
THE 26TH INTERNATIONAL EXPERTS SYMPOSIUM
CRITICAL ISSUES
IN AORTIC ENDOGRAFTING
MARCH 21 & 22 2024
COPENHAGEN/MALMÖ
SCANDIC TRIANGELN, MALMÖ
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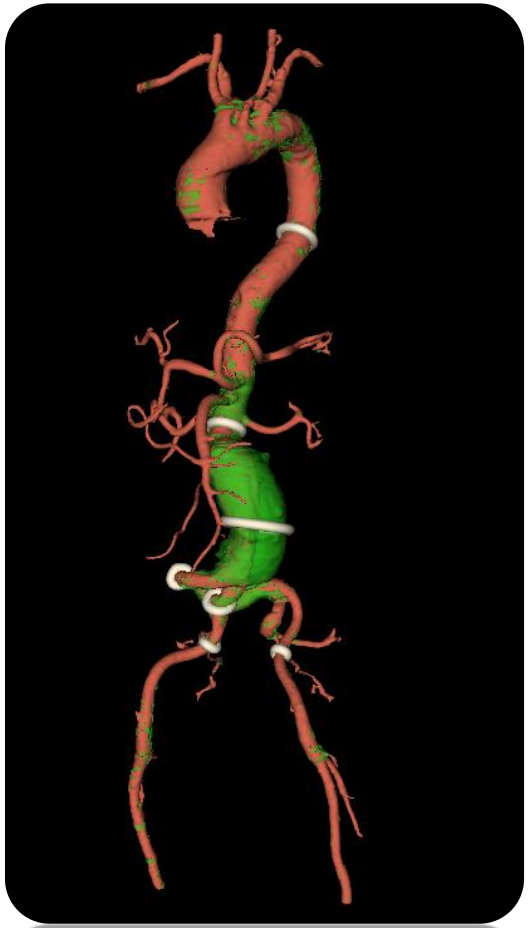

# AI in aortic imaging will improve planning and FU

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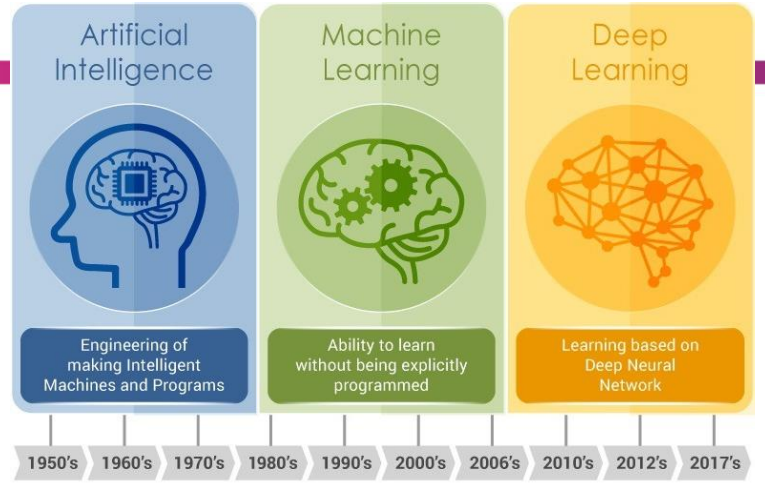
*Original Manuscript*

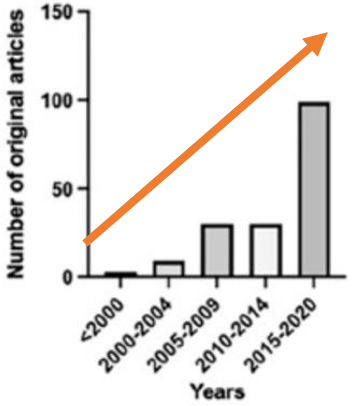
# Applications of Artificial Intelligence in Non-cardiac Vascular Diseases: A Bibliographic Analysis

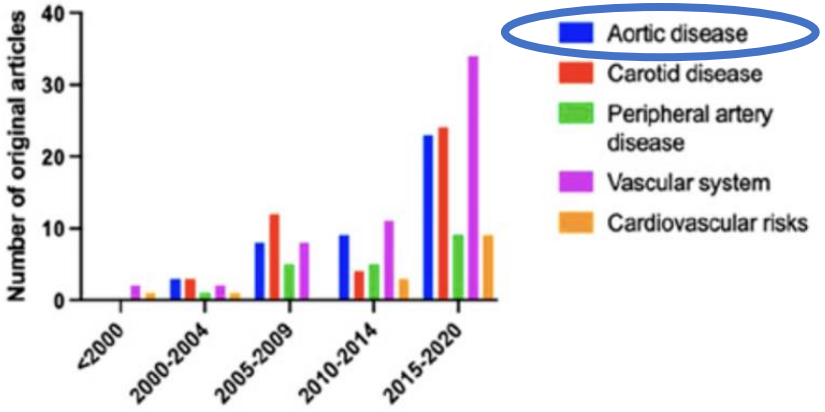
Angiology
2021, Vol. 0(0) 1–9

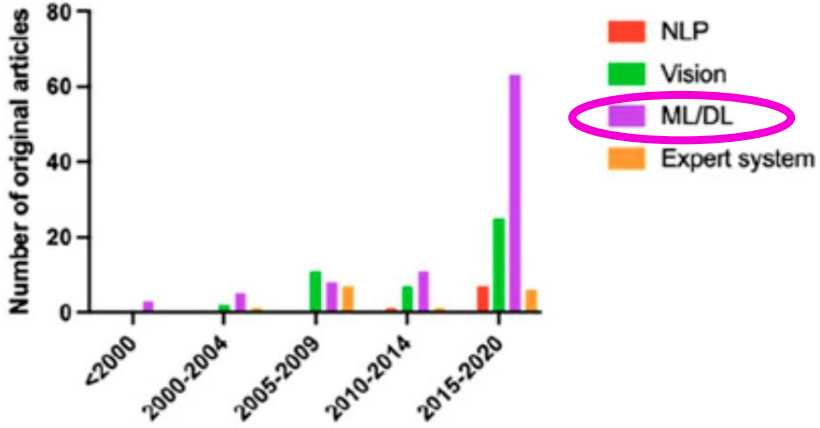
DOI: 10.1177/00033197211062280
journals.sagepub.com/home/ang
SAGE

Fabien Lareyre[1,2,3], Cong Duy Lê[1,3], Ali Ballaith[4], Cédric Adam[5], Marion Carrier[5], Samantha Amrani[1], Caroline Caradu[6], and Juliette Raffort[2,3,7]



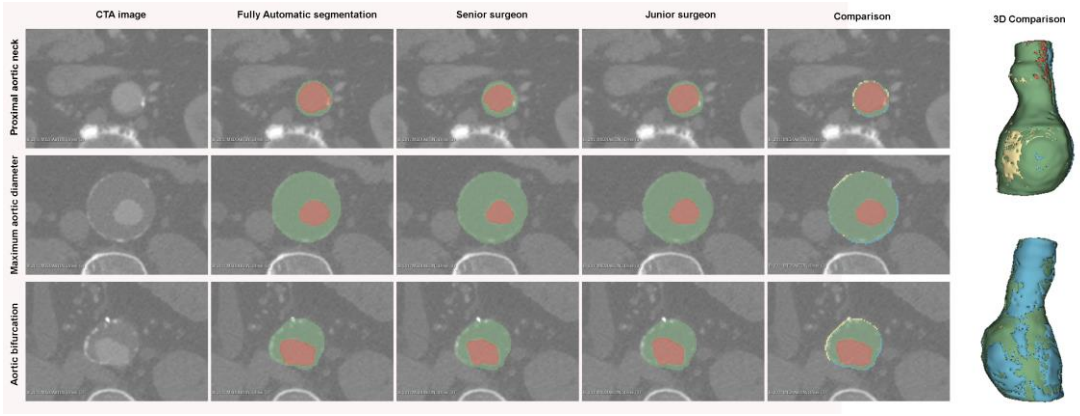

Temporal distribution of original articles included in the study. DL: deep learning; ML: machine learning; NLP: natural language processing.

