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Association between non-alcoholic fatty liver disease and progression of abdominal aortic aneurysm: a multicenter study

Ximing Wang[1†], Jingxiang Sun[2,3†], Na Chang[4], Menghan Liu[5] and Shuai Zhang[1*]

Abstract

Background The purpose of our study was to investigate the association between non-alcoholic fatty liver disease (NAFLD) and abdominal aortic aneurysms (AAA) progression using non-enhanced computed tomography (CT) and CT angiography (CTA).

Methods Patients with AAA and age- and sex-matched healthy subjects who underwent abdominal CTA and non-enhanced CT examination between January 2015 and January 2023 from four hospitals were retrospectively analyzed. Patients with AAA were divided into progression (growth rate > 10 mL/year) and non-progression groups, as well as those with NAFLD and without NAFLD, based on abdominal CT results. The Kaplan-Meier and Cox regression were used to investigate the association between NAFLD and AAA progression.

Results A total of 151 patients with AAA (mean age: 69.1 ± 10.5 years old, 133 men) were included, among which 66 patients (43.7%) had NAFLD. During a median of 10.7 months (6.0–76.0 months), 57 patients (37.7%) had AAA progression. The prevalence of NAFLD was significantly higher in the AAA group compared to the control group (43.7% vs. 31.1%, $p = 0.024$). Multivariable regression analysis revealed that the NAFLD was independently associated with AAA progression (HR, 4.28; 95% CI, 2.20–8.31; $p < 0.001$). The area under curve of combined NAFLD and AAA maximal diameter was 0.857 for predicting AAA progression.

Conclusions NAFLD on non-enhanced CT is an independent predictor of AAA progression. It can improve the diagnostic efficacy of predicting the progression of abdominal aortic aneurysms.

Clinical trial number Not applicable. This research is a retrospective analysis.

Keywords Non-alcoholic fatty liver disease, Abdominal aortic aneurysm, Fatty liver, Multidetector computed tomography, Growth

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Background

Non-alcoholic fatty liver disease (NAFLD) is a metabolic-associated fatty liver disease with a worldwide prevalence of 32% among adults (40% in males and 26% in females) [1]. NAFLD is strongly associated with diabetes mellitus, obesity, and dyslipidemia [2–4]. In addition, recent studies have also found that NAFLD is associated with elevated carotid media thickness, high-risk coronary plaques, arterial stiffness, coronary artery calcification, and other cardiovascular events [5–9]. Also, several studies found that patients with abdominal aortic aneurysm (AAA), defined as aortic enlargement with a diameter of ≥ 3 cm, are at increased risk for developing NAFLD [10]. Yet, so far, no studies have evaluated the prognostic value of NAFLD in AAA progression.

The potential links between NAFLD and AAA progression are complex. Previous studies have demonstrated that NAFLD is strongly associated with dysmetabolic conditions [2–4], which could be mediators contributing to AAA progression [11–13]. Additionally, previous studies have reported that NAFLD was related to systematic inflammation, macrophage activation, oxidative stress, and endothelial dysfunction, which act as promoting roles in AAA progression [14–17]. Moreover, Jaruvongvanich et al. [7] showed that patients with NAFLD had a higher degree of arterial stiffness. Several studies have indicated that an increased arterial stiffness may contribute to AAA progression [18]. These mechanisms support the notion that there may be a certain link between NAFLD and AAA presence and progression.

Non-enhanced CT examination is a non-invasive, fast, and reproducible imaging tool useful to evaluate hepatic steatosis (HS) by measuring the liver and spleen CT attenuation values [19]. For example, Chung et al. [20] suggested that HS on non-enhanced CT should be a possible clinical profile abnormality indicating metabolic syndrome, including NAFLD. On the other hand, CT angiography (CTA) is the standard for imaging aneurysms before intervention that can be used to evaluate the aorta in the acute setting to assess dissection, traumatic injury, and aneurysm rupture [21]. Therefore, the aim of our study was to investigate the association between NAFLD based on CT and the progression of AAA.

Methods

Patients

The institutional review board (IRB No. 2023 – 308) approved this retrospective study, and the requirement to obtain informed consent was waived.

Patients with AAA who underwent abdominal CTA and non-enhanced CT examinations at four hospitals between January 2015 and January 2023 were analyzed retrospectively. The inclusion criteria were as follows: (1) patients who underwent non-enhanced abdominal CT examination; (2) availability of a follow-up CTA scan at least 6 months after the initial CTA examination. The exclusion criteria were: (1) endovascular or open aortic repair at initial CT scan or within the imaging interval; (2) history of alcohol intake (≥ 30 g/d for men and ≥ 20 g/d for women); (3) presence of hepatitis B or hepatitis C virus infection, liver cirrhosis, or liver cancers; (4) using medication such as corticosteroids or amiodarone; (5) incomplete clinical data; (6) poor image quality. Age- and sex-matched healthy subjects (1:1) without AAA were included from one hospital and were used as a control group. The study flowchart is shown in Fig. 1.

The clinical data were obtained from medical records, including age, sex, body mass index, hypertension, hyperlipidemia, diabetes, and smoking history.

CT/CTA protocol

All abdominal CT images were obtained on the multidetector CT scanners (Somatom Force, Siemens Healthcare; Somatom Definition Flash, Siemens Healthcare; Ingenuity CT, Philips; Optima CT660, GE Healthcare; Discovery 750, GE Healthcare). The CT scanning was performed with coverage from the base of the neck to aortoiliac bifurcation in the supine position. The scanning parameters were as follows: tube voltage of 120 kV, pitch of 0.8-1.0, automatic tube current modulation, a matrix of 512 × 512, reconstructed slice thickness of 1 mm, and reconstructed slice interval of 1 mm. For CTA examination, 100–120 mL of contrast media (Omnipaque-350; GE Healthcare) was injected at the speed of 4 mL/s, followed by 50–60 mL saline flush at the same speed, using a power injector. The bolus tracking technique was used to trigger the acquisition after an attenuation threshold of 100 Hounsfield units (HU) reached the celiac trunk level for 6 s.

