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Intraluminal Thrombus Predicts Rapid Growth of Abdominal Aortic Aneurysms

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

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Background: Intraluminal thrombus (ILT) within abdominal aortic aneurysms (AAAs) may be a potential marker for subsequent aneurysm growth.

Purpose: To investigate the role of ILT in AAA progression as assessed with CT and MRI.

Materials and Methods: This was a retrospective study, with patient data included from January 2004 to December 2018 at a Veteran Affairs medical center. Male patients with AAA who underwent contrast material–enhanced CT at baseline and CT or black-blood MRI at follow-up (minimal follow-up duration of 6 months) were included. The maximal AAA diameter was measured with multiplanar reconstruction, and the annual growth rate of aneurysms was calculated. Uni- and multivariable linear regression analyses were used to determine the relationship between demographic and imaging factors and aneurysm growth.

Results: A total of 225 patients (mean age, 72 years ± 9 [standard deviation]) were followed for a mean of 3.3 years ± 2.5. A total of 207 patients were followed up with CT, and 18 were followed up with MRI. At baseline, the median size of the AAA was 3.8 cm (interquartile range [IQR], 3.3–4.3 cm); 127 of 225 patients (54.7%) had ILT. When compared with AAAs without ILT, AAAs with ILT had larger baseline diameters (median, 4.1 cm [IQR, 3.6–4.8 cm] vs 3.4 cm [IQR, 3.2–3.9 cm]; $P < .001$) and faster growth rates (median, 2.0 mm/y [IQR, 1.3–3.2 mm/y] vs 1.0 mm/y [IQR, 0.4–1.8 mm/y]; $P < .001$). Small AAAs (size range, 3–4 cm) with ILT grew 1.9-fold faster than did those without ILT (median, 1.5 mm/y [IQR, 0.9–2.7 mm/y] vs 0.8 mm/y [IQR, 0.3–1.5 mm/y]; $P < .001$). Medium AAAs (size range, 4–5 cm) with ILT had 1.2-fold faster growth than did those without ILT (median growth, 2.1 mm/y [IQR, 1.4, 3.7 mm/y] vs 1.8 mm/y [IQR, 0.9, 2.0 mm/y]; $P = .06$). In multivariable analysis, baseline diameter and ILT were independently positively related to aneurysm growth rate (standardized regression coefficient, 0.43 [$P < .001$] and 0.15 [$P = .02$], respectively).

Conclusion: Both maximal cross-sectional aneurysm diameter and the presence of intraluminal thrombus are independent predictors of abdominal aortic aneurysm growth.

Online supplemental material is available for this article.

Abdominal aortic aneurysm (AAA) disease is common and associated with high mortality (1). Approximately 200 000 people in the United States are diagnosed with AAAs per year, and ruptured AAA is the 10th leading cause of death in men older than 55 years (2). Currently, clinical management of patients with asymptomatic AAA is determined primarily by the maximal aneurysm diameter. Patients with AAAs larger than 5.5 cm are normally referred for elective repair, whereas AAAs smaller than 5.5 cm are most commonly followed with serial imaging at 6-month to 3-year intervals, depending on their size (2). This diameter-based management strategy has limitations, however, as a considerable number of small aneurysms rupture (1). Additional aneurysm features, including intraluminal thrombus (ILT), aneurysm wall inflammation, and biomechanical vessel wall stress, have been investigated as potential markers of rapid AAA growth and rupture (3–6).

ILT is present in the majority of aneurysms close to the repair threshold of 5.5 cm and in a considerable number of smaller aneurysms. Despite being common, the influence of ILT on AAA growth and rupture risk is still not fully understood, which is likely due to competing mechanical and biochemical effects. Studies demonstrate that ILT effectively reduces the mechanical stress experienced by the vessel wall (7–9). On the other hand, ILT can also induce hypoxia and mediate inflammatory processes that weaken the arterial wall (10,11). A few longitudinal studies have investigated the relationship between ILT and AAA growth and have found that ILT size, coverage, and volume were associated with AAA growth (3,12–14). However, these prior studies may be limited by *(a)* the use of US to measure AAA growth rate with large interoperator variability, *(b)* lack of multiplanar reconstruction (MPR) to measure the true maximal diameter of often

Abbreviations

AAA = abdominal aortic aneurysm, BMI = body mass index, ICC = intraclass correlation coefficient, ILT = intraluminal thrombus, IQR = interquartile range, MPR = multiplanar reconstruction

Summary

Intraluminal thrombus was an independent predictor of abdominal aortic aneurysm growth in a large patient cohort with repeated CT or MRI.

