with aortic root entry tears were excluded. In aneurysmal pathology, such a design does not allow for proximal sealing within the left ventricular outflow tract/aortic anulus.

The underlying pathology should guide the choice of the technique and whether to use a single or multistage approach. As the available data are still scarce, it remains premature to determine which approach is superior or to establish clear guidelines for choosing one over the other.

Ghoreishi *et al.* published a comprehensive review of a modular system for the off the shelf Endo-Bentall technique,

incorporating a self expanding TAVI valve introduced via the femoral artery.<sup>28</sup> In this paper, the authors emphasised using a through and through wire from the left ventricular apex to the femoral access site, which may significantly enhance device orientation and deployment. While it is suggested that cardiopulmonary bypass is not routinely required for this procedure, it is recommended to have it available on standby as a precautionary measure. Notably, it is underlined that Endo-Bentall planning and performance require a multidisciplinary approach in all phases of the patient's care.

As early results are published and presented, several technical challenges of the Endo-Bentall procedure have emerged. One major concern is the risk of coronary malperfusion due to misalignment of fenestrations or improper deployment of coronary stents; this risk justifies the proximity and readiness for mechanical circulatory support. The solutions for preserving coronary flow during the deployment include an uncovered proximal stent graft or large fenestrations to allow for free diastolic coronary blood flow, which, on the other hand, may induce proximal leakage. Other concerns are determining the minimum safe landing zone length in the coronaries, the suitability of the main left coronary length for sufficient landing, the optimal type and size of bridging stents, and flaring aggressiveness limits. Using branched devices or stenting the fenestrations enhances proximal sealing in aneurysmal pathologies, but whether fenestrations, even when stented, should be preferred over branches in treating aneurysmal pathologies remains to be determined. Insights from procedures involving the aortic arch and thoraco-abdominal regions could guide the Endo-Bentall procedure until further experience is gained.<sup>35,36</sup>

### Conclusions

The Endo-Bentall procedure represents an emerging advance in the endovascular treatment of ascending aortic pathologies, particularly for patients at high surgical risk. The method encompasses a true multidisciplinary challenge, where expertise from vascular surgery, cardiac surgery, and interventional cardiology intersects. While early experience suggests feasibility, current evidence is primarily based on case reports, inherently affected by publication bias and marked heterogeneity in methodology, resulting in a very low level certainty of evidence based on GRADE evaluation. Further research focusing on defining standardised selection criteria, establishing concrete procedural steps and approaches, and systematically recording in a dedicated registry, coupled with structured follow up protocols, is needed to optimise device design, improve technical execution, and assess long term outcomes in larger patient cohorts.

### CONFLICT OF INTEREST

None.

### FUNDING

None.

### APPENDIX A. SUPPLEMENTARY DATA

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ejvs.2025.07.026>.

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