CTA image analysis

The following AAA characteristics on baseline CTA were collected: the maximum diameter and total volume of AAA, the presence or absence of intraluminal thrombus (ILT), and the maximum diameter of ILT. Yet, only a volume of AAA was collected at the follow-up CTA.

This study defined AAA as a maximum aortic diameter ≥ 3 cm. ILT was defined as present if the ILT plus wall thickness exceeded 5 mm on CTA images. Measurements of the maximum diameter of AAA and ILT were performed on corresponding maximum cross-sections perpendicular to the long axis of the aorta with a multiplanar reconstruction method. The longitudinal measurement range of AAA volume was the upper and lower boundaries of AAA, which were defined as from the loss of parallelism of the aortic wall to the end of aortic dilatation. The growth rate was calculated as follows: (AAA

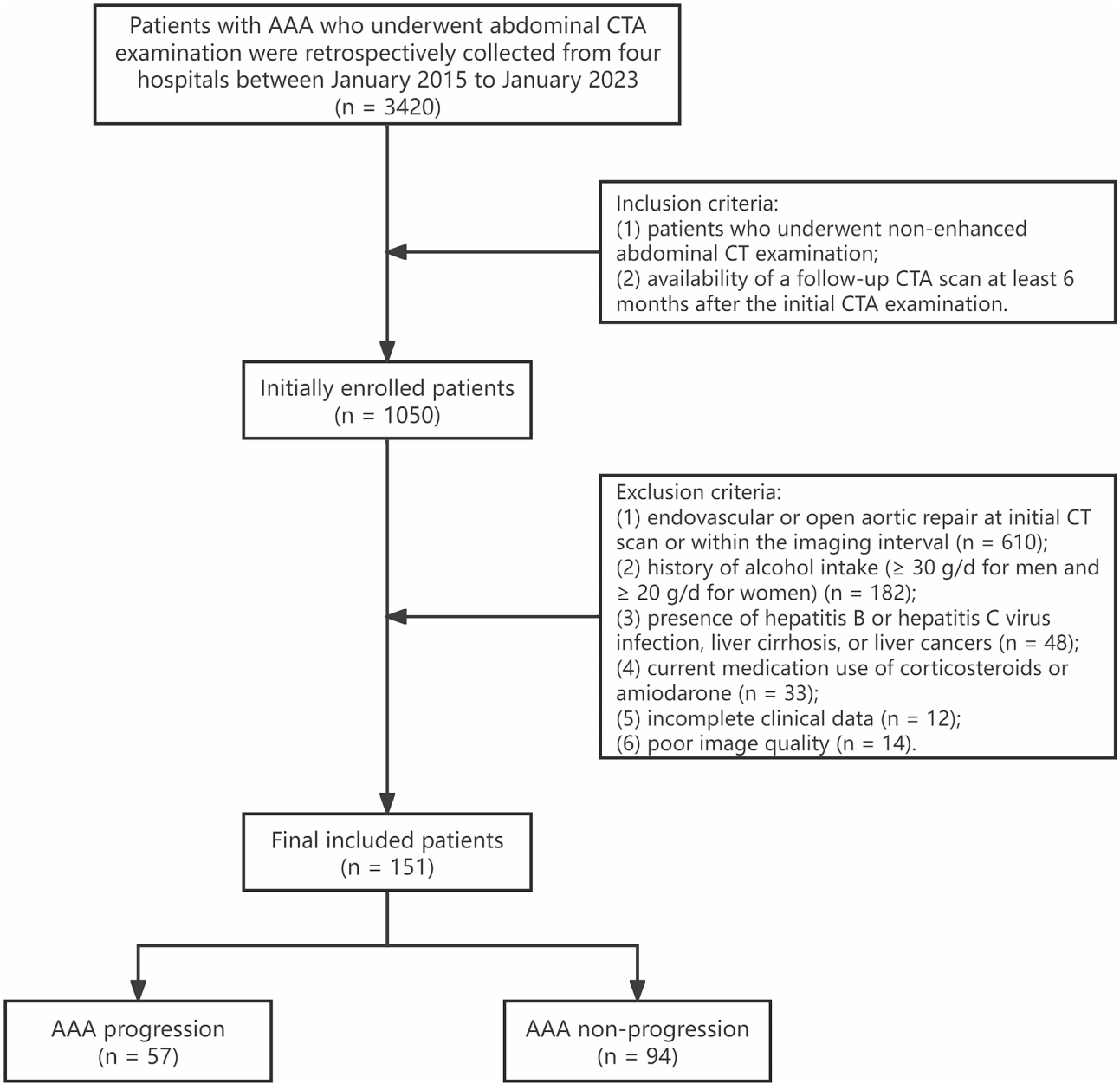

Fig. 1 Study flowchart

volume at follow-up - AAA volume at baseline) / follow-up years. Patients with an annual AAA growth rate > 10 mL were classified as a progression group, otherwise as the non-progression group [22].

Images were reviewed and measured with a post-processing workstation (syngo.via Siemens Force, Germany) and ITK-SNAP software (version 3.8.0, open source, http://www.itksnap.org). All images were reviewed by two radiologists (Z.S. and X.M.W., with 8 and 20 years of experience in vascular imaging, respectively) who were blinded to the patient's clinical information. Disagreements were resolved by discussion or by inviting a third, more experienced radiologist.

Definition of NAFLD

The liver-to-spleen attenuation values ratio < 1.0 on non-enhanced CT was defined as the presence of hepatic steatosis [19]. The liver and spleen attenuation values were obtained by drawing circular regions of interest (≥ 1 cm^2) in the largest possible regions [23]. The regions of interest of the liver were placed on the anterior and posterior segments of the right liver lobe, avoiding vascular and biliary structures. The hepatic attenuation value was calculated

as the mean of the two measurements. NAFLD was diagnosed as the presence of HS in the absence of excess alcohol intake or other causes of secondary HS [24], which were excluded from our study. A NAFLD case with AAA progression is shown in Fig. 2.

