COMBINING **VOLUMETRIC** AND **WALL SHEAR STRESS** ANALYSIS FROM CT TO ASSESS **RISK** OF ABDOMINAL **AORTIC ANEURYSM PROGRESSION**

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ORIGINAL RESEARCH • VASCULAR AND INTERVENTIONAL RADIOLOGY

Radiology

Combining Volumetric and Wall Shear Stress Analysis from CT to Assess Risk of Abdominal Aortic Aneurysm Progression

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Conflicts of interest are listed at the end of this article.

See also the editorial by Mitsouras and Leach in this issue.

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INTRODUCTION

- Abdominal aortic aneurysm (AAA)
  - Serious common pathologic abnormality
  - Men >65yrs prev 7.7% → 8.9% >74yrs
- AAA diameter ←→ rupture rate
- Threshold 50-55 mm or growth >10mm/yr
- Model may be insufficient in small AAA
  - prediction of rapid growth
  - context of heterogeneous population

INTRO

- Volumetric analysis → promising technique
- Morphologic changes that do not change maximal diameter
- Combined with functional analyis of vascular flow
  - Computational fluid dynamics:
    - Pressure parameters
    - Shear stress-derived parameters

- **Purpose of study**: identify volumetric and computational fluid dynamics parameters to define parameters to identify AAAs that are most likely to increase in size

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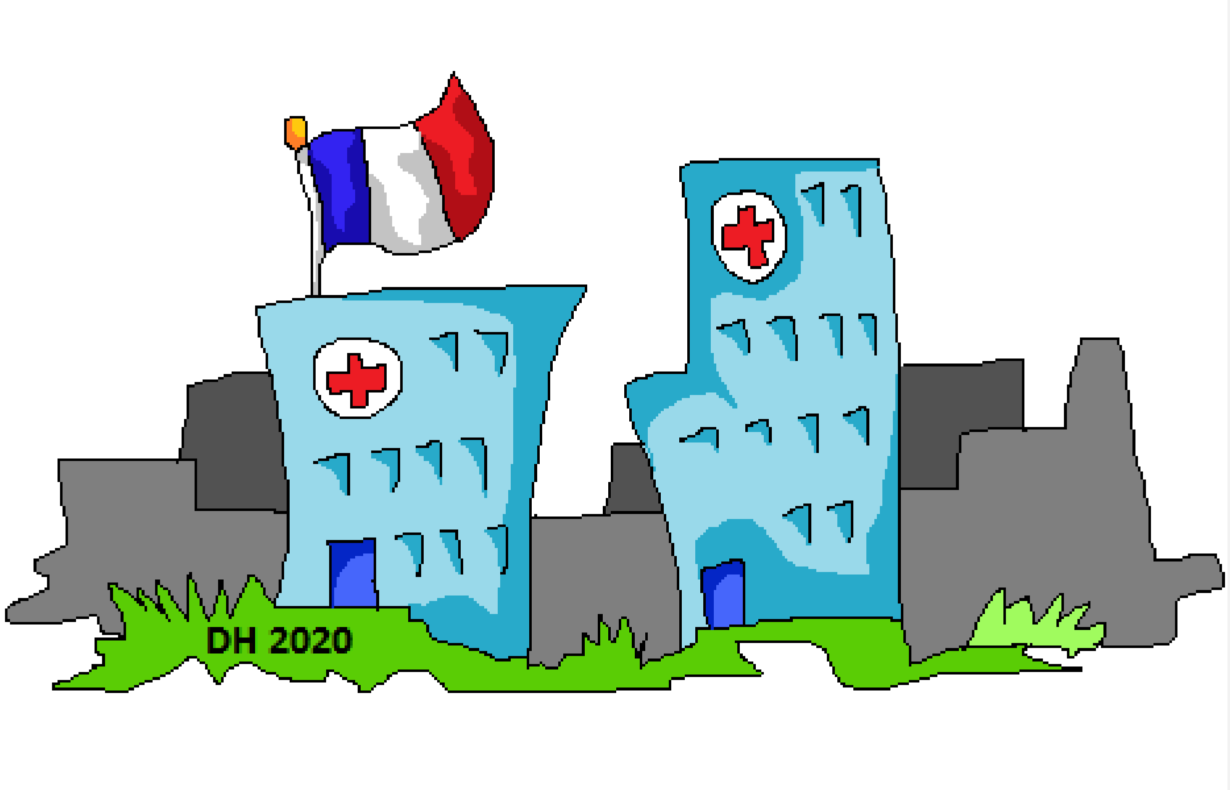
- Two university hospitals
- Referred to vascular surgery → inclusion
- Not included if:
  - acute aortic disease symptoms
  - aortic dissection
  - previous procedures
  - pregnancy
  - contraindication to contrast material-enhanced CT
  - incomplete CT imaging study
  - insufficient image quality



