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AI in aortic imaging will improve planning and FU

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Temporal distribution of original articles included in the study. DL: deep learning; ML: machine learning; NLP: natural language processing.
PRAEVAorta: AI using « Deep learning » with U-net network

- Validated for:
  - Pre-operative study of AAA. (1)
  - Immediate post-operative study. (2)

- Time gain: 9 times faster than human
- Volume Similarity: 0.97 ± 0.02
- DSC: 0.95 ± 0.02
- Pearson’s coefficient correlation = .99 (p<.0001)

- Ready for long term follow-up analysis

(1) : Fully automatic volume segmentation of infrarenal abdominal aortic aneurysm computed tomography images with deep learning approaches versus physician controlled manual segmentation (2021, JVS)
(2) : Fully automatic volume segmentation using deep learning approaches to assess aneurysmal sac evolution after infrarenal endovascular aortic repair (2022, JVS)
PRAEVAorta and Planning

**Series**: Aorte

**Exam date**: 2018-04-13

**Generated on**: 2022-03-16

**Patient ID**: P106

**Sex**: M

**Birthday**: 1955-12-18

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**Diagnostic**

- **Inferior max diameter**: ≤2.4 mm
- **Inferior volume**: ≤10.0 cm³

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**Surgical planning**

- **Total lengths**:
  - L2 = 143.0 mm
  - L2 = 143.0 mm

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**Matching algorithm**: identification of the CA, SMA, RAs and CIAs.

**Decision rule-based algorithm**: identification of extra RAs.

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**Present work**

- **Computed of the vascular tree**

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**Tomography scan images**

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**Automatic calculation of tortuosity indices and angulations**

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**Fully automated correct labeling of the main aortic branches**

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**Automatic branch detection of the arterial system from abdominal aortic segmentation** (2022, Med Biol Eng Comput)
PRAEVAorta report

Sagittal
Coronal

A
P
R
L

ortho_max_diameter
ortho_start_diameter
ortho_max_diameter
ortho_start_diameter
ortho_end_diameter
ortho_middle_diameter
ortho_end_diameter
ortho_middle_diameter
PRAEVAorta applied to follow-up

Median follow-up
CTA : 27 months (IQR : 20-40)
Clinical : 36 months (IQR : 23-45)

TEVAR
With a chimney for the Left subclavian artery

EVAR
With proximal cuff extension (with supra-renal bare stent)
Morphological analysis

Diameters

<table>
<thead>
<tr>
<th></th>
<th>Post-Op</th>
<th>FU (1-5y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>42.21</td>
<td>24.15</td>
</tr>
<tr>
<td>25% Percentile</td>
<td>52.33</td>
<td>46.13</td>
</tr>
<tr>
<td>Median</td>
<td>55.62</td>
<td>54.34</td>
</tr>
<tr>
<td>75% Percentile</td>
<td>59.25</td>
<td>59.47</td>
</tr>
<tr>
<td>Maximum</td>
<td>95.36</td>
<td>95.44</td>
</tr>
<tr>
<td>Range</td>
<td>53.15</td>
<td>71.29</td>
</tr>
<tr>
<td>Mean</td>
<td>56.92</td>
<td>55.97</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>9.041</td>
<td>13.35</td>
</tr>
<tr>
<td>Std. Error of Mean</td>
<td>1.198</td>
<td>1.768</td>
</tr>
</tbody>
</table>
Morphological analysis

Volume analysis

Good correlation between Volume and Diameter

<table>
<thead>
<tr>
<th></th>
<th>Global</th>
<th>Lumen</th>
<th>Thrombus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-96.96</td>
<td>-92.43</td>
<td>-99.11</td>
</tr>
<tr>
<td>25% Percentile</td>
<td>-23.83</td>
<td>-5.104</td>
<td>-34.98</td>
</tr>
<tr>
<td>Median</td>
<td>-6.122</td>
<td>9.367</td>
<td>-13.47</td>
</tr>
<tr>
<td>75% Percentile</td>
<td>6.730</td>
<td>21.33</td>
<td>8.012</td>
</tr>
<tr>
<td>Maximum</td>
<td>103.7</td>
<td>57.34</td>
<td>217.1</td>
</tr>
<tr>
<td>Range</td>
<td>200.7</td>
<td>149.8</td>
<td>316.2</td>
</tr>
<tr>
<td>Mean</td>
<td>-5.467</td>
<td>4.689</td>
<td>-9.758</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>33.88</td>
<td>28.93</td>
<td>52.53</td>
</tr>
<tr>
<td>Std. Error of Mean</td>
<td>4.527</td>
<td>3.866</td>
<td>7.083</td>
</tr>
</tbody>
</table>
Illustration of Fisher’s test comparing the distribution observed between the evolution of aneurysmal volume and the evolution of aneurysmal diameters

Aneurysm volume showed a better sensitivity in predicting aneurysm size increase overtime vs Dmax (p=0.0222)

<2mm in Dmax
≈10% in vol

-15mm
<50% in vol
Reference distance for stentgraft disjunction detection: distance from lowest renal artery to stent bifurcation