Two radiologists with more than 7 and 10 years of experience in abdominal CT blinded to the patient's clinical and AAA information measured the liver and spleen CT attenuation values on non-enhanced CT. Disagreements were resolved by discussion or by inviting a third, more experienced radiologist.

Statistical analysis

All statistical analyses were performed using SPSS 22.0 (IBM, Chicago, IL). The Shapiro-Wilk test was used to assess the normality of data distribution. The continuous variables were described as mean ± standard deviation or median [interquartile range (IQR)] and compared using a t-test or Mann-Whitney U test. The categorical variables were presented as percentages and compared using a χ^2 test. Univariate and multivariate Cox regression analyses were used to evaluate the predictive values of NAFLD for AAA progression. The results were reported as the hazard ratio (HR) with a corresponding 95% confidence interval (CI). Variables that were significant ($P<0.1$) in univariate analysis were included in multivariable analysis. Cumulative event rates of AAA progression were evaluated by using the Kaplan-Meier curves, and a log-rank test was performed to determine differences between Kaplan-Meier curves. We assessed the discriminative ability through receiver operating characteristic (ROC) curves and area under curve (AUC) values. Also, the AUC values were compared with the Delong test. The inter-observer and intra-observer reproducibility of imaging variables was assessed by using intraclass correlation coefficients and Cohen's kappa statistics. A p value < 0.05 was considered statistically significant.

Results

General characteristics

Among 3420 patients with AAA, 1050 meet the inclusion criteria; 899 were excluded due to endovascular or open aortic repair ($n=610$), history of alcohol intake ($n=182$), hepatitis B virus infection ($n=24$), hepatitis C virus infection ($n=7$), liver cirrhosis ($n=10$), liver cancer ($n=7$), current medication use of corticosteroids ($n=15$) and amiodarone ($n=18$), incomplete clinical data ($n=12$), and poor image quality ($n=14$). Finally, 151 patients with AAA (mean age: 69.1 ± 10.5 years old, 133 men) were included in the statistical analysis. A healthy control group included 151 participants (mean age: 69.0 ± 10.4 years old, 133 men). The prevalence of NAFLD (43.7% versus 31.1%; $p=0.024$), hypertension (62.9% versus 51.0%; $p=0.036$), and diabetes (28.5% versus 15.9%; $p=0.009$) in AAA group was significantly higher than that in the control group, while no significant differences were observed in other factors (all $p>0.05$). The

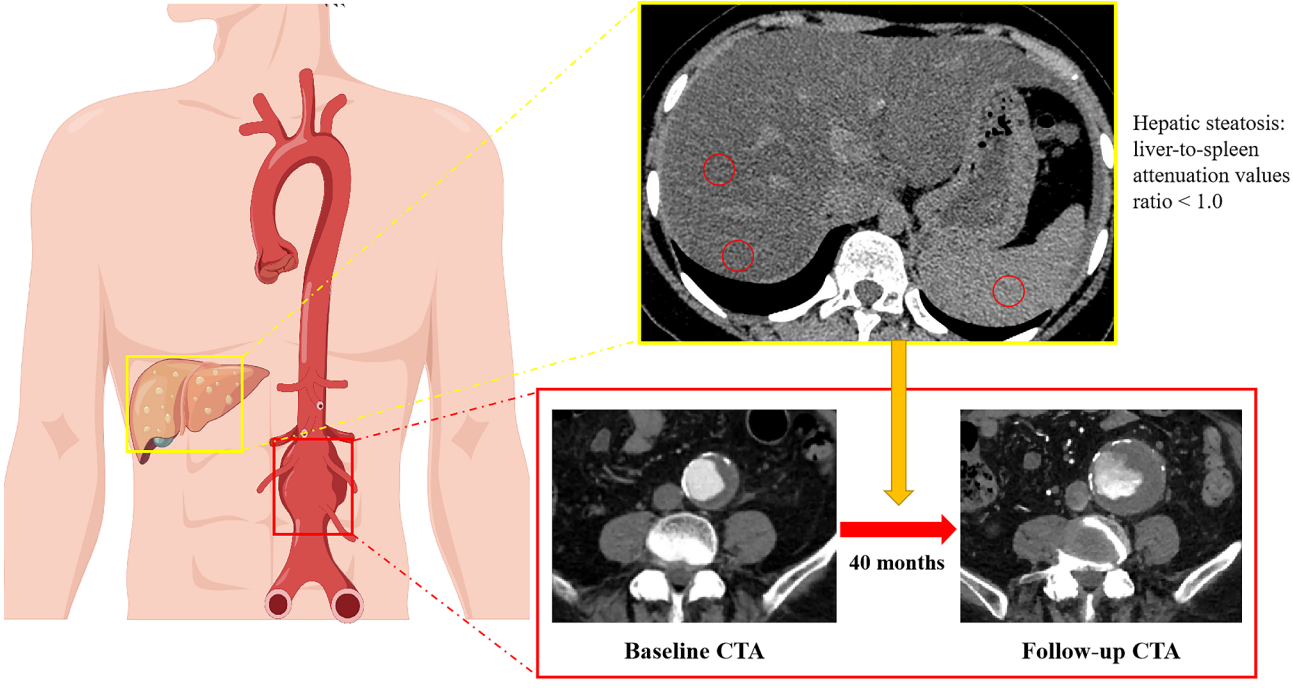

Fig. 2 The example of an NAFLD patient with abdominal aortic aneurysm progression. Non-enhanced abdominal CT examination showed the liver-to-spleen attenuation values ratio was < 1.0, which indicated the presence of NAFLD. CT angiography showed the aneurysm grew from 134.8 mL to 297.0 mL over 3.3 years at a growth rate of 49.2 mL/y. NAFLD, non-alcoholic fatty liver disease

