European Journal of Cardio-Thoracic Surgery 0 (2019) 1–4
doi:10.1093/ejcts/ezy458

CASE REPORT

Cite this article as: van Bakel TMJ, Burris NS, Patel HJ, Figueroa CA. Ascending aortic rupture after zone 2 endovascular repair: a multiparametric computational analysis. Eur J Cardiothorac Surg 2019; doi:10.1093/ejcts/ezy458.

Ascending aortic rupture after zone 2 endovascular repair: a multiparametric computational analysis

Theodorus M.J. van Bakel[a,b,c,*], Nicholas S. Burris[d], Himanshu J. Patel[e] and C. Alberto Figueroa[a,f]

[a] Department of Surgery, University of Michigan, Ann Arbor, MI, USA
[b] Thoracic Aortic Research Center, Policlinico San Donato IRCCS, San Donato Milanese, Italy
[c] Department of Vascular Surgery, University Medical Center Utrecht, Utrecht, The Netherlands
[d] Department of Radiology, University of Michigan, Ann Arbor, MI, USA
[e] Department of Cardiac Surgery, University of Michigan, Ann Arbor, MI, USA
[f] Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI, USA

* Corresponding author. Department of Surgery, University of Michigan, 2800 Plymouth Road B20-211W, Ann Arbor, MI 48105, USA. Tel: +1-734-5481660; fax: +1-734-2321234; e-mail: vanbakel@med.umich.edu (T.M.J. van Bakel).

Received 2 October 2018; received in revised form 20 November 2018; accepted 5 December 2018

Abstract

A 74-year-old woman expired from ascending aortic rupture 3 months following branched zone 2 endovascular aortic repair. Multiparametric image-based computational evaluation of this case suggested that the stiffness mismatch between the endograft and the native aorta increased haemodynamic loads and likely led to the rupture of the ascending aorta. This under-recognized phenomenon should be considered in preoperative planning and presents suggestions for endograft development.

Keywords: Thoracic endovascular aortic repair • Computational fluid dynamics • Aortic aneurysm • Aortic rupture

INTRODUCTION

Branched endografts obviate the need for extra-anatomical bypass surgery when performing thoracic endovascular aortic repair (TEVAR) in the arch. Early results are promising [1], but significant complications have been reported that warrant further investigation. In this article, we examine the case of an ascending aortic rupture following branched zone 2 TEVAR [2].

This study was approved by the institutional review board (HUM00112350), with a waiver of informed consent.

CASE REPORT

A 74-year-old woman presented with an asymptomatic mid-ascending aortic aneurysm (49 mm) and an proximal descending aneurysm (63 mm). Her medical history included hypertension, hypercholesteraemia and smoking. She had a family history of aortic aneurysms. An additional medical history is reported in the Supplementary Material. Annual imaging follow-up with computed tomography angiography (CTA) examinations showed rapid enlargement of the descending aortic diameter to 73 mm and a modest increase in the ascending aorta to 53 mm in 2 years (Fig. 1A). We elected to treat the larger aneurysm first with branched zone 2 TEVAR, anticipating a second stage repair of the ascending aorta 2 months thereafter.

The diameters of the proximal and distal landing zones for the descending aneurysm were 34 mm and 42 mm, respectively. The diameters and lengths of the proximal Gore TBE and distal Conformable Gore TAG endoprostheses were 37 × 100 mm and 45 × 150 mm, respectively, resulting in 9% proximal and 7% distal oversizing. Controlled hypotension (systolic pressure of 80 mmHg) was used to reduce the risk of malpositioning. The deployment of the branched proximal component, using the Gore TBE delivery system, resulted in 5-mm distal dislocation resulting in type Ia endoleak. Two proximal extension devices were deployed. After balloon dilation of these devices, proximal infolding and bird beaking were observed (Fig. 1B). As angiography showed brisk filling of the LSA and no pressure gradient was detected in the aortic arch, no additional procedures were performed. The patient recovered well and was discharged 10 days after the procedure. Blood pressure measurements and antihypertensive medication during follow-up are reported in the Supplementary Material, Table S1.

Thirty days post-TEVAR, CTA demonstrated stable position of the endograft without endoleak and an increase in the ascending aortic diameter by 1 mm (Fig. 1A). The patient suddenly expired 3 months post-TEVAR. Autopsy determined the cause of death to be haemopericardium due to a 4.0-cm longitudinal tear without associated dissection in the lesser curvature of the ascending aorta (Fig. 1B).