Key Results

- When compared with abdominal aortic aneurysms (AAAs) without intraluminal thrombus (ILT), AAAs with ILT had larger baseline diameters (median, 4.1 cm vs 3.4 cm, $P < .001$) and faster growth rates (median, 2.0 mm/y vs 1.0 mm/y, $P < .001$).
- In 3–4-cm AAAs at baseline, those with ILT grew 1.9 times faster than did those without ILT ($P < .001$).
- In multivariable analysis adjusted for baseline diameter and other risk factors, the presence of ILT was associated with aneurysm growth (0.54 mm/y greater when ILT was present, $P = .02$).

tortuous aortic geometries, and *(c)* small sample size and short follow-up duration.

This study aims to investigate the role of ILT in relation to the growth of AAA using thin-section cross-sectional imaging (CT or volumetric black-blood MRI) using MPR AAA diameter in a large cohort of patients. We hypothesized that the presence of ILT would be associated with more rapid AAA growth.

Materials and Methods

Study Population

This is a retrospective study. The institutional review board of University of California, San Francisco, and the San Francisco Veterans Affairs Medical Center approved this study, and the requirement for patient consent was waived by the institutional review board. This study was conducted in compliance with the Health Insurance Portability and Accountability Act. One author (M.D.H.) had full access to all data in the study and takes responsibility for its integrity and the data analysis. By querying the database of clinical radiology reports generated from January 2004 to December 2018, veterans with AAA detected with CT, high-spatial-resolution black-blood MRI, or PET/CT were identified. From this pool of patients, final study inclusion criteria were as follows: *(a)* patients underwent contrast material–enhanced CT at baseline with presence of AAA (abdominal aortic diameter ≥3 cm as measured with MPR) and *(b)* availability of a follow-up CT or MRI scan at least 6 months after the initial study. Exclusion criteria were as follows: *(a)* endovascular or open AAA repair prior to or within the imaging interval, *(b)* poor image quality not permitting reliable measurement of the aneurysm dimensions, and *(c)* saccular aneurysm morphology or aneurysms thought to be mycotic in origin or with concomitant dissection.

Demographic information for the study population, including age, smoking history, and presence or absence of hypertension, diabetes, and ischemic heart disease, was also recorded.

Image Acquisition

All CT studies were acquired helically by using clinical CT or multidetector CT scanners and standard institutional protocols. For each patient, the initial examination was a contrast-enhanced CT study, and a wide variety of CT protocols were used, including CT angiography, routine portal venous phase CT, and multiphase CT evaluation of hepatic, pancreatic, or renal masses. Similarly, a wide range of CT techniques is represented in the data, reflecting the changes in scanners and imaging technologies over the 14-year period. Nearly 90% of CT examinations were performed with GE Healthcare (Milwaukee, Wis) scanners, including several from the Lightspeed family, Discovery CT750 HD, and Revolution CT. A 120-kVp tube potential was common to all studies, with the exception of those performed using a dual-energy system, and automatic tube current modulation was applied in all examinations. Images were reconstructed at 1–5-mm thickness.

Black-blood MRI scans were acquired at 3 T (Magnetom Skyra; Siemens Healthcare, Erlangen, Germany) with an 18-channel body coil. A fast spin-echo sequence with variable flip angle (Sampling Perfection with Application-optimized Contrasts using Different Flip Angle Evolutions [SPACE]) and Delay Alternating with Nutation for Tailored Excitation (DANTE) blood suppression was used (DANTE-SPACE [15]). Images were acquired in the coronal plane during free breathing, with aortic coverage from the renal arteries to the aortoiliac

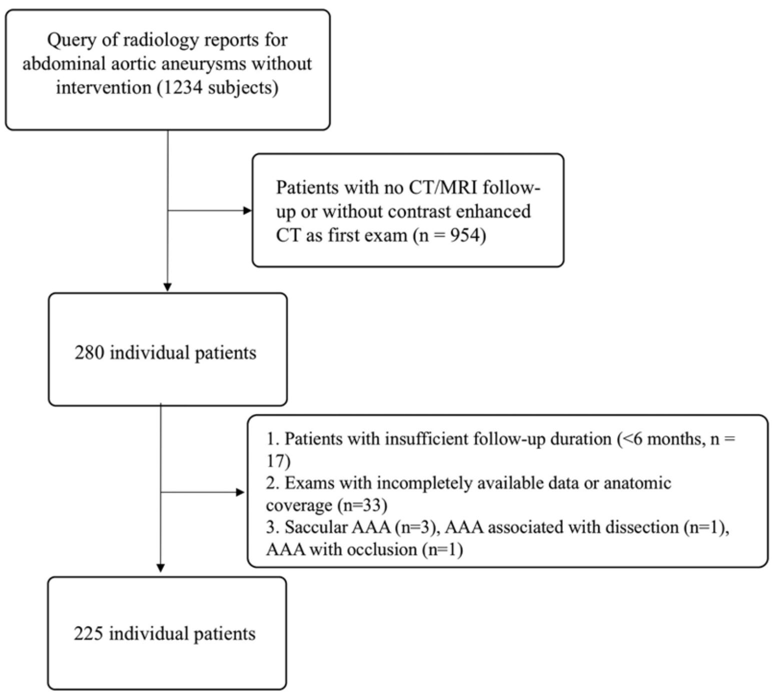

Figure 1: Patient selection flowchart. AAA = abdominal aortic aneurysm.