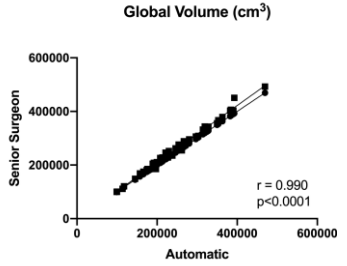
# PRAEVAorta : AI using « Deep learning » with U-net network

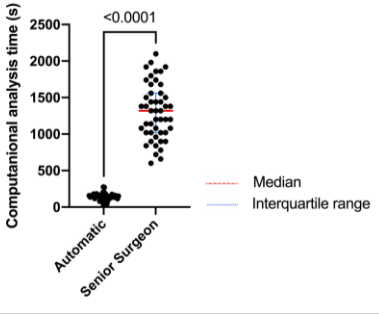
- Validated for :
  - Pre-operative study of AAA. (1)
  - Immediate post-operative study. (2)

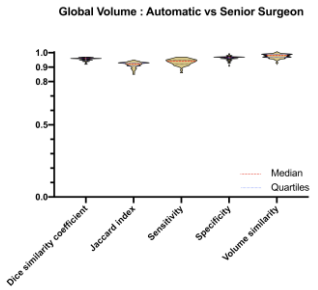
- Time gain : 9 times faster than human
- Volume Similarity : 0.97 ± 0.02
- DSC : 0.95 ± 0.02
- Pearson's coefficient correlation =.99 (p<.0001)

- Ready for long term follow-up analysis



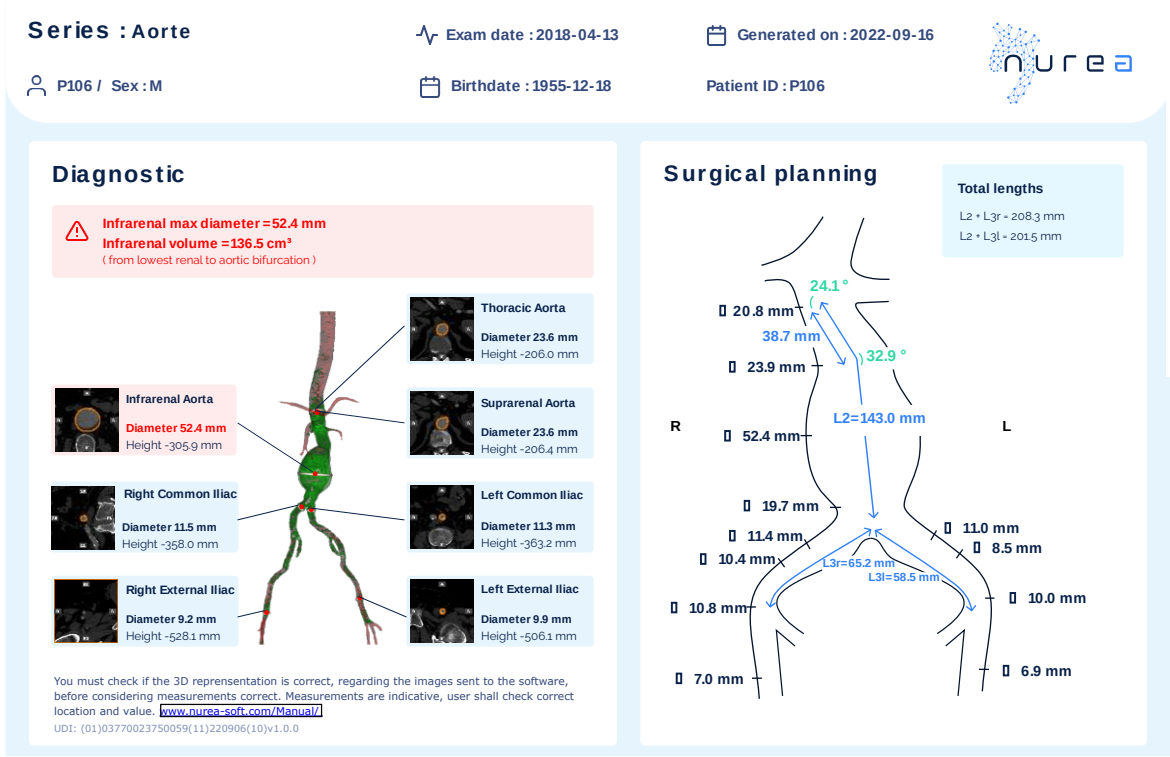



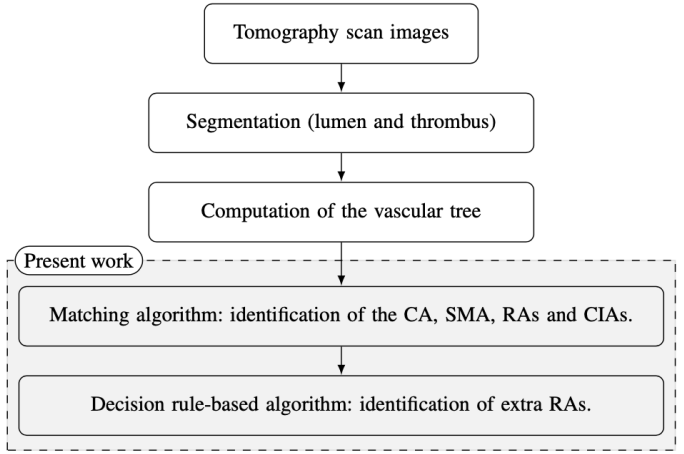



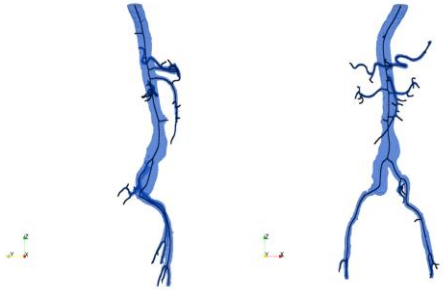




(1) : Fully automatic volume segmentation of infrarenal abdominal aortic aneurysm computed tomography images with deep learning approaches versus physician controlled manual segmentation (2021, JVS)
(2) : Fully automatic volume segmentation using deep learning approaches to assess aneurysmal sac evolution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

