A multi-disciplinary journal for clinicians and researchers with interest in the Aorta and its first-order branches, intended for cardiac surgeons, cardiologists, vascular surgeons, interventional radiologists, geneticists, molecular biologists, engineers, and industry scientists, among others.

Editor-in-Chief: John A. Elefteriades, MD

Co-Editor-in-Chief: Michael Jacobs, MD

Editors: Alan Dardik, MD, PhD
         Kim Eagle, MD
         Bart Muhs, MD
         Sandip Mukherjee, MD
         Santi Trimarchi, MD

Associate Editors: Mohamad Bashir, MD
                  Emily A. Farkas, MD
                  Bulat A. Ziganshin, MD

Official Journal of the Aortic Institute at Yale-New Haven Hospital

Published by

Science International Corp.
ISSN 2325-4637
Conform to the new standard for Left Atrial Appendage (LAA) Occlusion.

The TIGERPAW® System II with its unique Fastener technology is designed with soft silicone housing to minimize risk and damage to the friable LAA. Once implanted, the Fastener conforms to the shape and thickness of the patient’s appendage, resulting in 100% clinically proven occlusion.1

- Easy and rapid application (60 seconds or less)1
- Conforms to variable LAA size and thickness with pliable silicone housing
- Zero blood loss at device footprint

MAQUET — The Gold Standard.

Angled jaw aligned with Fastener elbow aids in optimal placement

Soft silicone housing for tissue conformity

Available in 7 & 9 Connector configuration


MAQUET is a registered trademark of MAQUET GmbH & Co. KG. TIGERPAW is a U.S. registered trademark of LAAx, Inc. Copyright 2013 MAQUET Cardiovascular LLC or its affiliates. All rights reserved. • LAAx/TIGERPAW: Federal (U.S.A.) law restricts this device to sale, distribution and use by or on the order of a physician. Refer to Instructions to Use for current indications, warnings, contraindications and precautions. 09/2013
MEASURED IN RESULTS.
MEDTRONIC SETS THE STANDARD FOR GLOBAL AORTIC CLINICAL EVIDENCE LEADERSHIP.

At 1 and 2 Years¹

MIGRATION 0%
TYPE I ENDOLEAK
RUPTURE POST IMPLANT

Most comprehensive abdominal aortic clinical program: 1,500+ patients studied worldwide²
1 out of 2 EVAR patients worldwide receives an Endurant stent graft³

Get results at www.medtronicendovascular.com

² Data on file at Medtronic.
³ BOXI data as of March 16, 2012.
Indications
The Endurant II Stent Graft System is indicated for the endovascular treatment of infrarenal abdominal aortic or aorto-iliac aneurysms in patients with the following characteristics:
- Adequate iliac/femoral access that is compatible with vascular access techniques, devices and/or accessories
- Proximal neck length of ≥ 10 mm
- Infra-renal neck angulation of ≤ 60°
- Distal fixation length of ≥ 15 mm
- Aortic neck diameters with a range of 19 to 32 mm
- Iliac diameters with a range of 8 to 25 mm
- Morphology suitable for aneurysm repair

Contraindications
The Endurant II Stent Graft System is contraindicated in:
- Patients who have a condition that threatens to infect the graft.
- Patients with sensitivities or allergies to the device materials.

Warnings and Precautions
- The long-term safety and effectiveness of the Endurant II Stent Graft System has not been established. All patients should be advised that endovascular treatment requires lifelong, regular follow-up to assess the health and the performance of the implanted endovascular stent graft. Patients with specific clinical findings (e.g., endoleaks, enlarging aneurysms or changes in the structure or position of the endovascular graft) should receive enhanced follow-up. Specific follow-up guidelines are described in the Instructions for Use.
- Patients experiencing reduced blood flow through the graft limb, aneurysm expansion, and persistent endoleaks may be required to undergo secondary interventions or surgical procedures.
- The Endurant II Stent Graft System is not recommended in patients unable to undergo or who will not be compliant with the necessary preoperative and postoperative imaging and implantation studies as described in the Instructions for Use.
- Renal complications may occur: 1) From an excess use of contrast agents. 2) As a result of emboli or a misplaced stent graft. The radiopaque marker along the edge of the stent graft should be aligned immediately below the lower-most renal arterial origin.
- Studies indicate that the danger of micro-embolization increases with increased duration of the procedure.
- The safety and effectiveness of the Endurant II Stent Graft System has not been evaluated in some patient populations. Please refer to the product Instructions for Use for details.

MRI Safety and Compatibility
Non-clinical testing has demonstrated that the Endurant II Stent Graft is MR Conditional. It can be scanned safely in both 1.5 T & 3.0 T MR systems under certain conditions as described in the product Instructions for Use. For additional information regarding MRI please refer to the product Instructions for Use.

Adverse Events
Potential adverse events include (arranged in alphabetical order): Amputation; Anesthetic complications and subsequent attendant problems (e.g. aspiration); Aneurysm enlargement; Aneurysm rupture and death; Aortic damage, including perforation, dissection, bleeding, rupture and death; Arterial or venous thrombosis and/or pseudoaneurysm; Arteriovenous fistula; Bleeding, hematoma or coagulopathy; Bowel complications (e.g., ileus, transient ischemia, infarction, necrosis); Cardiac complications and subsequent attendant problems (e.g. arrhythmia, myocardial infarction, congestive heart failure, hypotension, hypertension); Claudication (e.g., buttock, lower limb); Death; Edema; Embolization (micro and macro) with transient or permanent ischemia or infarction; Endoleak; Fever and localized inflammation; Genitourinary complications and subsequent attendant problems (e.g., ischemia, erosion, fistula, incontinence, hematuria, infection); Hepatic failure; Impotence; Infection of the aneurysm, device access site, including abscess formation, transient fever and pain; Lymphatic complications and subsequent attendant problems (e.g., lymph fistula); Neurologic local or systemic complications and subsequent attendant problems (e.g., confusion, stroke, transient ischemic attack, paraplegia, paraparesis, paralysis); Occlusion of device or native vessel; Pulmonary complications and subsequent attendant problems; Renal complications and subsequent attendant problems (e.g., confusion, stroke, transient ischemic attack, paraplegia, paraparesis); Vascular spasm or vascular trauma (e.g., iliofemoral vessel dissection, bleeding, rupture, death); Vessel damage; Wound complications and subsequent attendant problems (e.g. dehiscence, infection, hematoma, seroma, cellulitis).

Please reference product Instructions for Use for more information regarding indications, warnings, precautions, contraindications and adverse events.

CAUTION: Federal (USA) law restricts this device to sale by or on the order of a physician.
Editorial Board

Editor-in-Chief
John A. Elefteriades
Yale University
(New Haven, CT)

Co-Editor-in-Chief
Michael Jacobs
Maastricht University Hospital
(Maastricht, Netherlands)

Editors
Alan Dardik
Yale University
(New Haven, CT)
Kim Eagle
University of Michigan
(Ann Arbor, MI)
Bart Muhs
Yale University
(New Haven, CT)
Santi Trimarchi
Polilimico San Donato
(Milan, Italy)
Sandip Mukherjee
Yale University
(New Haven, CT)

Editor Emeritus
Randall B. Griep
Mount Sinai Medical Center
(New York, NY)

Associate Editors
Emily A. Farkas
Saint Louis University
(St. Louis, MO)
Bulat A. Ziganshin
Yale University
(New Haven, CT)
Mohamad Bashir
Liverpool Heart and Chest Hospital
(Liverpool, UK)

Editorial Board
Jean Bachet
Zayed Military Hospital
(Abu Dhabi, United Arab Emirates)
Steven Bailey
University of Texas Health Sciences Center
(San Antonio, TX)
Paul Barash
Yale University
(New Haven, CT)
Roberto Di Bartolomeo
University of Bologna
(Bologna, Italy)
Joseph Bavaria
University of Pennsylvania
(Philadelphia, PA)
Jean-Pierre Becquemin
Henri Mondor Hospital
(Creteil, France)
Michael A. Borger
Columbia University
(New York, NY)
Harisios Boudoulas
Aristotelian University
(Coloumbus, OH)
Alan C. Braverman
Washington University School of Medicine
(St. Louis, MO)
Duke Cameron
John Hopkins Hospital
(Baltimore, MD)
John Chang
Long Island Vascular Center
(Roslyn, NY)
Roberto Chiesa
University di Bologna
(Bologna, Italy)
Michael Coady
Stamford Hospital
(Stamford, CT)
Denton A. Cooley
Texas Heart Institute
(Houston, TX)

Lawrence Cohen
Yale University
(New Haven, CT)
Joseph Coselli
Texas Heart Institute/Baylor College of Medicine
(Houston, TX)
Michael Dake
Stanford University
(Stanford, CA)
George Dallas
Archimedes Analytical/Associate Yale Medical
(Hickory, NC)
Tirone E. David
Toronto General Hospital
(Toronto, ON)
Dimitrios Dougenis
Patras University School of Medicine
(Rio, Greece)
L. (Hank) Edmunds
University of Pennsylvania
(Philadelphia, PA)
Anthony Estrera
University of Texas-Houston Medical School
(Houston, TX)
Rosella Fattori
S. Orsola University Hospital
(Bologna, Italy)
Anthony Furnary
Starr-Wood Cardiac Group
(Portland, OR)
Valentin Fuster
Mount Sinai Medical Center
(New York, NY)
Leonard Girardi
New York Weill Cornell Medical Center
(New York, NY)
Gary Grunkemeier
Providence Health System
(Portland, OR)
Richard Gusberg
Yale New Haven Hospital
(New Haven, CT)
Ala Sami Haddadin  
Yale University  
(New Haven, CT)

Jay Humphrey  
Yale University  
(New Haven, CT)

Olga A. Iakoubova  
Celeri  
(Alameda, CA)

John S. Ikonomidis  
Medical University of South Carolina  
(Charleston, SC)

Jeffrey Indes  
Yale University  
(New Haven, CT)

Eric Isselbacher  
Massachusetts General Hospital  
(Boston, MA)

Ivan Jovin  
McGuire VA Medical Center  
(Richmond, VA)

Matthias Karck  
University of Heidelberg  
(Heidelberg, Germany)

Nicholas Kouchoukos  
Missouri Baptist Medical Center  
(St. Louis, MO)

George Koulias  
Stony Brook University  
(Stony Brook, NY)

Johannes Lammer  
Medical University  
(Vienna, Austria)

Frank A. Lederle  
VA Medical Center  
(Minneapolis, MN)

Scott LeMaire  
Baylor College of Medicine  
(Houston, TX)

George Letsou  
University of Texas-Houston Medical School  
(Houston, TX)

Jes S. Lindholt  
University Hospital of Odense  
(Odense, Denmark)

Bart Loeyes  
Ghent University Hospital  
(Ghent, Belgium)

Wei-Guo Ma  
Anzhen Cardiovascular Surgery  
(Beijing, China)

Jorge Mascaro  
Queen Elizabeth Medical Centre  
(Birmingham, UK)

George Matalanis  
Austin Hospital  
(Heidelberg, Australia)

Dianna Milewicz  
University of Texas Medical School  
(Houston, TX)

Raj K. Modak  
Yale New Haven Hospital  
(New Haven, CT)

Hamid Mojibian  
Yale University School of Medicine  
(New Haven, CT)

Frans Moll  
University Medical Center Utrecht  
(Utrecht, Netherlands)

Christoph Nienaber  
University Hospital Rostock  
(Rostock, Germany)

Dimitris Nikas  
Athens Medical Center  
(Athens, Greece)

Takao Ohki  
Jikei University School of Medicine  
(Tokyo, Japan)

Aung Oo  
Liverpool Heart and Chest Hospital  
(Liverpool, UK)

John Pepper  
Imperial College  
(London, UK)

John A. Rizzo  
Stony Brook University  
(Stony Brook, NY)

Flavio Rocha  
Virginia Mason Medical Center  
(Seattle, WA)

Natzi Sakalihasan  
University of Liege  
(Liege, Belgium)

Hans-Joachim Schaefer  
University of Saarlandes  
(Homburg, Germany)

Marc Schepens  
AZ St. Jan  
(Brugge, Belgium)

Oz Shapira  
Hebrew University  
(Jerusalem, Israel)

Bauer Sumpio  
Yale New Haven Hospital  
(New Haven, CT)

Li-Zhong Sun  
Capital Medical University  
(Beijing, China)

Wei Sun  
University of Connecticut  
(Storrs, CT)

Lars Svensson  
Cleveland Clinic  
(Cleveland, OH)

Robert Thompson  
Washington University School of Medicine  
(St. Louis, MO)

M. David Tilson III  
Columbia University  
(New York, NY)

Britt H. Tonnesen  
Roper Heart and Vascular Center  
(Charleston, SC)

Ramesh K. Tripathi  
Narayana Institute of Vascular Sciences  
(Bangalore, India)

Marko Turina  
University Hospital  
(Zurich, Switzerland)

Yuichi Ueda  
Tenri Hospital  
(Nari, Japan)

Gilbert R. Upchurch, Jr.  
University of Virginia Medical Center  
(Charlottesville, VA)

Paul Urbanski  
Herz and Gefaess Clinic  
(Neustadt, Germany)

Hence Verhagen  
Erasmus University Medical Center  
(Rotterdam, Netherlands)

Stephen Westaby  
The John Radcliffe Hospital  
(Oxford, UK)

Christopher White  
Ochsner Medical Center  
(New Orleans, LA)

Simona Zannetti  
Medtronic Cardio Vascular  
(Santa Rosa, CA)
Volume 3, Number 2, April 2015

**Original Research Article**

47  Maximum Diameter of Native Abdominal Aortic Aneurysm Measured by Angio-Computed Tomography: Reproducibility and Lack of Consensus Impacts on Clinical Decisions  
Caroline E. Mora, Claude D. Marcus, Coralie M. Barbe, Fiona B. Ecarnot, Anne L. Long

56  Temporary Perfusion Branches to Decrease Spinal Cord Ischemia in the Endovascular Treatment of Thoraco-Abdominal Aortic Aneurysms  
Parveen Jaya, Jason Constantinou, Hamish Hamilton, Krassi Ivancev

**State-of-the-Art Reviews**

61  Saccular Aneurysms of the Transverse Aortic Arch Treatment Options Available in the Endovascular Era  
Ourania Preventza, Joseph S. Coselli

67  Visceral Debranching for the Treatment of Thoracoabdominal Aortic Aneurysms  
Scott M. Damrauer, Ron M. Fairman

75  Arterial Stiffness Alterations and Inflammatory Response Following Endovascular Aortic Repair  
Konstantinos G. Moulakakis, Spyridon N. Mylonas, John Kakisis, Nikolaos P.E. Kadoglou, Ioannis Papadakis, George S. Sfyroeras, Constantine C.N. Antonopoulos, George Mantas, Ignatios Ikonomidis, Christos D. Liapis

**Case Reports**

81  Homograft Aortic Root Replacement with Saphenous Vein Graft Hemi-Cabrol for Prosthetic Aortic Valve Endocarditis  
Ioannis Dimarakis, Wilfred J. Wooldridge, Isaac Kadir

86  An L-Shaped Incision for an Extensive Thoracic Aortic Aneurysm and Coronary Artery Bypass Using the Left Internal Thoracic Artery  
Tomonobu Abe, Hiroto Suenaga, Hideki Oshima, Yoshimori Araki, Masato Mutsuga, Kazuro Fujimoto, Akihiko Usui

**Upcoming Meetings**

90  List of Upcoming Meetings
Maximum Diameter of Native Abdominal Aortic Aneurysm Measured by Angio-Computed Tomography
Reproducibility and Lack of Consensus Impacts on Clinical Decisions

Caroline E. Mora, MD, Claude D. Marcus, MD, Coralie M. Barbe, MD, Fiona B. Ecarnot, MSc, Anne L. Long, MD

1 Department of Radiology, University Hospital Reims, Hôpital Robert Debré, Reims, France
2 Clinical Research Unit, University Hospital Reims, Hôpital Robert Debré, Reims, France
3 EA3920, Department of Cardiology, University Hospital Besancon, Besançon, France
4 Department of Internal Medicine and Vascular Medicine, Pavillon M, Hospices Civils de Lyon, University Hospital Edouard Herriot, Lyon, France
5 Faculty of Medicine and Maieutic Charles Merieux, Claude Bernard Lyon 1 University, Oullins, France

Abstract

Background: Computed tomography angiography (CTA) is the reference technique for the measurement of native maximum abdominal aortic aneurysm (AAA) diameter when surgery is being considered. However, there is a wide choice available for the methodology of maximum AAA diameter measurement on CTA, and to date, no consensus has been reached on which method is best. We analyzed clinical decisions based on these various measures of native maximum AAA diameter with CTA, then analyzed their reproducibility and identified the method of measurement yielding the highest agreement in terms of patient management.