bifurcation. Imaging parameters were as follows: repetition time msec/echo time msec, 800/20; field of view, 32 × 32 cm; and 52 coronal slices with 1.3-mm thickness. A typical scanning time of 7 minutes yielded an isotropic resolution of 1.3 mm. Previous studies showed that black-blood MRI was as accurate as CT and that its resulting maximal diameter measurements were interchangeable (16).

Table 1: Demographic Data of Male Patients with and without Intraluminal Thrombus (ILT)

Characteristic	All (*n* = 225)	With ILT (*n* = 123)	Without ILT (*n* = 102)	*P* Value
Age (y)*	72 ± 9	72 ± 9	73 ± 10	.59
Hypertension †‡	170 (75.5)	90 (73.2)	80 (78.4)	.44
Diabetes mellitus‡	44 (19.6)	20 (16.3)	24 (23.5)	.18
Smoking history‡	65 (28.9)	44 (35.8)	21 (20.6)	.02
Baseline diameter (cm)*	3.8 (3.3–4.3)	4.1 (3.6–4.8)	3.4 (3.2–3.9)	<.001
Growth rate (mm/y)*	1.5 (0.8–2.6)	2.0 (1.3–3.2)	1.0 (0.4–1.8)	<.001

* Continuous variables are reported as mean ± standard deviation or median and interquartile range.
† Hypertension is defined as resting blood pressure of less than 140/90 mm Hg.
‡ Categorical variables are reported as number, with the corresponding percentage in parentheses.

Image Analysis

All images were transferred in Digital Imaging and Communications in Medicine format to an offline workstation, and analysis was performed with a commercial medical image viewer (Horos, version 3.0; *https://horosproject.org/*). Two reviewers with 6 and 8 years of experience (C.Z. and J.R.L., respectively) in reviewing abdominopelvic CT and black-blood MRI scans performed the image review and measurements. The maximal diameters of the AAAs were measured with an MPR method (16). By viewing the coronal and sagittal plane at the same time, the oblique axial plane that was perpendicular to the central line of the aorta was selected for the measurements. The reviewers moved the planes up and down to find the maximal diameter location. The AAA diameters at the earliest (baseline diameter) and latest time points were recorded, and the annual growth rate (millimeters per year) of each AAA was calculated as follows: (AAA diameter at the latest time point−AAA diameter at baseline)/follow-up duration in years.

At baseline, ILT was defined as present if the ILT plus wall thickness was greater than 5 mm on contrast-enhanced CT images. In the plane of maximal AAA diameter, the ILT and wall and lumen areas were recorded. Maximal ILT thickness in this plane was also recorded. The ILT area percentage was calculated as ILT area/total AAA area × 100%.

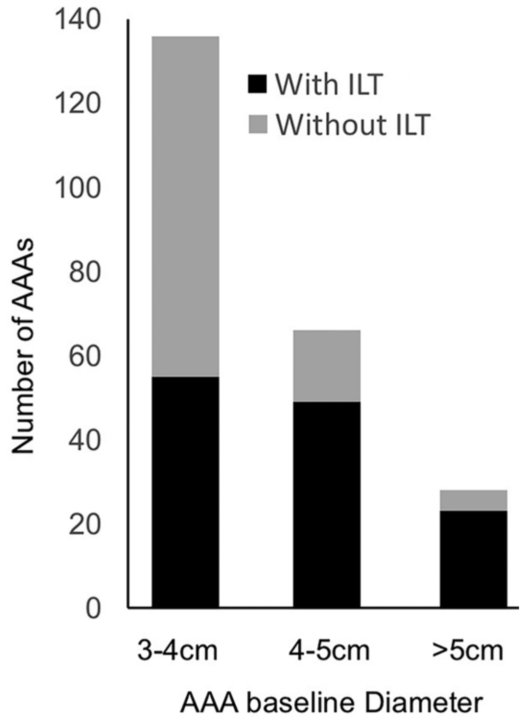

Figure 2: Distribution of intraluminal thrombus (ILT) across abdominal aortic aneurysm (AAA) diameter.

