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REPORT

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Standards of reporting in open and endovascular aortic surgery (STORAGE guidelines)

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Key question

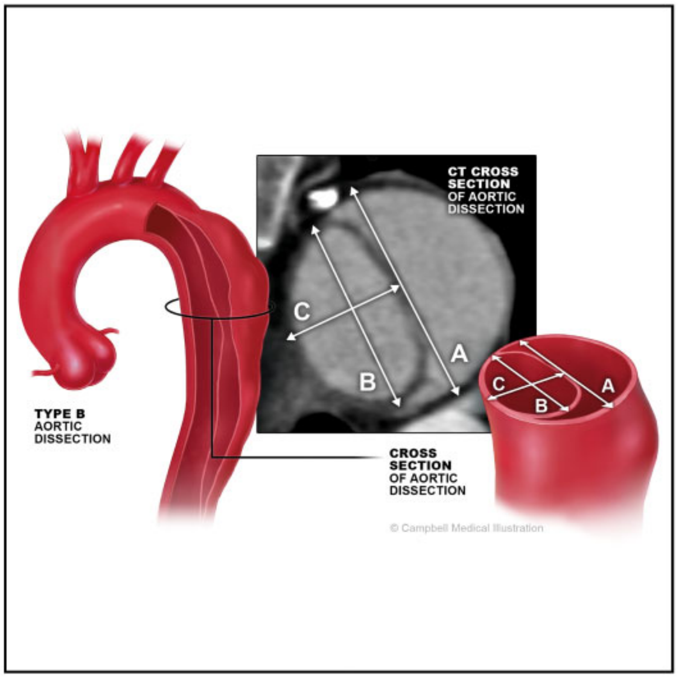
How can we improve the treatment of patients with aortic disease?

Key finding(s)

This document gives guidance to authors reporting on results in open and endovascular aortic surgery.

Take-home message

Finding a common language among those involved in the treatment of patients with aortic disease will ultimately improve outcomes.



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Abstract

The number of patients undergoing surgery on the thoracic and thoraco-abdominal aorta has been steadily increasing over the past decade. This document aims to give guidance to authors reporting on results in aortic surgery by clarifying definitions of aortic pathologies, open and endovascular techniques and by listing clinical parameters that should be provided for full presentation of patients' clinical profile and in particular, their outcome. The aim is to help find a common language in the treatment of aortic disease and to contribute to a better understanding of this patient population.

Keywords: Aorta • Guidelines • Data • Reporting

INTRODUCTION

The number of patients undergoing surgery on the thoracic and thoraco-abdominal aorta has been steadily increasing over the past decade. This development is reflected by an increasing number of manuscripts dealing with aortic diseases submitted to the European Journal of Cardio-Thoracic Surgery (EJCTS) and the Interactive CardioVascular and Thoracic Surgery (ICVTS). Both journals receive more than 200 manuscripts on this topic per year including original articles, review articles, descriptions of surgical techniques, case reports and images in cardio-thoracic surgery.

As can be expected, the quality of the manuscripts varies widely. Data reporting levels vary from studies with missing basic clinical data relevant in aortic surgery, manuscripts with inappropriately chosen parameters for multivariate risk analysis or propensity scoring, papers without clear definitions of end points to well-structured manuscripts with excellent study design. Frequently, reviewers point out faults in study design and data reporting, instead of focusing on the scientific content. Nevertheless, due to absence of standards of reporting in this field, even manuscripts complying with rigorous scientific standards are sometimes missing crucial information, making it impossible to compare results between groups.

The problem is manifold: (i) aortic surgery has almost become a subspeciality in our field and our ways to report the results have not kept up with the technical developments in the field; (ii) aortic patients are patients for life and many undergo multiple interventions over the years. This poses a challenge to follow-up and the level of differentiation with which we report our results; and (iii) aortic patients are now increasingly being treated by open and endovascular means and we have not yet found a common language that enables us to communicate our results accordingly.

This document is based on the writing committees' clinical experience in open and endovascular aortic surgery as well as writing and reviewing manuscripts on aortic disease. While there have been attempts to harmonize reporting of results in aortic surgery before [1], there have been substantial new developments in the field that have not been accounted for so far. We aim to clarify definitions of pathologies, open and endovascular techniques and provide lists of clinical parameters that should be provided for full presentations of patients' clinical profile and in particular their outcome. We aim to point out frequently made mistakes and inaccuracies in reporting on aortic pathologies. These guidelines should improve the quality of research submitted to journals in our field allowing the reviewers and editors to focus on scientific content rather than data quality. Researchers should not feel patronized by the data sets defined in this document. This report is an attempt to help define a common language in the care of patients with aortic diseases.

REPORTING ON RISK PROFILE AND COMORBIDITIES

Demographics, risk profile and comorbidities are usually reported at the beginning of the patient/methods section in most manuscripts. These data are necessary to describe the state of health and baseline characteristics of study patients.

Risk scores for cardiac operations include demographic data, comorbid data related to other organ systems, and details about cardiac function and anatomy. Doing the same for aortic disease management becomes more difficult because of heterogeneity in aortic anatomy and morphology, variability in the disease processes affecting the aorta, differences in how involved segments of the aorta affect an individual, fundamental differences in the treatment modalities for aortic disease, and local differences in experience with treatment approaches for aortic disease.

There are aortic pathologies, which may be treated in open or endovascular fashion with similar results. Endovascular repair is usually associated with lower operative mortality and morbidity than open repair. However, this advantage disappears with time, due to more frequently observed stent graft-related complications resulting in similar long-term mortality [2, 3]. Therefore, risk stratification of patients is essential for better comparison of study results, database analyses, therapies, and finally, to find the most appropriate aortic procedure for each individual patient. Currently available risk scores for perioperative risk assessment in cardiac surgery such as STS Risk Model [4] or EuroSCORE II [5] are widely used to assess the perioperative risk for mortality in cardiac procedures. However, they have not been validated for aortic diseases and their surgical and endovascular treatment modalities. As long as no risk stratification score for thoracic aortic disease has been developed, STS and EuroSCORE may be used only to compare studies, but not to calculate the actual risk in a specific group of aortic patients. A number of risk prediction scores are available in both elective and emergency abdominal aortic aneurysm repair. The large number of these models is partially result of their suboptimal performance. The list of currently available risk scores that may potentially be used to stratify the risk profile is given in Table 1. Most of them were validated externally. However, none of the current scoring systems appears ideal and none of them is applicable universally in both elective and acute aneurysm surgery. Reporting on abdominal aortic aneurysm, using one of the above-mentioned risk prediction scores will help to better demonstrate the study group risk profile.

