Patient-specific numerical simulation of endovascular aneurysm repair

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Disclosures

D. Perrin, J.-N. Albertini and S. Avril are cofounders of the company Predisurge SAS.
EVAR simulation history in our group

Research: from basic models to clinically relevant simulations

Stent-graft modelling

Generic simulation of stent-graft deployment

Patient-specific simulations

Simulation validation and assessment

Red: simulation
Grey: postoperative scan

2008 2012 2015

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FEA and stent-graft deployment simulation in aorta

- **Infra-renal aorta**
  - Simple
  - Low clinical interest

- **Coeliac artery**
  - Complex
  - Collateral arteries

- **Ascending aorta**
  - Straight zone
  - Limited interest

- **Aortic arch**
  - Complex
  - Tortuosity
  - Collateral arteries

**Branched**
- Complex
- Collateral arteries

**Fenestrated**
- Simple
- Limited interest

**Bifurcated**
- Complex
- Tortuosity
- Collateral arteries

**Tubular**
- Straight zone
- Limited interest

**SG**
- Virtual anatomy
- Patient-specific

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FEA and stent-graft deployment simulation in aorta

**Aortic sections**
- **Infra-renal aorta**
  - Simple
  - Low clinical interest
- **Coeliac artery**
  - Complex
  - Collateral arteries
- **Ascending aorta**
  - Straight zone
  - Limited interest
- **Aortic arch**
  - Complex
  - Tortuosity
  - Collateral arteries

**Aortic anatomy**
- **Tubular**
  - Simple
  - Low clinical interest
- **Bifurcated**
  - Complex
  - Collateral arteries
- **Fenestrated**
- **Branched**
  - Simple
  - Low clinical interest

**Complexity**
- Virtual anatomy
- Patient-specific

**Projects**
- Perrin et al. 2018
  - Un-published
- De Bock et al. 2012
- Perrin et al. 2015b
- Perrin et al. 2016
- Hemmler et al. 2018
- Arokiaraj et al. 2016
- Auricchio et al. 2013

**Contact**
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General information:

Pathologies of the aortic arch (aneurysm, dissection…)
Rare (5-10 cases for 100000/yr), high risk of mortality

Various treatment options
Open surgery = complex
Significant morbidity and mortality rates
30 days-mortality: until 15%

A significant fraction of patient population = high-risk patients deemed unfit for open surgery
Various treatment options: arch branched devices

Double Branch endograft
Bolton
Relay®

Custom-made device

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Main Objective

AIM:

To develop a patient specific FE model of double branch Bolton® device deployment in aortic arch aneurysm
MATERIAL & METHOD
**Geometry & Material**

**Simulation strategy**

**Validation**

<table>
<thead>
<tr>
<th></th>
<th>GRAFT</th>
<th>STENTS</th>
<th>AORTA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Software</strong></td>
<td>FreeCAD®</td>
<td>Matlab®</td>
<td>VMTK®</td>
</tr>
<tr>
<td><strong>Mesh</strong></td>
<td>Quad, 0.5mm</td>
<td>Beam, 0.3 mm</td>
<td>Triangular shell, 1.5 mm</td>
</tr>
<tr>
<td><strong>Material</strong></td>
<td>PET Orthotropic elastic</td>
<td>Nitinol Isotropic elastic</td>
<td>Constant thickness, Isotropic elastic</td>
</tr>
</tbody>
</table>

PERSONALIZED

Gasser et al 2006
Perrin et al 2015b
Perrin et al 2016
De Bock et al 2012
Demanget et al 2012 & 2013

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### Patients: N=3

<table>
<thead>
<tr>
<th>Case</th>
<th>Age</th>
<th>Sexe</th>
<th>ASA</th>
<th>Aneurysm diameter, mm</th>
<th>Ishimaru zone</th>
<th>Distal aortic neck</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64</td>
<td>M</td>
<td>3</td>
<td>62</td>
<td>0</td>
<td>Aortic bifurcation</td>
</tr>
<tr>
<td>2</td>
<td>73</td>
<td>M</td>
<td>3</td>
<td>58</td>
<td>0</td>
<td>Descending thoracic aorta</td>
</tr>
<tr>
<td>3</td>
<td>73</td>
<td>M</td>
<td>4</td>
<td>59</td>
<td>1</td>
<td>Iliac arteries</td>
</tr>
</tbody>
</table>