Statistical Analyses

Data were assessed for normality by using the Shapiro-Wilk test. Continuous data were summarized by using the mean ± standard deviation or median and interquartile range (IQR). Categorical data were expressed as counts or percentages. Continuous data were compared by using either the Mann-Whitney *U* test or Student *t* test. Categorical variables were analyzed by using the Fisher exact test. Spearman rank correlation was used to describe the correlation between measured parameters and AAA growth rate.

In 30 randomly selected data sets, both reviewers measured the AAA diameter, ILT thickness, and lumen and ILT area. The reproducibility of measurements was evaluated with the intraclass correlation coefficient (ICC) and coefficient of variation (which is equal to standard deviation between measurements/mean × 100%). Uni- and multivariable linear regression were performed to find the independent predictors of aneurysm growth. Unstandardized regression coefficients (β, with 95% confidence interval [CI]) and standardized regression coefficients (β) were recorded.

Post hoc sample size was calculated by using power analysis with 90% power and a 5% significance level (17). Post hoc sensitivity analysis for imaging modalities was performed by comparing the linear regression results obtained using only CT with the results obtained using combined CT and MRI data.

A *P* value of less than .05 was considered to indicate a significant difference. All *P* values were two-sided. Data analysis was performed with SPSS software (version 26.0; IBM, Armonk, NY).

Results

In total, 225 patients (all male, mean age, 73 years ± 9) were included in this study. The patient selection flowchart is shown in Figure 1. The median AAA diameter was 3.8 cm (IQR, 3.3–4.3 cm) at baseline, and 123 patients had AAAs containing ILT (54.7%) in the initial imaging examination. After mean follow-up of 3.3 years ± 2.5 (range, 0.5–9 years), the aneurysms

Table 2: Growth Rate of Abdominal Aortic Aneurysm by Diameter Range and Intraluminal Thrombus Status

Subgroup Based on Baseline Diameter (*n*)	ILT*	Baseline Diameter (cm)	*P* Value	Growth Rate (mm/y)	*P* Value
All (225)	...	...	<.001	...	<.001
Yes	123	4.1 (3.6–4.7)	...	2.0 (1.3–3.2)	...
No	102	3.4 (3.2–3.9)	...	1.0 (0.4–1.8)	...
3–4 cm (133)	...	...	.01		<.001
Yes	53	3.5 (3.2–3.8)	...	1.5 (0.9–2.7)	...
No	80	3.3 (3.2–3.6)	...	0.8 (0.3–1.5)	...
4–5 cm (64)	...	...	.07		.06
Yes	47	4.4 (4.2–4.7)	...	2.1 (1.4–3.7)	...
No	17	4.2 (4.2–4.3)	...	1.8 (0.9–2.0)	...
5–5.5 cm (17)	...	...	.48		.56
Yes	14	5.2 (5.1–5.4)	...	2.6 (2.1–4.4)	...
No	3	5.4 (5.2–5.4)	...	3.3 (3.1–4.9)	...
>5.5 cm (11)	...	...	.74		.37
Yes	9	5.8 (5.6–6.2)	...	3.1 (3.1–6.6)	...
No	2	5.9 (5.8–6.0)	...	2.1 (1.4–2.8)	...

Note.—Unless otherwise indicated, data are medians, and data in parentheses are the interquartile range. ILT = intraluminal thrombus.
* Data are numbers of patients.