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CT Imaging

- Two CT examinations
- Interval of 1 yr
- CT scanner of 2 x 32 or 64 detector row
- All contrast enhanced
  - 100 mL of iodinated contrast material
- Scanned from base of neck to ischium

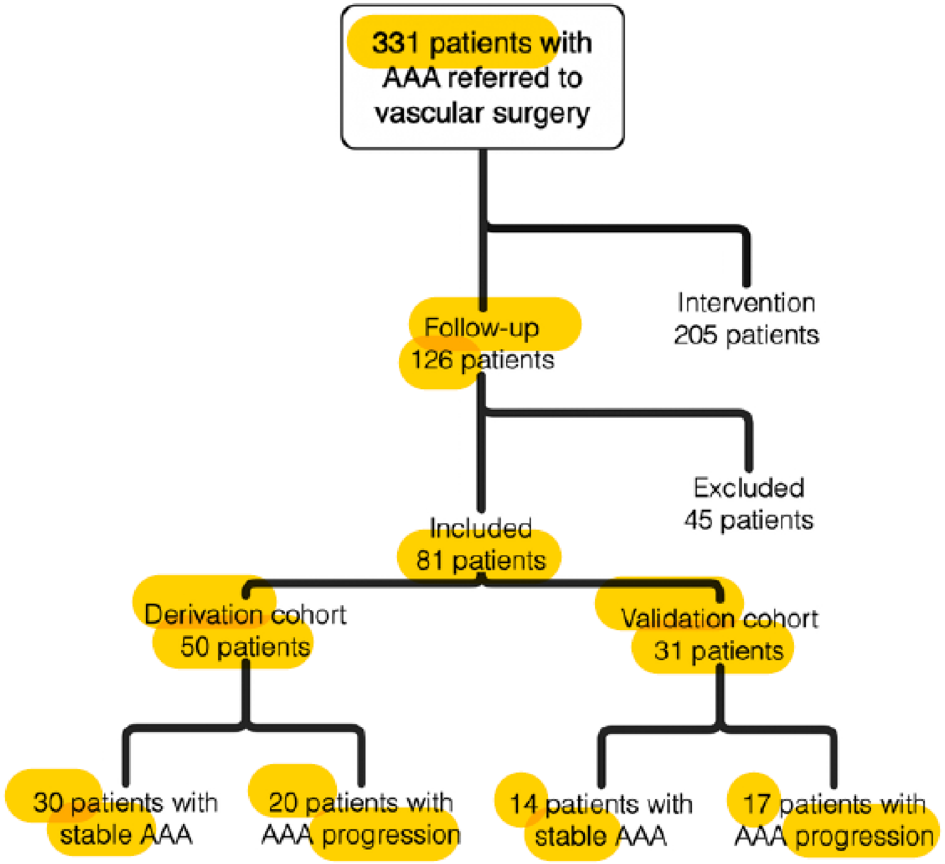

Figure 1: Flowchart of the study population. AAA = abdominal aortic aneurysm.

Table 1: Baseline Demographic and Clinical Characteristics of the Derivation and Validation Set Undergoing Computational Fluid Dynamics Analysis

Parameter	Derivation Set	Validation Set	*P* Value
Patient characteristic			
No. of study participants	50	31	
Age (y)	74 ± 7	72 ± 6	.27
No. of men	1 (2)	2 (6)	.31
Cardiovascular risk factors			
Hypertension	40 (80)	24 (77)	.78
Diabetes	15 (30)	5 (16)	.16
Dyslipidemia	43 (86)	21 (68)	.05
Ever smoked	44 (88)	21 (68)	<.001*
Coronary heart disease	12 (24)	10 (32)	.42
Intermittent claudication	4 (8)	8 (26)	.03*
Anticoagulant treatment	1 (2)	4 (13)	.12
BMI (kg/m²)	27 ± 4	27 ± 3.5	.76
Arterial pressure (mmHg)			
Systolic	133 ± 16	134 ± 14	.78
Diastolic	77 ± 9	75 ± 9	.33
Left ventricular ejection fraction (%)	61 ± 7	58 ± 6	.05
Abdominal aortic aneurysm characteristic			
Metrics			
Maximal diameter (mm)	47 ± 5	49 ± 4	.04*
<40 mm	5 (10)	0 (0)	
40–54 mm	41 (82)	19 (61)	
≥55 mm	4 (8)	12 (39)	
Volume (mL)	91 ± 35	99 ± 40	.35
Macroscopic shape			.23
Saccular	12 (24)	4 (13)	
Fusiform	38 (76)	27 (87)	
Presence of intraluminal thrombus	45 (90)	27 (87)	.69

Note.—Unless otherwise indicated, values are number of patients, with percentage in parentheses. Mean data are ± standard deviation. BMI = body mass index.

* *P* value less than .05 indicates statistical difference between derivation and validation sets.