Table 1 Baseline clinical characteristics between AAA and healthy control groups

Parameter	AAA group (*n* = 151)	Control group (*n* = 151)	*P* value
Age, year	69.1 ± 10.5	69.0 ± 10.4	0.956
Sex, male	133 (88.1)	133 (88.1)	1.000
Body mass index, kg/m^2	26.9 ± 2.5	27.2 ± 2.3	0.190
Hypertension	95 (62.9)	77 (51.0)	0.036
Hyperlipidemia	56 (37.1)	49 (32.5)	0.398
Diabetes	43 (28.5)	24 (15.9)	0.009
Smoking	88 (58.3)	79 (52.3)	0.298
NAFLD	66 (43.7)	47 (31.1)	0.024

Continuous variables are described as mean ± standard deviation (SD), and categorical variables are presented as numbers (%). AAA, abdominal aortic aneurysm; NAFLD, non-alcoholic fatty liver disease

Table 2 Baseline clinical and CTA characteristics between AAA progression and non-progression groups

Parameter	Progression group (*n* = 57)	Non-progression group (*n* = 94)	*P* value
Clinical characteristics			
Age, year*	69.3 ± 8.9	69.0 ± 11.3	0.156
Sex, male	52 (91.2)	81 (86.2)	0.352
Body mass index, kg/m^{2*}	26.6 ± 2.2	27.0 ± 2.6	0.120
Hypertension	38 (66.7)	61 (64.9)	0.824
Hyperlipidemia	19 (33.3)	37 (39.4)	0.457
Diabetes	22 (38.6)	21 (22.3)	0.032
Smoking	34 (59.6)	54 (57.4)	0.790
NAFLD	44 (77.2)	22 (23.4)	<0.001
Follow-up time (month)†	9.2 (6.6–22.6)	12.7 (6.7–31.0)	0.081
CTA characteristics			
AAA maximal diameter (mm)†	45.6 (41.3–53.0)	37.5 (34.8–41.7)	<0.001
AAA volume (mL)†	65.2 (45.4-124.1)	41.2 (25.5–63.8)	<0.001
Presence of ILT	54 (94.7)	78 (83.0)	0.035
ILT maximal diameter (mm)†	12.3 (7.5–19.4)	6.7 (3.4–11.9)	<0.001

Unless otherwise noted, the data are presented as the number of patients, with percentages in parentheses

*Data are means ± standard deviations

†Data are presented as the medians, with interquartile ranges in parentheses

AAA, abdominal aortic aneurysm; NAFLD, non-alcoholic fatty liver disease; ILT, intraluminal thrombus

demographic characteristics of AAA and control groups are summarized in Table 1.

Association of NAFLD and AAA progression

During a median follow-up of 10.7 months (6.0–76.0 months), 57 patients with AAA (37.7%) experienced AAA progression. Compared with non-progression group, patients with AAA progression had significantly higher prevalence of diabetes (38.6% vs. 22.3%; $p = 0.032$), higher prevalence of NAFLD (77.2% vs. 23.4%; $p < 0.001$), higher prevalence of ILT (94.7% vs. 83.0%; $p = 0.035$), larger AAA maximal diameter [median, 45.6 mm (IQR, 41.3–53.0 mm) vs. median, 37.5 mm (IQR, 34.8–41.7 mm); $p < 0.001$], larger AAA volume [median, 65.2mL (IQR, 45.4-124.1mL) vs. median, 41.2mL (IQR, 25.5-63.8mL); $p < 0.001$], and larger ILT maximal diameter [median, 12.3 mm (IQR, 7.5–19.4 mm) versus median, 6.7 mm (IQR, 3.4–11.9 mm); $p < 0.001$]. No significant differences were observed in other factors (all $p > 0.05$). Baseline clinical and CTA characteristics between AAA progression and non-progression groups are summarized in Table 2.

The Kaplan-Meier curves for progression-free survival stratified according to the NAFLD are shown in Fig. 3. For all patients, the event-free survival was significantly lower for patients with NAFLD than those without NAFLD (log-rank $p < 0.001$).

Univariate Cox regression analysis identified NAFLD (HR, 5.99; 95% CI, 3.21–11.19; $p < 0.001$), AAA maximal diameter (HR, 1.07; 95% CI, 1.04–1.09; $p < 0.001$), AAA volume (HR, 1.01; 95% CI, 1.00-1.01; $p < 0.001$), ILT (HR, 2.92; 95% CI, 0.91–9.37; $p = 0.072$), and ILT maximal diameter (HR, 1.06; 95% CI, 1.04–1.09; $p < 0.001$) as inputs to multivariable analysis. Multivariable Cox regression analysis revealed that NAFLD (HR, 4.28; 95% CI, 2.20–8.31; $p < 0.001$) and AAA maximal diameter (HR, 1.06; 95% CI, 1.01–1.11; $p = 0.010$) were independent predictors of AAA progression (Table 3).

Diagnostic performance

The AUCs of NAFLD, AAA maximal diameter, and combined AUC for both factors were 0.769, 0.793, and 0.857, respectively, for predicting AAA progression. The sensitivity and specificity were 77.2% and 76.6% for NAFLD, 80.7% and 71.3% for AAA maximal diameter, and 73.7% and 85.1% for the combined model, respectively. The AUC value of the combined model was higher than that of NAFLD (0.857 vs. 0.769, $p < 0.001$) and that of AAA maximal diameter (0.857 vs. 0.793, $p = 0.034$). There were no differences between the AUC of NAFLD and that of AAA maximal diameter (0.769 vs. 0.793, $p = 0.608$). The ROC curves of the three models are shown in Fig. 4.