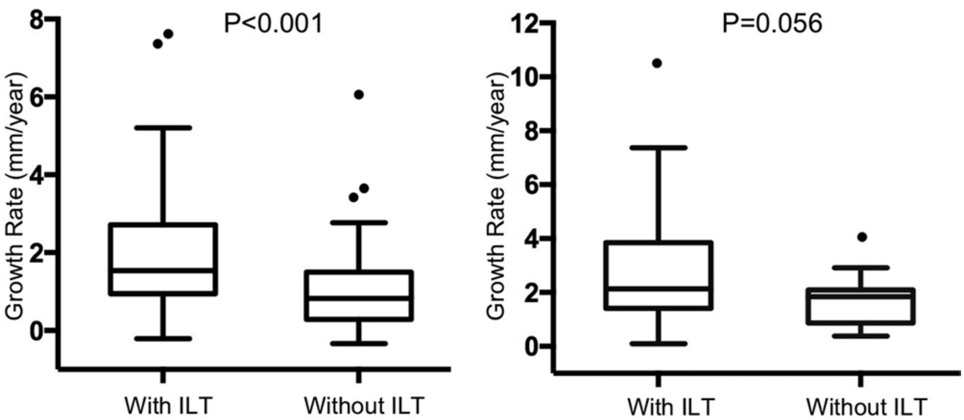

Figure 3: Box-and-whisker plots showing the growth rate of 3–5-cm abdominal aortic aneurysm (AAA) with and without intraluminal thrombus (ILT). Left: The 3–4-cm group. Right: The 4–5-cm group. AAAs with ILT tend to grow 1.9 and 1.2 times faster than AAAs without ILT, even when their baseline diameters are comparable (median, 3.5 cm [interquartile range, 3.2–3.8 cm] vs 3.3 cm [interquartile range, 3.2 cm–3.6 cm]; *P* = .01; 4.4 cm [interquartile range, 4.2–4.7 cm] vs 4.2 cm [interquartile range, 4.2–4.3 cm]; *P* = .066). Actual points are shown for outliers.

grew to a median diameter of 4.4 cm (IQR, 3.7–5.3 cm), with a growth rate of 1.5 mm/y (IQR, 0.8–2.6 mm/y). A total of 207 patients were followed up by using CT, and 18 patients were followed up by using MRI. The demographic data of patients with ILT and those without ILT are listed in Table 1. When compared with patients whose AAAs contained no ILT, patients with AAAs containing ILT were more commonly smokers, with larger baseline aneurysm diameters and faster aneurysm growth rates.

ILT was increasingly common when AAAs had larger diameters. The percentage of AAAs with ILT, grouped by aneurysm size, is shown in Figure 2. In a subgroup univariate analysis of AAAs of different sizes (Table 2, Fig 3), small (size range, 3–4-cm) and medium (size range, 4–5-cm) AAAs with ILT had 1.9- and 1.2-fold faster growth than did AAAs without ILT at similar sizes. No difference was found for AAAs larger than 5 cm.

Uni- and multivariate analyses were performed to uncover factors associated with aneurysm growth, and the results are shown in Table 3. For univariate analysis, baseline diameter, ILT, and smoking history were positively related to growth, whereas diabetes and body mass index (BMI) were negatively associated with growth. For multivariate analysis, baseline diameter and ILT were independently positively related to growth, whereas age and BMI were negatively independently associated with growth. Each 1-cm increase in baseline diameter was associated with a 1.0 mm/y higher growth rate; the presence of ILT was associated with a 0.5 mm/y higher growth rate; each 10-year increase in age was associated with a 0.3 mm/y higher growth rate; and a 10 kg/m^2 increase in BMI was associated with a 0.6 mm/y higher growth rate. Sample patient images are shown in Figures 4–6.

In AAAs with ILT (*n* = 123, Table E1 [online]), univariate analysis showed that baseline diameter, ILT area, ILT thickness, and smoking history were positively related to aneurysm growth; BMI and diabetes were negatively associated with growth. Multivariate analysis showed that diameter was positively related to growth, whereas BMI and ILT area were negatively associated with growth.

Table 3: Uni- and Multivariate Linear Regression Analysis for Abdominal Aortic Aneurysm Growth

	Univariate Analysis			Multivariate Analysis		
AAA Growth Rate	Unstandardized Coefficients*	Standardized Coefficients	*P* Value	Unstandardized Coefficients*	Standardized Coefficients	*P* Value
Baseline diameter (cm)	1.1 (0.8, 1.4)	0.49	<.001	0.97 (0.7, 1.2)	0.43	<.001
ILT	1.3 (0.9, 1.8)	0.36	<.001	0.54 (0.1, 1.0)	0.15	.02
Age (per 10-year increase)	−0.2 (−0.5, 0.05)	−0.11	.10	−0.29 (−0.54, (−0.44)	−0.14	.02
Body mass index (kg/m^2)	−0.07 (−0.22, −0.03)	−0.21	.002	−0.06 (−0.10, (−0.02)	−0.19	.002
Smoking history	0.7 (0.17, 1.2)	0.17	.01	0.25 (−0.24, 0.74)	0.06	.31
DM	−0.7 (−1.9, −0.1)	−0.15	.03	−0.29 (−0.82, 0.25)	−0.06	.29
Hypertension	−0.07 (−0.6, 0.5)	−0.02	.80	NA	NA	NA

Note.—Unless otherwise indicated, data are β values, and data in parentheses are the 95% confidence interval. AAA = abdominal aortic aneurysm, DM = diabetes mellitus, ILT = intraluminal thrombus, NA = not applicable.

* Defined as millimeter per year of growth per parameter unit change, or as specified.

