Imagerie pré-thérapeutique de l’aorte

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Current challenges of EVAR

- 60% of AAA patients are eligible to conventional EVAR
- High IFU non adherence (38-69%)
  - Leading to an increase of graft related adverse event
- Moving target
  - Third generation devices (Cook, Medtronic, Gore)
  - FEVAR, BEVAR
  - Sealing devices
    - Ovation
    - EVAS
Same indication for EVAR and OR

- AAA DMax
  - Dmax $\geq 5$ cm female and $5.5 \geq$ men
- Growth $\geq 1$ cm 1 year or $5$ mm 6 months
- Symptomatic AAA
- Balance between anatomic eligibility and clinical risk factors

Surgery

Stent-graft

RISK

ANATOMY
Imaging work-up

- CTA +++
  - Collimation 0.625mm for 3D
  - 1.25-2.5 mm for visualization
  - Gating just for TAA
  - C- and arterial phase?
  - 100ml at 4-5ml/s
  - Bolus tracking, threshold 150HU
  - Dual energy more useful for EVAR FU
  - Include aorta-pelvis and groin
  - MPR, CPR

Hu-DK-Cardiovasc-Diagnosis-Therapeutics-2018
Picel-AC-AJR-2018
Do not plan EVAR or open repair on standard abdominal CT
Renal failure after OR
MRA

• Renal failure (GFR 30-45ml/min)
  • T1-T2 SE sequences + CE-MRA
  • Macrocyclic GBCA
  • Similar assessment of EVAR assessiblity
• No visualization of intimal calcification
• Poor visualization of accessory renal arteries

• Severe renal failure (GFR<30ml/min) or Cl to GBCA
  • bSSFP sequences
  • Similar assessment of stent- sizing

2. Goshima-Radiology-2013
Measurements
Standardization of Dmax measurement

• CT-scan more reproducible than US for Dmax measurement $^1$
  • Smaller diameter with US (3.1±2.2mm)$^2$

• Confusion on Dmax measurement ‘Maximum aneurysm diameter should be measured perpendicular to the flow line of the vessel with reconstructed computed tomographic’$^3$

• However, centerline and thrombus can be eccentric

Dmax measurement should be taken on cranio-caudal or double oblique reformation

• ICC for Dmax growth
  • Axial 0.66-0.74, coronal 0.77, sagittal 0.82, DO 0.83

Dugas A et al. CVIR 2012;35:779-87
AAA segmentation and modeling

- Longitudinal view of the AAA
- Outerwall segmentation from the celiac trunk to one selected iliac artery
- Segmentation plans defined on transverse section of the AAA
- 3D rendering of the AAA lumen and thrombus
- Automated D-Max and volume measurements

Kauffmann C et al. EJR 2011;77:502-8
Validation of automated Dmax measurement

Fig. 4. Regression model between software and manual: mean of readings 1 and 2 between software (reader A) and radiologist #1 at baseline.

Kauffmann C et al
Eur J Radiol 2011
Dmax orthogonal to outerwall centerline

- Must be orthogonal to thrombus centerline not luminal centerline

Mean error outerwall centerline= \(-0.07 \pm 1.66\) mm, \(p = 0.7\)

Mean error lumen centerline=\(-1.24 \pm 2.01\) mm, \(p< 0.01\)
Accuracy & reproducibility for volume measurement

- **Accuracy**
  - <2 ml volume
  - <1 ml volume growth
  - <1% relative volume growth

- **Repeatability coefficient**
  - <6 ml volume
  - <7 ml volume growth
  - <6% relative volume growth

Proximal landing zone

- Diameter <32mm
- Length >15mm (Nellix, Ovation >10mm)
- Angulation <60°
- Conical neck +++
- Heavy calcification/thrombus covering >90%
Respect IFU!
Outcome and IFU adherence

Adverse outcome IFU adherence or not

EVAR outside IFU vs OR

More graft related adverse effect
HR=2.2

Better survival in OR HR=0.6

Do not plan EVAR or open repair on standard abdominal CT
Renal failure after OR
Distal aorta and iliac arteries

- Distal aorta
  - Residual lumen ≥15-18mm
  - Distal aorta diameter ≥ 20mm
- Common iliac diameter <25mm
- Length distal landing zone ≥ 10mm
- External iliac diameter ≥ 5-6mm
- Tortuosity ≤90°
- Anterior calcification >50% CFA