Reproducibility

The Cohen's kappa values of ILT and NAFLD were 0.917 (95CI%, 0.887–0.939) and 0.933 (95CI%, 0.874–0.992) for intra-observer agreement, and 0.930 (95CI%, 0.903–0.949) and 0.906 (95CI%, 0.837–0.975) for inter-observer agreement. The intraclass correlation coefficient of maximal aneurysm diameter, total aneurysm volume, ILT maximal diameter, and growth rate were 0.971 (95CI%, 0.960–0.979), 0.982 (95CI%, 0.976–0.987), 0.963 (95CI%, 0.950–0.973), and 0.977 (95CI%, 0.969–0.984) for intra-observer agreement, respectively, and 0.977 (95CI%, 0.968–0.983), 0.961 (95CI%, 0.946–0.971), 0.954 (95CI%,

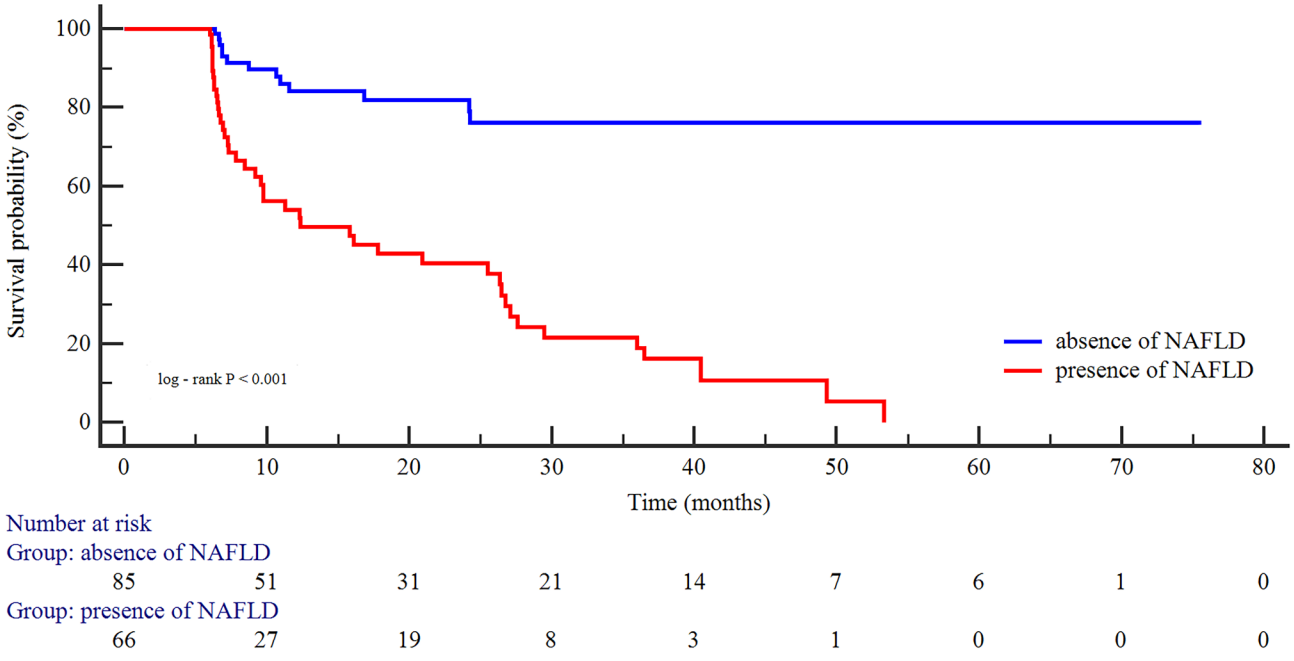

Fig. 3 Kaplan-Meier event-free survival curves of AAA progression events in patients with AAA. The patients with NAFLD had a lower event-free survival rate than those without NAFLD (log-rank $P < 0.001$). AAA = abdominal aortic aneurysm; NAFLD = non-alcoholic fatty liver disease

Table 3 Univariate and multivariate cox regression analyses of risk factors for progression of abdominal aortic aneurysm

Parameter	Univariate analysis		Multivariate analysis	
	HR (95%CI)	*P* Value	HR (95%CI)	*P* Value
Age, year	1.00 (0.98–1.02)	0.922	-	-
Sex, male	1.94 (0.77–4.86)	0.160	-	-
Body mass index, kg/m^2	0.95 (0.85–1.06)	0.334	-	-
Hypertension	0.95 (0.55–1.65)	0.855	-	-
Hyperlipidemia	1.06 (0.60–1.85)	0.850	-	-
Diabetes	1.52 (0.89–2.59)	0.125	-	-
Smoking	0.98 (0.58–1.67)	0.945	-	-
NAFLD	5.99 (3.21–11.19)	<0.001	4.28 (2.20–8.31)	<0.001
AAA maximal diameter (mm)	1.07 (1.04–1.09)	<0.001	1.06 (1.01–1.11)	0.010
AAA volume (mL)	1.01 (1.00-1.01)	<0.001	1.00 (0.99-1.00)	0.179
Presence of ILT	2.92 (0.91–9.37)	0.072	2.11 (0.57–7.852)	0.267
ILT maximal diameter (mm)	1.06 (1.04–1.09)	<0.001	1.026 (0.98–1.06)	0.323

AAA, abdominal aortic aneurysm; NAFLD, non-alcoholic fatty liver disease; ILT, intraluminal thrombus