Table 2: Comparison of Baseline, Mean Increases, and Follow-up Characteristics for Stable and Progression Groups in the Derivation Cohort

Parameter	Stable Group	Progression Group	*P* Value*
Baseline characteristic			
Total aneurysm volume (mL)	86 ± 40	100 ± 23	.11
Lumen	46 ± 18	60 ± 14	.005
Intraluminal thrombus	39 ± 29	40 ± 23	.74
Maximal diameter (mm)	46 ± 7	47 ± 4	.71
Maximal axial surface (cm²)	15 ± 4	16 ± 2	.10
Mean evolution characteristic			
Total aneurysm volume (mL)	3 ± 4	21 ± 14	<.001
Lumen	1 ± 6	4 ± 10	.02
Intraluminal thrombus	2 ± 7	17 ± 13	<.001
Maximal diameter (mm)	1 ± 2	4 ± 2	<.001
Maximal axial surface (cm²)	1 ± 1	2 ± 2	<.001
Follow-up characteristic			
Total aneurysm volume (mL)	89 ± 39	121 ± 33	.004
Lumen	47 ± 19	65 ± 18	<.001
Intraluminal thrombus	42 ± 29	56 ± 34	.11
Maximal diameter (mm)	47 ± 7	50 ± 4	.04
Maximal axial surface (cm²)	15 ± 4	18 ± 3	.01
Interval between CT scans (mo)	12 ± 3	12 ± 2	.06

Note.—Data are mean ± standard deviations.

* Comparison of the difference between stable and progression groups.

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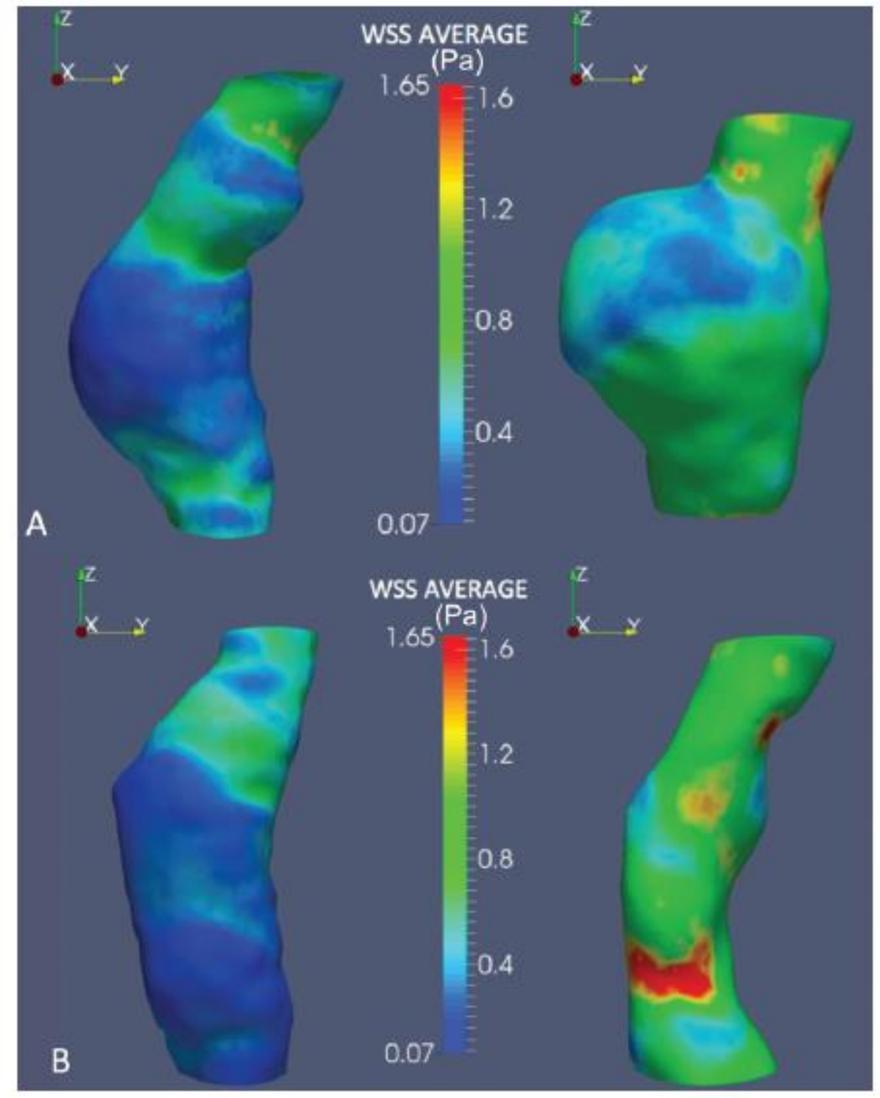
Statistical Analysis

- P value < .05 was considered to indicate a statistically significant difference

1) Derivation cohort (n=50) probability of progression
   - Threshold for volume progression >10 mL to classify patients (stable or progression groups)

2) Validation cohort (n=31)

3) Subanalysis of all aneurysms smaller than 50 mm (small aneurysm cohort)