Materials and Methods: Three sets of measures in 46 native AAA were obtained, double-blind by three radiologists (J, S, V) on orthogonal planes, curved multiplanar reconstructions, and semi-automated-software, based on the AAA-lumen centerline. From each set, the clinical decision was recorded as follows: “Follow-up” (if all diameters <50 mm), “ambiguous” (if at least one diameter <50 mm AND at least one ≥50 mm) or “Surgery ” (if all diameters ≥50 mm). Intra- and interobserver agreements in clinical decisions were compared using the weighted Kappa coefficient.

Results: Clinical decisions varied according to the measurement sets used by each observer, and according to intra and interobserver (lecture#1) reproducibility. Based on the first reading of each observer, the number of AAA proposed for surgery ranged from 11 to 24 for J, 5 to 20 for S, and 15 to 23 for V. The rate of AAAs classified as “ambiguous” varied from 11% (5/46) to 37% (17/46).

The semi-automated method yielded very good intra- and interobserver agreements in clinical decisions in all comparisons (Kappa range 0.83–1.00).

Conclusion: The semi-automated method seems to be appropriate for native AAA maximum diameter measurement on CTA. In the absence of AAA outer-wall-based software more robust for complex AAA, clinical decisions might best be made with diameter values obtained using this technique.

Key Words
Abdominal aortic aneurysm • Computed tomography • Reproducibility
Introduction

The maximum diameter of native abdominal aortic aneurysm (AAA) is the main parameter used to monitor patient care, since it is related to the risk of rupture. Surgery is recommended in men when the maximum diameter is 50 to 55 mm (depending on the country or when patients are at higher risk of rupture), or when AAA diameter grows by more than 10 mm per year [1-3]. Computed tomography angiography (CTA) is the reference technique for the measurement of AAA diameter when surgery is being considered. However, there is a wide choice available for the methodology of maximum AAA diameter measurement on CTA, and to date, no consensus has been reached on which method is best [4,5].

A gold standard imaging technique should have a high reproducibility rate. Previous studies of the reproducibility of diameter measurement by CTA have generally been based on analysis of the difference between diameter values. The most popular statistical method is the Bland and Altman method [6]. When applied to AAA diameter analysis, the clinical threshold is 5 mm for the coefficient of repeatability, and the clinically accepted range is -5 mm to +5 mm for the limits of agreement [7,8]. Mora et al. [5] recently showed that even using precise methodology, the reproducibility of maximum diameter measurements of native AAA on CTA may not meet recommended thresholds.

In the end, the clinical decision regarding management is based on a maximum diameter value that is measured in a non-consensual fashion, which may furthermore differ from one observer to another due to lack of reproducibility. The impact of various CTA-based measures of maximum AAA diameter, and the impact of reproducibility limits on the decision to operate have never been investigated.

Therefore, the aims of this study were to analyze the consequences on clinical decisions of such a wide choice of AAA maximum diameter measurement methodologies when using CTA; to analyze the reproducibility of these clinical decisions, and finally, to identify the method of measurement that yields the best agreement for patient management.

Materials and Methods

The details of CTA protocol, database constitution, analysis and patient selection have previously been described [5]. CTA acquisitions were not ECG (electrocardiogram) gated.

Male patients with non-operated infrarenal AAA undergoing CTA between January 1, 2010 and April 15, 2012 were retrospectively identified in the Picture Archiving and Communication System (PACS) (Impax version 5.2; Agfa, Mortsel, Belgium) of the Radiology Department of the University Hospital of Reims, France.

Patients were identified using the terms “aneurysm,” “aorta,” “abdominal,” and “male gender” and combined using the Boolean operators “AND” and “OR,” from the computerized indication for CTA examination in the PACS. After reading the whole indication for CTA examination, patients were excluded in case of inflammatory aneurysm, false aneurysm, aneurysm after open repair or stent-graft, thoracic, thoraco-abdominal or iliac artery aneurysms, or aortic diameter less than 30 mm. Older CTA were selected in case of multiple examinations for the same patient. CTA from eligible patients were re-analyzed on axial slices and only CTAs at the arterial phase after contrast injection showing an infrarenal AAA with a maximum external diameter in any direction greater than or equal to 30 mm were identified [5]. Only patients with an AAA greater than or equal to 40 mm and less than or equal to 60 mm were included in the present analysis. Age was the only patient characteristic that was recorded.

One junior resident (J), one senior vascular interventional radiologist (S) with, respectively, 3 and 20 years experience, and a specialist in vascular medicine with more than 15 years experience in vascular radiology (V), all blinded to previous radiological reports, independently measured maximum AAA diameter on each examination. Each observer performed two readings, at a minimum of 4 week intervals, yielding 6 series of measures: Junior readings 1 (J1) and 2 (J2), Senior readings 1 (S1) and 2 (S2), and Vascular readings 1 (V1) and 2 (V2).

Maximum external diameter was measured using 10 different methodologies. The slices of interest displaying the largest aneurysm diameter were selected by each observer (J, S, and V), although the slice numbers were not recorded.

First, nine measurements were performed on the PACS workstation:

1. On the selected axial slice (Figure 1A):
   • antero-posterior diameter Axial_APD,
   • transverse diameter Axial_TrD,
   • maximum diameter in any direction Axial_Dmax.

2. On the selected sagittal and coronal multiplanar reconstruction (MPR) images:
   • on sagittal MPR (Figure 1B), antero-posterior diameter Sag_APD and diameter perpendicular to the long axis of the aneurysm Sag_PerpD,
   • on coronal MPR (Figure 1C), transverse diameter Coro_TrD, and diameter perpendicular to the long axis of the aneurysm Coro_PerpD,

3. Using dedicated software (3D Voxar 6.3.2 Workstation, Toshiba Medical Visualization System Europe Ltd, Edinburgh, UK) providing curvilinear MPR:

Original Research Article

AORTA, April, 2015

Volume 3, Issue 2: 47-55
• on selected parasagittal reformatted images (Figure 1D), antero-posterior diameter perpendicular to the long axis of the aneurysm PSR _PerpD,
• on selected paracoronal reformatted images (Figure 1E), transverse diameter perpendicular to the long axis of the aneurysm PCR _PerpD.

Second, using dedicated 3D analysis software (Advanced Vessel Analysis Xpress, General Electric, Milwaukee, WI, USA),
the maximum diameter perpendicular to the centerline called Semi-automated_D was measured semi-automatically (Figure 1F and Figure 1G). This 3D analysis software creates the abdominal aortic lumen centerline once the observer has placed two points at the celiac aortic level and the aortic bifurcation, and then the software automatically provides cross sections perpendicular to this centerline. The cross-section containing the maximum aortic diameter in any direction perpendicular to the lumen centerline is visually selected by the observer, who then manually draws the outer limits of the AAA, including thrombus and the arterial wall. Then, the maximum diameter in any direction is automatically calculated.

The main difference between the two methods is that the centerline of MPR curvilinear is drawn manually when it is drawn automatically with the semi-automated method from the starting point to the ending point of the aorta.

The study was approved by the Institutional Review Board of Reims University Hospital, France.

Data are described as mean and standard deviation (SD) for quantitative variables and number (percentage) for qualitative variables. For each AAA and for each reading, the diameter values were classified into three different sets as follows:

- Orthogonal plane diameters (seven diameters)
- Curvilinear MPR diameters (two diameters)
- Semi-automated method (one diameter)

When analyzing values obtained for a single AAA in any one of the sets, the clinical decisions were recorded as follows:

- “Follow-up” if all diameters were less than 50 mm,
- “Intervention” if all diameters were greater than or equal to 50 mm
- “Ambiguous” if at least one other was greater than or equal to 50 mm and at least one other was less than 50 mm

As only one diameter was provided with the semi-automated method, the clinical decision was recorded as “Follow-up” in case of AAA less than 50 mm or “Intervention” in case of AAA greater than or equal to 50 mm.

For each reader, mean diameters obtained with each method were compared with the general linear model and the Student t test.

Proportions of “Intervention” decisions were compared between the two sets of measures of each individual observer (J1, S1, and V1) and between the same set of measures of two observers (J1 versus S1, J1 versus V1, and S1 versus V1) using Mac Nemar’s Chi² test.

Intra-observer (J1 versus J2; S1 versus S2, and V1 versus V2) and inter-observer agreement in terms of clinical decisions were compared using the Kappa coefficient (K). The weighted Kappa coefficient was used when clinical decisions were “Follow-up,” “Ambiguous,” or “Intervention.” Ordinary (non-weighted) Kappa coefficient was used when the clinical decision was a binary variable (“Follow-up” or “Intervention”), that is, for the semi-automated method. The strength of agreement was interpreted as very good when K was greater than 0.81, good when K was 0.61–0.80, moderate when K was 0.41–0.60, fair when K was 0.21–0.40, poor when K was less than 0.20.

A P value less than 0.05 was considered statistically significant. All analyses were performed using SAS version 9.0 (SAS Inc, Cary, NC, USA).

### Table 1. Comparison between abdominal aortic aneurysm (AAA) diameter values obtained from the first reading of each observer.

<table>
<thead>
<tr>
<th>Diameter*</th>
<th>Reading J1</th>
<th>Reading S1</th>
<th>Reading V1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial_APD</td>
<td>46.2 ± 6.1</td>
<td>46 ± 5.8</td>
<td>48 ± 6.2</td>
</tr>
<tr>
<td>Axial_TrD</td>
<td>47.5 ± 5.6</td>
<td>46.6 ± 5.7</td>
<td>48.3 ± 5.7</td>
</tr>
<tr>
<td>Axial_Dmax</td>
<td>51.5 ± 5.1</td>
<td>48.8 ± 5.2</td>
<td>51.1 ± 5.2</td>
</tr>
<tr>
<td>Sag_APD</td>
<td>47.3 ± 5.7</td>
<td>45.3 ± 6.0</td>
<td>48 ± 6.0</td>
</tr>
<tr>
<td>Sag_PerpD</td>
<td>47.3 ± 5.5</td>
<td>45 ± 5.7</td>
<td>48 ± 6.1</td>
</tr>
<tr>
<td>Coro_TrD</td>
<td>47.9 ± 5.9</td>
<td>46 ± 5.6</td>
<td>48.4 ± 5.9</td>
</tr>
<tr>
<td>Coro_PerpD</td>
<td>47.5 ± 5.7</td>
<td>44.7 ± 5.7</td>
<td>47.7 ± 5.6</td>
</tr>
<tr>
<td>PSR_PerpD</td>
<td>47 ± 5.9</td>
<td>45.1 ± 5.6</td>
<td>47.8 ± 5.7</td>
</tr>
<tr>
<td>PCR_PerpD</td>
<td>47.5 ± 5.5</td>
<td>45.5 ± 5.4</td>
<td>48.2 ± 5.9</td>
</tr>
<tr>
<td>Semi-automated_D</td>
<td>49.9 ± 5.3</td>
<td>48.9 ± 5.4</td>
<td>49.7 ± 5.9</td>
</tr>
</tbody>
</table>

P  0.0004  0.0006  0.125

Observers: J1, S1, V1; n = 46 AAA; diameters are expressed in mm as the mean ± standard deviation; * for diameter abbreviations, see Figure 1; PSR/PCR: parasagittal/paracoronal reconstruction.

### Table 2. Clinical decisions based on three sets of abdominal aortic aneurysm (AAA) maximum diameter values, for the first and second readings of each observer.

<table>
<thead>
<tr>
<th>Clinical decision</th>
<th>J1</th>
<th>J2</th>
<th>S1</th>
<th>S2</th>
<th>V1</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthogonal Plane Diameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow up (n)</td>
<td>18</td>
<td>16</td>
<td>24</td>
<td>24</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>Ambiguous (n)</td>
<td>17</td>
<td>15</td>
<td>17</td>
<td>13</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Intervention (n)</td>
<td>11</td>
<td>15</td>
<td>5</td>
<td>9</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Curvilinear MPR Diameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow up (n)</td>
<td>24</td>
<td>26</td>
<td>31</td>
<td>29</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>Ambiguous (n)</td>
<td>7</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Intervention (n)</td>
<td>15</td>
<td>15</td>
<td>8</td>
<td>9</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>Semi-Automated Method</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow up (n)</td>
<td>22</td>
<td>23</td>
<td>26</td>
<td>26</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Intervention (n)</td>
<td>24</td>
<td>23</td>
<td>20</td>
<td>20</td>
<td>23</td>
<td>23</td>
</tr>
</tbody>
</table>

n= 46 AAA; for each AAA, the clinical decision was established separately based on seven diameters measured for the “orthogonal planes” set, based on two diameters for the “curvilinear MPR diameters” set, and based on only one diameter with the semi-automated method.
Results

In total, 46 patients (corresponding to 46 CTA) were included in the present study. The mean age was 71 ± 9 years.

The comparisons of the 10 mean diameters noted by each observer on the first reading are reported in Table 1.

For readers J and S, there was a significant difference overall in mean diameters obtained with each method (P = 0.0004 and P = 0.0006 respectively). For reader J, the diameters that differed significantly were Axial_APD (P= 0.03), Axial_Dmax (P < 0.0001) and diameter measured by the semi-automated method (P= 0.02). For reader S, the diameters that differed significantly were Axial_Dmax (P= 0.003) and the semi-automated method (P= 0.0007).

Clinical Decisions

Clinical decisions based on the 3 sets of AAA maximum diameter values, from the first and second readings of each observer, are reported in Table 2. The clinical decision varied according to the sets used for each observer. The number of AAA proposed for “Intervention” ranged from 11 to 24 for J1, 5 to 20 for S1 and 15 to 23 for V1.