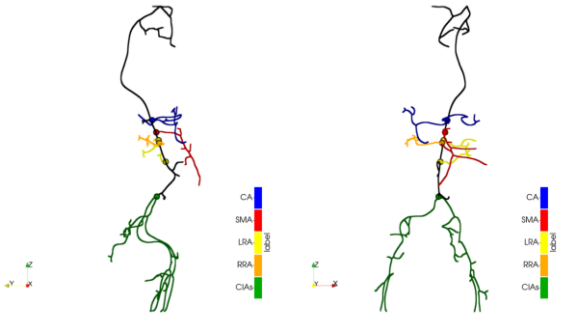
# PRAEVAorta and Planning



Fully automated correct labeling of the main aortic branches




Automatic calculation of tortuosity indices and angulations

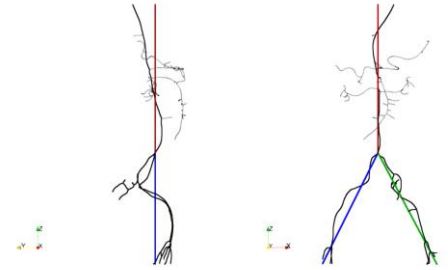
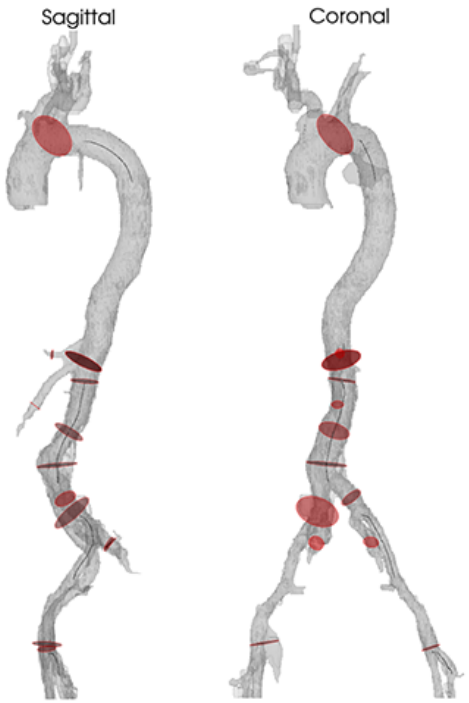
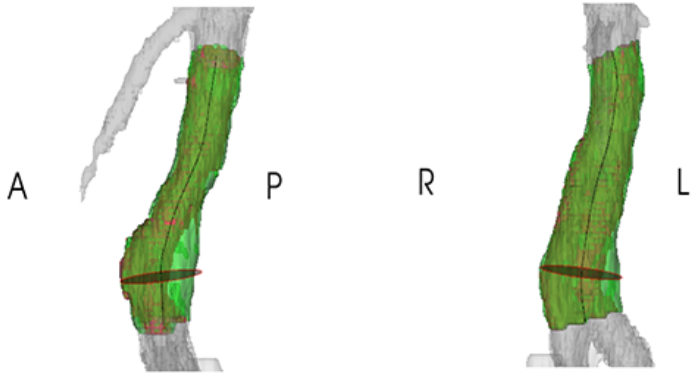


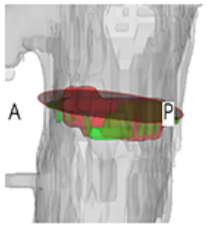
Fig. 7 Example illustrating the CIAs score evaluation: vascular tree (grey), branches corresponding to the aorta and CIAs (black), $\sqrt{(x^-(u^{cia_s},v^{cia_s}))^2+(z^-(u^{cia_s},v^{cia_s}))^2}$ (blue), $\sqrt{(x^+(u^{cia_s},v^{cia_s}))^2+(z^-(u^{cia_s},v^{cia_s}))^2}$ (green) and $z^+(u^{cia_s},v^{aorta})$ (red).

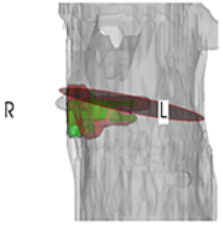
Automatic branch detection of the arterial system from abdominal aortic segmentation (2022, Med Biol Eng Comput)

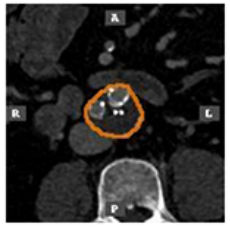
# PRAEVAorta report

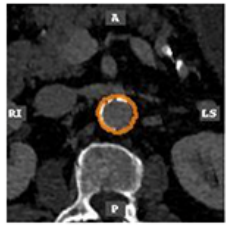




ortho_max_diameter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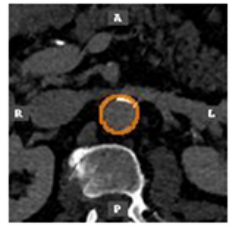
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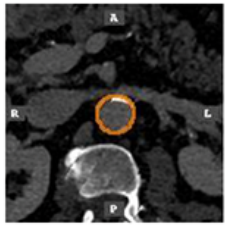
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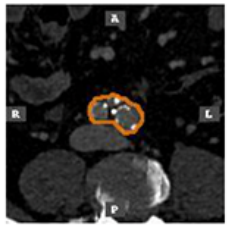
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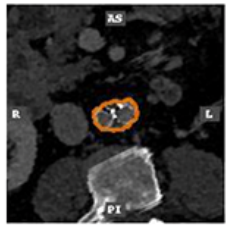
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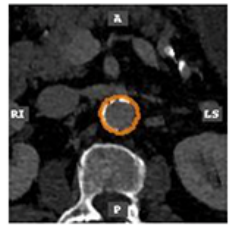
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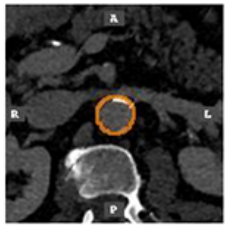
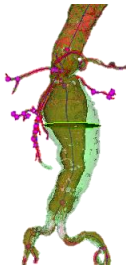
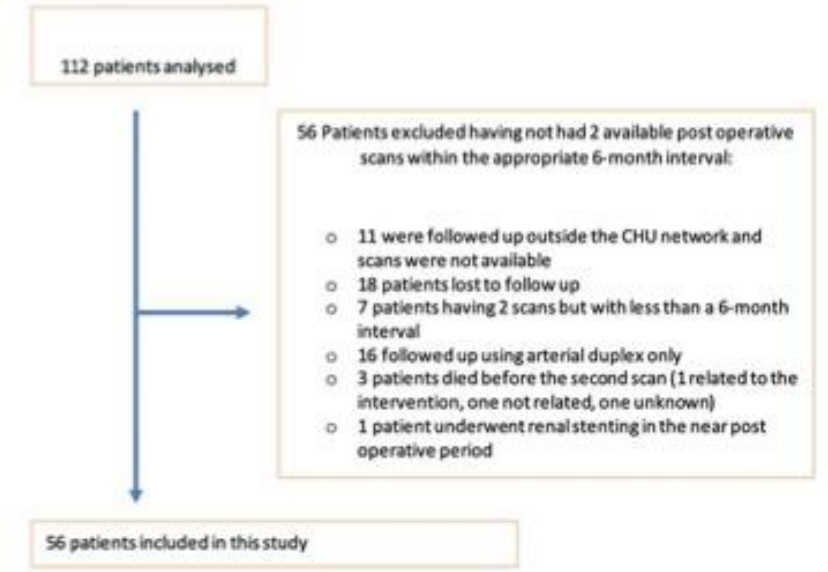
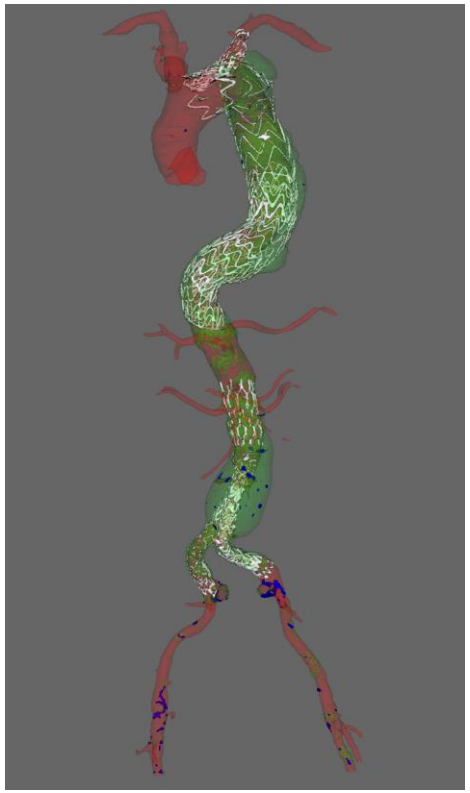