Computational analysis

FSI techniques were used to examine haemodynamic alterations attributable to the presence of the endograft. First, a pre-TEVAR model was created and validated [3]. Then, 2 additional models

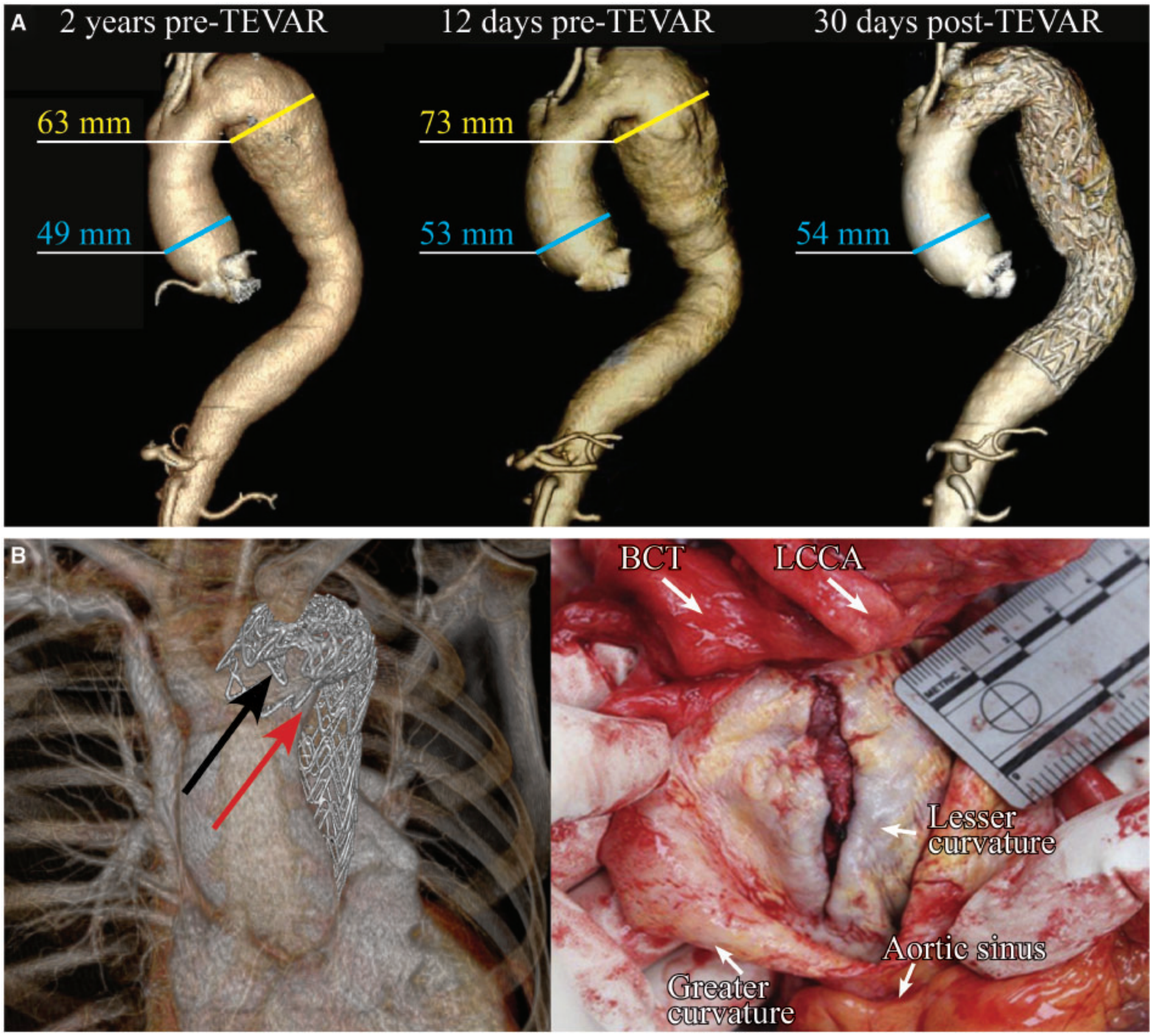

Figure 1: (**A**) Aortic wall outer diameters of the ascending and proximal descending aneurysms are reported over time. (**B**) Left: post-TEVAR infolding (black arrow) and bird beak (red arrow). Right: during autopsy, a 4.0-cm longitudinal tear was identified in the lesser curvature and 2.5 cm distal to the aortic valve. There was no associated dissection, and the tear did not extend to the proximal landing zone of the endograft. BCT: brachiocephalic trunk; LCCA: left common carotid artery; TEVAR: thoracic endovascular aortic repair.

were constructed: (i) post-TEVAR and (ii) virtual uncomplicated endograft deployment (i.e. without infolding and bird beak) [4].