DEFINITIONS OF AORTIC PATHOLOGIES

The underlying aortic pathology of the patient should be clearly stated throughout the text. If patients undergo multiple interventions, it has to be made clear whether the underlying pathology has changed, for example, a patient undergoes root replacement for type A dissection after elective thoracic endovascular aortic repair (TEVAR) for aneurysm of the descending aorta. The type of disease process should be stated using definitions as given in the 2010 American Heart Association (AHA) [14] and the 2014 European Society of Cardiology (ESC) [15] guidelines for aortic disease. It is important to differentiate the morphological changes and the underlying disease process, for example, aneurysm formation can occur due to various reasons such as inflammation or connective tissue disorders. Therefore, the term 'traumatic aortic injury' defines more the disease mechanism than the morphological changes, which could be dissection, rupture or pseudoaneurysm. The most common morphological changes are 'aneurysm', 'dissection', 'intramural haematoma (IMH)' and 'penetrating aortic ulcer'. Of course, as has been discussed in the literature, IMH and dissection can be difficult to distinguish, as there is certainly a time-dependent element as patients with IMH may progress into dissection. In these cases, the first imaging that was obtained should define the category. Ideally, data should not only contain data on the morphology but also on the underlying pathology such as disorders of connective tissue or in cases of mycotic aneurysm. It is recommended to define the aortic pathology based on the first imaging is available. If the pathology changes, for example, from IMH to overt dissection, this has to be reported including the timeline. This is especially important as a change in pathology might affect the indication to intervene.

Table 1: Currently available risk scores that may be used for patients undergoing aortic surgery

Aortic pathology	Risk score
Thoracic aorta	STS Risk Model [4] EuroSCORE I [5] EuroSCORE II [5]
Elective abdominal aortic aneurysm repair	British Aneurysm Repair score (BAR) [6] Endovascular aneurysm repair Risk Assessment (ERA) [7] Giles score [8] Mount Sinai score (MS) [9] Vascular Governance New West model (VGNW) [10]
Ruptured abdominal aortic aneurysm repair	Vascular Study Group of New England (VSGNE) [11] Glasgow Aneurysm Score (GAS) [12] Edinburgh Ruptured Aneurysm Score (ERAS) [13]

As patients become more complex, it is important to provide data on the sequence of events. Two possible ways to present complex patients are shown in Fig. 1A and B.

Aneurysm

Aneurysm is defined by a pathological enlargement of the aorta of more than 1.5 times the diameter of the adjacent healthy segment. Unfortunately, in patients with complex aortic pathologies, this definition is only of limited value and aortic diameter is a continuous variable so data describing aortic size should be better described as a measurement. Reference values and the decision to perform prophylactic operations for any given patient are dependent on pathology, age, sex, body surface area and height [15, 18].

In adult patients, it is reasonable to describe absolute maximum aortic diameters when characterizing patients with

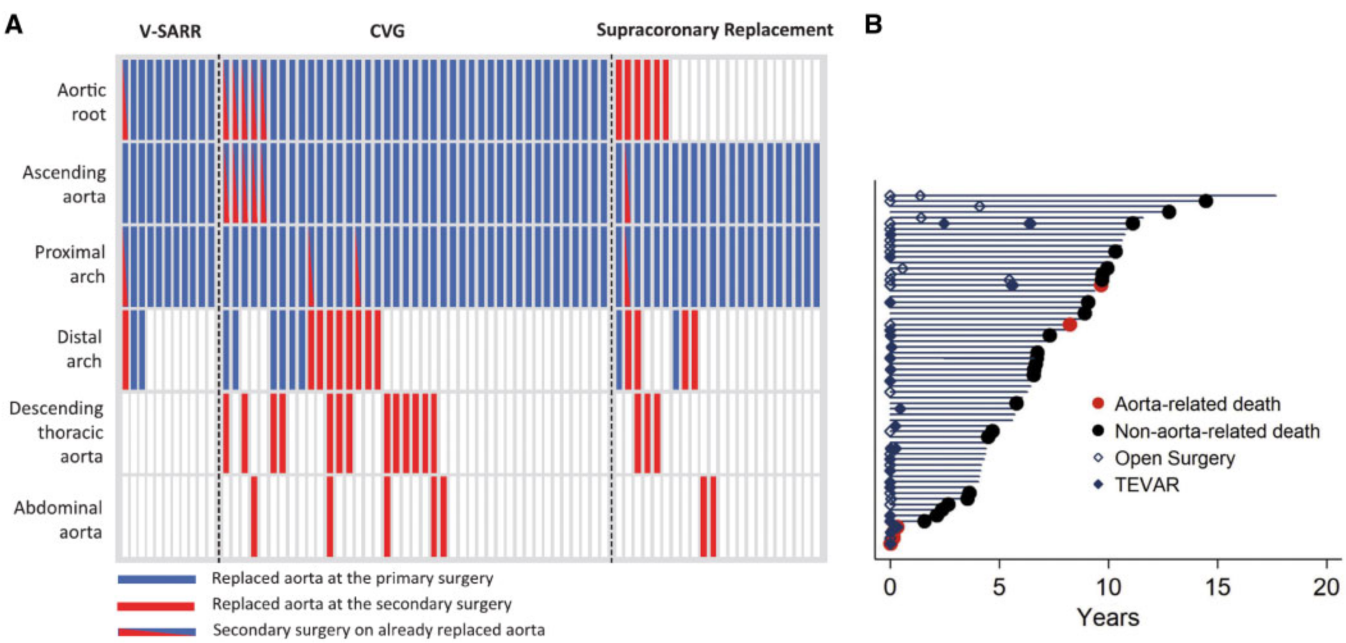

Figure 1: Two examples for reporting results in aortic surgery. All patients of the population in question are included. All interventions associated with each patient are shown. The timeline of each patient is clearly depicted. (**A**) Pattern of primarily and secondarily replaced aortic segments in patients with Marfan syndrome who underwent surgery for Stanford type A aortic dissection. Each vertical column represents 1 patient [16]. (**B**) Outcome of patients with intramural haematoma. Each bar represents 1 patient. The length of the bar represents duration of follow-up. The graph shows that aortic-related mortality basically only occurs during the first year after the event and that aortic interventions after the first year are rarely necessary [17]. Nevertheless, both graphs have their limitations. While (**A**) provides the sequence and location of interventions, there are no data on the time interval between interventions. In contrast, while (**B**) provides data on the time course of events, details regarding the operative procedure are lost. CVG: composite valved graft; TEVAR: thoracic endovascular aortic repair; V-SARR: valve-sparing aortic root replacement. Reprinted with permission from Schoenhoff *et al.* [17].

aneurysms but such descriptions should also describe the segment of aorta associated with such measurement. The problems in defining the correct aortic diameter will be discussed below. In children, *z*-scores should be given along with the size of the aorta. As there are multiple *z*-scores available that may differ significantly in a given patient, it should be stated which standard for the *z*-score was used.

Aortic dissection

According to the Stanford classification of aortic dissection, as interpreted by the current guidelines, a dissection is considered to be a type A dissection if the ascending aorta is involved, regardless of the location of the entry tear. Accordingly, a dissection in the aortic arch has to be considered a type B dissection. But as 90% of type B dissections occur distal to the left subclavian artery, the majority of data on type B dissection do not apply to aortic arch dissection. Nevertheless, the current guidelines do not support the notion of 'non-A/non-B' dissections, although this has also been discussed in the 2010 AHA guidelines acknowledging differing opinions even within the writing committee. The more recent 2014 ESC guidelines do not discuss this issue in any way. The guidelines on descending aortic disease of the European Society of Vascular and Endovascular Surgery state that type B dissections originate distal to the offspring of the left subclavian artery but recognize that there is no consensus regarding aortic arch dissections without involvement of the ascending aorta [18]. As there is evidence that patients with entries in the arch have a different clinical course than those with an entry in the descending aorta, the recently published European Association for Cardio-Thoracic Surgery (EACTS)/ European Society for Vascular Surgery (ESVS) position paper on open and endovascular aortic arch interventions has introduced non-A/non-B dissection as a separate clinical entity [19]. It is therefore recommended to at least report the proximal extent of type B dissection. If feasible, patients with non-A/non-B dissection should be analysed separately.