Reproducibility

Agreement between the two reviewers was excellent for measurement of maximal AAA diameter (mean, 4.5 cm ± 0.9 vs 4.5 cm ± 0.8; *P* = .26; ICC = 0.99), ILT area (mean, 5.6 cm^2 ± 2.5 vs 5.7 cm^2 ± 2.1; *P* = .59; ICC = 0.92), and ILT thickness (mean, 1.2 cm ± 0.5 vs 1.1 cm ± 0.5; *P* = .75; ICC = 0.96). The interreader variability for maximal diameter measurements was ±1.2 mm. Because the average AAA growth is 6.6 mm over 3.3 years, the coefficient of variation is 18% (1.2/6.6). To detect 10%, 20%, and 50% differences in aneurysm growth rate, the required sample sizes are 136, 34, and six, respectively, based on these data. Thus, our study sample size is sufficient to safely draw conclusions.

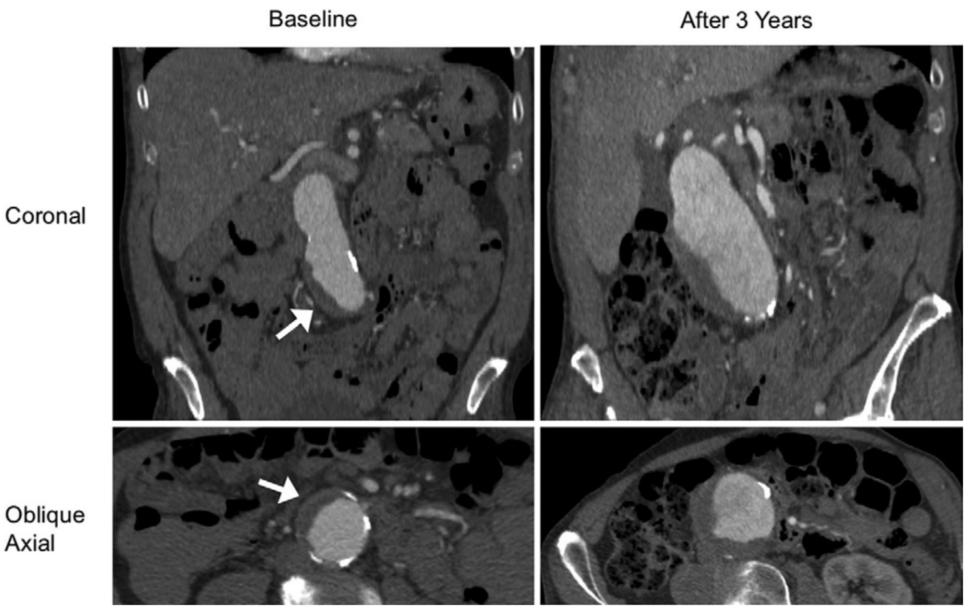

Figure 4: A patient (aged 85 years, male) with a fast-growing abdominal aortic aneurysm with intraluminal thrombus at baseline. Contrast-enhanced CT images (coronal and oblique axial planes) show that the aneurysm grew from 4.1 to 6.3 cm within 3 years at a growth rate of 7.3 mm/y. Arrow shows the intraluminal thrombus.

Post Hoc Sensitivity Analysis for Different Imaging Modalities

When using only CT data (*n* = 207), the linear regression results (including regression coefficients and *P* values) were similar when compared with the results obtained by using both CT and MRI data (*n* = 225). Independent parameters associated with growth were baseline diameter (β = 0.42, *P* < .001), presence of ILT (β = 0.16, *P* = .014), age (β = −0.15, *P* = .02), and BMI (β = −0.19, *P* = .003). Thus, the influence of using CT or MRI for follow-up was considered marginal.

Discussion

Intraluminal thrombus (ILT) is common in abdominal aortic aneurysms (AAAs). The influence of ILT on AAA growth is not fully understood. Previous studies were limited in that they did not use cross-sectional imaging or small sample sizes (*n* < 80). In this retrospective study, we found that ILT within AAAs was independently associated with faster aneurysm growth (*P* = .02). For 3–4- and 4–5-cm AAAs, when baseline aneurysm diameter was matched, the growth rate of AAAs with ILT was 1.9 times higher than that of aneurysms without ILT (*P* < .001). Our finding supports the role of ILT in predicting AAA progression and suggests that identification of ILT is important in AAA screening and surveillance imaging for better risk stratification and surveillance interval optimization. Several strengths of our study lent confidence to our conclusion, including the use of high-spatial-resolution cross-sectional imaging, standardized multiplanar reconstruction measurement methods, a large patient cohort, and a relatively long follow-up duration.