ortho_middle_diameter

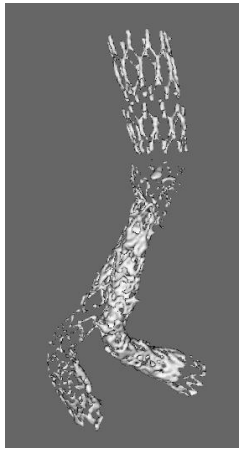
# PRAEVAorta applied to follow-up






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

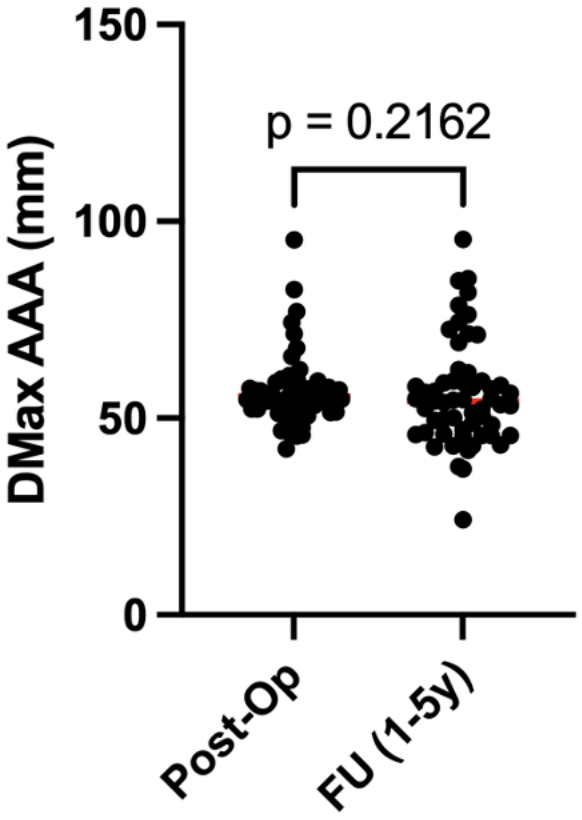


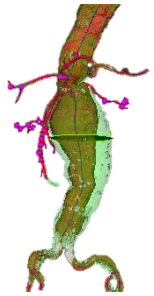
TEVAR
With a chimney for the Left subclavian artery

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

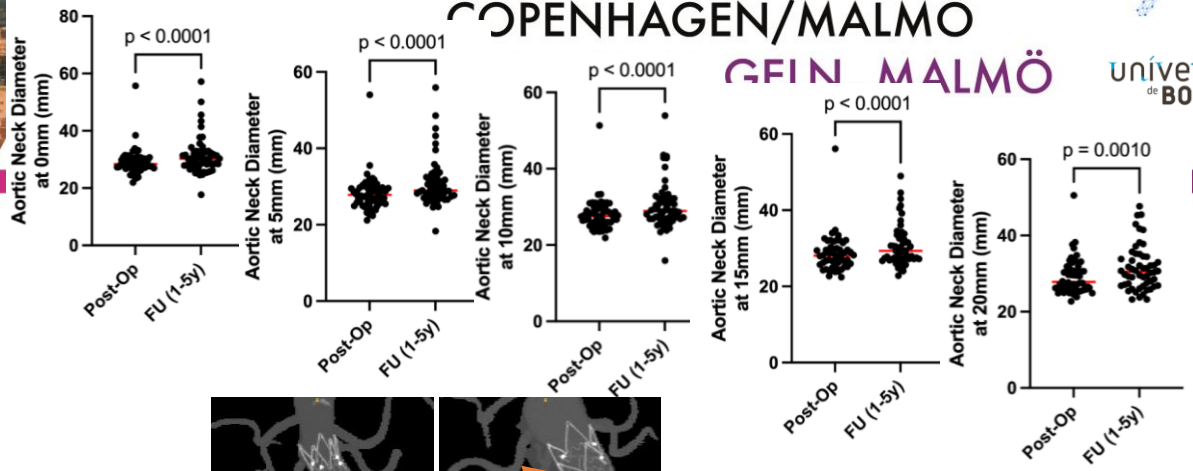
# Morphological analysis

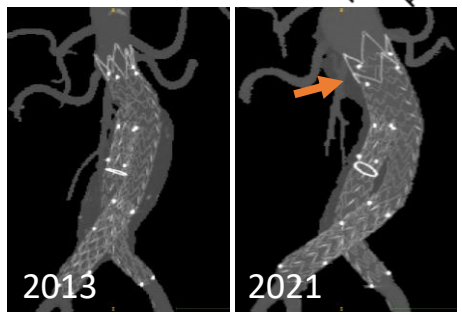
## Diameters

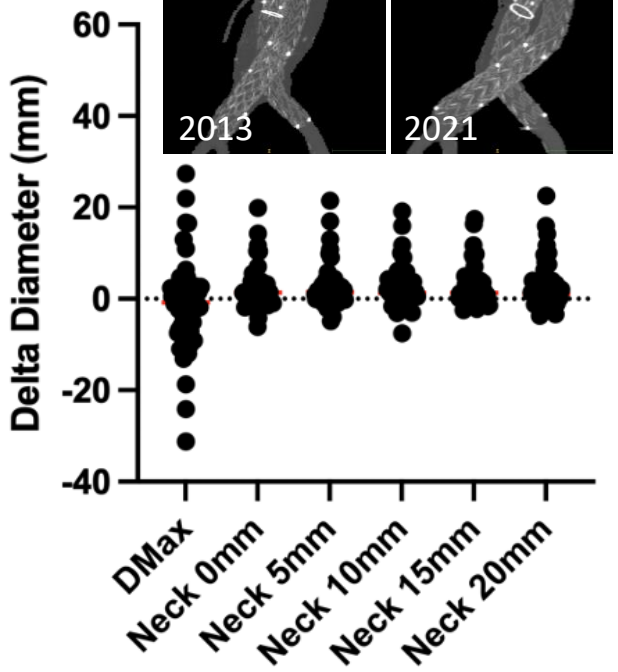


| | Post-Op | FU (1-5y) |
|---|---|---|
| Minimum | 42.21 | 24.15 |
| 25% Percentile | 52.33 | 46.13 |
| Median | 55.62 | 54.34 |
| 75% Percentile | 59.25 | 59.47 |
| Maximum | 95.36 | 95.44 |
| Range | 53.15 | 71.29 |
| | | |
| Mean | 56.92 | 55.97 |
| Std. Deviation | 9.041 | 13.35 |
| Std. Error of Mean | 1.198 | 1.768 |



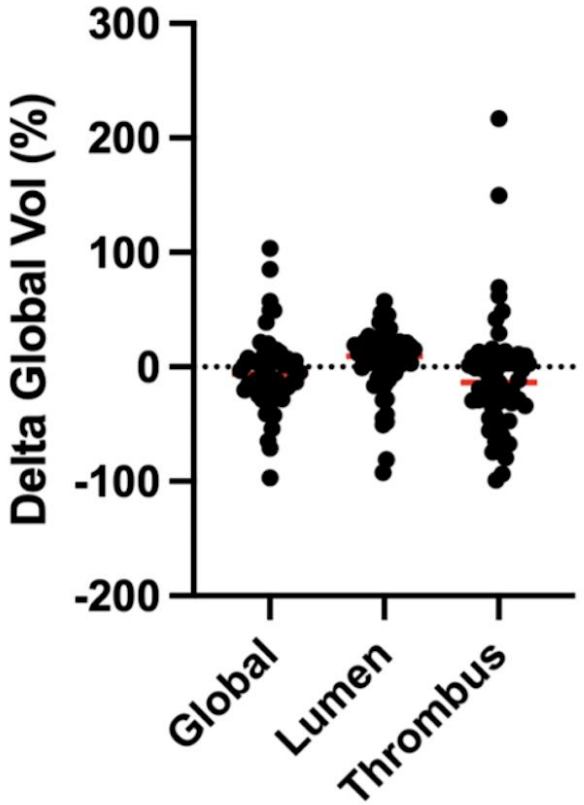



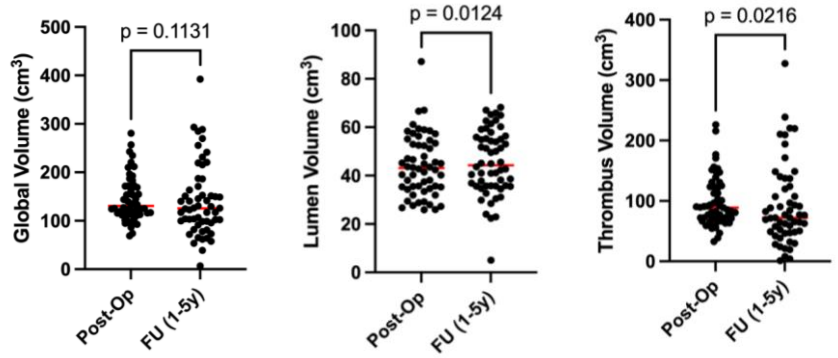

| | DMax |
|---|---|
| Minimum | -31.24 |
| 25% Percentile | -7.382 |
| Median | -0.7625 |
| 75% Percentile | 2.591 |
| Maximum | 40.59 |
| Range | 71.83 |
| | |
| Mean | -0.8364 |
| Std. Deviation | 11.41 |
| Std. Error of Mean | 1.525 |