RESULTS

- Prospective registry of infrarenal AAA included 331 patients
- Referral to surgical intervention n=205, not included

- Final group of 81 patients
- Mean maximal diameter was larger in validation cohort
- Intermittent claudication prevalence and ever-smoker status statistically different between groups (only values)

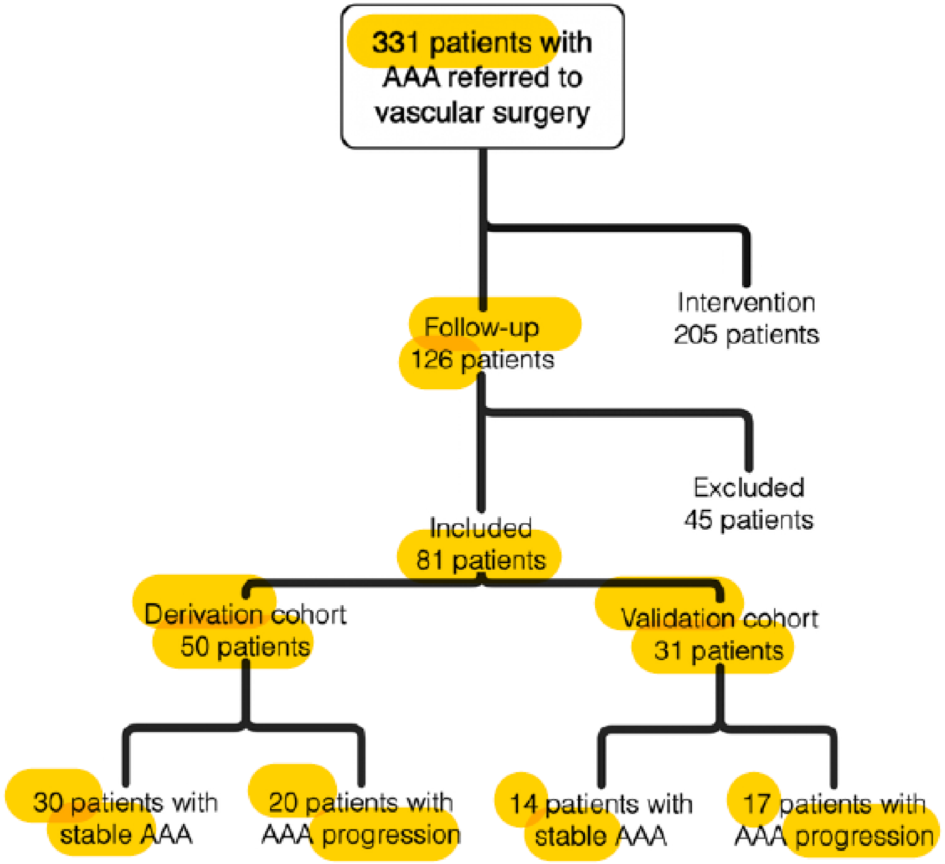


Figure 1: Flowchart of the study population. AAA = abdominal aortic aneurysm.

RESULTS

Derivation Cohort

- AAA **stable** in 30 patients and **progressed** in 20 patients
- Mean variation of volume was **21 mL** in progression group vs **3 mL** in stable group
- No difference between progression and stable groups for mean maximal diameter

Table 3: Comparison of Maximal Diameter versus a Regression Model for Predicting Aneurysm Progression

Parameter	Progression Threshold	Sensitivity (%)	Specificity (%)	AUC
Derivation cohort (*n* = 50)				
Maximal diameter	>42*	95 (19/20) [75, 100]	27 (8/30) [12, 46]	0.52 [0.36, 0.68]
Logistic regression model	>30†	90 (18/20) [68, 99]	60 (18/30) [41, 77]	0.78 [0.66, 0.91]
Validation set (*n* = 31)				
Maximal diameter	>42*	100 (17/17) [80, 100]	7 (1/14) [0, 34]	0.71 [0.51, 0.9]
Logistic regression model	>30†	76 (13/17) [50, 93]	86 (12/14) [57, 98]	0.79 [0.60, 0.97]
<50 mm aneurysm diameter set (*n* = 52)				
Maximal diameter	>42*	95 (19/20) [75, 100]	28 (9/32) [14, 47]	0.53 [0.37, 0.69]
Logistic regression model	>30†	80 (16/20) [56, 94]	81 (26/32) [64, 93]	0.79 [0.65, 0.93]

Note.—Data in parentheses are numerator/denominator; data in brackets are 95% confidence intervals. The regression model was on the basis of a probability greater than 30% of aneurysm progression from the derivation cohort and included lumen volume and wall shear stress. Results are shown for the derivation cohort, the validation cohort, and all study participants who had abdominal aortic aneurysm smaller than 50 mm. AUC = area under the receiver operating characteristic curve.

* Data are millimeters.

† Data are percentages.