Earlier studies of ILT with smaller sample sizes of 30–80 patients revealed that a larger thrombus burden, a rapid increase in thrombus area, and the extent of aneurysm wall covered by thrombus at CT were indicative of rapid growth or rupture of AAA (4,14,18). A more recent systematic review including 10 CT angiographic studies identified factors that were reported to be associated with increased AAA growth, including large AAA thrombus size, large baseline AAA diameter, high AAA wall stress, and presence of concomitant carotid artery disease (12). Six of the 10 studies reviewed either measured the anterior-to-posterior aneurysm diameter on axial images or did not specify the method of measurement, and only one included study reported the reproducibility of their assessment method. In addition, not all studies performed multivariate regression to adjust for confounders.

When compared with previous studies, this study demonstrates the association between the presence of ILT and more rapid growth of AAAs using a relatively large sample size (225 patients) with more than 3 years of follow-up. Although US remains one of the most frequently used modalities for AAA surveillance, its diagnostic accuracy is lower than that of CT or MRI, with measurement error up to 5 mm or larger (19,20). The MPR measurement method that we used for cross-sectional imaging of CT and black-blood MRI was standardized, with a small measurement error of 1.2 mm (15). We also performed a power analysis for post hoc sample size calculation, which is mostly absent in previous publications and increased confidence in our results. As AAAs with and without ILT may have 1.2–1.9-fold differences in growth rate, this result could also serve as the basis for designing future trials regarding AAA surveillance. If ILT can be confirmed as a risk factor for more rapid aneurysm progression in larger trials, then mediators of ILT development might be targeted by new therapeutics to reduce patient risk in much the same way that smoking cessation has been promoted by clinicians since smoking was discovered to strongly influence AAA initiation and progression.

AAA screening programs in the United States have been widely instituted to reduce the risk of life-threatening aneurysmal rupture. As the majority of AAAs found at screening will not warrant immediate intervention, it is of critical importance

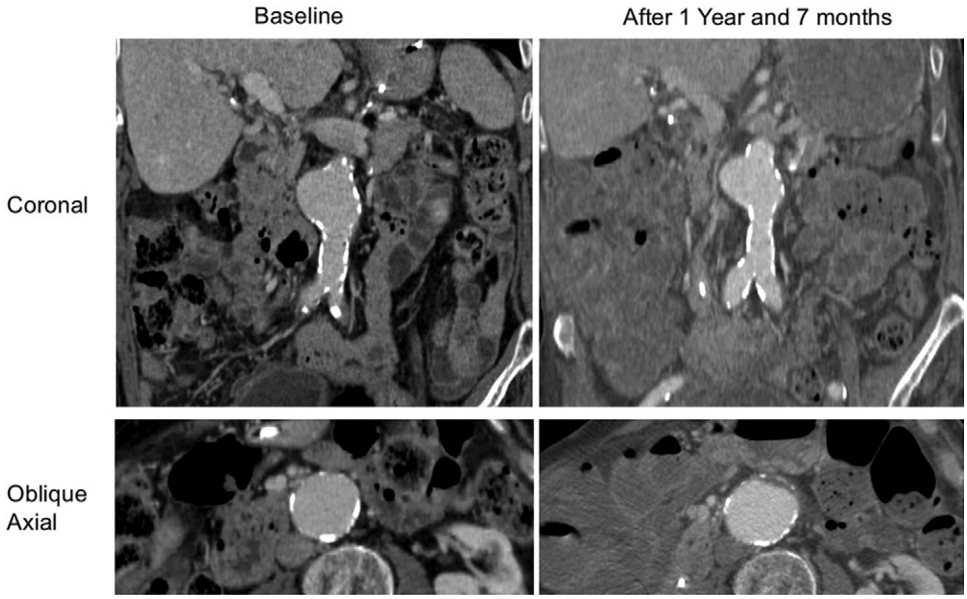

Figure 5: A patient (aged 88 years, male) with a slow-growing abdominal aortic aneurysm without intraluminal thrombus at baseline. Coronal and oblique axial contrast-enhanced CT images show that the aneurysm grew from 4.2 to 4.3 cm within 1 year and 7 months at a growth rate of 0.6 mm/y.