The clinical decision also varied between the first and second readings of a same observer, and between the first reading of 2 observers. The semi-automated method yielded the highest rate of AAA proposed for “Intervention”.

The differences in the number of patients proposed for “Intervention” based on each set of measures (intra- and inter-observer comparisons) are reported in Table 3. From one set of measures to another, the decision to proceed to intervention differed significantly for each observer.

When the same set of measures by each observer was considered, the decision to proceed to intervention differed statistically significantly from one observer to another in a total of six of nine comparisons.

Based on the first reading of each observer, the rate of AAAs classified as “Ambiguous” varied from 11% (5/46) to 37% (17/46).
Intra-Observer Agreement in Clinical Decisions

Intra-observer agreement in clinical decisions between the first and second readings of all observers is reported in Table 4. The highest rate of agreement was observed with Curvilinear MPR diameters for J (K = 0.95), and with the semi-automated method for S and V (K=1). The semi-automated method yielded 93.5% agreement for J (K=0.87).

Interobserver Agreement in Clinical Decisions

Inter-observer agreement in clinical decisions between the first reading of all observers is also reported in Table 5. The highest rates of agreement were observed with the semi-automated method, with a (non-weighted) Kappa coefficient ranging from 0.83 (J1 versus S1) to 0.96 (J1 versus V1).

Discussion

The aim of this study was to evaluate the impact on management of 46 patients with an AAA diameter between 40 mm and 60 mm, of the lack of consensual methodology for the measurement of maximum diameter, and of the inadequate reproducibility of AAA maximum diameter measurement on CTA. We showed that clinical decisions varied according to the measurement sets used by each observer; that they also varied between the first and second reading of a same observer, and between first readings of two observers. The semi-automated method yielded good intra- and interobserver agreement in terms of clinical decisions in all comparisons.

Given that there is no consensus or recommendation in clinical practice for the preference of any single diameter over another, we chose to analyze the clinical decisions made using three different measurement sets, namely measures performed on orthogonal planes, from curvilinear multiplanar reconstructions and with the semi-automated method.

This analysis showed that clinical decisions differed for a same observer from one set of diameters to another, and also from one observer to another, even when the two observers were using the same set of diameters. The rate of patients referred to “Intervention” varied consistently.

The semi-automated method yielded the highest rates of surgical indication (≥ 50 mm) for all observers, and for both readings (24, 20, and 23/46 patients for J1, S1, and V1 respectively; 23, 20, and 23/46 patients for J2, S2, and V2 respectively). This can likely be explained by the absence of an “ambiguous” option. Indeed, since only one diameter is obtained with the semi-automated method, only two clinical decisions are available, namely “Intervention” or “Follow-up”.

Intra-observer agreement in clinical decisions was very good, with a Kappa coefficient greater than 0.81 for all sets of measurements, except one at 0.80. The highest rate of agreement (100%) was observed for observers S and V with the semi-automated method.

Inter-observer agreement in clinical decisions was poorer, as three of the kappa values dropped to 0.60 or below. The highest rates of agreement were observed for all three observers with the semi-automated method (91.3% to 97.8%, corresponding to a
kappa coefficient ranging from 0.83 to 0.96), reflecting good strength of agreement.

These results should prompt a prudent attitude. Indeed, even when the Kappa coefficient is considered, in statistical terms, to be good or very good, closer analysis of the clinical decisions is mandatory to examine any discrepancies. For instance, the inter-observer agreement between J1 and S1 observed with the semi-automated method yielded a kappa coefficient of 0.83, indicating very good agreement. Nonetheless, nearly 10% of patients (4/46) had contrasting management recommendations.

Previous studies have analyzed the reproducibility of various methodologies for AAA maximum diameter measurements in order to reach a consensus on the method that yields the highest reproducibility, but that is nonetheless available in routine clinical practice [5, 9-12]. The question of reproducibility is especially crucial when CTA images are analyzed by several different clinicians during the patient’s management pathway.

To the best of our knowledge, this is the first study to report the impact of this multiplicity of measurement choices and their reproducibility on clinical decisions. Given that a difference of only a few millimeters may heavily impact on the choice of management strategy, the originality of this study lies in the determination of the type of measurement that gives the highest rate of agreement in terms of clinical decisions.

In a recent review of the Cochrane database, short-term mortality (defined as 30-day or in-hospital mortality) after endovascular AAA repair and after open surgery were respectively 1.4% and 4.2% [13]. On the other hand, the rate of rupture of a 50 mm-AAA per 1000 person-years was estimated at 6.4 (95%CI 4.3–9.5) in men in the RESCAN meta-analysis [14]. The recent IMPROVE trial showed that the 30-day mortality rate after rupture in patients was 35.4% in the endovascular strategy group and 37.4% in the open repair group [15]. Overall mortality is likely higher, as some patients die before reaching hospital. Therefore, the clinical decision in patients with AAA diameters close to the threshold has serious consequences for patient outcome, and a few millimeters can potentially influence the course of a patient’s life.

The type of measurement and the reproducibility may only slightly affect intra- and inter-observer agreement in terms of clinical decisions when the AAA is small, that is, diameter less than 40 mm, or when the AAA is clearly very big, that is, greater than 60 mm. Even if there is a difference of 10 mm between two readings by the same observer or between two observers, the decision will still be “Follow-up” in the first case and “Intervention” in the second. However, for AAAs with a diameter close to the threshold value for Intervention (50 mm), in either direction (above or below), the impact of a few mm difference may be of greater importance. For this reason, we decided to limit our analysis to AAA with axial_Dmax ranging from 40 mm to 60 mm, as being the zone where lack of reproducibility is most likely to tip the balance from one management strategy to the other. In addition, inclusion of smaller and bigger AAA might have interfered with the results, by respectively increasing the rates of “Follow-up” and “Intervention.”

The semi-automated method provides a more realistic representation of AAA anatomy and consequently, the maximum diameter in any direction perpendicular to the lumen centerline estimated with this approach is closer to the real maximum diameter. However, in case of tortuous AAA with asymmetric thrombus, the Dmax measured perpendicular to the lumen centerline do not really represent the ‘real’ Dmax. A centerline based on the thrombus envelop (AAA outer-wall centerline) is in this case more adapted. Unfortunately, most of the software used with CT are based on the lumen centerline [16], even if some publications are based on AAA outer-wall centerline [11,17,18]. Software providing the AAA outer-wall centerline was not available in our Radiology Department.

With the semi-automated method, only one diameter value is provided for each AAA, leading to only two clinical outcomes, namely “Follow-up” or “Intervention.” Therefore, the problematic clinical situation of an “Ambiguous” decision, leading to a decision to propose Intervention in a patient who in fact only requires Follow-up, or vice versa, is removed. A recent study showed that the semi-automated method led to more reproducible results between different observers [5]. Indeed, when using this method, human Intervention during the different steps of CT analysis is reduced, and is limited to the observer having to place two points at the celiac aortic level and the aortic bifurcation, choosing the slice of interest, then

Mora, C. et al.
delimiting the outer wall of the aorta manually [5]. In the present study, the semi-automated method also yielded the highest rate of agreement in clinical decisions between observers, and between the first and second readings of two observers.

The study has some limitations that deserve to be acknowledged. Firstly, as the CTA protocol did not include cardiac gating, it is not possible to know whether measures were performed in the systolic or diastolic phase. However, this does not influence the results, since the same sets were read by all observers. Secondly, we did not record for each patient the presence or absence of wall calcifications, which might have helped identify external diameter. Similarly, we did not record the location (concentric or eccentric) of any thrombus, which might have affected measurement with the semi-automated method. However, again, these points should not influence the results, since all observers read the same sets. Thirdly, we did not record AAA morphology; therefore, we could not discuss the impact of complex morphology on decisions agreements.

**Conclusion**

Even when AAA maximum diameter was measured on CTA considered as the gold standard, clinical decisions varied according to the measurement sets used by each observer, varied between readings by one observer and between the first readings of two observers. The semi-automated method, using lumen-based software, yielded very good intra- and inter-observer agreement in clinical decisions in all comparisons. These findings suggest that the semi-automated method seems to be appropriate for AAA maximum diameter measurement on CTA. In the absence of AAA outer-wall based software more robust for complex AAA, clinical decisions on whether or not to proceed to Intervention might reliably be made with diameter values obtained using this technique.

**Conflict of Interest**

The authors have no conflict of interest relevant to this publication.

References


15. Investigators IT. Endovascular or open repair strategy for ruptured abdominal aortic aneurysm: 30 day outcomes from IMPROVE randomised trial. BMJ. 2014;348:f7661. DOI: 10.1136/bmj.f7661


EDITOR’S COMMENTS AND QUESTIONS

Comments

Mora and colleagues provide interesting, important information on the technique of aortic size measurement and the variations in different measurements. This work is highly important, as so many of our decisions in aortic diseases are based on size. The Editors have some questions for the authors.

Questions

1. You decided to include the wall in your diameter measurement. How do you identify the wall when contrast is used, opacifying the lumen only? The case you illustrate has a highly calcified rim, facilitating identification of the wall. What do you do if it is not calcified?

CT offers a good resolution in any direction, and in most cases interface between peri-arterial tissues (fat) and AAA walls is easy to find, even if the walls are not calcified. In a few cases, if adenopathies, inferior vena cava, duodenum, small bowel are close to the aortic wall, the wall may be more difficult to identify and this requires a meticulous analysis of the slice.

2. Is it intuitively clear that the measurement with the least variability is the “true” one, as you state? Could not a method be consistent yet inaccurate? Please comment.

Unfortunately, we do not know in fact what the real maximum diameter is. Maximum diameter has to be measured on a cross-section perpendicular to the centerline. Lumen centerline is the more frequently used with angioCT but has drawbacks in case of tortuous AAA with asymmetric thrombus. The AAA-wall centerline provides real cross-section perpendicular to the AAA, however softwares are less widespread.

3. Are there not very current commercially available programs, which identify the center line without the reader’s needing to mark two center line points?

There are currently commercially available programs which identify the center line without the reader’s needing to mark two center line points. However placing two points on the celiac aortic level and the aortic bifurcation limits the volume of the data to analyze.
Temporary Perfusion Branches to Decrease Spinal Cord Ischemia in the Endovascular Treatment of Thoraco-Abdominal Aortic Aneurysms

Parveen Jayia, MRCS, Jason Constantinou, FRCS*, Hamish Hamilton, FRCS, Krassi Ivancev, MD, PhD
Department of Vascular Surgery, Royal Free Hospital NHS Trust, London, United Kingdom

Based on a Presentation at the 2013 VEITH Symposium, November 19–23, 2013 (New York, NY, USA)

Abstract

Background: Spinal cord ischemia (SCI) is one of the most feared complications following the repair of thoraco-abdominal aortic aneurysms (TAAA). Endovascular repair of TAAA is now possible with branched stent grafts, but spinal cord ischaemia rates are still unacceptably high. A number of techniques have been utilized to reduce these levels, however, SCI remains a challenge to endovascular repair of TAAA. The use of sac perfusion branches aims to reduce the incidence of this catastrophic complication.

Methods: A retrospective analysis of all patients undergoing branched endovascular aortic repair for all thoraco-abdominal aneurysms (TAAA) using custom made devices during January 2008 to August 2014. We describe a two staged technique in which perfusion of segmental vessels is maintained by a temporary endoleak through an open perfusion branch, incorporated within the branched stent graft, followed by a closure of this branch at a later date to complete exclusion of the aneurysm.

Results: Forty-seven patients underwent TAAA repair. Twenty-five (53%) had a two-stage procedure using either a sac perfusion branch or a target vessel to perfuse the sac. Nine patients (19.15%) suffered some form of SCI with eight patients having temporary SCI (lasting less than 72 hours) and one patient having permanent SCI. Of eight patients that had temporary spinal cord ischemia, all had a perfusion strategy. There was one case of permanent SCI (2.13%).

Conclusion: Sac perfusion branches provide a safe method for preventing SCI, however this needs to be used in conjunction with controlling MAP and CSF drainage.

Key Words
Spinal cord ischaemia • Aneurysm • Perfusion • Thoraco-abdominal

Introduction

Spinal cord ischaemia (SCI) resulting in complete paraplegia or paraparesis is a recognized complication during the treatment of thoracic or thoraco-abdominal aortic aneurysms (TAAA). The symptoms can be apparent immediately (early SCI) or present up to 72 hours later (delayed SCI) [1]. Open surgical and endovascular repair have been associated with SCI, with some studies reporting incidences ranging between 11.4% to 22% [2]. The risk of SCI is increased by a number of factors such as the extent of the aneurysm and the corresponding stent graft length used and the number of posterior intercostal and lumbar arteries covered. There is much debate regarding the best intra-operative and post-operative adjuncts to prevent or minimise SCI. Spinal cord protection strategies...
have included adopting a 2-stage repair approach, reducing metabolic rate via induced hypothermia, measuring somatosensory-evoked potentials (SSEPs) and motor-evoked potentials (MEPs), monitoring cerebrospinal fluid (CSF) pressure, and reperfusion of intercostal arteries. A new and evolving technique is to maintain perfusion of intercostal and lumbar vessels by having an intentional endoleak [3]. This prevents complete thrombosis of the aneurysm sac, thereby maintaining spinal cord perfusion via the intercostals and lumbar arteries. We report our experience of using a two-staged technique in our high risk patients where either a temporary open branch incorporated into the main stent graft device or a target vessel is left open. These are then closed at a later date.

**Methods**

A two-center retrospective analysis of all patients undergoing branched endovascular aortic repair for all thoraco-abdominal aneurysms (TAAA) using custom made devices during January 2008 to August 2014. The team structure did not change and involved the same senior endovascular surgeons and senior interventional radiologists at both centers.

**Patients**

All patients with Type II-IV TAAA greater than 5.5 cm, those who had a rapidly expanding aneurysm sac (>1 cm in 1 year), or those patients who were symptomatic were included in the study (Table 1). All patients were discussed at the local vascular multidisciplinary meeting prior to the procedure taking place.

**Endovascular Technique**

A two-staged approach was used for endovascular repair for type II-IV TAAAs that were deemed high risk for SCI. Each custom made Cook® branched device had a temporary perfusion branch included in the design to create the temporary endoleak, or otherwise a target vessel (coeliac branch) was used as a perfusion branch (Figure 1). Each case was individually planned using TeraRecon 3D planning software.

In the first stage under general anesthesia, the custom made branched stent-graft was deployed and the branches connected to the visceral vessels. A sac perfusion branch was left open, allowing perfusion of the intercostal and lumbar vessels. A spinal drain was inserted. All patients were transferred to ITU post operatively where mean arterial pressure (MAP) was maintained above 90mmHg and spinal fluid was drained to ensure that the spinal cord pressure was lower than 10 cm of water. The management of spinal cord drains was standardized under a set institutional protocol. Patients were neurologically assessed hourly in ITU. Within a period of 3-months postoperatively, the patient underwent the second stage of the procedure where the sac perfusion branches were embolized with Amplatz® plugs or the branch intended for the visceral vessel was connected, to allow complete exclusion of the aneurysm. Completion angiograms to assess for endoleaks were performed at this stage. The patients were then discharged 24–48 hours following closure of the perfusion branch.