RESULTS

Validation Cohort

- AAA **stable** in 14 patients and **progressed** in 17 (total 31) patients
- No difference between proposed and classical model

Small Aneurysm Cohort

- **Smaller than 50 mm** at baseline (n=52)
- This model provided (in this group) statistically better AUC (area under the receiver operating characteristic curve) than maximal diameter

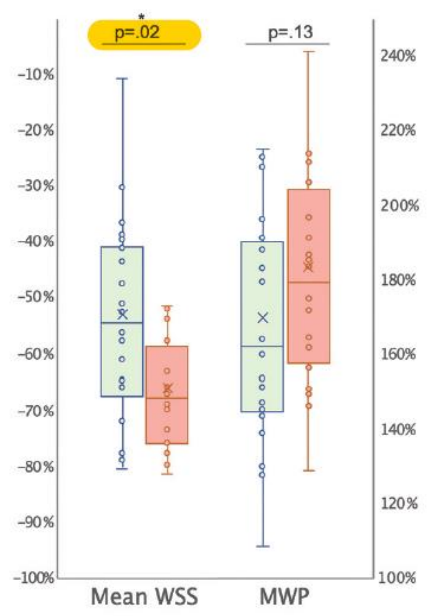


Figure 3: Box plot comparison of initial indexed computational flow dynamic characteristics for stable and progression aneurysm groups in the derivation cohort. The stable group and the progression group correspond to the green boxes and red boxes, respectively. Wall shear stress (WSS) reduction was higher in the progression group than in the stable group (−66% vs −53%, respectively; $P = .02$). There was no difference in maximal wall pressure (MWP) between the progression and the stable group (183% vs 169%, respectively; $P = .13$). Percentage scales on the left and right sides are for indexed mean WSS values and MWP values, respectively.

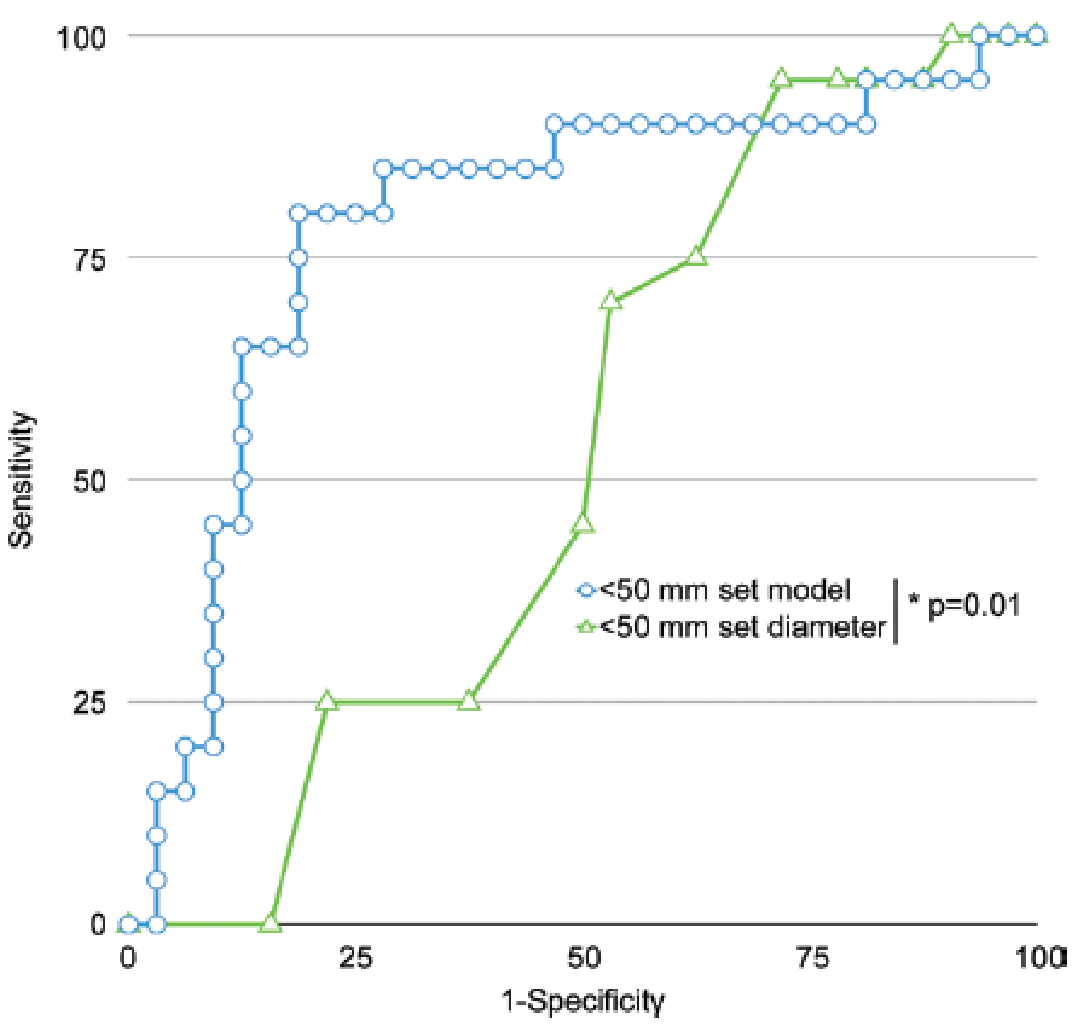


Figure 5: Receiver operating characteristic curves of maximal diameter measurement (triangles) and regression model including lumen volume and wall shear stress for predicting progression (circles) for aneurysms smaller than 50 mm in diameter (51 patients). The regression model provided statistically better areas under the receiver operating characteristic curve than maximal diameter alone (0.79 vs 0.53, respectively; $P = .01$).