Malperfusion in acute aortic dissection

Malperfusion has been shown to be the main determinant in the outcome of acute aortic dissection [20]. It has been shown that the number of malperfused organ systems correlates with the mortality rate in this patient population. Therefore, reporting malperfused organ systems and the number thereof is mandatory.

Stages of aortic syndromes

Aortic syndromes are termed 'acute' for any aortic syndrome diagnosed between the onset of symptoms and 14 days, 'subacute' between 15 days and 90 days and 'chronic' thereafter.

Aortic intramural haematoma

The current ESC guidelines define IMH as a circular or crescent-shaped thickening >5 mm of the aortic wall with the absence of dissecting membrane, intimal disruption or false lumen flow. While current guidelines see IMH as a separate entity, distinction between IMH and dissection may not always be possible in clinical practice. There is certainly a time-dependable variable regarding diagnosis, as patients frequently present with new intimal lesions 24–48 h after the initial imaging studies are done. The current definition of IMH may be challenged as more sophisticated imaging methods will be able to identify more primary entry tears and therefore more frequently identify IMH as a precursor of acute aortic dissection.

Penetrating aortic ulcer

The current ESC guidelines on aortic disease define penetrating aortic ulcer (PAU) as an ulceration of an aortic atherosclerotic plaque penetrating through the internal elastic lamina into the media. It is thought that PAU occurs in 2–7% of all patients with acute aortic syndromes. While there are no controlled studies regarding the natural history of PAU in different settings, reports have shown that PAU can result in the development of aortic aneurysm, IMH or aortic dissection. Patients presenting with PAU frequently have a high atherosclerotic burden. Risk factors for PAU include advanced age, male gender, tobacco smoking, hypertension, coronary artery disease, chronic obstructive pulmonary disease, and presence of abdominal aneurysm. In a study from the Mayo Clinic including 105 patients, ulcerations were located in the descending aorta in 94% of patients, in 11% in the aortic arch and 10% presented with PAUs in multiple locations [21]. PAU can be difficult to distinguish from so-called ulcer-like projections. Ulcer-like projections are most frequently associated with IMH, whereas according to the current definition in the ESC guidelines, PAU has to be associated with an atherosclerotic process.

ANALYSIS OF AORTIC IMAGING

There is no universally accepted standard how to measure and report aortic diameters. Current guidelines recommend giving the maximum aortic diameter as measured perpendicular to the flow in the aorta. The guidelines recommended to give the maximum diameter including the aortic wall when using computed tomography (CT) imaging and excluding the aortic wall when referring to diameters acquired by echocardiography. If we assume that the aortic wall has a thickness of 1.5–2.0 mm, this will, in many cases, have an impact on the decision whether to proceed to surgery or not (Fig. 2).

Most publications that form the basis of our decision-making process today do not specify in detail how measurements were obtained and man publications use CT and echocardiography images interchangeably. Of note, some of the more recent publications referring to abdominal aortic aneurysms specifically refer to the external diameter as obtained by CT imaging.

For the purpose of reporting in scientific publications, we recommend the use of CT or magnetic resonance imaging (MRI) whenever possible, as these measurements are less susceptible to interobserver variability. CT images can be reformatted again every time they are analysed as opposed to images that have been saved by the echocardiographer at the time the images were acquired. The authors should state whether they measured the maximum diameter including or excluding the aortic wall. The method used should, of course, be consistent regarding all patients in the given population. For future studies, we recommend acquiring aortic measurements including the aortic wall using CT or MR imaging. When the research question being addressed is dependent upon detailed imaging analysis, it is

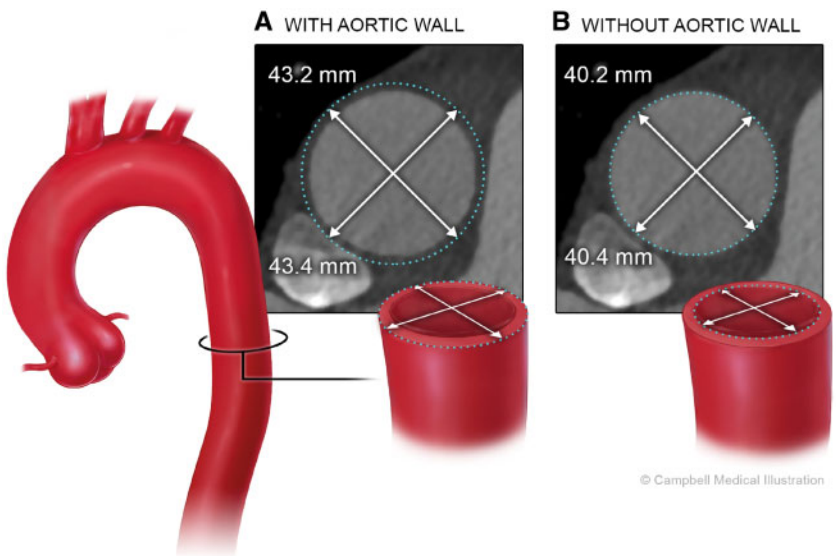

Figure 2: Measuring the maximal diameter (**A**) with or (**B**) without the aortic wall yields significantly different results. When using computed tomography imaging, it is recommended to give the external diameter, including the aortic wall.

recommended that the validity of measurements be assessed for interobserver and intraobserver variability using a small sample (typically 10–20 samples) blinded analysis.

CT is the most commonly used imaging modality to assess the aorta. Reporting on CT imaging, it is necessary to include the following information: (i) the name of CT scanner with number of detector rows and spatial resolution, (ii) information on CT data acquisition with reference to the electrocardiogram gating, (iii) systolic versus diastolic and arterial versus venous data acquisition, (iv) usage of contrast material, (v) imaging slice thickness and (vi) number of observers and information on patient-identifying data availability.

Reporting on aortic anatomy

The aorta is divided into 5 sections: the aortic root, the ascending aorta, the aortic arch, the descending thoracic aorta and the abdominal aorta. Since the introduction of endovascular techniques, a more detailed and treatment-oriented classification of aortic segments has become necessary (Fig. 3). Regarding aortic arch anatomy, we refer to the types I, II and III aortic arch configurations oriented to the position of the innominate artery. In type I aortic arch, all 3 supra-aortic arteries branch off in the same horizontal plane at the outer arch curvature. If the innominate artery originates between the horizontal planes of the outer and inner curvatures of the aortic arch, it is type II aortic arch. In type III aortic arch, the innominate artery originates below the plane of the inner curvature of the aortic arch [22]. There are different aortic arch configurations and multiple names were introduced for various arch anatomical variations. Using any of them requires a clear definition. One of the most common misnomers is 'bovine arch'. Bovine arch is usually used to describe the aortic arch configuration when the innominate artery and the left carotid artery have a common offspring from the arch or the left carotid artery originates from the innominate artery. In cattle, there is only one single great vessel originating from the aortic arch. As a true bovine aortic arch does not resemble any of the common human aortic arch variations, the term 'bovine arch' with regard to patients should be avoided. It is recommended to use a descriptive aortic arch naming, such as 'common origin of the innominate artery and left common carotid artery' or 'origin of the left common carotid artery from the innominate artery' [23]. If there is a separate offspring of the left vertebral artery, it should be mentioned.