**Results**

From 2008 to 2014, a total of 47 patients underwent TAAA repair. Of these, 25 (53%) had a 2-stage procedure using either a sac perfusion branch or a target vessel to perfuse the sac. Forty-five percent (n=1) of the aneurysms were Type II TAAA.

Of the 25 patients, 19 (76%) patients with Type II and 6 (24%) with Type III TAAA aneurysms underwent
sac perfusion with either a temporary branch or target vessel being left open. Perfusion strategies were not use in Type IV thoraco-abdominal aneurysms.

**Spinal Cord Ischemia (SCI)**

Nine patients (19.15%) suffered some form of SCI with eight patients having temporary SCI (lasting less than 72 hours) and one patient having permanent SCI. Five of the nine patients had perfusion branches that were closed in a second procedure and 3 patients had a target vessel deliberately left open (coeliac artery) that was successfully connected in a second procedure. Of eight patients that had temporary spinal cord ischemia, all had a perfusion strategy, and all recovered. There was one case of permanent SCI (2.13%). This patient had a Type II TAAA and did not have a perfusion branch as he was one of the early cases completed in the series.

Of the eight patients with temporary SCI, seven had Type II TAAA and one occurred in a Type III TAAA. There were no aneurysm ruptures during the interval from the first to second stage.

**Spinal Drain**

Forty-six patients had a spinal drain with most patients having a drain in for 2 days (n=23). The remaining had a spinal drain in for 3 days (n=20) and three patients had it only in for 24 hours.

**Mortality**

There was only one intra-operative death. This was in a patient who had a pre-operative contained thoracic rupture that decompensated hemodynamically intra-operatively.

There were five deaths (10.6%) within 30 days. The causes of death were bowel ischaemia (n=3), multi-organ failure (n=1) and limb ischaemia (n=1).

Six patients needed further surgical interventions following primary endovascular TAAA repair. The interventions ranged from laparotomies for bowel ischaemia (n=3), lower limb salvage (n=1, fem-fem crossover, n=1 embolectomy) and one above-knee amputation for lower limb ischaemia.

**Discussion**

SCI is a recognized complication of TAAA repair. Due to the multi-factorial cause of SCI, several strategies have been proposed.

In 1996, Safi described the importance of re-implanting intercostal arteries in conjunction with moderate hypothermia. This group prospectively analyzed 343 patients who had undergone either type I, II or III TAAA repair and showed that the benefit of reattachment was greatest for intercostals in the lower thoracic regions, in particular T9 through to T12 [4]. They also showed that greater benefit was seen for Type II TAAA, probably due to the greater aortic coverage, when combined with other spinal adjuncts such as spinal drainage. A series in 1993 by Svensson of 1509 patients showed that the greatest risk of paraplegia again was seen in Type II TAAA, where rates of 35% were reported. In this series, 45% (n=684) had undergone reimplantation of intercostal arteries but it was difficult to identify how many were within the Type II TAAA group [5].

Monitoring motor evoked potentials (MEPS) has also been shown to be a reliable technique to assess spinal cord function intra-operatively during TAAA repair. In a study of 112 patients (n=70 Type II TAAA), reduction in MEP correlated significantly with spinal cord ischaemia. However, even though it is a helpful tool to detect early SCI, MEP monitoring cannot guarantee prevention of delayed spinal cord ischemia [6].

A 2-staged repair has been shown in open surgery to be effective in reducing paraplegia rates. In a retrospective study of 90 patients, a 2-stage approach was effective with no SCI seen after the second stage even when there were a large number of intercostal/lumbar arteries sacrificed [7].

We now use a 2-stage endovascular approach for all type II TAAAs whereby a temporary endoleak is created, allowing perfusion of the aneurysm sac and hence the spinal cord. This can be achieved either by the inclusion of a temporary perfusion branch or by simply leaving a target vessel open. In our series, nine patients (19.15%) developed neurological symptoms following closure of the perfusion branch. The majority of these occurred in patients with Type II TAAA (n=8) with the remainder (n=1) occurring in Type III TAAA. Eight out of nine of these cases were temporary and resolved within 30 days. There was one patient with permanent disability in our series but this patient did not have sac perfusion (this was due to the fact that he was one of the
first cases to have endovascular TAAA repair in the unit and the use of sac perfusion was not practiced. We believe that it is more important to stage cases and maintain sac perfusion as a concept, rather than specifically use perfusion branches. This could be achieved using various strategies, such as leaving the distal completion of stenting into the iliac arteries as a further stage, leaving a deliberate type 3 endoleak between undersized thoracic grafts for subsequent closure, or by delayed closure of a target visceral vessel branch.

Our findings suggest that maintaining sac perfusion to allow spinal cord perfusion is crucial in order to avoid the catastrophic complication of SCI. It is vital for high-risk patients to have spinal cord drainage and maintenance of an adequate MAP and avoidance of anemia [8].

One problem with our technique is that there remains a risk of aneurysm rupture due to the intentional temporary endoleak. In our small series of patients we did not see any aneurysm ruptures whilst waiting for the second stage of the procedure to be performed. If an aneurysm rupture were to occur we could simply repair this by percutaneous closure of the perfusion branches under local anesthesia. This technique can only be used in patients with an intact aortic sac and is contraindicated in those with a contained leak such as our patient that demised perioperatively. The efficacy of a temporary perfusion branch may be influenced by other parameters such as turbulent flow, shear stresses, or embolization, which paradoxically may induce spinal cord ischemia.

**Conclusion**

Controlled perfusion of the intercostal vessels with a temporary endoleak is feasible. Sac perfusion branches may be a useful adjunct to prevent SCI, providing protection to spinal cord perfusion during the immediate post-operative period, when the risk of cardiovascular instability is greatest. As the general applicability of endovascular solutions to complex anatomical challenges increases, further innovations to prevent complications such as paraplegia are necessary. We believe that sac perfusion branches provide a safe method for preventing SCI, however this needs to be used in conjunction with controlling MAP and CSF drainage. In the future, we plan to develop this model further to be used as a predictive tool as well as a protective tool. We believe that we will be able to perform “test-occlusions” of the branches whilst clinically monitoring neurological function and/or monitoring motor evoked potentials. If there is a disturbance in neurological function the branches need not be closed immediately, allowing time for development of collateral circulation.

**Conflict of Interest**

Krassi Ivancev is sponsored by COOK.

### Table 1. Patient Characteristics and Risk Factors.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean Age (years)</strong></td>
<td>72.09</td>
<td>68%</td>
</tr>
<tr>
<td><strong>Male</strong></td>
<td>32</td>
<td>68%</td>
</tr>
<tr>
<td><strong>Female</strong></td>
<td>15</td>
<td>32%</td>
</tr>
<tr>
<td><strong>Aneurysm Diameter (cm)</strong></td>
<td>6.8</td>
<td>68%</td>
</tr>
<tr>
<td><strong>Previous Aortic Repair:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>37</td>
<td>79%</td>
</tr>
<tr>
<td>Open Aortic Repair</td>
<td>6</td>
<td>13%</td>
</tr>
<tr>
<td>Endovascular Repair</td>
<td>4</td>
<td>8%</td>
</tr>
<tr>
<td><strong>No of branches:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>21%</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>77%</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>2%</td>
</tr>
<tr>
<td><strong>Cardiovascular Risk Factors:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes Mellitus</td>
<td>5</td>
<td>6%</td>
</tr>
<tr>
<td>Hypertension</td>
<td>38</td>
<td>48%</td>
</tr>
<tr>
<td>Smoking</td>
<td>11</td>
<td>14%</td>
</tr>
<tr>
<td>Ischemic Heart Disease</td>
<td>17</td>
<td>21%</td>
</tr>
<tr>
<td>Renal Failure</td>
<td>9</td>
<td>11%</td>
</tr>
<tr>
<td><strong>American Society of Anesthesiologists (ASA) Grade:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>68%</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>26%</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 1. Patient Characteristics and Risk Factors.

Jayia, P. et al.
References


Cite this article as: Jayia P, Constantinou J, Hamilton H, Ivancev K. Temporary Perfusion Branches to Decrease Spinal Cord Ischemia in the Endovascular Treatment of Thoraco-Abdominal Aortic Aneurysms. AORTA 2015;3(2):56-60. DOI: http://dx.doi.org/10.12945/j.aorta.2015.14-045
Saccular Aneurysms of the Transverse Aortic Arch: Treatment Options Available in the Endovascular Era

Ourania Preventza, MD*, Joseph S. Coselli, MD
Department of Cardiovascular Surgery, the Texas Heart Institute, and Division of Cardiothoracic Surgery, Michael E. DeBakey Department of Surgery, Baylor College of Medicine, Houston, Texas, USA

Abstract

Saccular aneurysms of the aortic arch, whether single or multiple, are uncommon. The choice of repair technique is influenced by patients' comorbidities and age. Repairing saccular aneurysms with traditional open techniques can be technically demanding; therefore, endovascular technology and a variety of hybrid approaches have been developed to facilitate such repairs and, potentially, to improve clinical outcomes, especially in high-risk patients. There have been no large, randomized studies to compare the outcomes of these different treatment options in patients with single or multiple saccular aneurysms of the arch. In this review, we outline the etiology and common locations of these aneurysms, the different open, completely endovascular, and hybrid techniques used to treat them, and the treatment selection process.

Key Words:
Saccular aneurysms • Aortic arch • Chimney and snorkel technique • Hybrid technique

Introduction

Saccular aneurysm of the transverse aortic arch is an uncommon clinical entity whose natural history is poorly understood. Saccular aneurysms in general, including those of the transverse aortic arch, have been characterized as having a higher risk of rupture than fusiform aneurysms. Addressing a similar entity in the abdominal aorta, the Joint Council of the Society of Vascular Surgery and North American Chapter of the International Society of Cardiovascular Surgery has recommended the repair of all saccular aneurysms of the abdominal aorta, regardless of their size or symptomatology [1]. As new technology has emerged for treating aortic pathology, new paradigms for aneurysm therapy have been developed, including a variety of open, hybrid, and completely endovascular, catheter-based techniques. To date, however, there have been no large randomized trials to compare the outcomes of these different interventions. Reports of meta-analyses have been published but must be interpreted carefully because of the heterogeneity among patients and studies [2]. We outline the different methods for treating single or multiple saccular aneurysms of the aortic arch, and we explain our preference for certain techniques.

Etiology, Location, and Natural Course of Saccular Aneurysms

Fusiform aortic aneurysms are primarily due to connective tissue disorders, which are frequently associated with genetic conditions. In contrast, saccular aneurysms of the aorta have a wide variety of causes, including both active and remote infection [3, 4], inflammatory diseases such as tuberculosis and syphilis [5-7], degeneration and progression of a penetrating aortic ulcer, prior trauma or aortic surgery [3, 8], Behçet disease, and Takayasu arteritis. In a series recently reported by Shang et al. [9] at the University of
Pennsylvania, the majority of saccular aneurysms arose as a consequence of atherosclerotic disease. Although the true natural history of saccular aneurysms remains unknown, their perceived malignancy has driven cardiovascular surgeons to use a lower diameter-based threshold for repairing saccular aneurysms than they use for repairing fusiform aneurysms.

The location of aortic saccular aneurysms is variable. Common locations include the inner curvature of the transverse aortic arch and close to the celiac axis, projecting posteriorly [10]. In the recent report by Shang et al. [9], among 322 saccular aneurysms, 68.1% were located in the descending aorta, 24.2% in the abdominal aorta, 7.1% in the arch, and 0.6% in the ascending aorta.

**Repair Techniques for Saccular Aneurysms of the Aortic Arch**

**Open Repair**

Most studies of the surgical management of transverse aortic arch pathology have focused on fusiform aneurysms. Recent series have produced very promising results, particularly in high-volume centers of excellence in aortic surgery. Leshnower and colleagues [11] reported a mortality of 9.7%, an overall incidence of stroke of 2.8%, and a temporary neurologic deficit rate of 5.6% among 145 patients who underwent total arch replacement. Among 721 patients who underwent arch replacement over a 17-year period at the University of Michigan, 30-day mortality was 5%, the incidence of stroke was 4.7%, and the 10-year survival rate was 65% [12]. Promising results were also reported by Thomas et al. [13] regarding 209 patients who underwent open arch replacement operations. Of the 65 patients who underwent total arch replacement, postoperative mortality rates were 5.5% for elective and 10% for emergency procedures, and stroke rates were 5.5% for elective and 10% for emergency procedures.

Various cerebral protection strategies were used in the abovementioned series: moderate hypothermia, deep hypothermia, antegrade cerebral perfusion, and retrograde cerebral perfusion. Endovascular and hybrid techniques were introduced in an attempt to avoid circulatory arrest and cardiopulmonary bypass in high-risk patients, thereby reducing mortality and stroke risk. In 1991, Ukrainian surgeon Nikolay Volodos and his colleagues [14] performed the first hybrid aortic arch operation, combining open surgery with debranching of the aortic arch and stent grafting. This patient was reportedly still alive with a stable endoprosthesis in February 2013 [15]. Since then, several techniques have been used to treat fusiform or saccular aneurysms of the arch: classic aortic arch debranching with endovascular exclusion of the arch, combinations of branch-artery stent placement and endovascular repair, stent graft fenestration, and branched stent grafting. These alternatives are not mutually exclusive, because surgical bypass of the head vessels at the neck can facilitate fenestrated and branched endografts.

**Branched Stent Grafts**

Custom-made branched stent grafts have been used for both fusiform and saccular arch aneurysm repair, but experience with these devices remains limited and investigational, and the different grafts and the techniques for using them are at various stages of development. Also, custom-manufacturing these devices necessarily delays treatment. In addition, there is only anecdotal evidence in the United States to support the use of these devices [16, 17]. As Chuter et al. [16] noted, these grafts allow endovascular bypass to the branches of the aorta through branches of the stent graft. These authors deployed a stent graft in the innominate artery to maintain flow, and a second stent graft in the aortic arch to exclude a saccular aneurysm on the inner curve. However, if the disease was at the orifice of the stented branch artery, the use of this technique resulted in endoleak. More extensive experience has been reported by Yokoi and colleagues [18], who examined results from 35 Japanese centers at which 383 patients were treated with a precurved fenestrated endograft. Among these patients, 141 were treated for lesions in zones 0 and 1. The other 242 patients were treated for zone 2 and 3 lesions. The endografts in this series were fabricated according to preoperative 3-dimensional computed tomographic images. Nineteen types of 3D curved stent skeletons and 8 types of graft fenestrations for arch vessels were used. Their endograft designs were based on data from 1000 clinical cases of arch endografting with a custom-made device. The tip of their
Preventza, O. et al.             Saccular Aneurysms of the Transverse Aortic Arch

63 State-of-the-Art Review

devices was short and soft in order to facilitate safe access in the ascending aorta.

Using branched stent grafts also necessitates manipulating the arch and arch vessels. This poses a risk to patients with atherosclerosis of these vessels; a University of Pennsylvania study showed that the combination of aortic arch atheroma and intraoperative instrumentation of the aorta is associated with stroke in patients undergoing thoracic endovascular aortic repair [17]. Yokoi et al [18], in their series, had a low rate of cerebrovascular accidents. They attributed this finding to the precurved shape of their endograft and the orientation of the fenestration toward the supra-aortic arch vessels, which reduced the amount of wire and catheter manipulation that was necessary in the arch. Long-term data are not yet available due to the early stage of this study, and durability will be the key for widespread use of this technology.