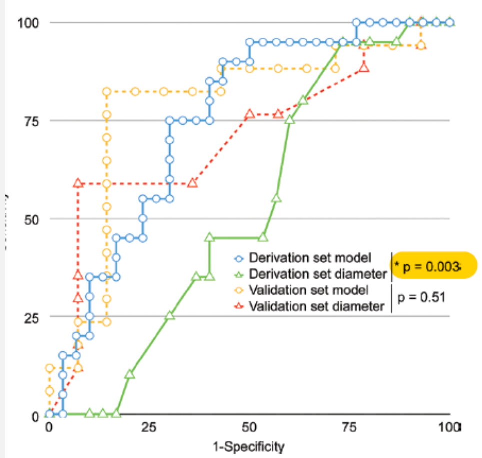


Figure 4: Receiver operating characteristic curves of a regression model that included lumen volume and wall shear stress (circles) versus maximal diameter measurement alone (triangles) for predicting aneurysm progression for the derivation set (solid lines, 50 patients) (area under the receiver operating characteristic curve [AUC], 0.78 vs 0.52, respectively; $P = .003$). Data from the validation set (dashed lines, 31 patients) are also shown (AUC, 0.79 vs 0.71 for the regression model versus maximal diameter measurement alone, respectively; $P = .51$).

DISCUSSION

Population-wide screening programs

→ Increased detection rates of small AAAs

→ development of different prognostic tools

→ assessment of progression risk of AAA

DISCUSSION

Significant correlation (←→ AAA growth at 1 yr):

- **greater lumen volumen -** prothrombotic factor (greater surface of interaction between blood and pathologic aortic wall)
- **lower shear stress -** correlated with aneurysmal growth

- High WSS values → protective role from aneurysmal growth (antithrombotic factor)
- blood flow-induced mechanical degradation of intraluminal thrombus

- Better **AUC** and **prognostic characteristics** than if using maximal diameter alone (AAAs <50 mm maximal diameter)
  - AUC: ↑ **0.79** vs ↓ **0.53**
  - Useful model in early AAAs

- Strength of model combining **morphologic** and **functional parameters** with **antagonistic actions**