It is recommended to report whether a bicuspid aortic valve was present. If reporting in detail, the Sievers classification should be used.

Longitudinal reporting on morphological outcome

Open aortic surgery carries risk of suture aneurysm, development of new aortic pathology in not replaced aortic segments, prosthesis infection, etc. In endovascular repair, the aneurysm sac is left intact and the false lumen of the dissected aorta frequently remains under pressure. Therefore, reporting on morphological outcome requires aortic imaging on a regular basis. The completeness of aortic imaging must be reported by giving frequency of data acquisition, date of the last follow-up CT and the number of patients lost from CT follow-up. In case of multiple follow-up CTs, it is recommended to report results of all of them and not only on the first and last CT. More information on follow-up reporting is available in 'Statistical and data reporting guidelines for the European Journal of Cardio-Thoracic Surgery and the Interactive CardioVascular and Thoracic Surgery' [24]. Comparisons between follow-up measurements should be made only between identical diagnostic modalities (CT to CT, MRI to MRI, sonography to sonography, etc.).

Reporting on endovascular aneurysm treatment requires presentation of changes in dimensions of residual aneurysm sac, which determines the treatment success or failure. Similar, in case of aortic dissection, parallel to reporting on true lumen diameter, the total aortic diameter change is essential to evaluate the treatment success. Aneurysm growth or dissected aortic growth after endovascular repair is an indicator of insufficient

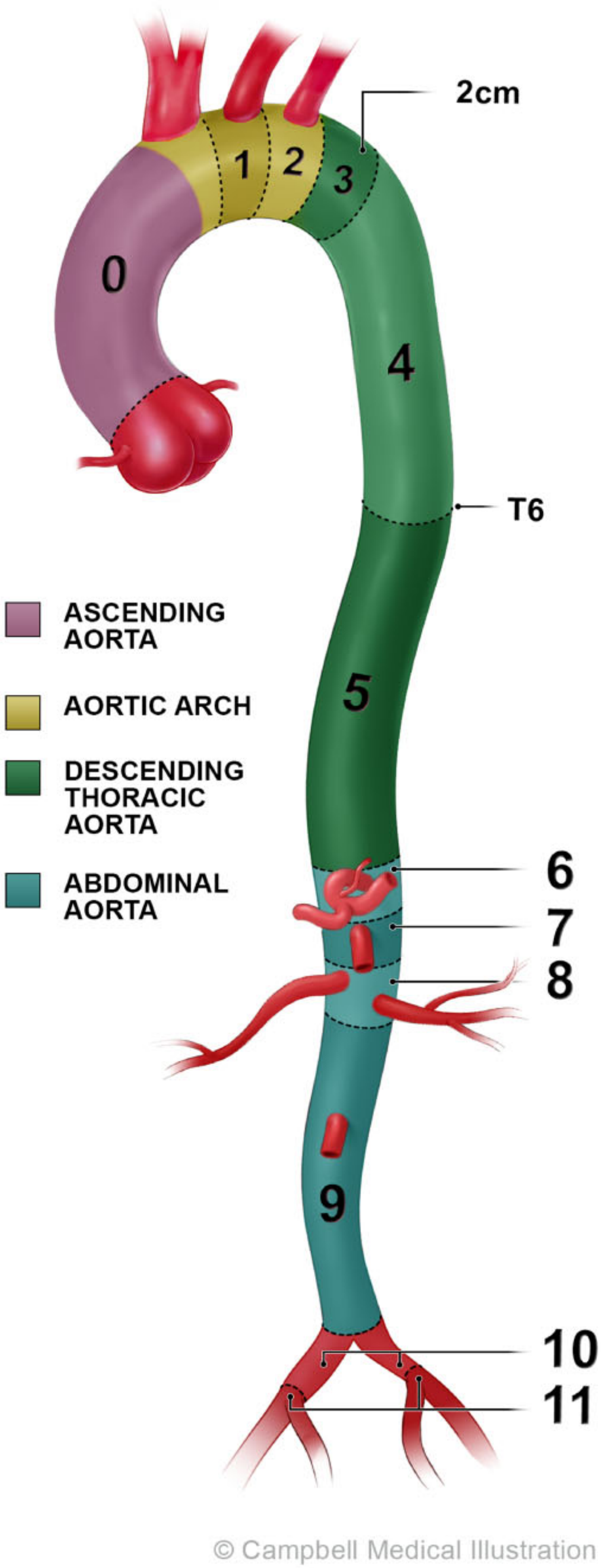

Figure 3: Classification of aortic segments by Ishimaru zones 0–11 with the corresponding anatomical landmarks (20).

aortic stabilization and therefore treatment failure. As the aorta grows in all 3 dimensions, not only diameter but also length and volume are relevant parameters that should be given.

Reporting on aortic diameter

Aortic diameter measurements must be obtained on the planes perpendicular to the aortic centreline using multiplanar CT reformation or 3-dimensional reconstruction. Aortic diameter measurements according to the axial or any other methods lead to underestimation or overestimation of the true aortic diameter. It is recommended to report on maximal and minimal aortic diameter, especially in case of large aneurysm, which tends to be oval. To describe the aortic ellipticity, the ellipticity index, defined as maximum diameter divided by minimal diameter, can be calculated. Circularity is defined as an ellipticity index <1.1. When reporting on dissected aortic diameter maximal and minimal diameters of the aortic true lumen and maximal total diameter of the aorta should be included (Fig. 4). As the outline of the aorta is not defined by the contour of contrast agent but by the aortic wall, aortic diameter must be measured including the aortic wall. However, if the focus of the study is the lumen diameter, it may be reported parallel to the outer wall measurement.

Reporting on aortic length and tortuosity

Aortic length changes throughout life [25] and is influenced by acute aortic dissection [26, 27]. Aortic lengthening may occur in patients with aneurysm treated conservatively or with TEVAR [28]. Therefore, aortic length should be measured and reported. The measurements should be obtained between reproducible end points. Lengths of aortic segments should be obtained at the following levels:

1. Aortic root, beginning at the plane corresponding to the nadirs of all 3 aortic cusps and extending to the sinotubular junction.
2. Ascending aorta, beginning at the sinotubular junction and extending to the plane immediately proximal to the origin of the brachiocephalic artery.
3. Aortic arch, beginning at the plane immediately proximal to the origin of the brachiocephalic artery and extending to a plane immediately distal to the left subclavian artery's origin.
4. Descending thoracic aorta, beginning at a plane immediately distal to the origin of the left subclavian artery and extending to a plane immediately proximal to the coeliac trunk.
5. Abdominal aorta, beginning below the diaphragm and extending to a plane at the aortic bifurcation.

Aortic length should be measured along the centreline between the planes defined above. As thoracic aorta is tortuous and descending aorta gets tortuous with age or due to aortic pathology, it is recommended to report on aortic tortuosity. Aortic tortuosity can be calculated as the ratio of the incremental curve length of the centreline to the linear distance between its 2 end points defining aortic segment of interest (Fig. 5).