# Morphological analysis

## Volume analysis




| | Global | Lumen | Thrombus |
|---|---|---|---|
| Minimum | -96.96 | -92.43 | -99.11 |
| 25% Percentile | -23.83 | -5.104 | -34.98 |
| Median | -6.122 | 9.367 | -13.47 |
| 75% Percentile | 6.730 | 21.33 | 8.012 |
| Maximum | 103.7 | 57.34 | 217.1 |
| Range | 200.7 | 149.8 | 316.2 |
| | | | |
| Mean | -5.467 | 4.689 | -9.758 |
| Std. Deviation | 33.88 | 28.93 | 52.53 |
| Std. Error of Mean | 4.527 | 3.866 | 7.083 |




Good correlation between Volume and Diameter

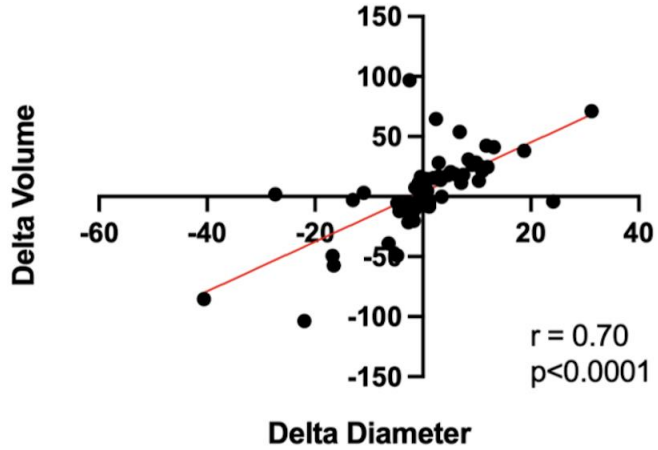
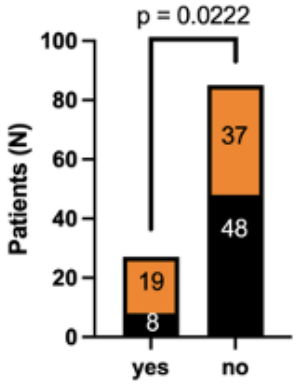
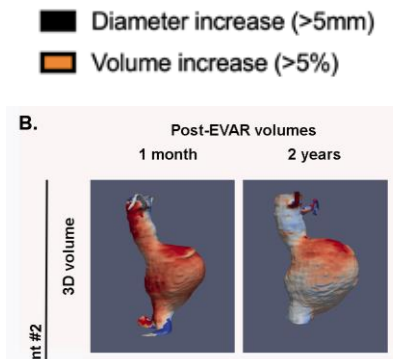


Illustration of Fisher's test comparing the distribution observed between the evolution of aneurysmal volume and the evolution of aneurysmal diameters

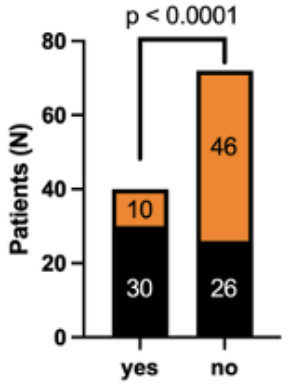
Aneurysm volume showed a better sensitivity in predicting aneurysm size increase overtime vs Dmax (p=0.0222)

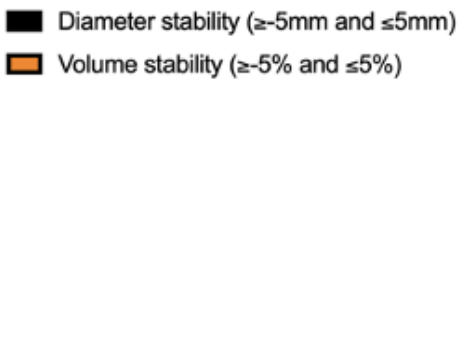


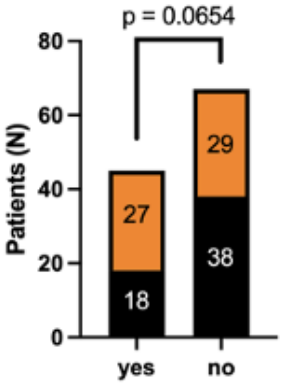







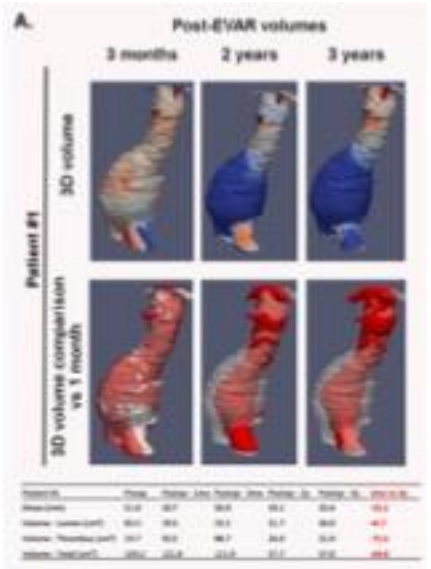




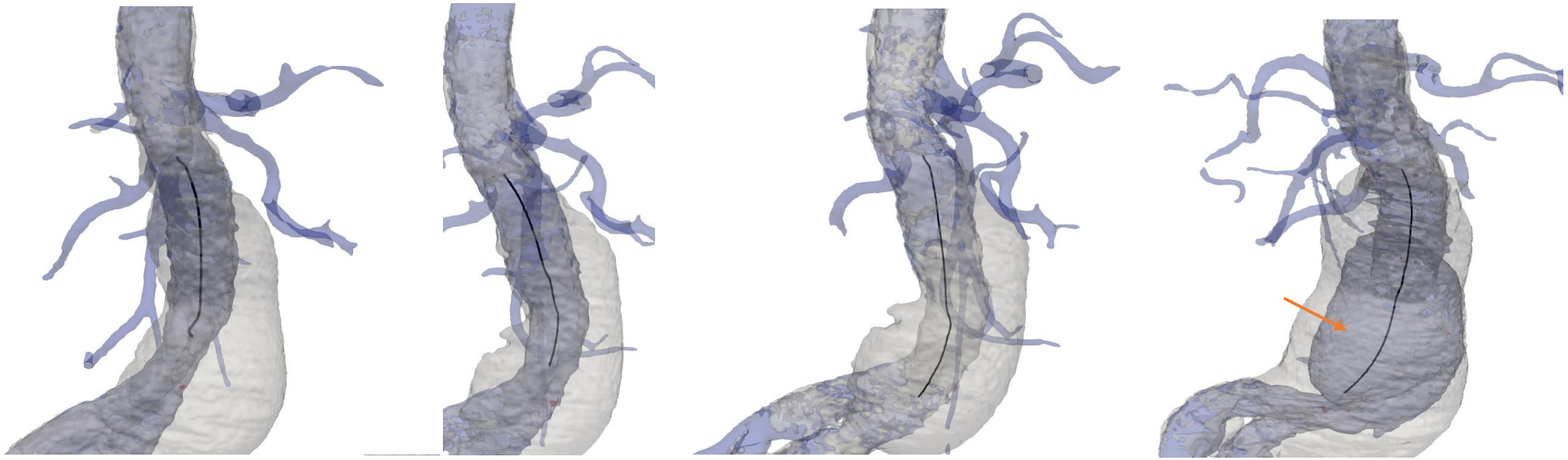





<2mm in Dmax
≃10% in vol

-15mm
<50% in vol

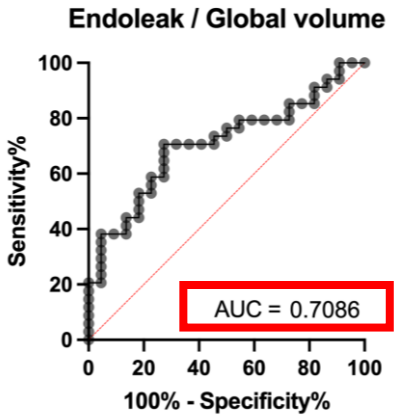
Reference distance for stentgraft disjunction detection: distance from lowest renal artery to stent bifurcation