Double-Barrel, Chimney, and Snorkel Grafting Technique

Double-barrel, chimney, and snorkel grafting are essentially different terms for the same technique that uses commercially available stent grafts. This technique was described as a rescue procedure to be used when a head vessel (left common carotid or innominate artery) is inadvertently covered, but it has also been described in different sequence for other situations. Wire and sheath access is gained from the branch vessel into the ascending aorta, alongside the undeployed stent graft with which the arch will be covered [19]. Baldwin et al. [19] reported using this technique to treat 4 saccular aneurysms and 1 penetrating ulcer in 7 patients who each previously had a stroke. The authors raised concerns about mechanical interaction between the branch stent and the aortic stent, as well as the possibility that hemodynamic forces within the aortic arch could cause stent fracture or vessel injury. In a review of 18 reports by Moulakakis et al. [20], among 124 patients (26% with degenerative aneurysms) 136 chimney grafts were used (25 in the innominate artery, 50 in the left common carotid artery, and 51 in the left subclavian artery). The stroke rate was 4%, and early mortality was 4.8%. The main disadvantage of this technique was the potential for endoleak (which occurred in 18.5% of cases) due to large “gutters” along the main graft. In addition, it was evident that in cases in which the innominate and the left common carotid artery were stented, complication rates were significantly elevated (44% and 22%, respectively). For the chimney technique, there is no consensus regarding which type of branch stent (covered vs. bare, self-expanding vs. balloon-expandable) [19-21] best promotes the technical success and long-term durability of the repair. This technique also requires manipulating and instrumenting the arch vessels, so the risk of stroke could be especially high in patients with multiple saccular aneurysms, in which atherosclerosis can be substantial [9]. In addition, if it is necessary to land the endograft in zone 0, extra-anatomic bypass is required [22].

Supra-aortic Arch Debranching, Hybrid Repair

This repair can be achieved via median sternotomy with the use of a prefabricated, trifurcated, bifurcated, or inverted Y graft. Alternatively, the reconstruction can be performed via extra-anatomic bypasses. Through a median sternotomy, a partial occluding clamp is applied to the ascending aorta, and the proximal anastomosis is performed with the main trunk of the Y graft. The individual distal anastomoses are performed first to the left subclavian artery, then to the left common carotid artery, and finally to the innominate artery. If the left subclavian artery is not easily reached, a left carotid–to–subclavian artery bypass is performed. This bypass is followed by the endovascular exclusion of the arch via antegrade or retrograde delivery of the stent graft. Compared to the previously mentioned endovascular techniques, this technique has the advantage of rerouting blood flow before stent graft delivery, potentially reducing neurologic sequelae. In addition, the endovascular part of the procedure is relatively simple, and the surgical part does not necessarily require exposing the aneurysm.

The morbidity associated with surgical debranching depends on the surgical accessibility of the branch. We have used this technique in high-risk patients with multiple saccular aneurysms of the arch for whom we considered open repair to be contraindicated by their substantial comorbidity [23] (Figure 1). Contemporary series of hybrid arch procedures with zone 0 (ascending aorta) as the proximal landing zone in high-risk patients have reported mortality rates of 0 to 29.6% and stroke rates of 0 to 11% [22, 24-27].
Figure 1. Intraoperative angiograms showing aortic arch debranching of all head vessels. (A) Aorto-innominate bypass, aorto–left common carotid artery (LCCA) bypass, and aorto–left subclavian artery (LSCA) bypass are performed, and multiple saccular aneurysms of the arch are visible. (B) Debranching is complete, and all saccular aneurysms have been excluded with two endovascular stent-grafts. (From Preventza O, Aftab M, Coselli JS. Hybrid techniques for complex aortic arch surgery. Tex Heart Inst J. 2013;40:568-571. Reproduced with permission.)

Paraplegia has been reported also (0-7%) [22, 24-27] and is associated with more extensive coverage of the descending thoracic aorta. Careful review of the literature is required because hybrid repair of the aortic arch in different series does not refer only to Zone 0 but includes also zones 1, 2, and 3. It is well documented that zone 0 landings are more strongly associated with various risks, including the risk of stroke, than are landings in the other zones, so it is important to make appropriate comparisons among similar patient populations [22, 24-27]. In addition, landings in the native zone 0 pose a risk of retrograde ascending aortic dissection, as previously reported [25]; this is not the case when the ascending aorta has been replaced with a Dacron graft.

Discussion

Meaningful comparison among the abovementioned hybrid techniques is complicated by the heterogeneity of both the studies and the patients. The techniques were not specifically developed to treat saccular aneurysms of the arch, and outcomes were not reported specifically for patients with these aneurysms. Patients also differed with regard to their comorbidities and characteristics and the selection biases of their treating physicians. For patients whose comorbidities would make open repair prohibitively risky, our preferred first-line therapy has been aortic arch debranching via median sternotomy, which is performed off-pump, followed by endovascular stent grafting to exclude the transverse aortic arch. Many saccular aneurysms of the transverse aortic arch are thin-walled and prone to rupture, as well as subject to severe, superimposed atherosclerosis and thrombosis, placing patients at risk for stroke. The concept of rerouting the blood to the brachial cephalic vessels before stent graft deployment and endovascular manipulation holds the promise of reduced risk of rupture and stroke secondary to atheroma.

Although useful in concept, the technique remains an off-label use of the currently available devices. The branched stent techniques currently under development are still experimental, and the graft devices must be custom-made to suit individual patients and their pathologies. Because many patients with single or multiple saccular aneurysms of the transverse aortic arch present with a variety of disease processes, many of which necessitate urgent intervention, significant delay is not optimal. In such cases, the double-barrel
or chimney technique can be used in conjunction with extra-anatomic bypass, but concerns about the durability of the side-branch stents and the manipulation of wires and catheters in the arch have been already addressed. Consequently, the ultimate goal should be to develop effective techniques that use off-the-shelf, readily available devices.

In the absence of comparative randomized clinical trials, it is difficult to compare the abovementioned hybrid and total endovascular techniques. In addition, any comparison of the open technique with the hybrid or total endovascular technique is unfair because the patient populations treated with these techniques are fundamentally different, and because an individualized approach can offer the best results.

**Conclusion**

In patients who present with single or multiple saccular aneurysms of the arch and for whom open repair is not contraindicated, we believe that traditional surgical repair should remain the standard therapy. In high-risk patients, hybrid repair with aortic arch debranching via median sternotomy and antegrade or retrograde stent delivery for arch exclusion is our preferred approach.

**Acknowledgement**

Stephen N. Palmer, PhD, ELS, contributed to the editing of the manuscript.

**Conflict of Interest**

W. L. Gore & Associates and Cook Medical, Inc have provided travel expenses for Dr. Preventza in the past. Dr. Preventza serves as a consultant for Medtronic, Inc. Dr. Coselli was provided program support by and has given lectures for W. L. Gore & Associates, and he serves as principal investigator for clinical trials conducted by W.L. Gore & Associates, Medtronic, Inc., and Cook Medical. In addition, Dr. Coselli serves as a consultant to and receives royalties from Vascutek Ltd., a subsidiary of Terumo Corporation.

**Comment on this Article or Ask a Question**


Cite this article as: Preventza O, Coselli JS. Saccular Aneurysms of the Transverse Aortic Arch: Treatment Options Available in the Endovascular Era. AORTA 2015;3(2):61-66. DOI: http://dx.doi.org/10.12945/j.aorta.2015.14-046
Visceral Debranching for the Treatment of Thoracoabdominal Aortic Aneurysms

Scott M. Damrauer, MD, Ron M. Fairman, MD
Division of Vascular Surgery and Endovascular Therapy, Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania, USA

Based on a Presentation at the 2013 VEITH Symposium, November 19–23, 2013 (New York, NY, USA)

Abstract
Surgical repair of thoracoabdominal aortic aneurysms (TAAA) is associated with significant morbidity and mortality. Hybrid approaches that involve visceral debranching and aortic endografting allow for an alternative approach in certain high-risk patients. In most circumstances the visceral vessels can be bypassed in a retrograde manner from the iliac arteries via a midline laparotomy, and the aortic aneurysm subsequently excluded with standard aortic endografts. These procedures avoid the extensive two-cavity exposure, aortic cross-clamping, and mechanical circulatory support that comprise open TAAA repair, and offer the theoretical advantage of being less invasive. Despite this, outcomes have been mixed with reported perioperative mortality rates of 0% and 34% and permanent paraplegia rates of 0% to 13% in most major series. The reported outcomes, as well as the variation between centers, highlight the importance of patient selection in undertaking hybrid repair. In practice, the best outcomes are achieved in patients who have high-risk anatomy, rather than high-risk comorbidities.

Key Words:
Thoracoabdominal aortic aneurysm • Visceral debranching • Hybrid operation • Thoracic endovascular aortic repair (TEVAR)

Introduction
Surgical repair of thoracoabdominal aortic aneurysms (TAAA) is a formidable undertaking for both patient and surgeon. Clinical outcomes at high-volume centers are excellent, with cumulative 30-day mortality rates reported as less than 10% in selected series [1, 2]. Larger, more representative databases show that real-world experience does not duplicate these results. In a study using the National Inpatient Sample (NIS) from 1988 to 1998 the overall morbidity was shown to be greater than 50% and mortality was 23% [3]. Totally endovascular approaches are available at select institutions, and are reported to have better outcomes with low rates of mortality, morbidity, and spinal cord ischemia [4-6]; unfortunately, these are not generalizable due to restrictions on access to devices and need for custom fabrication.

Hybrid procedures offer an alternative approach to TAAA management. Relying on a combination of standard open techniques and off-the-shelf endovascular stent grafts, they are broadly applicable to a wide range of patient anatomy. First described by Quinones-Baldrich and colleagues at the University of California Los Angeles (UCLA), these approaches rely on debranching of the visceral aorta followed by standard endovascular aneurysm repair, covering the entire affected aortic segment [7]. Because hybrid approaches avoid the extensive two cavity exposure, aortic cross-clamping, and mechanical circulatory support that comprise open TAAA repair, they offer the theoretical advantage of being less invasive. Despite this, results following hybrid repair have been mixed, with outcomes varying widely depending on both patient and surgeon related factors. In reality,
hybrid repair is no less of an undertaking for either patient or surgeon, but rather a different undertaking that can offer specific advantages in distinct subsets of patients.

**Technical Details**

Hybrid TAAA repair is a two-staged procedure, consisting of open visceral debranching followed by aortic endografting. The first stage, visceral debranching, is most commonly achieved from a transabdominal approach via midline laparotomy. In the absence of prior laparotomy, this allows ready exposure of all of the visceral vessels as well as the iliac arteries. Retrograde bypasses are typically constructed from the common iliac arteries using prosthetic conduit and the target vessels are ligated proximal to the revascularization to prevent endoleaks after placement of the aortic stent graft. An iliac conduit is also fashioned to facilitate arterial access for the endovascular portion of the repair.

The second stage of the hybrid repair, consisting of aortic endografting to exclude the aneurysm, can be performed at the same operative setting or, as has become our practice, in a delayed fashion. By delaying the aortic endografting portion of the procedure, the patient is given time to recover and the physiological insult is distributed over time. The patients typically remain hospitalized between the first and second stages.

One technical advantage of the hybrid repair is the ability to tailor the visceral reconstruction to patient specific anatomy. For any individual patient, there may be multiple potential bypass configurations and there are a number of important principles to guide in selecting the most appropriate option: these are best illustrated through the example of a recent patient treated at our institution.

A 66 year-old female presented with a 7cm Type III TAAA (**Figure 1**). She had previously undergone an aortic arch replacement as well as a TEVAR (thoracic endovascular aneurysm repair) for a descending aortic aneurysm and the remainder of the aorta was aneurysmal. She had atrial fibrillation and chronic obstructive pulmonary disease and had previously suffered from a pulmonary embolus, acute respiratory distress syndrome, and recurrent pneumonias. She was not felt to be a candidate for traditional open repair and was accordingly offered a hybrid procedure.

The visceral debranching was performed via a midline laparotomy to allow a direct anterior approach to the renal and visceral vessels. The distal common iliac arteries were isolated bilaterally to serve as inflow for the bypass grafts. When selecting a site on the iliac artery to seat the proximal bypass anastomosis, care must be taken to insure that there is sufficient artery proximal to the bypass to allow the iliac limb of the endograft to obtain a distal seal. Although iliac artery based bypasses are by-and-large the most common configuration, the native infrarenal aorta can be used as a basis for the grafts, assuming it is free of aneurysmal disease. Alternatively, if there is extensive aortic or aorto-iliac aneurysmal or occlusive disease, the infrarenal aorta can be replaced with a tube graft sewn to the aortic bifurcation or with a bifurcated graft to the common iliac arteries, and the visceral bypasses based on the replaced segment. In either case, attention, again, must be paid to leave enough normal aorta or proximal graft to provide an appropriate seal zone for the planned endograft.
After isolating the bypass inflow, the target vessels were isolated. Celiac artery revascularization was accomplished via a bypass to the common hepatic artery and was done in a manner that allowed preservation of hepatic and gastric perfusion. From the anterior approach it is usually most straightforward to select the hepatic artery as the recipient site for the bypass as this can be isolated in the omental bursa, or lesser sac. The proximal celiac artery must also be dissected, but only enough to allow the vessel to be ligated after completion of the bypass. By revascularizing the hepatic artery but ligating the celiac trunk, the left gastric and splenic arteries can continued to be perfused by retrograde filling of the proximal hepatic artery. In this patient, the superior mesenteric artery (SMA) was isolated in the omental bursa as it emerged from behind the pancreas. Although the SMA can also be easily identified at the base of the transverse mesocolon, the former location has the advantage of being well proximal to the origin of the middle colic artery, and allows for the ligation of the SMA just proximal to the bypass. The left renal artery was isolated proximally as it branched from the aorta and the right renal artery was identified as it emerged from behind the vena cava; when preparing the renal arteries, care must be taken to insure that the bypass is proximal to any early renal branches.

Prosthetic bypass grafts are used for the revascularization, which can be accomplished with a variety of straight, bifurcated, and custom-branched graft configurations. Target vessels can be revascularized individually or in series with jump grafts. In this patient, bilateral bifurcated Dacron grafts were used to revascularize the right renal and hepatic arteries from the right common iliac artery, and the left renal and superior mesenteric arteries from the left common iliac artery. We have subsequently changed our practice to use a jump graft from the SMA to hepatic artery; this allows us to reserve one of the Dacron limbs for use as a conduit to facilitate subsequent introduction of the stent-graft. The grafts are tunneled retroperitoneally so that they are excluded from the peritoneum and separated from the bowel; the iliac conduit is left buried in the lower abdominal subcutaneous tissue for later exposure.