Reporting on aortic volume

Volumetric measurements are valuable methods to describe aortic aneurysm progress and to monitor aortic remodelling after

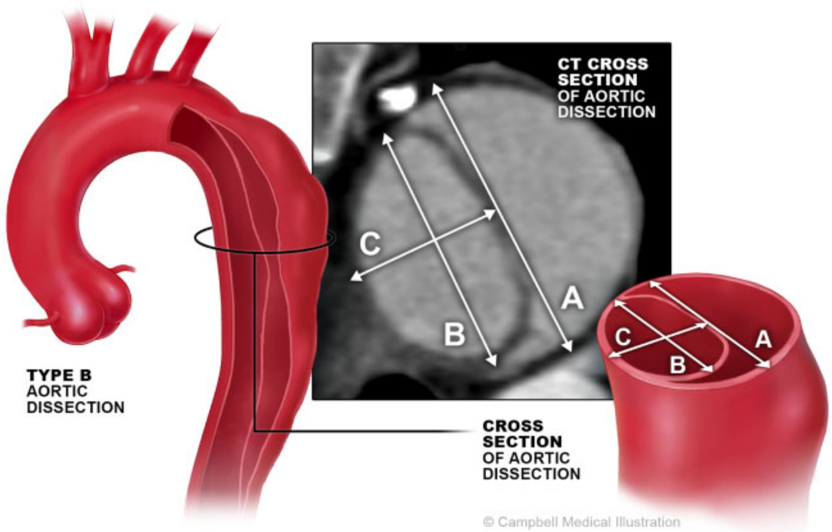

Figure 4: When reporting on the dissected aortic diameter, the maximal total diameter of the aorta (**A**), the maximal (**B**) and minimal diameters (**C**) of the aortic true lumen should be included.

endovascular treatment of aneurysm or dissection. Aortic volume is defined as the volume within the aortic wall's outer surface. Aortic volume can be calculated using automated or semi-automated fashions available in multiple software tools. It is recommended to carefully inspect and eventually correct manually the automatically constructed 3-dimensional aortic models. Aortic volume can be measured for aortic segments mentioned in paragraph: 'Reporting on aortic length and tortuosity', or for other aortic segments of interest such as aneurysm or local dissection. Aortic true and false lumen volume should be reported separately.

Mandatory aortic anatomical parameters

Not every report with aortic morphological parameters used as end points must contain all above-mentioned parameters. However, mandatory aortic anatomical parameters are aortic diameter including aortic wall measured at a clearly defined level. If possible, length and volume of defined aortic segments should be given.

Reporting on landing zone anatomy

Landing zone (LZ) is the aortic segment used in endovascular aortic treatment to anchor the stent graft. The LZ can be within a vascular graft. The sealing effect in the LZ between aortic wall and stent graft is necessary to facilitate aneurysm thrombosis. When reporting on LZ anatomy, its proximal and distal diameter measured perpendicular to the centreline, LZ length measured along the lesser curvature in case of LZ in tortuous aortic segments as well as in the aortic arch, presence of thrombus or dissection in case of an altered aortic segment should be included. If LZ is a dissected aorta (for example, distal LZ in patients with type B aortic dissection), true lumen maximal diameter, ellipticity and area-derived diameter parallel to total aortic diameter at the level of LZ should be reported. Stent grafts do not always cover the total length of the LZ. Accurate landing in the distal LZ covering its entire length is frequently not possible [29]. Along with the length of anatomical LZ, the length of functional LZ, meaning the length of the anatomical LZ covered with stent graft, should be reported.

CATEGORIZATION AND DETAILS OF OPEN SURGICAL PROCEDURES

The type of procedure that was performed should be stated using common surgical terminology. Qualitative and semi-quantitative statements such as 'extensive 2/3 arch replacement' should be avoided. As has already been discussed, given the rising number of patients receiving open and endovascular treatments, it seems reasonable to refer to the treatment-based classification using the terminology 'zones 0–4' when describing surgery on the aortic arch as set forth by the Society for Vascular Surgery Ad Hoc Committee on TEVAR Reporting Standards [30]. Again, 'distal arch aneurysm' covers a wide range of anatomical variations and replacing the arch using a frozen-elephant trunk (FET) with an anastomosis proximal to the left carotid artery and selective reimplantation using separate grafts is not adequately covered in the current definitions.

For the purpose of these standards of reporting, total arch replacement is defined as replacing the entire aorta (or excluding it from circulation) from the offspring of the innominate artery to a point beyond the offspring of the left subclavian artery. Reimplantation or revascularization of the supra-aortic branches can be performed in many ways and the method used is not part of the definition of total arch replacement. To harmonize the standards of reporting in open and endovascular aortic arch treatment, defining total arch replacement as replacing (or excluding from circulation) aortic zones 0, 1 and 2 seems reasonable. In the proposed standard of reporting, a 'zone 2 TEVAR' would be reported as a procedure excluding zones 4, 3 and 2 from circulation and a typical 'frozen elephant trunk procedure' would be described as a procedure excluding zones 0, 1 and 2 from circulation.

All other procedures on the arch are defined as 'partial arch replacement'. The term 'hemi-arch' has been widely used for

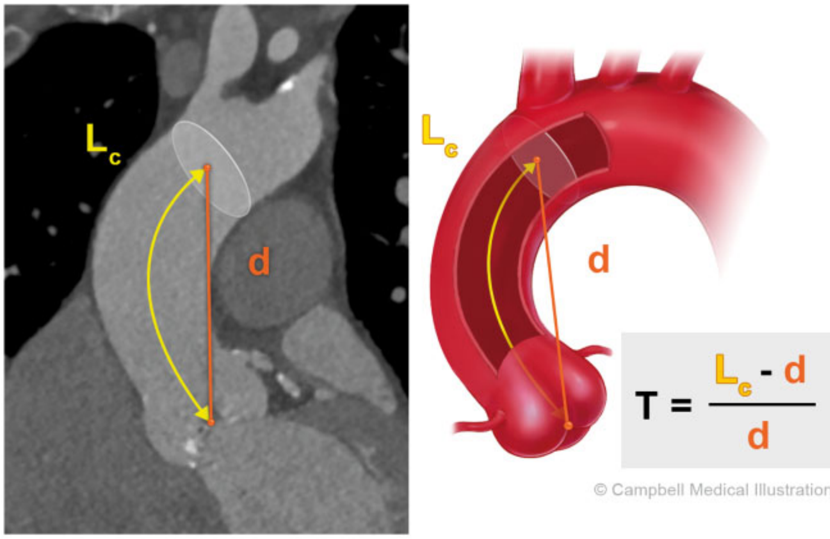

Figure 5: Aortic tortuosity (T) can be calculated as the ratio of the incremental curve length of the centreline (Lc) to the linear distance between the 2 end points defining the aortic segment of interest (d).

decades but also covers a wide range of surgical strategies from just replacing the ascending aorta and performing an open distal anastomosis to resecting the entire concavity of the arch down to the proximal descending aorta. Therefore, the sustained use of the term 'hemi-arch' is discouraged. Please see the 'Standards of reporting checklist' for a summary of how to report open aortic procedures. As mentioned previously, the sequence of events has to be stated clearly in the paper. A pure summary of all procedures 'patients underwent *x* root replacements, *y* total arches and *z* thoraco-abdominal repairs' is of little use as the information on whether the patients after root replacement had the arch replaced or the ones that underwent thoraco-abdominal aortic repair (TAAR) is lost if data are presented in this fashion. In the digital era, space is not as limited as it was and detailed data can be presented as a table or within supplementary data available online.