Vascular deformation mapping was used to calculate the normalized index of distensibility (NID) from the pre-TEVAR and 30-day post-TEVAR image data. Increased NID indicates higher aortic wall stresses.

The details of the methods and limitations of the FSI and vascular deformation mapping analyses are reported in the Supplementary Material.

Computational results

The ascending aortic pulse pressure increased by 35% post-TEVAR (Fig. 2A). Virtual uncomplicated endograft deployment decreased the ascending aortic pulse pressure by only 2 mmHg compared to post-TEVAR. This finding is consistent with the intraoperative pressure measurements and indicates that the increased pulse pressure was not caused by the infolded proximal extension device.

Haemodynamic wall shear stresses in the ascending aorta were higher in both the post-TEVAR and the virtual uncomplicated endograft deployment model compared to pre-TEVAR (Supplementary Material, Fig. S3).

Figure 2B depicts the pre-TEVAR and 30-day post-TEVAR NID maps. NID increased in the unstented segments of the aorta post-TEVAR. NID increased by 173% in the location corresponding to the site of rupture, suggesting that this region experienced higher stresses post-TEVAR.

COMMENT

A stiffness mismatch between the endograft and the native proximal aorta increases the pulse pressure in the ascending aorta, resulting in higher regional wall stresses that may contribute to rupture. This under-recognized phenomenon should be considered in preoperative planning. Patients presenting with a proximal descending and concomitant ascending aortic aneurysm should be counselled to undergo ascending aortic repair