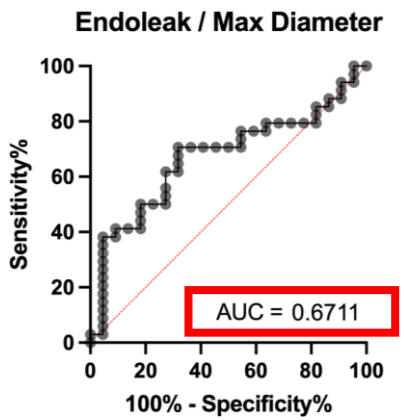


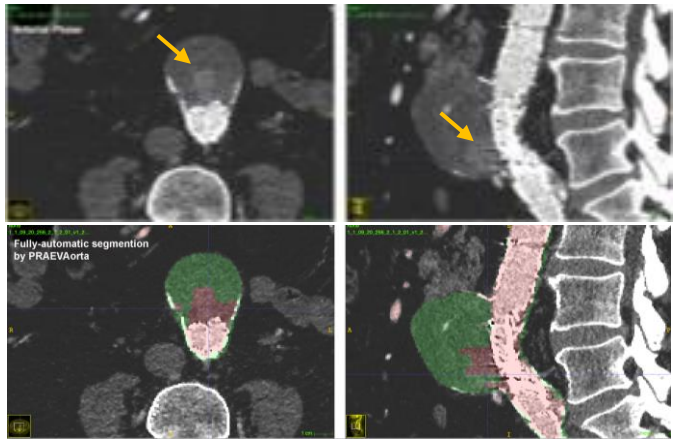
| | 2013 | 2014 | 2015 | 2019 |
|---|---|---|---|---|
| Dmax (mm) | 61.3 | 58.6 | 55.9 | 86.8 |
| Volume (cm3) | 290 | 269 | 252 | 641 |
| Distance (mm) | 78.6 | 99.7 | 113.3 | 142.3 |

# Endoleak detection

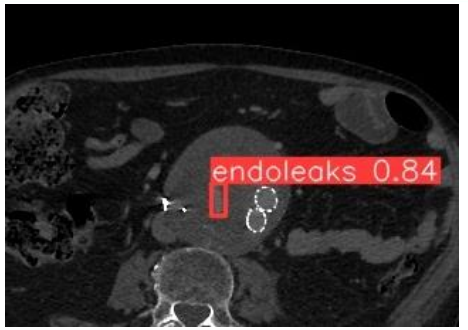
| | Value (%) | 95% CI |
|---|---|---|
| **PRAEVAorta (vs Senior Surgeon)** | | |
| **Sensitivity** | 89.47 | 80.58 to 94.57 |
| **Specificity** | 91.25 | 83.02 to 95.70 |
| **Positive Predictive Value** | 90.67 | 81.97 to 95.41 |
| **Negative Predictive Value** | 90.12 | 81.70 to 94.91 |

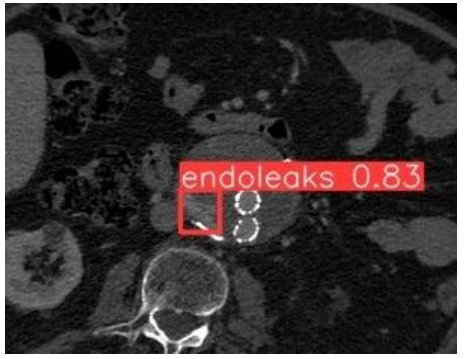


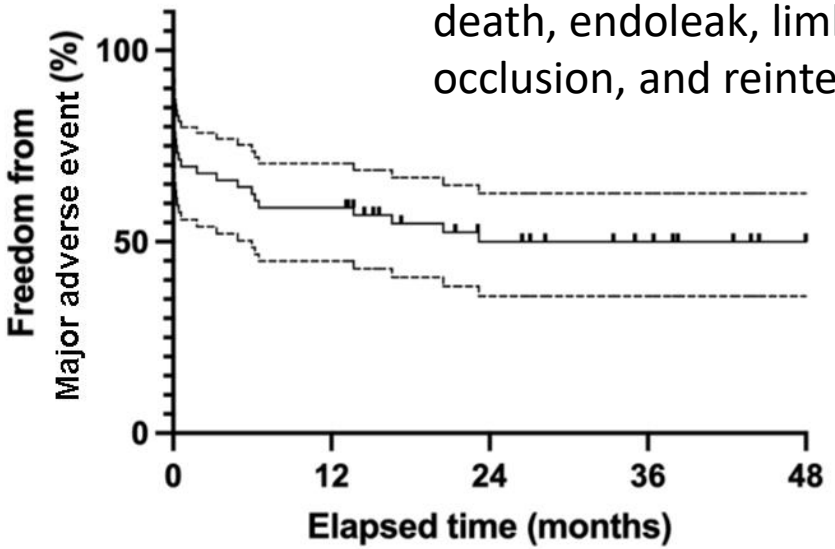

Lumen
Thrombus



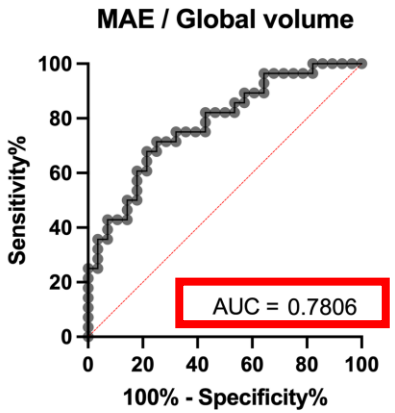



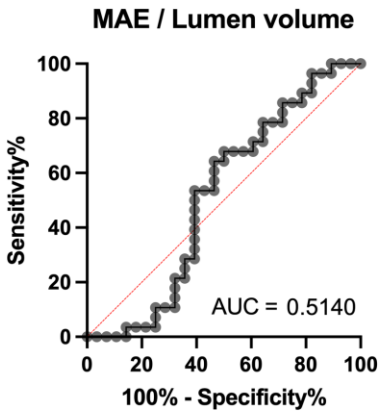

# Predictive performance of volume analysis for MAEs

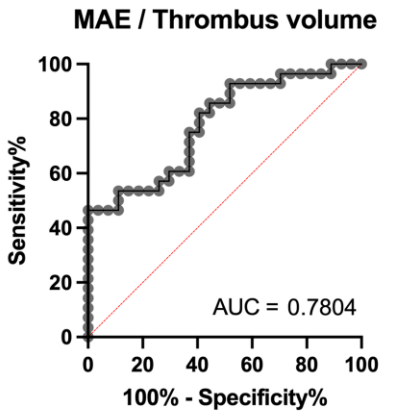
Major adverse events (MAEs) defined as aneurysm-related death, endoleak, limb occlusion, and reintervention.