CARDIOPULMONARY BYPASS AND HYPOTHERMIC CIRCULATORY ARREST

Cardiopulmonary bypass (CPB) and especially hypothermic circulatory arrest (HCA) and cerebral perfusion are key features of open aortic surgery. There is a plethora of CPB and HCA strategies that are used for aortic surgery. In order to understand the reported results, it is important to provide data on how CPB and HCA were performed. Although very technical in nature, there is surprisingly little uniformity in the reporting of CPB and HCA strategies. A large number of papers even fail to mention where temperature was measured, making it impossible to understand the basic concept of their approach.

In many complex aortic procedures performed today, the heart is already (or still) beating while 1 or more supra-aortic branches are still perfused with what is called 'antegrade cerebral perfusion'. We therefore suggest differentiating between (i) lower body arrest time, (ii) myocardial arrest time and (iii) cerebral arrest and/or perfusion time, respectively, cerebral perfusion time. Furthermore, it is recommended to report on any neuromonitoring strategies that were applied, such as near-infrared spectroscopy or measurement of intracranial pressure.

CATEGORIZATION AND DETAILS OF ENDOVASCULAR PROCEDURES

The number of endovascular devices grows continuously. Reporting all procedural details is necessary, as there are important differences between available endovascular products and techniques.

Reporting on endograft components

Besides the name of the product, a precise description of the configuration including the endograft fabric, support system, fixation components, radial force, modularity and graft sizes should be provided. For uniformity of aortic manuscripts, the various stent graft configurations should be understood as follows:

- Scallop: it refers to endograft fabric removed at its proximal or distal portion to extend LZ. The uncovered portion is dedicated to the orifice of aortic branch aiming to be preserved. In this scenario, LZ including aortic branch is partially covered by covered and uncovered stent graft and is not comparable to the classic LZ with circumferential aorta-to-fabric attachment.
- Fenestration: It is a window in the endograft fabric for the aortic branches located in—corresponding to the normal-calibre aorta—the sealing zone of the graft. Within the fenestration, additional stent grafts are placed to improve the sealing and stability of fenestrated stent graft.
- Branched stent grafts (stent grafts with side-arm branches): They have fenestrations with cuffs. They are applied in patients with visceral or arch vessels originating from the aortic aneurysm and not from the aortic sealing zone. Side

arms are connected with them using additional covered stent grafts providing a sealing across a gap between the stent graft main body and the target visceral or arch vessel. Side-arm branches may be oriented antegrade and retrograde and located inside or outside the stent graft. Branches orientation, location and number should be reported.

- Parallel grafts are bare or covered stents deployed into 1 or more visceral or arch vessels parallel to the main aortic stent graft. They extend the sealing zone beyond the origin of the respective aortic branches. As parallel grafts carry high risk of endoleak due to the gaps between them, aorta and main stent graft, careful evaluation of endoleak and size of gaps is necessary. When reporting on parallel grafts, it is necessary to add information on endotension and provide a precise evaluation of aortic aneurysm size changes during follow-up. Channels between the parallel graft and the main aortic stent graft may lead to endotension which is defined as pressure within the aneurysm sac without evidence of endoleak as the cause [31].
- *Debranching* visceral or arch vessels is a surgical procedure including bypass or transpositions of vessels to originate their perfusion from the aortic location that will not be covered by the intended aortic stent graft. Debranching extends the effective LZ with circumferential aorta-to-fabric attachment.

Reporting on endovascular procedures

There are numerous details that are necessary to report on endovascular procedure. In case of isolated stent graft implantation, basic details such as access site and entry method (cut-down versus percutaneous, surgical conduits for stent graft delivery and predilatation of access vessels), procedural time, fluoroscopy time, contrast volume, results of intraoperative angiography including endoleaks, stent graft apposition, length of functional proximal and distal LZ, degree of oversizing, conversion to open surgery and any other intraoperative complications should be given. To improve the accuracy of stent graft deployment in the LZ, several haemodynamic adjuncts, such as lowering systemic blood pressure with antihypertensive, altering cardiac inflow by venous balloon occlusion, cardiac slowing or rapid cardiac pacing, can be applied and should be reported. Neuromonitoring with evoked potentials and cerebrospinal fluid (CSF) catheter are applied in thoracic and thoraco-abdominal procedures to early detect spinal cord ischaemia and eventually treat it via active drainage of the spinal cord [32]. The position of transcranial motor-evoked potentials and somatosensory-evoked potentials electrodes along with the timing of potential measurements and CSF catheter management should be given.

Frequently, endovascular procedures are accompanied by open surgical procedures, such as transposition of the left subclavian artery, carotid-subclavian bypass, double transposition and any other debranching for arch or visceral vessels. These procedures, their timing (prior, simultaneously or second to endovascular treatment) and reason (planned in advance versus necessity due to postprocedural complications) should be given.

Not every endovascular procedure is performed according to the instructions for use of the device. For different reasons, such as advanced age or poor general condition, endovascular approaches are being applied despite conflict with instructions for use. In these patients, the reason for endovascular treatment and anatomical details being in contrast to device requirements should be reported ('off-label use'). Some serious intraoperative complications, such as retrograde aortic dissection, incidental occlusion of arch or visceral vessels, aortic rupture, etc., may be reasons for conversion to open surgical repair. Conversion required at the original operation is a primary conversion and is an emergency situation. Secondary conversion can be urgent or elective. Details on conversion, such as timing, urgency and reasons should be reported.

REPORTING OUTCOMES AFTER AORTIC INTERVENTIONS

Success in aortic surgery can be defined as complete removal of the aneurysm and absence of complications. Nevertheless, complete removal of the aneurysm (or dissection) is more frequently impossible. Depending on the comorbidities, it might be a wise decision to perform a limited procedure during an index procedure. Therefore, different parameters have to be found to define outcome after aortic interventions.

It cannot be stressed enough that completeness of follow-up is of paramount importance. It is preferable to have a limited data set if these data can be collected from all patients. It is of little value to the surgical community to classify operations into successful and unsuccessful. Today's complex aortic patients cannot be treated by a single intervention and most of them will need surgical care several times over the course of many years. If a patient undergoes replacement of the ascending aorta and a hemiarch procedure due to type A dissection, makes a full recovery after an uneventful postoperative course and then comes back 8 years later with a dilatation of the distal arch—was the initial procedure then successful or unsuccessful? It is therefore important to clearly state what was done during the initial surgery and what the timeline of the patient was regarding reinterventions. Only then can we extract meaningful information on how to treat these patients. Please refer to the 'Standards of reporting checklist'.

Neurological complications and outcomes

Stroke has emerged as the main factor determining quality of life after aortic surgery. Unfortunately, 'stroke' is not very well defined in most publications concerning the aorta and comparisons are difficult.