Aortic endografting for exclusion of the aneurysm can be done concomitantly or in a delayed fashion, and there are not significant data to unambiguously recommend one approach over another [8]. Proponents of simultaneous procedures argue that the staged approach leaves the patient susceptible to rupture in the intervening period, although there are little data, other than anecdotal experience, to support this approach [9]. Our practice is to perform the stent-graft procedure after the patient has recovered from the debranching, but on the same admission. The delayed approach offers the advantage that it allows the patient to recover from many of the physiological insults of the debranching procedure before exposing them to the risks associated with the placement of the stent grafts. This is especially important in terms of renal function, as it allows the kidneys to recover from the ischemia associated with the bypass before subjecting them to the nephrotoxic iodinated contrast necessary for the endovascular portion of the case.

The patient presented here had a relatively uneventful post-operative course and returned to the operating room on post-operative day 19 for endovascular stent-grafting. A combination of thoracic endografts and a bifurcated abdominal device were used to extend from the previous TEVAR into the proximal common iliac arteries (Figure 2). The choice of endovascular device should be based on surgeon experience and preference and patient anatomy; there is no systematic advantage of one device over another for this procedure. Because of the previous intervention and extent of planned coverage, a spinal drain and somatosensory evoked potential (SSEP) monitoring were used for spinal cord protection. The patient tolerated the procedure well and was discharged home on post-operative day 9 from the stent-graft.

Clinical Outcomes

The hybrid approach has many theoretic advantages (Table 1). Although certainly not a “minimally invasive” procedure, visceral disbranching can be accomplished via a standard laparotomy, without entering the chest cavity, and does not involve aortic cross-clamping or mechanical circulatory support. Because of this, hybrid repair is thought to have the theoretical advantage of being “less-invasive” than...
open TAAA repair and theoretically results in less physiological derangement. It was initially hoped that hybrid repair would result in less coagulopathy, ischemia–reperfusion injury, bacterial translocation, sepsis, end-organ damage, and renal failure, culminating in reduced length of stay and lower morbidity and mortality. In practice, the results of published series have been mixed (Table 2), leaving ambiguity as to the exact role for hybrid repairs [9-24].

In 2009 Quinones-Baldrich and colleagues from the University of California Los Angeles (UCLA) reported the follow-up for their first patient and the results of their overall experience in 20 cases [19]. At 10 years, the index patient for hybrid repair was alive and well without the need for further intervention and no aneurysm related morbidity. Among a mixed cohort of high-risk patients who underwent hybrid procedures for aortic arch pathology (three patients) and thoracoabdominal and juxtarenal aortic aneurysms (seventeen patients), they reported nine major complications in six patients (32%), one case of permanent paraplegia (out of 15 patients at risk, 6.6%), and no perioperative mortality (0%). With a mean of 16 months of follow-up they identified 3 endoleaks (30%, one type I, three type II), and no bypass thrombosis.

### Table 1. Theoretical advantages of visceral debranching and hybrid TAAA repair

<table>
<thead>
<tr>
<th>Technical advantage</th>
<th>Theoretic benefit to patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>No thoracotomy</td>
<td>Decreased post-operative pain, decreased pulmonary complications</td>
</tr>
<tr>
<td>No aortic cross-clamp</td>
<td>Less end-organ ischemia, minimized ischemia-reperfusion injury, decreased renal failure, decreased spinal ischemia</td>
</tr>
<tr>
<td>No need for cardiopulmonary support</td>
<td>Less hemodynamic instability, decreased coagulopathy</td>
</tr>
</tbody>
</table>

**Figure 2.** Three-dimensional reconstruction (A) and maximum intensity projection images (B) of follow-up CTA, demonstrating excluded aneurysm and patent ilio-mesenteric and ilio-renal bypasses.
or aneurysm enlargement. There were two reinterventions (10%, one type I and one type II endoleak). The overall survival was 76% at 2 years. Based on their durable outcomes, low morbidity and mortality, and little need for reintervention, the UCLA group concluded that hybrid repair offered significant advantages to traditional open repair, especially for high-risk patients.

Hughes and colleagues from Duke report similar outstanding outcomes [12]. Among 58 patients who underwent hybrid repair, there was a 9% rate of perioperative mortality and a 4% rate of permanent paraplegia. Interestingly, the paraplegia rate was nil among the final 25 patients in the series, all of whom had staged repairs. Those patients who underwent staged repairs also had shorter combined operative times, decreased intraoperative transfusions, and were more likely to be extubated in less than 24 hours than those who had single-stage procedures. With a median follow-up of 26 months, there was a 95% graft patency rate, and all thromboses were clinically silent. There was no intervention for required for any endoleaks.

The excellent early results achieved in these studies are complemented by recent publications attesting to the durability of the visceral artery bypass grafts and low rates of late aortic related death. In 46 patients with 164 grafts, Shaherdan and colleagues report an 86% 5-year primary patency rate [25]. Patency at 5-years for individual bypasses ranged from 69% for the right renal artery to 100% for the hepatic artery, with the left renal and SMA between 87% and 88%. Among the 32 patients surviving past the perioperative period, there were 6 deaths due to procedure related respiratory failure, and only 2 deaths due to aortic or branch vessel complications.

The experience reported by Patel and colleagues from Massachusetts General Hospital (MGH) stands in stark contrast. A recognized high volume center for aortic surgery, MGH has traditionally reported out-

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Patients</th>
<th>30-day Mortality</th>
<th>Permanent paraplegia</th>
<th>Endoleaks</th>
<th>Graft patency</th>
<th>Overall survival</th>
<th>Mean Follow-up (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhou (24)</td>
<td>2006</td>
<td>31</td>
<td>3.2%</td>
<td>0%</td>
<td>6%</td>
<td>95%</td>
<td>90%*</td>
<td>16</td>
</tr>
<tr>
<td>Black (10)</td>
<td>2006</td>
<td>22</td>
<td>23%</td>
<td>0%</td>
<td>42%</td>
<td>98%</td>
<td>NA</td>
<td>9.5</td>
</tr>
<tr>
<td>Lee (15)</td>
<td>2007</td>
<td>17</td>
<td>24%</td>
<td>0%</td>
<td>12%</td>
<td>96%</td>
<td>76%*</td>
<td>8</td>
</tr>
<tr>
<td>Van de Mortel (23)</td>
<td>2008</td>
<td>16</td>
<td>31%</td>
<td>0%</td>
<td>13%</td>
<td>95%</td>
<td>69%*</td>
<td>13</td>
</tr>
<tr>
<td>Quinones-Baldrich (19)</td>
<td>2009</td>
<td>20</td>
<td>0%</td>
<td>6.6%</td>
<td>30%</td>
<td>100%</td>
<td>76%*</td>
<td>17</td>
</tr>
<tr>
<td>Donas (11)</td>
<td>2009</td>
<td>58</td>
<td>8.6%</td>
<td>3.4%</td>
<td>17%</td>
<td>97%</td>
<td>74%*</td>
<td>22</td>
</tr>
<tr>
<td>Drinkwater (9)</td>
<td>2009</td>
<td>107</td>
<td>15%</td>
<td>8.4%</td>
<td>33%</td>
<td>87%*</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Patel (18)</td>
<td>2009</td>
<td>23</td>
<td>17%</td>
<td>4%</td>
<td>23%</td>
<td>90%</td>
<td>68%*</td>
<td>6</td>
</tr>
<tr>
<td>Kabbani (13)</td>
<td>2010</td>
<td>36</td>
<td>8.3%</td>
<td>0%</td>
<td>39%</td>
<td>93%</td>
<td>80%*</td>
<td>6</td>
</tr>
<tr>
<td>Patel (17)</td>
<td>2010</td>
<td>29</td>
<td>3.4%</td>
<td>3.4%</td>
<td>34%</td>
<td>95%</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Kuratani (14)</td>
<td>2010</td>
<td>86</td>
<td>2.3%</td>
<td>0%</td>
<td>17%</td>
<td>99%</td>
<td>86%*</td>
<td>88</td>
</tr>
<tr>
<td>Smith (21)</td>
<td>2011</td>
<td>24</td>
<td>12.5%</td>
<td>8.3%</td>
<td>12%</td>
<td>99%</td>
<td>NA</td>
<td>12</td>
</tr>
<tr>
<td>Hughes (12)</td>
<td>2012</td>
<td>58</td>
<td>9%</td>
<td>4%</td>
<td>NA</td>
<td>95%</td>
<td>62%*</td>
<td>26</td>
</tr>
<tr>
<td>Tshomba (22)</td>
<td>2012</td>
<td>52</td>
<td>14%</td>
<td>1.9%</td>
<td>7.7%</td>
<td>93%</td>
<td>77%*</td>
<td>24**</td>
</tr>
<tr>
<td>Rossett (20)</td>
<td>2014</td>
<td>76</td>
<td>34%</td>
<td>11%</td>
<td>3%</td>
<td>99%</td>
<td>NA</td>
<td>30</td>
</tr>
<tr>
<td>Massoni (16)</td>
<td>2014</td>
<td>45</td>
<td>24%</td>
<td>13%</td>
<td>NA</td>
<td>79%</td>
<td>45%*</td>
<td>26</td>
</tr>
</tbody>
</table>

* 30 day ** median at end of follow-up period 1-year Kaplan-Meier survival 5-year Kaplan-Meier survival Freedom from aortic-related deaths at end of follow-up 6-year Kaplan-Meier survival
standing results with open TAAA repair [26]. When Patel and colleagues examined the outcomes of hybrid procedures in 23 high-risk individuals who were not candidates for open TAAA (type I-III) repair, they reported a 4.3% rate of permanent paraplegia and a 26% in-hospital mortality rate, all of which were higher than what they observed in their contemporaneous open experience (3.9% permanent paraplegia and 10% mortality) [18]. With a mean follow-up period of 166 days, there were 7 graft thromboses out of 70 grafts (10%) and five endoleaks (22%, three type I and two type II), three of which required reintervention. The poor results obtained in the patients who underwent hybrid repair lead the MGH group to conclude that the morbidity and mortality profile should limit the use of the hybrid repair, and that many patients unfit for open repair were simply unfit for surgical intervention of any kind.

This sobering appraisal is further supported by a study from the North American Complex Abdominal Aortic Debranching Registry that demonstrated a 14% SCI rate among 159 patients treated at a total of 13 institutions [27]. This rate significantly exceed that which has been reported for open repair in most specialized aortic centers [1, 2], and suggests that despite avoiding many of the issues related to spinal cord perfusion in traditional open repairs, hybrid approaches are not able to improve upon those outcomes.

The different outcomes obtained in these studies likely reflect differences in the underlying cohorts between the centers and highlight the importance of patient selection in hybrid repair. In examining the specifics of the patient cohorts, the MGH cohort appears to be higher risk with regard to patient comorbidities and physiology, suggesting that although hybrid repair may offer some advantage in morbidity and mortality, it is certainly not a low-risk endeavor. Despite the outstanding outcomes of the UCLA and Duke groups, the MGH experience demonstrates that there are, in fact, limits to how far the hybrid technique can be pushed, and that in extremely high-risk patient populations, a non-operative approach may be advisable.

The largest single series in the literature is a multi-intuitive European study reported by Drinkwater and colleagues [9]. Reporting on 107 consecutive hybrid repairs, they had a 93% technical success rate, an 8% rate of permanent paraplegia, and a 15% 30-day mortality rate. There was 86% graft patency at 30-days and an initial endoleak rate of 33%. Although these results are quite similar to those reported by MGH, Drinkwater et al. offer an alternative interpretation of their experience. They highlight that the even though their cohort is high risk, based on the patients’ comorbidities and the fact that many were previously denied open repair, their outcomes compare favorably with those reported in the non-selected, real-world studies of open TAAA repairs, where morbidity ranges from 19% to 23% [3, 28]. This leads them to conclude that despite the fact that hybrid TAAA carries a significant associated morbidity and mortality, it offers a viable alternative to traditional open repair in high risk patients.

A recent meta-analysis of 19 studies encompassing 507 patients demonstrated similar results [29]. The authors report a pooled rate of 30-day mortality at 12%, a pooled rate of permanent paraplegia of 4.5%, and a pooled rate of renal insufficiency of 8.8%. During a mean follow-up period of 34 months, the graft patency was 96% and there was a 23% rate of endoleak, with 27% of those patients requiring reintervention. Because a pooled analysis was performed, these results are likely heavily biased by those of Drinkwater and colleagues, which comprised 20% of the patients [9], but, nonetheless, provide the best estimates of the morbidity and mortality associated with hybrid TAAA repair. Based on these data, hybrid repairs carry a significant, but not necessarily prohibitive, associated morbidity and mortality, especially when considering the overall risk profile of the patients being offered this type of intervention.

Current role in TAAA Management

Based on the available literature and our clinical experience, careful patient selection is key. Although hybrid repairs may allow high-risk patients to have outcomes equal to those published from administrative surgical databases, they do not approach those reported at select centers of excellence with significant expertise in open TAAA repair, even when the hybrid repairs are performed at the same high volume centers. Although they may offer a viable alternative...
for patients at slightly higher than average operative risk, or for those who have isolated high risk comorbidities (i.e. chronic lung disease), patients who are deemed unfit for open TAAA repair are likely unfit for hybrid repair as well.

Not all “high-risk” patients, however, are the same. In relatively healthy individuals who are considered high risk due to anatomic features, the hybrid approach offers a reasonable treatment option. In fact, hybrid repair may have the most to offer as a re-operative approach to recurrent TAAA. By allowing the surgeon to avoid densely scarred operative fields and obliterated tissue planes, the hybrid approach facilitates repair for individuals who would otherwise not have a viable open approach to their pathology. This is best demonstrated by both the Duke and UCLA experiences, in which they reported outstanding outcomes in a cohort for which the hybrid repair constituted a repeat aortic operation (55% to 60% of the patients) [19, 30]. This has been reinforced by our experience, in which the best outcomes are achieved in patients who have specific anatomic reasons that make them unsuitable for open TAAA repair.

In the end, it is clear that despite many theoretical advantages, and the impression that it is less invasive than standard open TAAA repair, hybrid repair is still a significant undertaking with real risks of associated morbidity and mortality. Although there is a clear role for hybrid repair in patients who are good physiological candidates for operative intervention, but have specific anatomical challenges that preclude traditional open repair, hybrid repair has little to offer for the true physiologically high-risk patient. It should be remembered that hybrid repair is no less of an operation than traditional open repair, it is just a different one.

**Conflict of Interest**

The authors have no conflict of interest relevant to this publication.

**References**


Cite this article as: Damrauer SM, Fairman RM. Visceral Debranching for the Treatment of Thoracoabdominal Aortic Aneurysms. AORTA 2015;3(2):67–74. DOI: http://dx.doi.org/10.12945/j.aorta.2015.14-066
Arterial Stiffness Alterations and Inflammatory Response Following Endovascular Aortic Repair

Konstantinos G. Moulakakis, MD, PhD, MSc, FEBVS*, Spyridon N. Mylonas, MD, MSc, John Kakisis, MD, PhD, Nikolaos E. Kadoglou, MD, PhD, Ioannis Papadakis, MD, George S. Sfyroeras, MD, PhD, MSc, FEBVS, Constantine C.N. Antonopoulos, MD, PhD, MSc, George Mantas, MD, MSc, Ignatios Ikonomidis, MD, Christos D. Liapis, MD, Ph.D, FACS, FRCS

*Department of Vascular Surgery, Medical School, University of Athens, Greece
2Department of Cardiology, Attikon University Hospital, Athens, Greece

Based on a Presentation at the 2013 VEITH Symposium, November 19–23, 2013 (New York, NY, USA)

Abstract

Endovascular abdominal aortic aneurysm repair (EVAR) and thoracic aortic aneurysm repair (TEVAR) have been widely incorporated into clinical practice. However, changes in arterial stiffness and post-implantation syndrome after aortic endografting remain important issues under investigation. The aneurysm sac wall motion after successful EVAR and TEVAR reflects complex interactions between all the components of the excluded aneurysm, including true compliance of the aneurysm wall itself, intra-aneurysm sac pressure, remodeling of the thrombus, and mechanical characteristics of the endograft. Experimental and clinical studies have shown that aortic endografting results in increased arterial stiffness in animal models. It can be assumed that the alterations of aortic mechanical properties can have a direct impact on heart output. The long-term impact of these mechanical changes on cardiovascular outcomes and the potential effects of different endografts on hemodynamics are important issues under investigation.