#### Preop & Postop CT-scan

Graftplans and fabrics data provided by the manufacturer

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Stentgraft assembly and pre-stressed:
- Oversizing: tie constraint
- Radial compression: bridging stents placement & stent-grafts crimping
Pre-stressed Deployment Morphing Mechanical equilibrium

Ao: idealized tubular shell

Geometry & Material Simulation strategy Validation

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SGs placed in the intended position:
- Global rotation
- Proximal landing zone
Bridging stents bending (1)
Stent-grafts released (2)
The tubular shell of the aorta is deformed to come back to its preoperative geometry

SGs are maintained in the shell => submitted to deformations
Mechanical equilibrium

SG: stressed
Ao: stressed

Boundary conditions:
- Aortic extremities fixed
- Friction coefficient SG/Aorta (0.4 + proximal: rough)
Sensitivity analysis (1 case)

Quantitative analysis (3 cases)
Stent segmentation on post-operative CT and comparison with Matlab®
x 3 error values: $e_D$, $e_L$, $e_T$

Qualitative analysis (3 cases)
Superimposition
Defect of apposition
Kink
...

Diameter_Simu Diameter_Postop

$e_D = \frac{\text{Diameter}_\text{Simu}}{\text{Diameter}_\text{Postop}}$

Sensitivity analysis (1 case)

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RESULTS
Results

Case 1

Case 2

Case 3

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Results

Bolton double branch simulation
06/09/2018
Lucie Derycke, with PrediSurge
Results

Belton double branch simulation
03/09/2018
Lucie Derycke, with PrediSurge
Friction coefficient

Results: sensitivity analysis

Friction coefficient

Fdist = 0.4

Fprox = 0.4/0.1

A

B

Fprox = rough

Fdist = 0.4

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Results: sensitivity analysis

Figure 8: Error values of diameter eD (A), longitudinal eL (B) and transverse errors eT (C) for each stents depending of Young modulus. Stents are numbered from 1 (proximal) to 15 (distal); X axis: stent number, Y axis: error values in mm

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Results

Case 1

Case 2

Case 3

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Results

Bolton double-branch stentgraft simulation
Lucie Derycke, 23/08/2018
With PrediSurge
Results

Bolton double-branch stentgraft simulation
Lucie Derycke, 23/08/2018
With PrediSurge
Results
Results: qualitative analysis

TORSION case n°2

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Results: qualitative analysis

TORSION case n°2

Rotation 0°

Rotation 135°
Results: qualitative analysis

TORSION case n°2

Rotation 135°
Results: qualitative analysis

COLLAPSE Case n°3

A

B

C

D

E

F

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Results: qualitative analysis

COLLAPSE Case n°3

Bolton double-branch stentgraft simulation
Lucie Delvycke, 23/05/2018
With PrediSurge
Results: BRIDGING STENTS CONFIGURATION

-60° -30° -0° +30° +60° +75° -75°

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Results

Rotation -75°
DISCUSSION
Endovascular Aortic Arch Challenges

Custom-made device
Measures on preop CT

Device alignment
Secure device

Device durability
New set of physiological loads

Tools are needed for planning to help the practitioner and to improve the device properties

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Discussion

Overall satisfying agreement between simulations and post-operative CT scans:

Mean error values: \( e_D = 1.95\% \); \( e_L = 2.9 \text{ mm} \); \( e_T = 5.45 \text{ mm} \)

Promising potential and ability of numerical simulation:

- to predict complex stent-graft deployment in challenging anatomy like aortic arch aneurysms

- to detect potential complication, such as collapse

- to understand stent-graft behavior and conformability, such as in torsion configuration

Tool compatible with clinical decision-making model

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Derycke et al, Annals of Biomedical Eng, 2018, in revision
Software solutions assisted by numerical simulation

Optimize design, preoperative planning and implantation of medical devices

- Company founded in May 2017
- Focus on endovascular repair (EVAR) of aortic aneurysms
- Graphical user interface
- Over 200 cases
- On-going clinical trials for CE and FDA approval
Funding:
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DANKE SCHÖN!

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Prof Jean-Noël Albertini, Prof Stéphane AVRIL

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