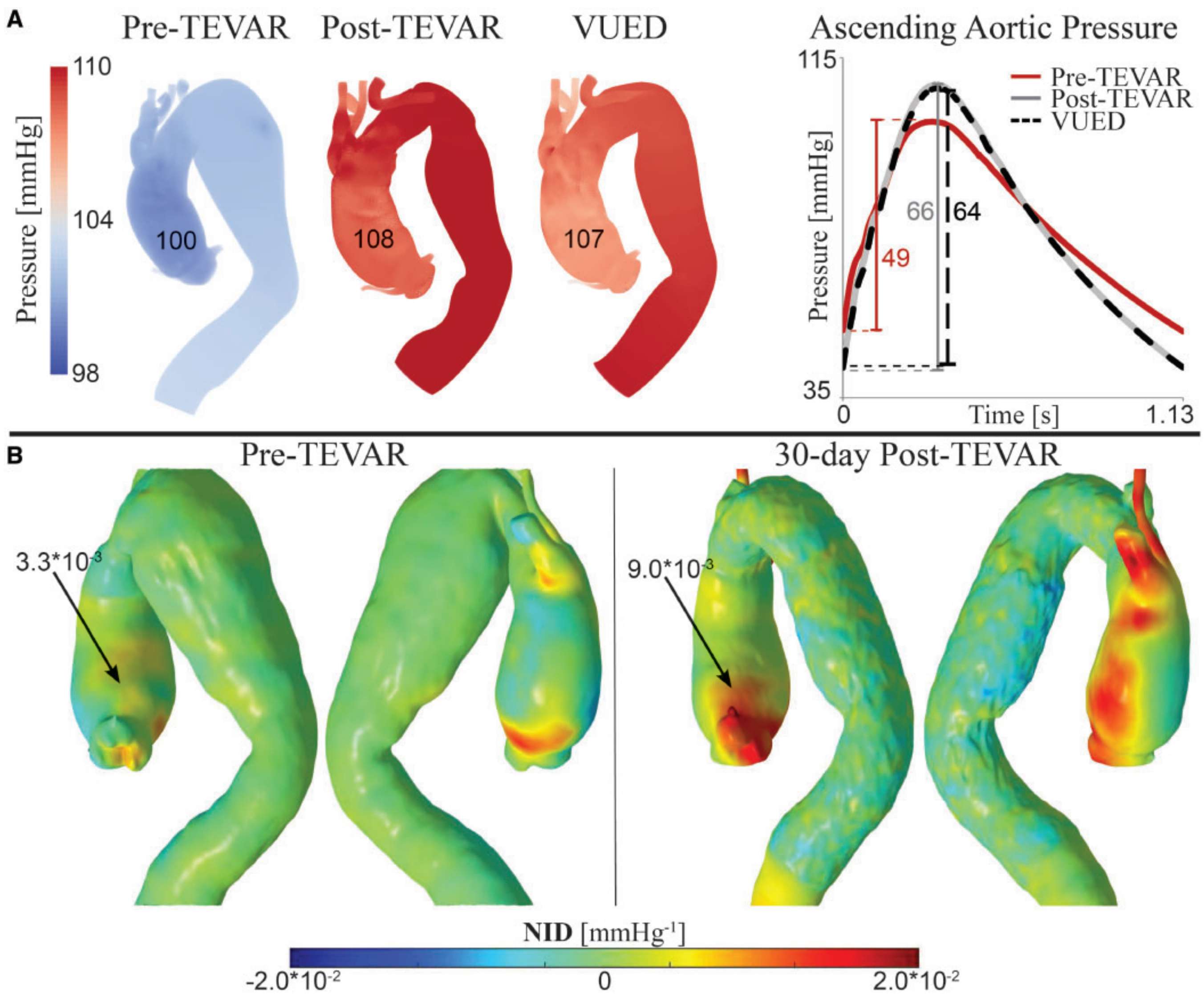

Figure 2: (**A**) Left: peak systolic pressure maps. Right: ascending aortic pressure waveforms. Pulse pressure increased by 35% post-TEVAR. VUED resulted in minimal changes compared to post-TEVAR. (**B**) Pre-TEVAR (left) and 30-day post-TEVAR (right) NID maps. NID: normalized index of distensibility; TEVAR: thoracic endovascular aortic repair; VUED: virtual uncomplicated endograft deployment.

with a frozen elephant trunk procedure and early completion TEVAR.

Another potential aetiology (albeit not confirmed during autopsy or imaging studies) that could have contributed to aortic rupture in this patient is guidewire or device-induced ascending aortic injury during deployment.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

ACKNOWLEDGEMENTS

We acknowledge the significant contributions of Ignas B. Houben and Christopher J. Arthurs to the computational analysis that is presented in this study.

Funding

This work was supported by the European Research Council FP/2007-2013 [307532]; the Edward B. Diethrich Professorship; the Radiologic Society of North America Research Fellow Grant (RF1502), the US National Institutes of Health [R35CA197701 and U01CA166104]; the Aikens Aortic Grants Program and the Frankel Cardiovascular Center. Funding sources also include the Joe D. Morris Professorship; the David Hamilton Fund and the Phil Jenkins Breakthrough Fund. Computing resources were provided by the National Science Foundation [1531752] Acquisition of Conflux.

Conflict of interest: Himanshu J. Patel serves as a consultant and copatent holder with W.L. Gore and as a consultant for Medtronic Inc. and Terumo Inc.; Nicholas S. Burris is entitled to royalties from the licensure of intellectual property

studied in this research. The VDM technology has been licensed to Imbio, LLC. All other authors declared no conflict of interest.

REFERENCES

[1] van Bakel TM, de Beaufort HW, Trimarchi S, Marrocco-Trischitta MM, Bismuth J, Moll FL *et al*. Status of branched endovascular aortic arch repair. Ann Cardiothorac Surg 2018;7:406–13.

[2] Patel HJ, Dake MD, Bavaria JE, Singh MJ, Filinger M, Fischbein MP *et al*. Branched endovascular therapy of the distal aortic arch: preliminary results of the feasibility multicenter trial of the gore thoracic branch endoprosthesis. Ann Thorac Surg 2016;102:1190–8.

[3] van Bakel TM, Arthurs CJ, Nauta FJ, Eagle KA, van Herwaarden JA, Moll FL *et al*. Cardiac remodelling following thoracic endovascular aortic repair for descending aortic aneurysms†. Eur J Cardio-Thoracic Surg 2018: 1–10. doi:10.1093/ejcts/ezy399.

[4] van Bakel TM, Arthurs CJ, van Herwaarden JA, Moll FL, Eagle KA, Patel HJ *et al*. A computational analysis of different endograft designs for Zone 0 aortic arch repair†. Eur J Cardio-Thoracic Surg 2018;54:389–96.