In a time where results after open surgery have to be compared to those of endovascular interventions and the lines between these options are beginning to blur, we should aim for a more universally applicable definition. When faced with the same challenge, the writing committee responsible for the 'Updated standardized end point definitions for transcatheter aortic valve implantation: The Valve Academic Research Consortium-2 consensus document' agreed on a list of definitions [33]. The VARC-2 writing committee further endorsed the use of the modified Rankin score to differentiate patients with disabling (mRS $\geq$ 2 and increase $\geq$1 from baseline) and non-disabling stroke (mRS < 2). We believe that this is a crucial aspect of reporting outcomes after open and endovascular aortic surgery. Furthermore, while neurological symptoms after major surgery in patients undergoing HCA are more frequently difficult to evaluate and may change considerably over the first postoperative hours and even days, clinical outcomes after 90 days as proposed by the VARC-2 writing committee will give a much more realistic picture of how the patient is actually doing. Moreover, 90 days or 3 months coincide with the time frame for routine follow-up after aortic surgery in many centres. As surgery of aortic aneurysm is mostly prophylactic, we need solid outcome data to compare the risk of dissection or rupture against the risk for disabling neurological events.

Delirium

Postoperative delirium (POD) is a common phenomenon occurring after cardiac surgery and even more frequent in patients undergoing HCA. The latest European Society of Anaesthesiology evidence-based and consensus-based guidelines on POD [34] define POD as either 'etiologically non-specific organic cerebral syndrome characterized by concurrent disturbances of consciousness and attention, perception, thinking, memory, psychomotor behaviour, emotion and the sleep–wake schedule' or as 'a disturbance in attention (i.e. reduced ability to direct, focus, sustain and shift attention) and awareness (reduced orientation to the environment)' according to ICD-10 or DSM-5 criteria, respectively. While POD by definition is temporary, it is nonetheless a source of additional morbidity and the incidence should be noted when reporting complications in patients undergoing thoracic aortic surgery.

Spinal cord injury

The advent of periprocedural spinal cord injury (SCI) due to the increased use of stent grafts either by endovascular means or as a frozen elephant trunk warrants a separate reporting of SCI. Authors should state the rate of perioperative SCI and/or paraplegia, measures taken (e.g. elevation of perfusion pressure, CSF drainage) and outcome after 90 days. It should be stated whether there was any preoperative SCI and/or paraplegia and whether CSF drainage was used or not and whether it was introduced after the event or before. It would be helpful to report how CSF drainage was managed, as there are still considerable differences in protocols between centres. While paraplegia is a clinical diagnosis, the diagnosis of SCI should only be given after imaging has confirmed the aetiology of the neurological impairment. The terms 'paraplegia' and 'paraparesis' only relate to motor function of the lower extremities. 'Paraplegia' is a complete loss—'paralysis'—of motor strength of the lower extremities, whereas 'paraparesis' refers to impaired motor strength.

Death

In deceased patients, every measure possible should be undertaken to elucidate the cause of death and it should be stated clearly in the manuscript. Death should be reported as being either aortic-related or non-aortic-related. Reporting death from cardio-cerebro-vascular disease only can be misleading as it may under- or over-report death associated with open or endovascular aortic surgery, for example, multi-organ failure (MOF) due to malperfusion in acute dissection or unrelated stroke.

In the past, authors have reported 'operative', 'perioperative' and 'in-hospital' mortality. As is the standard for reporting of coronary, valve and other cardiac surgery outcomes, mortality should be reported as operative mortality defined as 30-day and/or hospital stay whichever is longer. Additionally, survival should be reported using estimates such as the Kaplan–Meier method respecting the continuous nature of time as a variable, and when reporting, values include specific timepoints such as 30 days, 6 months, 1 year, 5 years, followed by 5-year intervals, if applicable.

Myocardial infarction

Perioperative myocardial failure has become less of a problem over the years. Nevertheless, contemporary large series report about 8% myocardial failure in total aortic arch replacement. Myocardial failure has to be differentiated from myocardial infarction. Patients with postsurgical failure may be supported with mechanical circulatory support until the heart has recovered. We therefore recommend reporting the number of patients in need for postoperative mechanical circulatory support and potentially the mode of support as well as the number of patients with perioperative myocardial infarction [35].

Follow-up

Reports on outcomes at various follow-up intervals should be reported using estimates such as the Kaplan–Meier method respecting the continuous nature of time as a variable, and when reporting, values include specific timepoints such as 30 days, 6 months, 1 year, 5 years and 5-year intervals. Authors should refrain from using poorly defined terms such as short-, mid- and long-term outcomes. Actual average or median time of follow-up should be reported as well as the manner in which follow-up was performed (e.g. retrospective data collection, active contact via telephone, scheduled anniversary, etc.), as well as what was being followed (i.e. survival, imaging, symptoms, quality of life, etc.).

CONCLUSION

Over the past decade, aortic surgery has almost developed into a subspecialty. Our ways of reporting results have not kept up with the advances in the field. Creating a common language and reporting data in a standardized fashion requires a substantial effort by everyone involved. Nevertheless, it will enable us to make better and more informed decisions to benefit patients presenting with aortic disease.

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REFERENCES

[1] Turina MI, Shennib H, Dunning J, Cheng D, Martin J, Muneretto C *et al.*; EACTS/ESCVS Committee. EACTS/ESCVS best practice guidelines for reporting treatment results in the thoracic aorta. Eur J Cardiothorac Surg 2009;35:927–30.

[2] Lederle FA, Freischlag JA, Kyriakides TC, Matsumura JS, Padberg FT Jr, Kohler TR *et al*. Long-term comparison of endovascular and open repair of abdominal aortic aneurysm. N Engl J Med 2012;367:1988–97.

[3] Dangas G, O'Connor D, Firwana B, Brar S, Ellozy S, Vouyouka A *et al*. Open versus endovascular stent graft repair of abdominal aortic aneurysms: a meta-analysis of randomized trials. JACC Cardiovasc Interv 2012; 5:1071–80.

[4] Shahian DM, O'Brien SM, Filardo G, Ferraris VA, Haan CK, Rich JB *et al*. The Society of Thoracic Surgeons 2008 cardiac surgery risk models: part 1—coronary artery bypass grafting surgery. Ann Thorac Surg 2009;88: S2–22.

[5] Nashef SAM, Roques F, Sharples LD, Nilsson J, Smith C, Goldstone AR. EuroSCORE II. Eur J Cardiothorac Surg 2012;41:734–44; discussion 744–5.

[6] Grant SW, Hickey GL, Grayson AD, Mitchell DC, McCollum CN. National risk prediction model for elective abdominal aortic aneurysm repair. Br J Surg 2013;100:645–53.

[7] Barnes M, Boult M, Maddern G, Fitridge R. A model to predict outcomes for endovascular aneurysm repair using preoperative variables. Eur J Vasc Endovasc Surg 2008;35:571–9.

[8] Giles KA, Schermerhorn ML, O'Malley AJ, Cotterill P, Jhaveri A, Pomposelli FB *et al*. Risk prediction for perioperative mortality of endovascular vs open repair of abdominal aortic aneurysms using the Medicare population. J Vasc Surg 2009;50:256–62.

[9] Egorova N, Giacovelli JK, Gelijns A, Greco G, Moskowitz A, McKinsey J *et al*. Defining high-risk patients for endovascular aneurysm repair. J Vasc Surg 2009;50:1271–9.e1.

[10] Grant SW, Grayson AD, Purkayastha D, Wilson SD, McCollum C. Logistic risk model for mortality following elective abdominal aortic aneurysm repair. Br J Surg 2011;98:652–8.