The main features of PIS include fever, leukocytosis, elevated C-reactive protein levels, and coagulation disturbances. Endograft design appears to influence this inflammatory response following aortic endografting; woven polyester endografts have been shown to be associated with greater inflammatory response compared to polytetrafluoroethylene (PTFE) stent grafts. The purpose of this paper is to review the literature to elucidate arterial stiffness alterations and inflammatory response after EVAR and TEVAR and the impact of endograft design on aortic stiffness and the post-inflammatory response.

Key Words:
Stiffness • Mechanical properties • Aorta • Post-implantation syndrome • Pulse wave velocity (PWV) • EVAR • TEVAR

Introduction

Evolution in the endovascular area has influenced the management of aortic pathologies. Since Parodi and coworkers [1] performed the first endovascular abdominal aortic aneurysm repair (EVAR) in early
1990, substantial progress has been made in treating patients with abdominal aortic aneurysms (AAAs). Endovascular aortic repair of AAA is widely accepted as a safe, effective and less invasive treatment as an alternative to open AAA surgical repair. Thoracic endovascular aortic repair (TEVAR) for descending thoracic aortic aneurysms was first reported by Dake in 1994 [2]. The benefits of TEVAR regarding operative morbidity and mortality, as documented in numerous trials and registries, have led to widespread acceptance of this less invasive modality for the management of thoracic aortic aneurysms. Although EVAR and TEVAR have been widely incorporated into clinical practice, changes in arterial stiffness after aortic endografting and post-implantation syndrome remain important issues under investigation. The effect of different endografts on aortic stiffness and compliance has not been evaluated. The purpose of this paper is to review the literature to elucidate these issues and also to investigate the impact of endograft material on arterial stiffness and inflammatory response after aortic endografting.

**Arterial Stiffness after EVAR and TEVAR and the Impact of Endograft Type**

Although endovascular techniques for the repair of aortic pathologies have emerged as an effective alternative treatment modality to conventional open repair, limited data exist concerning the biomechanical changes induced by endograft implantation. Experimental studies have shown that aortic endografting results in increased arterial stiffness in animal models [4]. Also, it can be assumed that the alterations of aortic mechanical properties can have a direct impact on heart output.

Mechanical parameters that have been used to analyze and describe the mechanical properties are the elastic modulus and the pulse wave velocity (PWV). The elastic modulus is the most common mechanical parameter used to describe the behavior of elastic material and its behavior (deform or break) when subjected to a force or stress. Therefore, aortic elastic modulus corresponds to the range of stresses occurring during the change of blood pressure. The initiation, growth, and eventual rupture of an aneurysm are prompted by changes in elasticity of the aortic wall. Knowledge of the elasticity of the aorta is also important for the design of aortic endografts because their stability, once inserted, depends to a large degree on the elastic behavior of the segment of the aorta to which they are attached [4, 5]. The pulse wave velocity (PWV) is accepted as the most simple, robust, and reproducible method to determine the regional arterial stiffness. There is a linear correlation between the speed of travel of pulse along an arterial segment and arterial stiffness. To calculate PWV, the distance between the two sites at which the pulse wave is being recorded is divided by the time of travel of the wave from the first to the second site [4, 5].

Contrary to open AAA surgical repair, the aneurysm sac remains intact after aortic endografting, and intrasac pressure may often persist following successful endovascular exclusion [6]. In addition, AAA wall motion after successful EVAR reflects complex interactions between all the components of the excluded aneurysm which evolve over time, including true compliance of the aneurysm wall itself, intra-aneurysm sac pressure with possible different effects for peak, mean, and pulse pressures, remodeling of the thrombus, stiffness characteristics of the graft, and systemic pressure [7].

Several studies have shown that vascular compliance in AAA patients is increased by EVAR at the level of the aneurysmal sac. Elastic modulus and aortic stiffness as indices of wall compliance following EVAR and the influence of different endografts have been determined using dynamic magnetic resonance angiography (MRA). In the study by Van Herwaarden et al. [8], EVAR resulted in increased aneurysm sac aortic stiffness and elastic modulus. Elastic modulus and aortic stiffness measurements at the aneurysm neck were 94% and 60% higher in PTFE endografts (Excluder, Gore Medical, Flagstaff, Arizona, USA) compared to those with a woven Dacron graft (Talent, Medtronic, Minneapolis, Minnesota, USA). The authors concluded that the presence of an endoleak did not seem to have an effect on wall compliance following EVAR. However, the design of the stent-graft did influence compliance at the level of the neck the level at which proximal sealing of the endograft in the aorta occurs. A similar study by Long A et al. [7] analyzing AAA wall motion using tissue Doppler imaging (TDI) showed a significant decrease in AAA compliance...
after successful EVAR, which remained stable during later follow-up.

Pulse wave velocity (PWV) optimizes the assessment of vascular elasticity, quantifies artery wall parameters, and thus is considered an ideal index for comprehensive assessment of patients with cardiovascular diseases [9]. In a recently reported prospective study from our Department, we assessed changes in carotid-femoral PWV (c-fPWV) in patients undergoing EVAR [8]. Patients with AAA appeared to have significantly elevated c-fPWV levels compared to age- and sex-matched controls. The composition of the arterial extracellular matrix plus its spatial organization may predominantly explain the increased arterial stiffness in AAA patients. In addition, we found an association between stent-graft implantation and c-fPWV increase. An important regulator of arterial compliance following endografting is the engineering characteristics of stent grafts. In a subsequent prospective study we evaluated the effects of different types of endografts on PWV in patients undergoing EVAR [9]. One hundred eighteen consecutive men with AAA undergoing elective EVAR were enrolled in the study. Our study revealed that the endograft type was an independent predictor of c-fPWV change in the AAA group. The latter effect was independently associated with the endograft type. In particular, a greater increase of c-fPWVC was recorded after implantation of a woven endograft when compared to ePTFE endograft. These results are, however, inconsistent to the study by Herwaarden et al. [8]. Thus, the need for further investigation of the impact of the endograft design on the arterial stiffness is underlined.

Preliminary data of an ongoing trial in our Department suggest that stent-graft implantation in the thoracic aorta leads to PWV increase. The impact of the endograft design on these hemodynamic changes is under investigation.

Clinical Implications of Altered Arterial Stiffness after EVAR and TEVAR

The influence that different aortic repair modalities exert on central hemodynamics depends widely on the site of intervention. It can be assumed that the hemodynamic impact exerted by a vascular prosthesis in the descending aorta may be more severe than implanting the endograft in the abdominal aorta. Ioannou et al., in an experimental study, showed that the aortic arch contributes about 50% of total arterial compliance and as a consequence endograft implantation in the ascending aorta results in significant decrease in aortic compliance, which has been shown to cause systolic hypertension through augmentation of both the running and the reflected waves [12-14]. The authors concluded that development of a more compliant prosthesis, which matches the host artery compliance, may be expected to reduce the hemodynamic changes induced after their implantation. Tzilalis et al. [15] in a clinical study concerning 11 young patients treated with TEVAR for thoracic aortic transection noticed that 9 patients had postoperative arterial hypertension after TEVAR, and four had persistent hypertension during the follow-up period. The aortic endografts produced a discontinuation of the pulsatile waves with a subsequent increase of aortic PWV. The authors concluded that increased PWV is an important risk factor for future cardiovascular events and should be evaluated in all patients after TEVAR.

A recent study by Takeda Y. et al. [16] investigating the mechanical changes in 40 patients undergoing EVAR found that endografting raised aortic vascular stiffness, induced left ventricular (LV) hypertrophy, and impaired LV diastolic function. The heart adapts to higher systolic loads via both hypertrophy and ventricular systolic stiffening (increased end-systolic pressure-volume relationship), which can severely affect cardiovascular reserve function. The authors concluded that low LV distensibility at baseline may be related to the impairment of exercise tolerance after EVAR; thus it is necessary to evaluate LV diastolic function and aortic stiffness before and immediately after EVAR in order to improve the cardiovascular outcome and longer term overall survival after EVAR. The long-term impact of these mechanical changes on cardiovascular outcomes requires further investigation. Notably, a nonsignificant tendency toward cardiovascular deaths was apparent in the EVAR trial in the endovascular group during the 24-month interval [17, 18]. Although cardiovascular mortality was primarily due to the poor general health status of those patients or the required secondary interventions, a harmful effect of even slight alterations in aortic stiff-
ness induced by endografts should be considered. Whether this subtle hemodynamic impact represents an increased risk factor for patients with already impaired cardiac compensatory mechanisms needs to be investigated.

Post-Implantation Syndrome and Type of Endograft

Post-implantation syndrome (PIS) is a systemic inflammatory response frequently observed after endovascular treatment of abdominal (EVAR) and thoracic aortic aneurysms (TEVAR). The main features of PIS include fever, leukocytosis, elevated C-reactive protein and coagulation disturbances. This systemic inflammatory reaction is also associated with increased serum levels of cytokines, such as interleukin IL-6, IL-8, IL-1 and tumor necrosis factor-alpha (TNF-a). Mechanisms that have been proposed to explain this systemic inflammatory reaction include injury to the vascular endothelium and manipulation of the introducer catheters and sheaths inside the aneurysmal thrombus during the endovascular procedure, resulting in white cell activation and release of various cytokines [19]. Recently, the role of procalcitonin (PCT) has also been investigated [20].

The intramural thrombus, which remains in situ after EVAR, has previously been reported to be a source of proteases and speculated to be involved in development of late complications after EVAR. However none of these hypotheses have been confirmed. In a recently published study from our Department, we found that the volume of new-onset thrombus is associated with the development of PIS after EVAR, whereas chronic mural thrombus appears to be an inert material. In addition, inferior mesenteric artery (IMA) patency and contrast medium volume were irrelevant to the inflammatory response after EVAR [21].

Furthermore, endograft type appears to influence the inflammatory response following EVAR. Results of a recently reported study from our institution, based on 88 patients followed clinically and by cytokines perioperatively, support the hypothesis that implantation of stent grafts based on woven polyester are associated with a stronger inflammatory response compared to PTFE stent grafts. The inflammatory response was transient during the early postoperative phase and was not associated with adverse clinical events [22]. Voûte et al. [23] confirmed the same hypothesis, reporting that PIS occurred almost exclusively in the first 3 days after woven polyester endograft implantation and the first 2 days after PTFE endograft implantation.

An ongoing prospective trial in our department, evaluating the inflammatory response and renal function after elective thoracic endovascular aortic repair, suggests that endograft implantation in patients with TAAs may stimulate the inflammatory response during the early postoperative period. However, renal function does not seem to be deteriorated and influenced by the inflammatory response [24].

Clinical Implications of PIS after EVAR and TEVAR

The clinical manifestation of PIS includes fever and lumbar back pain. This biological response following EVAR is not always spontaneously attenuated and could lead to the development of SIRS even several days after the operation [19]. This issue raises concerns of postoperative morbidity, especially in patients at high risk, including the elderly with several comorbidities. Although previous studies have reported that PIS may result in severe complications, such as pulmonary dysfunction, cardiovascular events, and renal insufficiency, leading to prolonged hospitalization, according to our experience in 88 patients, PIS was not associated with perioperative adverse clinical events. Although transient pyrexia and patient discomfort may be present, PIS usually follows a benign course [22]. However, close surveillance of patients developing an excessive inflammatory response postoperatively or patients with severe comorbidities is suggested. In addition, a further theoretical concern could be that the post-implantation syndrome may be associated with late complications such as endoleaks, stent graft migration and aneurysm rupture. However, this hypothesis remains to be validated in future studies.

Conclusions

Cardiovascular mortality remains the main cause of death among AAA patients treated with endovascular repair. Increased arterial stiffness observed after
EVAR and TEVAR represents a concern. The negative impact of endografting on aortic compliance would be expected to increase left ventricular after-load and myocardial energy requirements and may be related to adverse long-term outcomes. The long-term impact of these mechanical changes on cardiovascular outcomes and the potential differential effects of different endografts on central hemodynamics require further investigation. Post implantation syndrome usually is transient during the early postoperative phase and follows a benign course. The clinical impact of the PIS has been diminished during recent years. We suggest a close surveillance of patients—especially those at high risk, including the elderly with several comorbidities—who may develop an excessive inflammation response postoperatively.

Conflict of Interest

The authors have no conflict of interest relevant to this publication.

References

2. Dake MD, Miller DC, Semba CP, Mitchell, Moulakakis, K.G. et al. Arterial Stiffness and Inflammatory Response after EVAR/TEVAR

Cite this article as: Moulakakis KG, Mylonas SN, Kakisis J, Kadoglou N, PE, Papadakis I, Sfyroeras GS, Antonopoulos C. CN, Mantas G, Ikonomidis I, Liapis CD. Arterial Stiffness Alterations and Inflammatory Response following Endovascular Aortic Repair. AORTA 2015;3(2):75-80. DOI: http://dx.doi.org/10.12945/j.aorta.2015.14-071

EDITOR’S COMMENTS

Tulio Navarro, MD
Department of Surgery
Faculty of Medicine, Federal University of Minas Gerais
Belo Horizonte - Minas Gerais - Brazil

This is an outstanding “translational” review, bridging basic science and biomechanical concepts into the clinical scenario—demonstrating that the implantation of an endograft subtly changes arterial hemodynamics. These changes can be measured by pulse wave velocity. These adverse changes lead to increased afterload on the heart. In patients with impaired cardiac reserve, these changes may be a risk factor for cardiovascular adverse events and even mortality. The authors present suggestive data to this effect.

The authors also pinpoint the inflammatory Post Implantation Syndrome, more frequently seen with Dacron grafts. Although in vulnerable patients this Post Implantation Syndrome can lead to Systemic Inflammatory Response Syndrome, the majority of patients manifest a short-lived, benign course.
Homograft Aortic Root Replacement with Saphenous Vein Graft Hemi-Cabrol for Prosthetic Aortic Valve Endocarditis

Ioannis Dimarakis, MD, PhD, MRCS*, Wilfred J. Wooldridge, FRCA, Isaac Kadir, FRCS (C-Th)
Department of Cardiothoracic Surgery, Wythenshawe Hospital, Manchester, UK

Abstract
A 44-year-old female presented with prosthetic valve endocarditis with periannular abscess involving the left coronary ostium. We describe cryopreserved aortic homograft root replacement with hemi-Cabrol reimplantation of the left coronary ostium using the long saphenous vein.