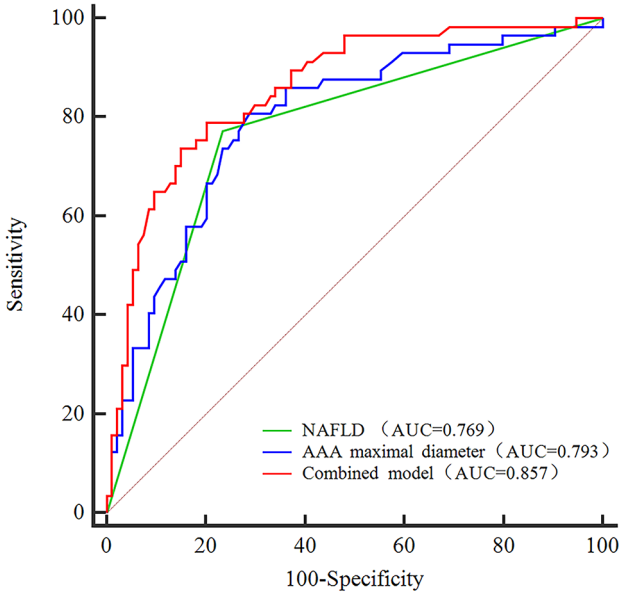

Fig. 4 Receiver-operator characteristic curves for predicting AAA progression using AAA maximal diameter, NAFLD and combined model (AAA maximal diameter and NAFLD). AAA = abdominal aortic aneurysm; NAFLD = non-alcoholic fatty liver disease

0.938–0.967), and 0.964 (0.950–0.973) for inter-observer agreement, respectively.

Discussion

Growing evidence has shown that NAFLD is associated with cardiovascular disease [5, 6]. Noninvasive detection of NAFLD in patients with AAA may be of great significance. Therefore, our study investigated the association between NAFLD and AAA progression. Our study found that NAFLD (HR, 4.28; 95% CI, 2.20–8.31; $p < 0.001$) was an independent predictor of AAA progression. Additionally, we found that the combined AAA maximal diameter and NAFLD had an AUC of 0.857 for predicting AAA progression. NAFLD based on CT may

serve as a reliable, easy-operated and noninvasive marker to predict the AAA progression.

In our study, we found the maximal diameter of AAA was an independent predictor of the AAA progression. Previous studies showed that AAA maximal diameter was closely associated with AAA progression and was widely accepted as the main parameter to predict the AAA progression in the clinic [25, 26]. In addition, we investigated the relationship between NAFLD and AAA progression. We showed that NAFLD (HR, 4.28; 95% CI, 2.20–8.31; $p < 0.001$) was an independent predictor of the AAA progression, and NAFLD had an AUC of 0.769 for predicting AAA progression. Increasing studies reported that NAFLD is associated with several cardiovascular diseases and ischemic stroke, independently of traditional cardiovascular risk factors [26, 27]. And Mahamid et al. [10] compared clinical characteristics between 495 patients with AAA and 500 healthy controls and found that AAA patients were at increased risk for NAFLD, which was consistent with our study. And our study further investigated the correlation between NAFLD and AAA progression. And, it is unusual that smoking, a well-known risk factor for AAA progression, was not associated with AAA progression in my study. We presume that sample size and selection bias of retrospective design may account for this discrepancy.

The potential links between NAFLD and AAA progression are complex. Previous studies have demonstrated that NAFLD is strongly associated with dysmetabolic conditions (diabetes mellitus, obesity, dyslipidemia, and so on), which could be mediators contributing to the progression of AAA [2–4, 11–13]. In addition, previous studies have reported that NAFLD was related to systematic inflammation, macrophage activation, oxidative stress, and endothelial dysfunction [14–16]. All of these factors act as promoting roles in the progression of AAA [17]. Moreover, Jaruvongvanich et al. [7] showed a higher degree of arterial stiffness in NAFLD patients compared with controls by a systematic review and meta-analysis. Several studies have reported that increased arterial stiffness may be a contributing factor to AAA progression [18]. These mechanisms support the notion that there may be a certain association between NAFLD and AAA presence and progression. Additionally, NAFLD, a key manifestation of ectopic fat, is strongly associated with systemic inflammation, insulin resistance, and oxidative stress, which are central to coronary artery disease pathogenesis. Similarly, epicardial adipose tissue promotes atherosclerosis by secreting pro-inflammatory cytokines, contributing to plaque vulnerability and adverse cardiac events [28]. Both NAFLD and ectopic fat have emerged as independent predictors of subclinical and clinical coronary artery disease and cardiac function [29]. Integrating NAFLD and epicardial adipose tissue assessment into routine care may enhance early detection and guide targeted interventions, such as metabolic therapies. Nowadays, there is no relevant literature to explore the relationship between NAFLD based on CT and AAA progression. We filled this gap for the first time and proposed that NAFLD and AAA progression are closely related.

Our study want to prove that NAFLD has a certain value through the findings that the prevalence of NAFLD is different in the aneurysm group and the healthy control group, and then prove the significance of NAFLD for aneurysm progression. Therefore, we included the healthy control group. Age- and sex-matched healthy subjects (1:1) without AAA were retrospectively collected as a control group. Because they were suspected of having aortic disease, they had imaging examinations, but they were actually healthy.

For NAFLD, liver biopsy is the diagnostic reference standard [8]. However, the biopsy is an invasive modality with potential complications, thus it is not available for routine clinical practice. CT has been considered to be an easy-operated, accurate, and reliable tool to measure the HS [19]. And CTA is also considered as the most accurate method for assessing AAA characteristics [21]. Several studies have confirmed that the detection of AAA with CTA would predict AAA progression events [19, 23, 25, 30]. Meyrignac et al. [22] combined volumetric and wall shear stress analysis from CT to assess the risk of AAA progression. And Zhu et al. [31] investigated the role of ILT in AAA progression as assessed with CT. Several studies showed that the AAA diameter and volume measured with CT could predict AAA progression [25, 30]. Therefore, compared with ultrasound and magnetic resonance, although ultrasound and magnetic resonance were also used to assess the HS in the clinic, CT examination can benefit from concomitant assessment of AAA characteristics during the acquisition of liver fat information [2].