[11] Robinson WP, Schanzer A, Li Y, Goodney PP, Nolan BW, Eslami MH *et al*. Derivation and validation of a practical risk score for prediction of mortality after open repair of ruptured abdominal aortic aneurysms in a U.S. regional cohort and comparison to existing scoring systems. J Vasc Surg 2013;57:354–61.

[12] Visser JJ, Williams M, Kievit J, Bosch JL. Prediction of 30-day mortality after endovascular repair or open surgery in patients with ruptured abdominal aortic aneurysms. J Vasc Surg 2009;49:1093–9.

[13] Tambyraja A, Murie J, Chalmers R. Predictors of outcome after abdominal aortic aneurysm rupture: Edinburgh Ruptured Aneurysm Score. World J Surg 2007;31:2243–7.

[14] Hiratzka LF, Bakris GL, Beckman JA, Bersin RM, Carr VF, Casey DE Jr *et al*. 2010 ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM Guidelines for the diagnosis and management of patients with thoracic aortic disease. Circulation 2010;121:266–369.

[15] Erbel R, Aboyans, V Boileau, C, Bossone E, Bartolomeo RD, Eggebrecht H *et al*; ESC Committee for Practice Guidelines. 2014 ESC Guidelines on the diagnosis and treatment of aortic diseases: document covering acute and chronic aortic diseases of the thoracic and abdominal aorta of the adult. The Task Force for the Diagnosis and Treatment of Aortic Diseases of the European Society of Cardiology (ESC). Eur Heart J 2014;35: 2873–926.

[16] Rylski B, Bavaria JE, Beyersdorf F, Branchetti E, Desai ND, Milewski RK *et al*. Type A aortic dissection in Marfan syndrome: extent of initial surgery determines long-term outcome. Circulation 2014;29:1381–6.

[17] Schoenhoff FS, Zanchin C, Czerny M, Makaloski V, Gahl B, Carrel T *et al*. Aorta related and all-cause mortality in patients with aortic intramural haematoma. Eur J Vasc Endovasc Surg 2017;54:447–53.

[18] Riambau V, Böckler D, Brunkwall J, Cao P, Chiesa R, Coppi G *et al*. Management of descending thoracic aorta diseases: clinical practice guidelines of the European Society for Vascular Surgery (ESVS). Eur J Vasc Endovasc Surg 2017;53:4–52.

[19] Czerny M, Schmidli J, Adler S, van den Berg JC, Bertoglio L, Carrel T *et al.*; EACTS/ESVS Scientific Document Group. Current options and, recommendations for the treatment of thoracic aortic pathologies involving the, aortic arch: an expert consensus document of the European Association for, Cardio-Thoracic Surgery (EACTS) and the European Society for Vascular Surgery (ESVS). Eur J Cardiothorac Surg 2019;55: 133–62.

[20] Czerny M, Schoenhoff F, Etz C, Englberger L, Khaladj N, Zierer A *et al*. The impact of pre-operative malperfusion on outcome in acute type A aortic dissection: results from the GERAADA Registry. J Am Coll Cardiol 2015;65:2628–35.

[21] Cho KR, Stanson AW, Potter DD, Cherry KJ, Schaff HV, Sundt TM. Penetrating atherosclerotic ulcer of the descending thoracic aorta and arch. J Thorac Cardiovasc Surg 2004;127:1393.

[22] Casserly IP, JS Yadav. Carotid intervention. In: Casserly IP, Sachar R, Yadav, JS (eds). Manual of Peripheral Vascular Intervention. Philadelphia, PA: Lippincott Williams & Wilkins, 2005, 83–109.

[23] Layton KF, Kallmes DF, Cloft HJ, Lindell EP, Cox VS. Bovine aortic arch variant in humans: clarification of a common misnomer. AJNR Am J Neuroradiol 2006;27:1541–2.

[24] Hickey GL, Dunning J, Seifert B, Sodeck G, Carr MJ, Burger HU *et al.*; EJCTS and ICVTS Editorial Committees. Statistical and data reporting guidelines for the European Journal of Cardio-Thoracic Surgery and the Interactive CardioVascular and Thoracic Surgery. Eur J Cardiothorac Surg 2015;48:180–93.

[25] Rylski B, Desjardins B, Moser W, Bavaria JE, Milewski RK. Gender-related changes in aortic geometry throughout life. Eur J Cardiothorac Surg 2014;45:805–11.

[26] Rylski B, Blanke P, Beyersdorf F, Desai ND, Milewski RK, Siepe M *et al*. How does the ascending aorta geometry change when it dissects? J Am Coll Cardiol 2014;63:1311–19.

[27] Rylski B, Muñoz C, Beyersdorf F, Siepe M, Reser D, Carrel T *et al*. How does descending aorta geometry change when it dissects? Eur J Cardiothorac Surg 2018;53:815–21.

[28] O'Neill S, Greenberg RK, Resch T, Bathurst S, Fleming D, Kashyap V. An evaluation of centerline of flow measurement techniques to assess migration after thoracic endovascular aneurysm repair. J Vasc Surg 2006; 43:1103–10.

[29] Berezowski M, Morlock J, Beyersdorf F, Jasinski M, Plonek T, Siepe M *et al*. Inaccurate aortic stent graft deployment in the distal landing zone: incidence, reasons and consequences. Eur J Cardiothorac Surg 2018;53: 1158–64.

[30] Fillinger MF, Greenberg RK, McKinsey JF, Chaikof EL; Society for Vascular Surgery Ad Hoc Committee on TEVAR Reporting Standards. Reporting standards for thoracic endovascular aortic repair (TEVAR). J Vasc Surg 2010;52:1022–33.

[31] Donas KP, Marchiori E, Inchingolo M, Torsello G. Surgical treatment of endotension after chimney endovascular repair of a symptomatic juxtarenal aneurysm. Ann Vasc Surg 2017;41:279.e5–e8.

[32] Maier S, Shcherbakova M, Beyersdorf F, Benk C, Kari FA, Siepe M *et al*. Benefits and risks of prophylactic cerebro-spinal fluid catheter and evoked potential monitoring in symptomatic spinal cord ischemia low-risk thoracic endovascular aortic repair. Thorac Cardiovasc Surg 2018; doi: 10.1055/s-0038-1642611 [Epub ahead of print].

[33] Kappetein AP, Head SJ, Généreux P, Piazza N, van Mieghem NM, Blackstone EH *et al.*; Valve Academic Research Consortium (VARC)-2. Updated standardized endpoint definitions for transcatheter aortic valve implantation: the Valve Academic Research Consortium-2 consensus document (VARC-2). Eur J Cardiothorac Surg 2012;42:S45–60.

[34] Aldecoa C, Bettelli G, Bilotta F, Sanders RD, Audisio R, Borozdina A *et al*. European Society of Anaesthesiology evidence-based and consensus-based guideline on postoperative delirium. Eur J Anaesthesiol 2017;34: 192–214.

[35] Thielmann M, Sharma V, Al-Attar N, Bulluck H, Bisleri G, Bunge JJH *et al*. ESC Joint Working Groups on Cardiovascular Surgery and the Cellular Biology of the Heart Position Paper: perioperative myocardial injury and infarction in patients undergoing coronary artery bypass graft surgery. Eur Heart J 2017;38:2392–407.