Key Words
Prosthetic valve endocarditis • Aortic root abscess • Re-operative surgery • Homograft • Cabrol

Introduction
Reoperation for prosthetic aortic valve endocarditis remains associated with high perioperative mortality [1]. Varying degrees of tissue destruction and anatomical distortion are typical and therefore must be considered during preoperative surgical planning. We report a case of prosthetic aortic valve endocarditis with extensive annular abscess formation that did necessitate modification of our initial strategy.

Case Presentation
A 44-year-old female presented to her local district general hospital with clinical symptoms and signs of sepsis including malaise, rigors, pyrexia, and raised inflammatory markers. In the fortnight preceding this admission she had also been briefly admitted on two occasions with generalized malaise, low-grade pyrexia, and a documented neurological event that completely resolved. On both occasions, investigations were inconclusive and the treating physicians discharged the patient.

She had undergone aortic valvotomy at the age of 12 as a result of congenital bicuspid aortic valve, going on to have a mechanical aortic valve replacement at the age of 34 for severe aortic stenosis.

Medical history included severe asthma for which on three occasions she had required admission to intensive care for intubation and ventilation. She was also known to have a solitary kidney with reduced glomerular filtration rate. She was immobilized in a wheel chair after developing bilateral steroid-related calcaneal avascular necrosis.

Investigations confirmed the diagnosis of aortic prosthetic valve endocarditis and, having been declined surgery by her local cardiac surgical department, she was referred to our center for further management. Blood cultures from the referring hospital as well as our unit were positive for *Staphylococcus epidermidis*, known to cause biofilms on prosthetic material within the bloodstream. Sensitivity-guided antibiotic treatment was commenced with intravenous vancomycin, rifampicin, and ceftazidime. Transesophageal echocardiography showed a circumferential aortic root abscess with large
prosthetic valve vegetation. Computed tomography demonstrated solitary hepatic and splenic lesions compatible with established infarcts.

Following multidisciplinary discussion (microbiology, cardiology, and cardiac surgery teams) and discussion with the patient, urgent surgery as a second redo procedure was decided upon, as she remained unwell and in worsening heart failure. In view of the patient’s young age and clinical findings, a cryopreserved aortic homograft was ordered from the national tissue bank with size matching based on knowledge of the in situ prosthesis dimensions and preoperative echocardiographic annulus measurements.

Standard anaesthesia technique was used with single lumen endotracheal intubation and routine hemodynamic/monitoring lines. Intraoperative transesophageal echocardiogram confirmed the presence of a large vegetation prolapsing into the left ventricular outflow tract and evidence of a posterior paravalvular leak into a large root abscess cavity (Figure 1 and Figure 2). Good left ventricular function was documented.

Following an uneventful redo median sternotomy, cardiopulmonary bypass was started between a right axillary arterial and a percutaneously inserted right femoral venous cannula. The pericardial space was dissected to allow insertion of right superior pulmonary vein and retrograde cardioplegia cannulae. A large root abscess was found centered over the commissure between the left and noncoronary sinuses extending inferiorly into the roof of the mitral valve.

The in-situ mechanical prosthesis was excised and all infected and/or necrotic tissue was radically resected and sent for microbiology culture. Due to the anatomical extent of the periannular abscess following debridement, an aortic homograft root replacement was carried out with interrupted polypropylene non-pledgeted sutures. The left coronary button tissue was friable and a hemi-Cabrol anastomosis with a segment of long saphenous vein was carried out (Figure 3). The right coronary button was anastomosed in a routine fashion. As the ascending aorta was

**Figure 1.** Modified transverse aortic valve view on intraoperative 2D transesophageal echocardiography. The two asterisks (*) depict aortic root abscess cavities. The dashed arrow demonstrates the in situ bileaflet mechanical aortic prosthesis. The solid arrow shows the ostium of the left coronary artery. LA, left atrium; RA, right atrium.
aneurysmal. The aorta was excised up to the innominate artery and aortic continuity was achieved with a Hemashield graft (Boston Scientific Corporation, Natick, MA). The anastomosis to the distal ascending aortic stump was carried out under a brief period of lower body circulatory arrest and antegrade selective cerebral perfusion. The patient was separated from cardiopulmonary bypass with no difficulties. She developed respiratory failure postoperatively and needed tracheostomy but recovered gradually. She was discharged following completion of eight weeks of intravenous antibiotics as advised by our clinical infection specialists.

**Discussion**

Data from the International Collaboration on Endocarditis—Prospective Cohort Study demonstrated that prosthetic valve endocarditis accounted for over 20% of all enrolled cases, with persistent bacteremia, heart failure, intracardiac abscess, and stroke being the strongest predictors of mortality [2]. It further highlighted that in comparison to native valve endocarditis, the incidence of intracardiac abscesses was significantly greater in prosthetic valve endocarditis.

Recommendations for indications and timing of

---

**Figure 2.** Color flow Doppler long-axis aortic valve view on intraoperative 2D transesophageal echocardiography. The solid arrow shows the paravalvular communication with the aortic root abscess cavities (*). The dashed arrow demonstrates the in situ bileaflet mechanical aortic prosthesis. AMVL, anterior mitral valve leaflet; AscAo, ascending aorta.

**Figure 3.** Three-dimensional computed tomographic reconstruction: The arrow shows the saphenous vein hemi-Cabrol graft anastomosed to the anterior surface of the homograft.
we opt for cryopreserved aortic homograft root replacement if available. We acknowledge the fact of structural deterioration especially in younger patients [8] and we do convey this to patients during the informed consent process.

It is worth mentioning that the patient described exhibited phenotypic features of Turner syndrome, including short stature, webbed neck, low posterior hairline, broad chest, congenital aortic stenosis, and solitary kidney. Unfortunately she declined to undergo cytogenetic evaluation.

In conclusion, aortic prosthetic valve endocarditis remains a daunting surgical entity that requires aggressive patient-tailored management. As the complexity of surgical repair may demand use of aortic homograft root reconstruction with or without coronary anatomy restoration, knowledge of operative alternatives is essential to achieve a satisfactory outcome.

Conflict of Interest

The authors have no conflict of interest relevant to this publication.

References


Cite this article as: Dimarakis I, WJ Wilfred, Kadir I. Homograft Aortic Root Replacement with Saphenous Vein Graft Hemi-Cabrol for Prosthetic Aortic Valve Endocarditis. AORTA 2015;3(2):81-85. DOI: http://dx.doi.org/10.12945/j.aorta.2015.14-047
EDITOR’S QUESTIONS

1. How will you follow the saphenous vein graft?
   Our imaging follow up includes early postoperative and subsequently annual high-resolution cardiac computed tomography or magnetic resonance aortography looking specifically at the vein graft. In addition, annual transthoracic echocardiographic surveillance is planned to assess and monitor homograft function as well as biventricular function, a surrogate marker of vein graft disease. We will do this for annually for 5 years and then carry on indefinitely at increasing intervals or as symptoms dictate. In addition, secondary prevention of vein graft disease in the form of high dose statins, ACE inhibitor, aspirin and lifestyle modification has been advised.

2. Did you consider routing the saphenous vein graft posteriorly, to the right side of the graft?
   This is exactly what we have done.
An L-Shaped Incision for an Extensive Thoracic Aortic Aneurysm and Coronary Artery Bypass Using the Left Internal Thoracic Artery

Tomonobu Abe, MD*, Hiroto Suenaga, MD, Hideki Oshima, MD, Yoshimori Araki, MD, Masato Mutsuga, MD, Kazuro Fujimoto, MD, Akihiko Usui, MD

Department of Cardiac Surgery, Nagoya University Graduate School of Medicine, Nagoya, Japan

Abstract
An L-shaped incision combining an upper half mid-sternotomy and a left antero-lateral thoracotomy at the fourth intercostal space has been proposed by several authors for extensive aneurysms involving the aortic arch and the proximal thoracic descending aorta. This approach usually requires the division of the left internal thoracic artery at its mid position, thus making it unusable for coronary artery bypass. We herein report a modified surgical approach for simultaneous extensive arch and proximal thoracic descending aorta replacement and coronary artery bypass using the left internal thoracic artery combining a left antero-lateral thoracotomy at the sixth intercostal space and upper mid-sternotomy. The visualization of the whole diseased aorta down to the level below the hilum of the left lung was good, and the integrity of the left internal thoracic artery graft was preserved by early heparin administration before sternotomy.

Key words
Thoracic Aortic Aneurysm • Coronary Artery Bypass • Mammary Arteries

Introduction
Many surgical approaches have been published to accomplish graft replacement of extensive aortic aneurysms involving the aortic arch [1-4]. Since most of them include partial or complete transverse sternotomy and division of the left internal thoracic artery (LITA) [1, 3, 4], some modification is necessary to use the LITA for coronary artery bypass. We herein report a modified L-shaped incision combining an upper mid-sternotomy and a left antero-lateral thoracotomy to use the LITA for its whole length.

Case Presentation
A 61-year-old male was referred from the Department of Cardiology for surgical treatment of a thoracic aortic aneurysm (Figure 1). The patient was hypertensive, and was an ex-smoker. He had undergone a coronary angiogram as a part of preoperative evaluation, and it showed a long 50–75% lesion in his proximal left anterior descending artery (LAD) (Figure 2). His cardiologist indicated that a coronary artery bypass to the LAD was also needed.

The aneurysm was large, with a maximal short axis diameter of 60 mm, and extended from the level of the left subclavian artery to the level below the hilum of the left lung (Figure 1). Although we usually prefer to perform aortic arch replacement via median sternotomy [5], we considered that the distal end of the aneurysm was too far to sew just from a me-
We typically make an L-shaped incision in such cases, combining upper partial mid-sternotomy and left intercostal thoracotomy at the fourth or fifth intercostal space (ICS) [1]. For this patient, however, we thought that it would be better if we could use the LITA for coronary artery bypass, and we thought that this might be possible by making a lower thoracotomy. We planned to make an L-shaped incision combining partial upper sternotomy and left thoracotomy at the sixth ICS.

For surgery, the patient was placed in the supine position. A rolled pad was placed behind the left scapula. A gentle curved skin incision was made from the suprasternal notch to the left chest over the seventh rib (Figure 3). The subcutaneous areolar tissue and the periostium were incised with a cautery device over the sternum. The sixth ICS was reached by dividing the pectoralis fascia and lower fibers of the pectoralis major muscles. The ICS was entered by dividing the intercostal muscles along the top of the seventh rib. At the left lateral sternal border, the ICS was carefully dissected, being careful not to injure the internal thoracic artery. At this point, we carefully checked the hemostasis, and gave 5,000 units of intravenous heparin.

Three minutes after the heparinization, we performed an upper sternotomy and transverse sternotomy from the sixth ICS to the mid-sternal incision. The LITA was divided with the sternum using a saw. Both ends of the LITA were identified and clipped. After obtaining hemostasis of the sternal edge with bone wax, we started to cut the intercostal muscles further down to the patient’s back from inside the left hemithorax. Then, the chest wall was elevated with a retractor. We started to harvest the LITA with a cautery and an ultrasonic scalpel. It was easier than usual to harvest the LITA via a mid-sternal incision, because the chest wall was so highly elevated. The LITA was freed from the chest wall up to the level of the subclavian vein.

After preparing the descending aorta, and exposing the right femoral artery, a full dose of heparin was given. The clip on the LITA was removed, and we confirmed good pulsatile free flow. An extensive aortic replacement was performed using a Dacron graft with four branches with the aid of selective cerebral perfusion [6] (Figure 4). After completing all anastomoses for the arch and proximal thoracic descending aorta reconstruction, the aorta was unclamped and the coronary artery bypass was performed with a beating heart. The total amount of blood lost was
approaches have been published, including two-stage operations [2], bilateral anterior thoracotomy [3], lower sternotomy and thoracotomy [4] and upper sternotomy and thoracotomy [1].

We prefer to use the last approach, since we think this approach provides good access to the arch branches. The division of the left internal thoracic artery at the ICS which we use for the thoracotomy is inevitable. Considering that the patient was in his early 60s, we wanted to use the LITA for this particular patient. The most frequent level of termination of the left internal thoracic artery is the 6th ICS [7], so we made the thoracotomy at this level. We found that the visualization of the aortic arch and the thoracic descending aorta was good, and the LITA could be harvested in good condition with the patient only needing a small dose of heparin. The amount of intraoperative blood loss was small despite early heparinization.

In conclusion, we performed a combined extensive thoracic aortic replacement with an L-shaped incision and a coronary artery bypass to the LAD using the LITA. It was possible to use the full length of the LITA after making the incision and placing the thora-

Discussion

An extensive aortic aneurysm including the aortic arch is a surgical challenge. Conventional aortic repair including replacement with a vascular prosthesis cannot be accomplished by either single mid-sternotomy or left thoracotomy. Many ap-

Figure 3. A postoperative photograph showing the curved skin incision over the upper sternum and the left seventh rib.

Figure 4. A postoperative computed tomography scan showing the Dacron graft and the left internal thoracic artery anastomosed to the left anterior descending artery.
cotomy at the lower ICS and by performing heparinization before the sternotomy.

Conflict of Interest

The authors have no conflict of interest relevant to this publication.

References


EDITOR’S QUESTIONS

1. Why did you select your specific approach in preference to a frozen elephant trunk to accommodate the descending aneurysm component?

Frozen elephant trunk is associated with a significant percentage of spinal cord injury with a reported incidence ranging from 0–24%. The incidence has also been quite high based on our own experience.

We therefore prefer to perform end-to-end surgical anastomosis under direct vision for young patients who could likely survive the surgery and then go home in a good condition. We reserve the frozen elephant technique, which obviously is a useful modality, for patients who are at high risk to be treated by a direct surgical approach.
**Upcoming Meetings**

**September**

1. Transcatheter Aortic and Mitral Valve Interventions
   European Association for Cardio-Thoracic Surgery
   September 14-15, 2015
   Windsor, United Kingdom
   Meeting information available at: www.eacts.org/academy/2015-programme

2. Aortovascular Summit 2015: A Multidisciplinary Team Approach
   New York-Presbyterian Columbia University Medical Center
   September 18-19, 2015
   New York, New York
   Meeting information available at: www.columbiasurgery.org/node/7406

3. 25th World Society of Cardiothoracic Surgeons Annual Meeting
   September 19-22, 2015
   Edinburgh, Scotland
   Meeting information available at: www.wscts2015.org

**November**

1. Southern Thoracic Surgical Association 62nd Annual Meeting
   November 4-7, 2015
   Orlando, Florida
   Meeting information available at: stsa.org/62ndannual

2. 8th Postgraduate Course - Surgery of the Thoracic Aorta
   November 9-10, 2015
   Bologna, Italy
   Meeting information available at: www.noemacongressi.it

3. 2015 Annual Scientific Meeting
   Australian and New Zealand Society of Cardiac and Thoracic Surgeons
   November 15-18, 2015
   Adelaide, Australia
   Meeting information available at: www.anzsctsasm.com

**October**

1. 29th European Association for Cardio-Thoracic Surgery Annual Meeting
   October 3-7, 2015
   Amsterdam, Netherlands
   Meeting information available at: www.eacts.org