Our results showed the association between NAFLD and AAA presence and progression, which provided new perspectives on the prevention and management of AAA. Multiple studies have reported that several potential interventions, including lifestyle modification, dietary modification, exercise, weight loss, and medications, will be effective in the management of NAFLD [32–35]. Therefore, these modalities could also be valuable for AAA prevention and treatment. The findings are preliminary, and further research is needed to confirm a causal relationship. Recent studies showed that metabolic dysfunction-associated fatty liver disease has a wide impact on the cardiovascular system and may be a risk factor for AAA [36]. These highlighted the broader implications of integrating metabolic and vascular health assessments for comprehensive patient risk management. In addition

to physical examination in hypertensive patients [37], NAFLD patients usually underwent abdominal imaging studies, such as abdominal CT and sonography. Especially for patients with AAA, NAFLD, and AAA diameter on CT could be applied in clinical risk stratification and patient management.

This study is a multicenter study, which improves the statistical power of the study, enhances the extrapolation and representativeness of the research results, improves the diversity of subjects, comprehensively reflects the characteristics of different populations, and is convenient for verification and replication of the research results, and improves the reliability of the study.

Our study had some limitations. Firstly, from an initial pool of 3420 AAA patients, we only included 151 AAA patients, which may lead to selection bias. This study is inevitably limited due to its retrospective design. And, some laboratory test variables for assessing liver function were not recorded and therefore were not included in this study. Further prospective studies with large sample sizes, relatively long follow-up duration, and detailed clinical data are warranted. Secondly, there are some limitations to diagnosing NAFLD using imaging rather than histopathology. However, diagnosing NAFLD using CT examination was simple, noninvasive, and effective [19]. Previous studies proposed that the liver-to-spleen attenuation values ratio < 1.0 on non-enhanced CT was defined as the presence of hepatic steatosis [19]. Under normal conditions, the density of the liver is higher than that of the spleen. Because the increase in liver fat content leads to a decrease in liver density, the liver-to-spleen attenuation values ratio is < 1.0 on non-enhanced CT. It is also convenient to measure and evaluate the accuracy of fatty liver, so we use the liver-spleen ratio method. Thirdly, our study was a multiple-center study. And different CT scanners were used to evaluate the HS. However, their CT protocols were similar. In particular, tube voltage, a major parameter affecting CT value measurements, was consistent. Therefore, the accuracy of CT diagnosis is not compromised. And our results for the assessment of HS showed excellent reliability by intraclass correlation coefficients. Fourthly, we chose a > 10 mL/year threshold for defining AAA progression based on previous literature [22]. We performed the three-dimensional analysis (volume) for AAA progression, which may not be as easily measured in the clinic as two-dimensional data (diameter) but is considered more accurate and beneficial [38].

Conclusions

In conclusion, there is a link between NAFLD and the presence and progression of AAA. We found that NAFLD and the maximal diameter of AAA were independent predictors of the AAA progression. Thus, NAFLD based on CT may be a reliable, easy-to-operate, and noninvasive marker to predict the AAA progression.

Abbreviations

AAA	Abdominal aortic aneurysm
AUC	Area under curve
CI	Confidence interval
CTA	Computer tomography angiography
HS	Hepatic steatosis
HR	Hazard ratio
ILT	Intraluminal thrombus
NAFLD	Non-alcoholic fatty liver disease
ROC	Receiver operating characteristic

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None.

Author contributions

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by SZ, JS, NC, and ML. The first draft of the manuscript was written by SZ, and all authors commented on previous versions of the manuscript. ML and XW were accountable for all aspects of the work and for ensuring that questions related to the accuracy or integrity of any part of the work were appropriately investigated and resolved. All authors read and approved the final manuscript.

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Data availability

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Declarations

Ethics approval and consent to participate

This retrospective study was approved by *Shandong Provincial Hospital, Institutional Review Board* (*No. 2023 – 308*) and was conducted in accordance with *the Declaration of Helsinki*. The requirement for informed consent was waived due to the retrospective nature of this study. Consent to Participate declaration: not applicable.

Consent to publish

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Teng ML, Ng CH, Huang DQ, et al. Global incidence and prevalence of nonalcoholic fatty liver disease. Clin Mol Hepatol. 2023;29:S32–42.
2. Kosmalski M, Śliwińska A, Drzewoski J. Non-alcoholic fatty liver disease or type 2 diabetes Mellitus-The Chicken or the Egg Dilemma. Biomedicines 11:1097.
3. Divella R, Mazzocca A, Daniele A, Sabbà C, Paradiso A. Obesity, Nonalcoholic Fatty Liver Disease and Adipocytokines Network in Promotion of Cancer. Int J Biol Sci. 2019;2023;15:610–616.
4. Martin A, Lang S, Goeser T, Demir M, Steffen HM, Kasper P. Management of Dyslipidemia in patients with non-alcoholic fatty liver disease. Curr Atheroscler Rep. 2022;24:533–46.