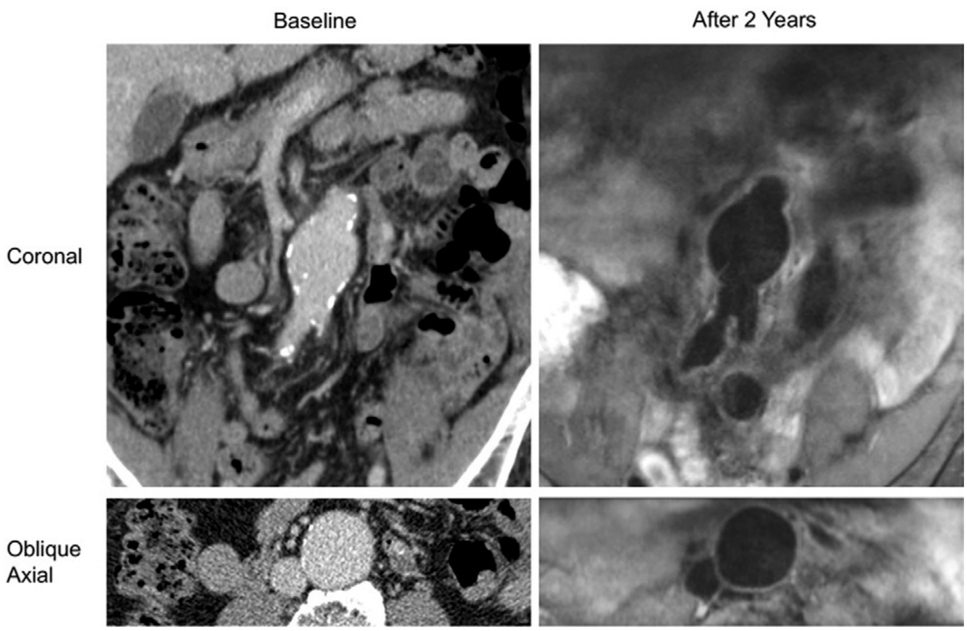

Figure 6: A patient (aged 83 years, male) who was followed up with black-blood MRI. The abdominal aortic aneurysm had no intraluminal thrombus at baseline or follow-up. Coronal and oblique axial contrast-enhanced CT images show that the aneurysm had a 4.0-cm diameter at baseline; 2 years later, black-blood MRI shows that the aneurysm grew to 4.2 cm at a growth rate of 1 mm/y.

to optimize a surveillance imaging strategy (21,22). According to the most recent guidelines from the Society for Vascular Surgery, a 12-month surveillance interval is recommended for 4.0–4.9-cm AAAs, and a 3-year surveillance interval is recommended for 3.0–3.9-cm AAAs (2). However, this recommendation is based on baseline aneurysm diameter only. In our subgroup study of AAAs with diameters of 3.0–5.0 cm, those containing ILT grew 1.6–1.9 times faster than those without ILT. Given the intermediate prevalence of ILT in AAAs in this diameter range, as shown in our study (40.4%–74.2%) and previous studies (3), patients with ILT could be followed more closely and patients without ILT could be followed less closely.

In our subgroup analysis of AAAs with ILT, multivariate analysis suggested that ILT area was negatively related to AAA growth, whereas ILT thickness tended to be positively associated with AAA growth (without statistical significance), and the percentage of ILT area within the aneurysm had no significant correlation with AAA growth. The exact mechanisms by which ILT influences aneurysm growth or rupture are clearly not yet fully known (23–25), with seemingly contradictory observations likely reflecting competing effects of ILT on aneurysm biomechanics (protective) and vessel wall biochemistry (deleterious) (26). This simple observation demonstrates the need for further high-quality experimental studies.

There were several limitations of our study. First, only male patients were included due to the institutional practice conditions in the Veterans Affairs health care system. Nevertheless, the estimated prevalence of AAA in the general population is much higher in males than in females, and the previous systematic review summarized 87% male patients in all included studies (12,27). Second, this is a single-center retrospective study. Very few large AAAs (qualified as those larger than 5.5 cm) were included, as most of them underwent intervention. Third, we performed two-dimensional analysis for ILT but did not quantify ILT volume and other three-dimensional geometric parameters. Although three-dimensional analysis of ILT features may be beneficial, our study focused on AAA features easily observed and measured in standard practice to increase the chance of clinical applicability.

In conclusion, both maximal diameter and the presence of intraluminal thrombus (ILT) were independent predictors of abdominal aortic aneurysm (AAA) growth. Identification of ILT is important in routine surveillance imaging of AAA; the presence of ILT may be useful in further studies to optimize follow-up intervals to detect growth of AAA.

Author contributions: Guarantors of integrity of entire study, J.R.L., M.D.H.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; agrees to ensure any questions related to the work are appropriately resolved, all authors; literature research, C.Z., J.R.L., D.S., M.D.H.; clinical studies, C.Z., J.R.L., Y.W., M.D.H.; statistical analysis, C.Z., Y.W.; and manuscript editing, all authors

Disclosures of Conflicts of Interest: **C.Z.** disclosed no relevant relationships. **J.R.L.** disclosed no relevant relationships. **Y.W.** disclosed no relevant relationships. **W.G.** disclosed no relevant relationships. **D.S.** disclosed no relevant relationships. **M.D.H.** disclosed no relevant relationships.

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