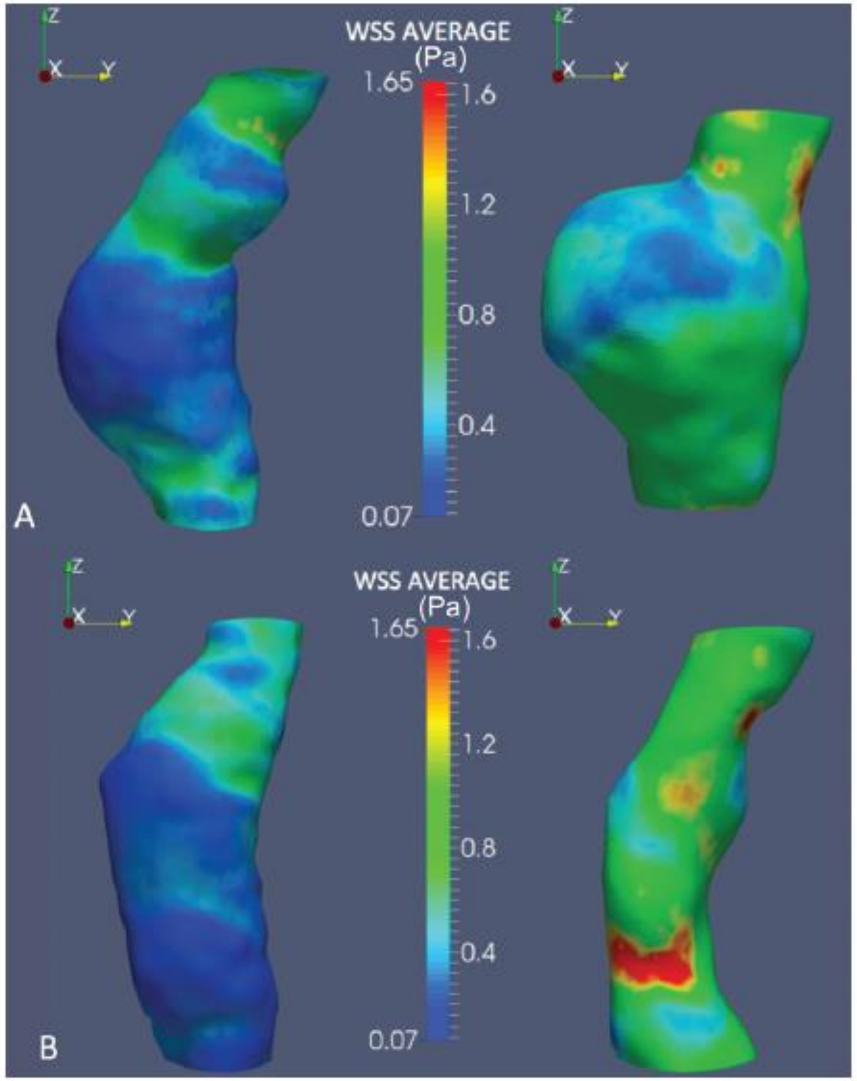


Figure 2: Comparison of wall shear stress (WSS) pattern on the lumen wall. Images show, *A*, aneurysms with saccular morphologic structure and, *B*, aneurysms with fusiform morphologic structure. Regardless of macroscopic shape, aneurysms from the progression group (left side) show low WSS values, whereas aneurysms from the stable growth group (right side) show high WSS values on the lumen wall.

DISCUSSION

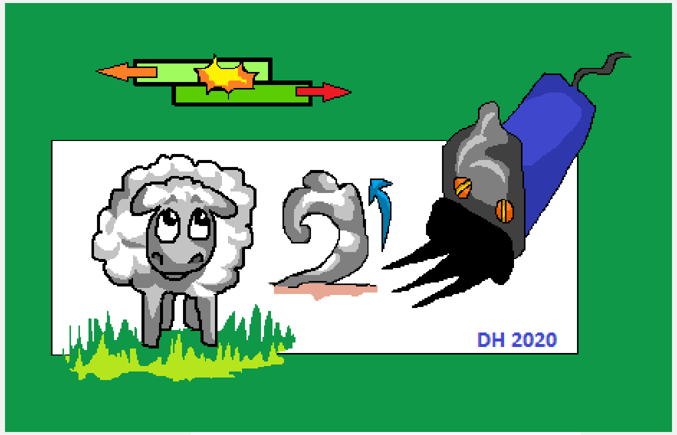
- Better **AUC** and **prognostic characteristics** than if using maximal diameter alone (AAAs <50 mm maximal diameter)
  - AUC: **0.79** vs **0.53**
  - Useful model in early AAAs

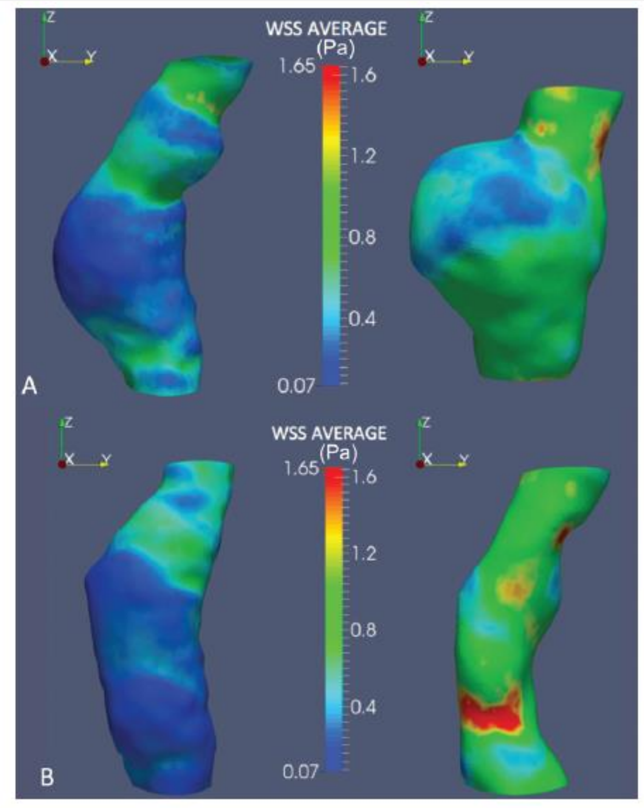
CONCLUSION

- High wall shear stress within aneurysm
→ protective factor regarding growth rate

- Increased lumen volume correlated with aneurysmal volumetric growth

- Model integrating these two antagonistic factors
→ better prognostic values for assessing AAAs progression risk than maximal diameter alone, especially when <50mm