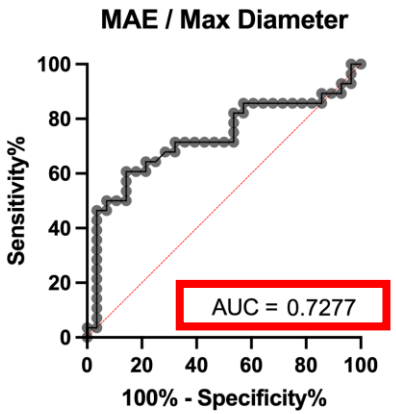



| | 0 | 12 months | 24 months | 36 months | 48 months |
|---|---|---|---|---|---|
| N at risk | 56 | 34 | 21 | 16 | 9 |
| Survival % | - | 58.9 | 50.0 | 50.0 | 50.0 |
| 95% CI | - | 44.9-70.5 | 35.8-62.6 | 35.8-62.6 | 35.8-62.6 |



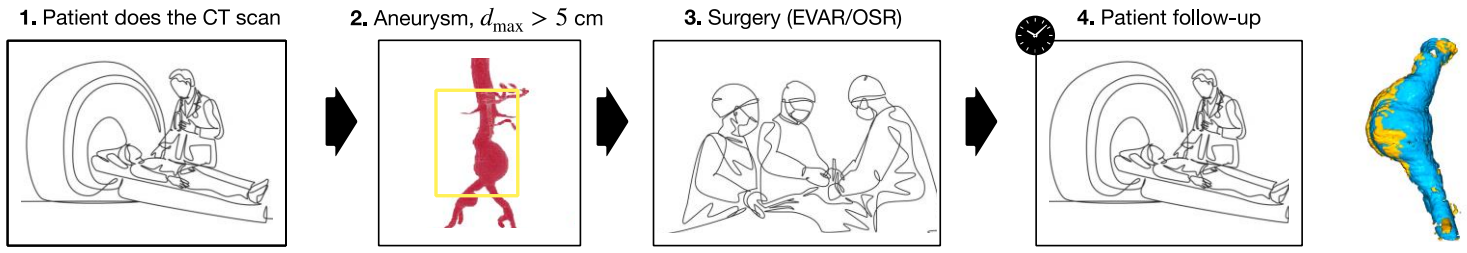



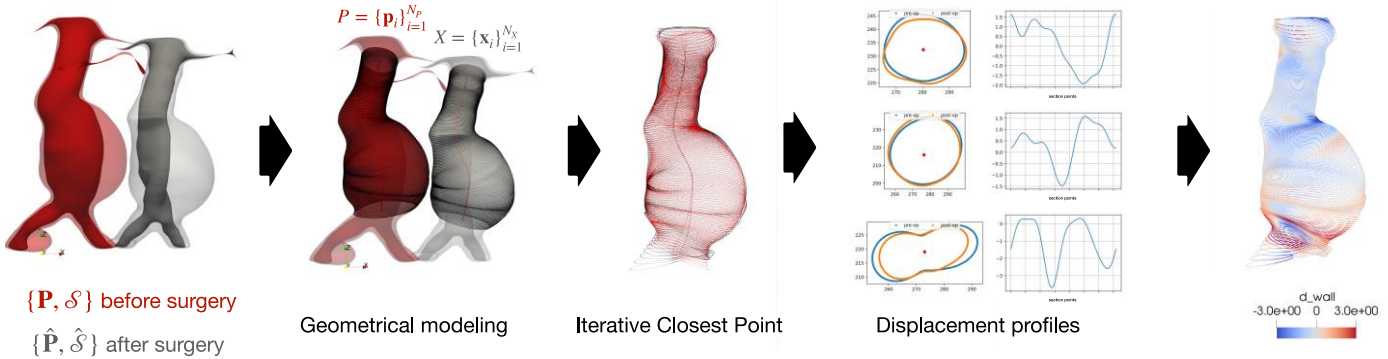



## Work in progress : shear stress analysis and risk of rupture

# **Registration pipeline.** Registered aneurysm



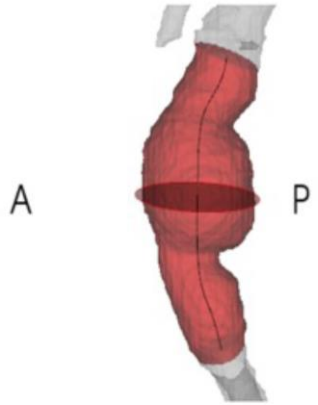





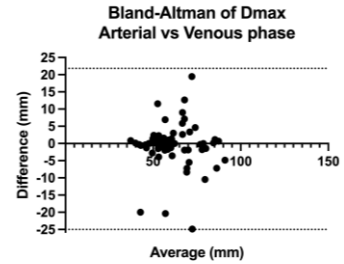

PhD : Vers l'évaluation du risque des AAA par modélisation géométrique et simulations hémodynamiques d'ordre réduit
Ludovica Saccaro, Angelo Iollo

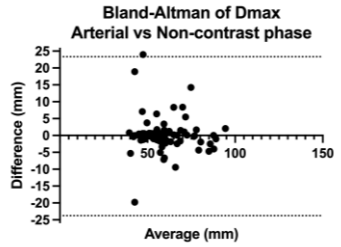
# Comparison of fully automatic segmentation using PRAEVAorta2 for diameters and volumes

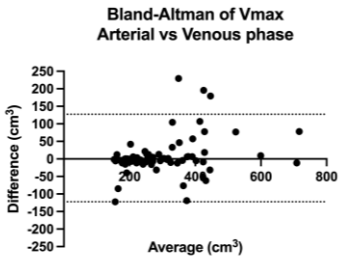
82 patients with arterial, venous and non-contrast phase CT

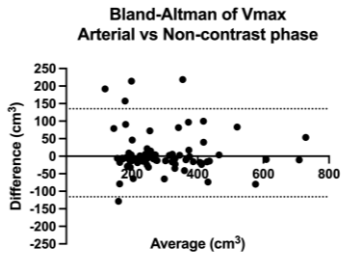



| Fully automatic segmentation | Arterial phase (ground truth) | Venous phase | p value | Non-contrast phase | p value |
|---|---|---|---|---|---|
| Max aortic transverse diameter (mm) | 60.2±12.4 | 61.8±18.7 | .476 | 60.4±17.3 | .540 |
| Global Volume ($cm^3$) | 298.2±125.9 | 295.8±16.4 | .445 | 288.5±125.4 | .186 |
| Lumen Volume ($cm^3$) | 153.8±62.0 | 159.5±64.7 | .014 | NA | NA |
| Thrombus Volume ($cm^3$) | 138.0±90.5 | 130.6±89.7 | .074 | NA | NA |
| Time for analysis (sec)* | 213.9±102.7 | 114.4±36.1 | <.001 | 140.0±288.7 | <.001 |