Picel-AC et al. AJR 2014
Celiac trunk, SMA, IMA, internal iliac

• Beware of large IMA
  • Risk of bowel ischemia
    • Rule out SMA stenosis
    • Evaluate patency of internal IIA

• Do not cover both IIAs
  • If you have to extend in both EIA
  • Snorkel or IBG
  • Bell bottom technique
Predictor of type II endoleak

- Patent IMA ($p<0.001$)
- N of patent lumbar arteries ($p<0.001$)
- Sac diameter and thrombus circumference
  - NS for Ward et al
  - $P=0.02$ for Muller Wille

Ward-TJ-CVIR-2014
Muller-Will-R-CVIR-2014
Procedure planning: lumen and thrombus segmentation
Planning fluoroscopic projections

- Define centerlines
  - Aorta, iliac, renal arteries
  - CT, SMA
  - Internal iliac arteries

- Propose and define the best working view for each procedural steps
  - Orthogonal projection to target vessel centerline
  - Adjust if needed for C-arm mechanical range
3D/3D Registration

- Perform a CBCT
  - Before draping
- Automatic bone registration
  - Spine/spine
- Fine tuning of registration based on vascular
  - Calcification alignment
  - Vessel ostia
- Projection of 3D CT mesh on fluoroscopy
- Synchronization of C-arm, table, magnification with the new 3D/3D coordinates
Biplanar 2D Fluoroscopy/3D registration

- Separate VR of spine and aortic lumen from CT
- Spine fusion /biplanar fluoroscopy
- Replacement of spine by aortic lumen

**Advantage**
- Dose
- Easy

**Drawback**
- Absence of precise vascular alignment
Limitation of rigid registration
FEVAR BEVAR
Stent-graft rotation & FEVAR

- 37% rotation of delivery device during insertion
  - Mean rotation 25°
  - Rotation is associated with
    - Iliac tortuosity
    - Iliac calcification
    - SG length
  - More type I and III endoleak if rotation
Mechanical deformation of the vessel by an endovascular device modifies the geometry.
Patient geometry reconstruction and FEA simulation

ORS software

Patient from LCTI database

Numerical Model

Spine

Surrounding Abdominal Fat

Pelvic Bone

Lumen

Thrombus

Thrombus
Device Characterization (Cook Medical)

Equivalent mean properties for typical sections of body and leg catheters:

<table>
<thead>
<tr>
<th>Section</th>
<th>$\Theta$ (mm)</th>
<th>$E$ (kPa)</th>
<th>$\nu$ (-)</th>
<th>$\rho$ (kg/mm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body outer catheter</td>
<td>6.85</td>
<td>$5.74 \times 10^6$</td>
<td>0.3</td>
<td>$1.673 \times 10^{-6}$</td>
</tr>
<tr>
<td>Leg outer catheter</td>
<td>5.22</td>
<td>$1.093 \times 10^6$</td>
<td>0.3</td>
<td>$1.764 \times 10^{-6}$</td>
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<tr>
<td>Inner catheter</td>
<td>1.25</td>
<td>$1.930 \times 10^6$</td>
<td>0.3</td>
<td>$8.00 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

Stent (Steel/nitinol)

Graft (Dacron)

- $E_{\text{axial}} = 402$ MPa
- $E_{\text{circ.}} = 165$ MPa
Results: Arterial deformation by guidewires
Results: Stent-Graft Deployment

LS-DYNA keyword deck by LS-PrePost
Time = 0, #nodes=351440, #elem2d=39208, #elem3d=1103130
Strong match between simulation and per operative fluoroscopy

- A 3D/3D registration followed by a 2D/3D registration was used to overlay the simulation results onto the fluoroscopic images.

- Simulation error was defined as the 2D Modified Hausdorff Distance (MHD) between the centerlines of the simulated and real tools.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Roadmap from Image Fusion</th>
<th>Roadmap From Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>48.77</td>
<td>1.91</td>
</tr>
<tr>
<td>2</td>
<td>8.94</td>
<td>0</td>
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<tr>
<td>3</td>
<td>50.78</td>
<td>5.19</td>
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<tr>
<td>4</td>
<td>35.15</td>
<td>4.88</td>
</tr>
<tr>
<td>Mean</td>
<td>35.91±19.27</td>
<td>2.99±2.48</td>
</tr>
</tbody>
</table>
Conclusion

• Pre-operative imaging based on CTA
• Respect imaging based IFU for better results
• Software-assisted procedure planning improve device selection
• FEA will allow patient specific procedure rehearsal
  • Improve device selection
  • Per-operative guidance
  • Need automated workflow and improved computation time