5. Bc B, Jaiswal RK, Gupta PK, Paudel R, Subedi RK. Carotid intima-media thickness in patients with non-alcoholic fatty liver Disease attending a Tertiary Care Center: a descriptive cross-sectional study. JNMA J Nepal Med Assoc. 2021;59:454–9.
6. Arslan U, Yenerçağ M. Relationship between non-alcoholic fatty liver disease and coronary heart disease. World J Clin Cases. 2020;8:4688–99.
7. Jaruvongvanich V, Chenbhanich J, Sanguankeo A, Rattanawong P, Wijarnpreecha K, Upala S. Increased arterial stiffness in nonalcoholic fatty liver disease: a systematic review and meta-analysis. Eur J Gastroenterol Hepatol. 2017;29:e28–35.
8. Koulaouzidis G, Charisopoulou D, Kukla M, et al. Association of non-alcoholic fatty liver disease with coronary artery calcification progression: a systematic review and meta-analysis. Prz Gastroenterol. 2021;16:196–206.
9. Mantovani A, Csermely A, Petracca G, et al. Non-alcoholic fatty liver disease and risk of fatal and non-fatal cardiovascular events: an updated systematic review and meta-analysis. Lancet Gastroenterol Hepatol. 2021;6:903–13.
10. Mahamid M, Khoury T, Mahamid B, Sbeit W, Mari A, Nseir W. The interplay between abdominal aortic aneurysm, metabolic syndrome and fatty liver disease: a retrospective case-control study. Diabetes Metab Syndr Obes. 2019;12:1743–9.
11. Betancourt-Garcia MM, Vatcheva K, Thakur A, et al. Diabetes and its effect on abdominal aortic aneurysm growth rate in hispanic patients. Ann Vasc Surg. 2019;61:254–60.
12. Cronin O, Walker PJ, Golledge J. The association of obesity with abdominal aortic aneurysm presence and growth. Atherosclerosis. 2013;226:321–7.
13. Ahmed R, Ghoorah K, Kunadian V. Abdominal aortic aneurysms and risk factors for adverse events. Cardiol Rev. 2016;24:88–93.
14. Schuster S, Cabrera D, Arrese M, Feldstein AE. Triggering and resolution of inflammation in NASH. Nat Rev Gastroenterol Hepatol. 2018;15:349–64.
15. Polimeni L, Del Ben M, Baratta F, et al. Oxidative stress: new insights on the association of non-alcoholic fatty liver disease and atherosclerosis. World J Hepatol. 2015;7:1325–36.
16. Villanova N, Moscatiello S, Ramilli S, et al. Endothelial dysfunction and cardiovascular risk profile in nonalcoholic fatty liver disease. Hepatology. 2005;42:473–80.
17. Gao JP, Guo W. Mechanisms of abdominal aortic aneurysm progression: a review. Vasc Med. 2022;27:88–96.
18. Lu Q, Jiang X, Zhang C, Zhang W, Zhang W. Noninvasive Regional aortic stiffness for monitoring the early stage of abdominal aortic aneurysm in mice. Heart Lung Circ. 2017;26:395–403.
19. Jang W, Song JS. Non-invasive imaging methods to evaluate non-alcoholic fatty liver disease with Fat quantification: a review. Diagnostics (Basel). 2023;13:1852.
20. Chung J, Park HS, Kim YJ, Yu MH, Park S, Jung SI. Association of hepatic steatosis index with nonalcoholic fatty liver Disease diagnosed by Non-enhanced CT in a Screening Population. Diagnostics (Basel). 2021;11:2168.
21. Golledge J. Abdominal aortic aneurysm: update on pathogenesis and medical treatments. Nat Rev Cardiol. 2019;16:225–42.
22. Meyrignac O, Bal L, Zadro C, et al. Combining Volumetric and Wall Shear Stress Analysis from CT to assess risk of abdominal aortic aneurysm progression. Radiology. 2020;295:722–9.
23. Ichikawa K, Miyoshi T, Osawa K, et al. Prognostic value of non-alcoholic fatty liver disease for predicting cardiovascular events in patients with diabetes mellitus with suspected coronary artery disease: a prospective cohort study. Cardiovasc Diabetol. 2021;20:8.
24. Chalasani N, Younossi Z, Lavine JE, et al. The diagnosis and management of nonalcoholic fatty liver disease: practice guidance from the American Association for the study of Liver diseases. Hepatology. 2018;67:328–57.
25. Wanhainen A, Mani K, Golledge J. Surrogate markers of abdominal aortic aneurysm progression. Arterioscler Thromb Vasc Biol. 2016;36:236–44.
26. Khan S, Verma V, Verma S, Polzer S, Jha S. Assessing the potential risk of rupture of abdominal aortic aneurysms. Clin Radiol. 2015;70:11–20.
27. Xu J, Dai L, Zhang Y, et al. Severity of nonalcoholic fatty liver disease and risk of future ischemic stroke events. Stroke. 2021;52:103–10.
28. Yamaura H, Otsuka K, Ishikawa H, Shirasawa K, Fukuda D, Kasayuki N. Determinants of non-calcified low-attenuation coronary plaque burden in patients without known coronary artery disease: a coronary CT Angiography Study. Front Cardiovasc Med. 2022;9:824470.
29. Ishikawa H, Sugiyama T, Otsuka K, et al. Impact of epicardial adipose tissue on diastolic dysfunction in patients with chronic coronary syndrome and preserved left ventricular ejection fraction. Eur Heart J Imaging Methods Pract. 2024;2(1):qyae056.
30. Ristl R, Klopf J, Scheuba A, et al. Growth prediction model for abdominal aortic aneurysms. Br J Surg. 2022;109:211–9.
31. Zhu C, Leach JR, Wang Y, et al. Intraluminal Thrombus predicts Rapid Growth of Abdominal aortic aneurysms. Radiology. 2020;294:707–13.
32. Vilar-Gomez E, Martinez-Perez Y, Calzadilla-Bertot L, et al. Weight loss through lifestyle modification significantly reduces features of nonalcoholic steatohepatitis. Gastroenterology. 2015;149:367–e15.
33. European Association for the Study of the Liver; European Association for the Study of Diabetes. European Association for the Study of Obesity. EASL-EASD-EASO clinical practice guidelines for the management of non-alcoholic fatty liver disease. J Hepatol. 2016;64:1388–402.
34. Blazina I, Selph S. Diabetes drugs for nonalcoholic fatty liver disease: a systematic review. Syst Rev. 2019;8:295.
35. Powell EE, Wong VW, Rinella M. Non-alcoholic fatty liver disease. Lancet. 2021;397:2212–24.
36. Jia Y, Li Y, Yu J, et al. Association between metabolic dysfunction-associated fatty liver disease and abdominal aortic aneurysm. Nutr Metab Cardiovasc Dis. 2024;34(4):953–62.
37. Fukuda S, Watanabe H, Iwakura K, et al. Multicenter investigations of the prevalence of abdominal aortic aneurysm in elderly Japanese patients with hypertension. Circ J. 2015;79(3):524–9.
38. Kauffmann C, Tang A, Therasse E, et al. Measurements and detection of abdominal aortic aneurysm growth: Accuracy and reproducibility of a segmentation software. Eur J Radiol. 2012;81:1688–94.

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