<table>
<thead>
<tr>
<th>Year</th>
<th>Dmax (mm)</th>
<th>Volume (cm³)</th>
<th>Distance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>61.3</td>
<td>290</td>
<td>78.6</td>
</tr>
<tr>
<td>2014</td>
<td>58.6</td>
<td>269</td>
<td>99.7</td>
</tr>
<tr>
<td>2015</td>
<td>55.9</td>
<td>252</td>
<td>113.3</td>
</tr>
<tr>
<td>2019</td>
<td>86.8</td>
<td>641</td>
<td>142.3</td>
</tr>
<tr>
<td></td>
<td>Value (%)</td>
<td>95% CI</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------</td>
<td>-----------------</td>
<td></td>
</tr>
<tr>
<td>PRAEVAorta (vs Senior Surgeon)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>89.47</td>
<td>80.58 to 94.57</td>
<td></td>
</tr>
<tr>
<td>Specificity</td>
<td>91.25</td>
<td>83.02 to 95.70</td>
<td></td>
</tr>
<tr>
<td>Positive Predictive Value</td>
<td>90.67</td>
<td>81.97 to 95.41</td>
<td></td>
</tr>
<tr>
<td>Negative Predictive Value</td>
<td>90.12</td>
<td>81.70 to 94.91</td>
<td></td>
</tr>
</tbody>
</table>

**Endoleak detection**

- **Sensitivity**: 89.47 (80.58 to 94.57)
- **Specificity**: 91.25 (83.02 to 95.70)
- **Positive Predictive Value**: 90.67 (81.97 to 95.41)
- **Negative Predictive Value**: 90.12 (81.70 to 94.91)

![Graphs showing Endoleak detection metrics with AUC values: 0.7086 for Sensitivity and 0.6711 for Specificity.](image-url)

- **Lumen**
- **Thrombus**
Predictive performance of volume analysis for MAEs

Major adverse events (MAEs) defined as aneurysm-related death, endoleak, limb occlusion, and reintervention.

<table>
<thead>
<tr>
<th>Elapsed time (months)</th>
<th>MAE / Global volume</th>
<th>MAE / Lumen volume</th>
<th>MAE / Thrombus volume</th>
<th>MAE / Max Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freedom from MAE (%)</td>
<td>Sensitivity %</td>
<td>Sensitivity %</td>
<td>Sensitivity %</td>
<td>Sensitivity %</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>12 months</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>24 months</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>36 months</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>48 months</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>N at risk</td>
<td>56</td>
<td>34</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>Survival %</td>
<td>-</td>
<td>58.9</td>
<td>50.0</td>
<td>50.0</td>
</tr>
<tr>
<td>95% CI</td>
<td>-</td>
<td>44.9-70.5</td>
<td>35.8-62.6</td>
<td>35.8-62.6</td>
</tr>
</tbody>
</table>

AUC = 0.7806
AUC = 0.5140
AUC = 0.7804
AUC = 0.7277
Work in progress: shear stress analysis and risk of rupture

Registration pipeline. Registered aneurysm

1. Patient does the CT scan
2. Aneurysm, $d_{max} > 5$ cm
3. Surgery (EVAR/OSI)
4. Patient follow-up

$P = (p, \delta)$ before surgery
$\{\tilde{P}, \tilde{\delta}\}$ after surgery

Geometrical modeling
Iterative Closest Point
Displacement profiles
Comparison of fully automatic segmentation using PRAEVAorta2 for diameters and volumes
82 patients with arterial, venous and non-contrast phase CT

<table>
<thead>
<tr>
<th>Fully automatic segmentation</th>
<th>Arterial phase (ground truth)</th>
<th>Venous phase</th>
<th>p value</th>
<th>Non-contrast phase</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max aortic transverse diameter (mm)</td>
<td>60.2±12.4</td>
<td>61.8±18.7</td>
<td>.476</td>
<td>60.4±17.3</td>
<td>.540</td>
</tr>
<tr>
<td>Global Volume (cm³)</td>
<td>298.2±125.9</td>
<td>295.8±16.4</td>
<td>.445</td>
<td>288.5±125.4</td>
<td>186</td>
</tr>
<tr>
<td>Lumen Volume (cm³)</td>
<td>153.8±62.0</td>
<td>159.5±64.7</td>
<td>.014</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Thrombus Volume (cm³)</td>
<td>138.0±90.5</td>
<td>130.6±89.7</td>
<td>.074</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Time for analysis (sec)*</td>
<td>213.9±102.7</td>
<td>114.4±36.1</td>
<td>&lt;.001</td>
<td>140.0±288.7</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

PRAEVAorta®2 algorithms produce comparable results for assessing Dmax and Vmax across the 3 different phases.

Optimize AAA FU by identifying at-risk patients from non-dedicated scans or non-contrast CTs

- number of scans / patient
- healthcare costs
- patient exposure to radiation and contrast media
84 yo patient: Comparison of angio CT scans

from 2021

from 2023
Automated segmentation of the infra renal aorta with analysis:

- Max diameter
- Global volume/ lumen, wall volume
- Neck diameters, lengths and volumes
Neck enlargement
Plan for FEVAR for increasing risk of type Ia EL after EVAR ??

Infrarenal Maximal Diameter: 56.4 mm
Volume Infrarenal: 144.0 cm³

Infrarenal Maximal Diameter: 67.5 mm
Volume Infrarenal: 166.6 cm³
Take Home Message

- **AI**
  - **Surgical planning**
    - with all important measurements and automatic branch detection
  - **Follow-up**
    - Global volume = better predictive value vs Dmax
    - Detect endoleak, and predict complications
    - Neck enlargement = seems important to monitor (not done in current practice)

- **AI = Big Diagnostic help**
  - More Patients, more CT-scans analyzed, easier and quicker surveillance
  - Detect patients at risk of reintervention and rupture early on
Thank you for your attention