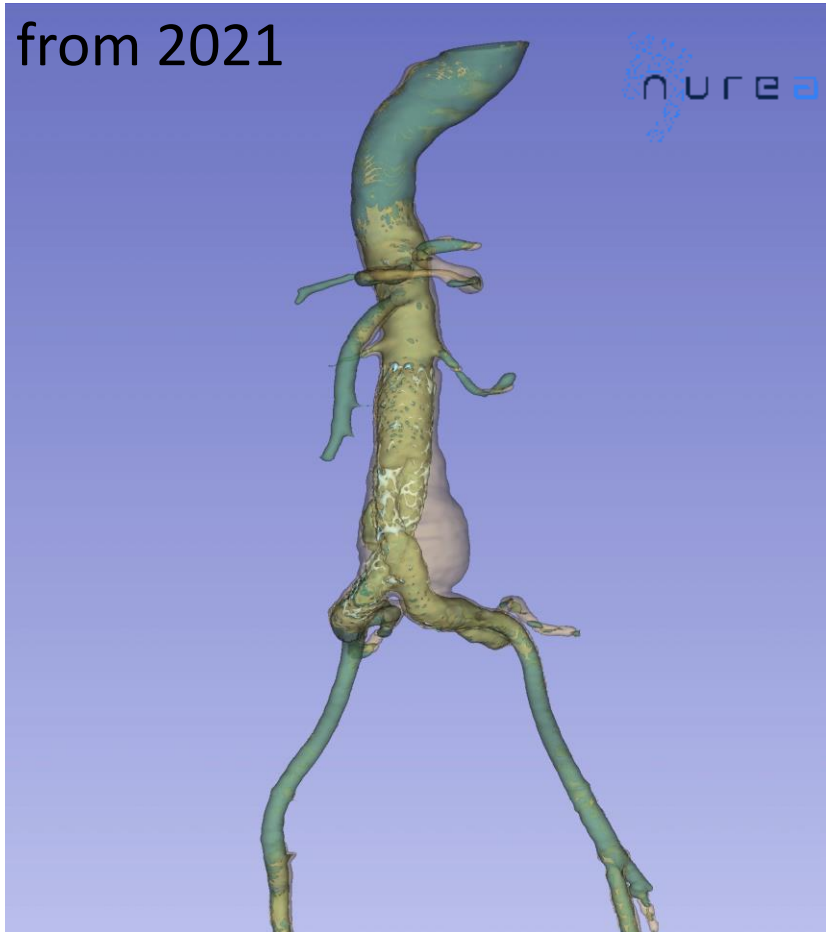



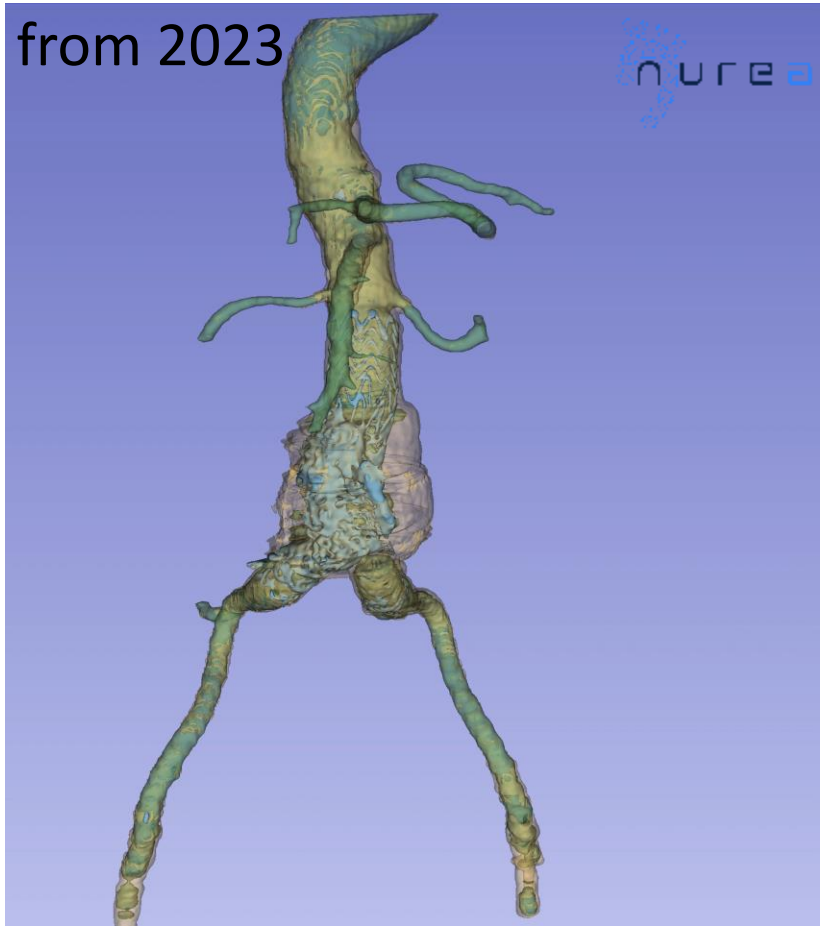

PRAEVAorta®2 algorithms produce comparable results for assessing Dmax and Vmax across the 3 different phases.

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



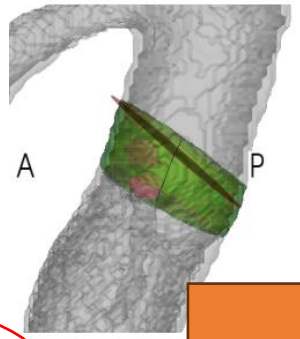



# Automated segmentation of the infra renal aorta with analysis :

- Max diameter
- Global volume/ lumen, wall volume
- Neck diameters, lengths and volumes

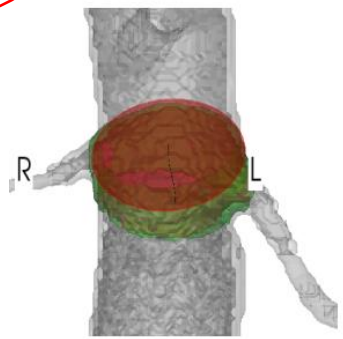
## Report edited for 2021

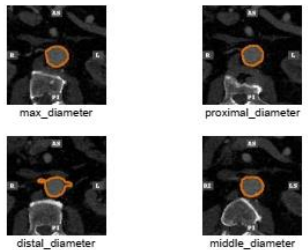
Patient's Name: P044




| | | |
|---|---|---|
| JuxtaRenalAorta | | |
| Diameter | max_diameter | 31.52 mm |
| | proximal_diameter | 30.17 mm |
| | distal_diameter | 30.72 mm |
| | middle_diameter | 30.79 mm |
| | lumen_min_diameter | 25.86 mm |
| | lumen_proximal_diameter | 28.17 mm |
| | lumen_distal_diameter | 29.15 mm |
| | lumen_middle_diameter | 28.35 mm |
| Length | ZAxis_distance | 9.40 mm |
| | StraightLine_distance | 10.77 mm |
| | Geodesic_distance | 10.86 mm |
| Tortuosity | Tortuosity | 1.01 |
| Volume | Lumen_volume | 6.07 cm3 |
| | Thrombus_volume | 1.47 cm3 |
| | Calcification_volume | 0.01 cm3 |

Infrarenal Maximal Diameter: 56.4 mm
Volume Infrarenal: 144.0 cm³



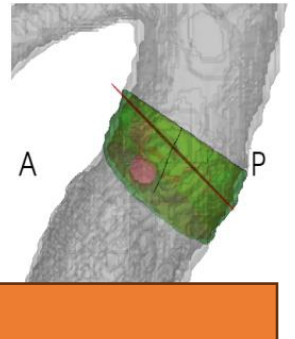




UDI: (01)03770023750004(11)221223(10)v1.0.2 7/19

Neck enlargement
Plan for FEVAR for increasing risk of type Ia EL after EVAR ??

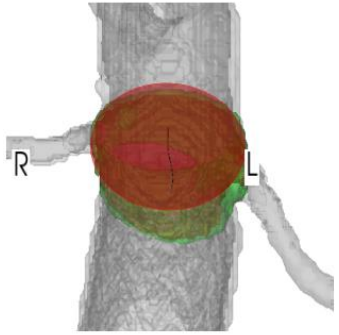
## Report edited for 2023

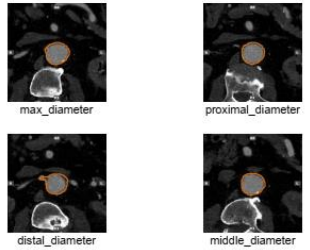
Patient's Name: P044




| | | |
|---|---|---|
| JuxtaRenalAorta | | |
| Diameter | max_diameter | 34.64 mm |
| | proximal_diameter | 32.90 mm |
| | distal_diameter | 33.44 mm |
| | middle_diameter | 33.86 mm |
| | lumen_min_diameter | 27.99 mm |
| | lumen_proximal_diameter | 29.96 mm |
| | lumen_distal_diameter | 28.39 mm |
| | lumen_middle_diameter | 31.04 mm |
| Length | ZAxis_distance | 10.98 mm |
| | StraightLine_distance | 12.76 mm |
| | Geodesic_distance | 12.96 mm |
| Tortuosity | Tortuosity | 1.02 |
| Volume | Lumen_volume | 8.42 cm3 |
| | Thrombus_volume | 1.79 cm3 |
| | Calcification_volume | 0.04 cm3 |
| | Total_volume | 10.26 cm3 |
| AWT_INDEX | AWT_index | 17.93 % |

Infrarenal Maximal Diameter: 67.5 mm
Volume Infrarenal: 166.6 cm³




UDI: (01)03770023750004(11)221223(10)v1.0.2 7/19

# 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