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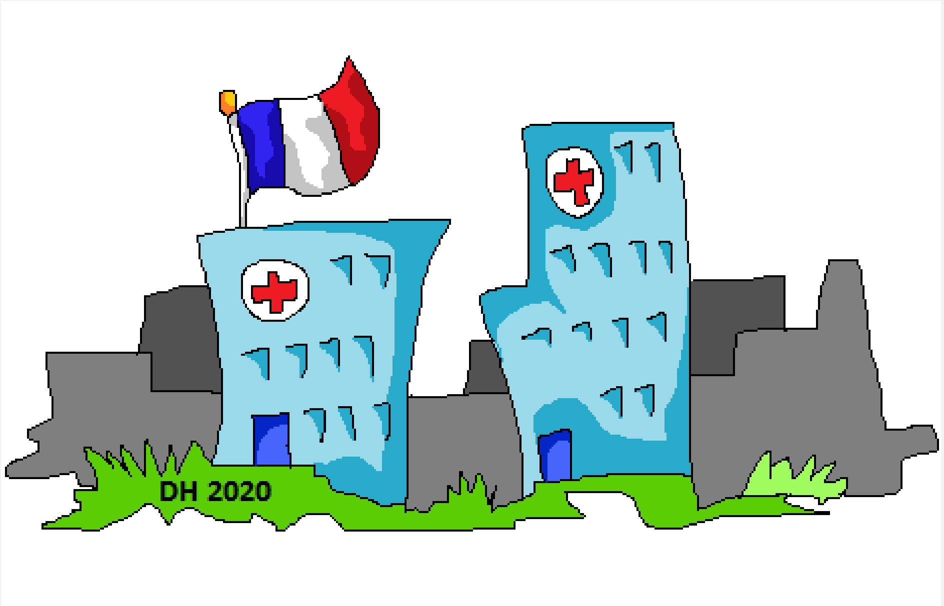

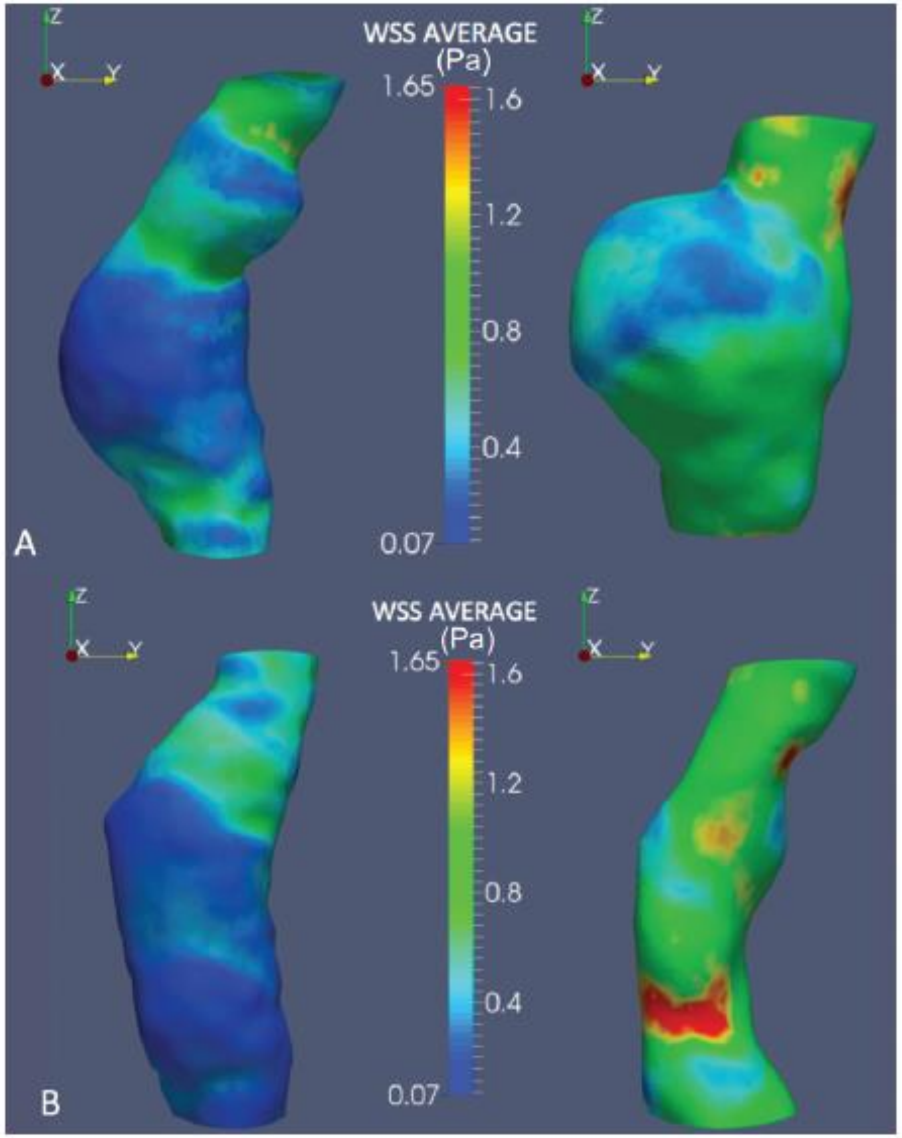

THANK YOU!