

Original Article

Quantitative analysis of hemodynamic changes in patients with Alzheimer's disease based on carotid Doppler ultrasonography

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Abstract: Objective: To investigate carotid hemodynamic alterations in patients with Alzheimer's disease (AD) using carotid Doppler ultrasonography and to evaluate the associations between hemodynamic indices and cognitive impairment. Methods: A total of 150 patients with AD and 150 cognitively normal controls matched by age, sex, and education level were enrolled between January 2024 and December 2025. Cognitive function was assessed using the Mini-Mental State Examination (MMSE) and Clinical Dementia Rating (CDR) scale. Carotid Doppler ultrasonography was performed to measure intima-media thickness (IMT), peak systolic velocity (PSV), end-diastolic velocity (EDV), mean velocity (MV), pulsatility index (PI), and resistance index (RI) of the bilateral common carotid arteries (CCA) and internal carotid arteries (ICA). Differences between groups, correlations between hemodynamic indices and cognitive scores, and the diagnostic performance of carotid indices were analyzed. Results: Compared to controls, patients with AD showed significantly lower MMSE scores and higher CDR scores ($P < 0.05$). The bilateral CCA IMT was significantly increased in the AD group, whereas PSV, EDV, and MV of the bilateral CCA and ICA were significantly decreased and PI and RI were significantly increased ($P < 0.05$). In patients with AD, PSV, EDV, and MV were positively correlated with MMSE scores and negatively correlated with CDR scores, while PI and RI showed opposite correlations ($P < 0.05$). Furthermore, as CDR severity increased, blood flow velocities decreased and vascular resistance indices increased. The combined model incorporating left ICA PSV, left ICA RI, and right CCA IMT demonstrated good diagnostic performance for AD, with an area under the curve (AUC) of 0.873. Conclusion: Patients with AD exhibit significant carotid vascular structural and hemodynamic abnormalities characterized by increased IMT, reduced blood flow velocity, and elevated vascular resistance. These alterations are closely associated with cognitive impairment severity. Carotid Doppler ultrasonography may provide a non-invasive and clinically useful approach for auxiliary assessment of AD.

Keywords: Alzheimer's disease, Doppler ultrasonography, carotid artery, haemodynamics, cognitive function, diagnosis

Introduction

Alzheimer's disease (AD) is the most widespread neurodegenerative condition and the primary cause of cognitive impairment [1, 2]. A substantial burden is placed on patients, families and healthcare systems as a result of progressive cognitive decline, memory impairment and functional deterioration. The global population is ageing rapidly, which means that the number of people with AD is increasing. This makes it very important to identify people at

risk as soon as possible and to develop ways of treating them. While the exact causes of AD are still unclear, there is growing evidence that vascular dysfunction is a key factor in the development of cognitive impairment [3, 4]. At present, the early diagnosis of AD still faces many challenges. Traditional diagnostic methods, including clinical scale assessments, cerebrospinal fluid biomarker detection, and imaging examinations, have certain limitations in terms of sensitivity, specificity, or invasiveness [5, 6]. Therefore, it is of great clinical significance to

explore simple, noninvasive biomarkers that can reflect early pathophysiologic changes of the disease.

Carotid Doppler ultrasonography is a non-invasive, convenient and reproducible imaging technique that enables the simultaneous evaluation of vascular morphology and blood flow characteristics. Indices such as peak systolic velocity (PSV), end-diastolic velocity (EDV), mean velocity (MV), pulsatility index (PI) and resistance index (RI) can provide quantitative data on arterial compliance, vascular resistance and cerebral perfusion status [7]. Recent advances in vascular imaging research suggest that assessing multiple haemodynamic indices together may be more effective in identifying vascular abnormalities associated with cognitive impairment. However, the association between the severity of cognitive impairment and carotid Doppler-derived haemodynamic changes, as well as the ability of these indices to assist in the identification of Alzheimer's disease (AD), require further investigation [8].

Therefore, the aim of this study was to systematically evaluate carotid structural and haemodynamic alterations in patients with AD using carotid Doppler ultrasonography. We also investigated the relationship between carotid haemodynamic indices and cognitive function, as assessed using the Mini-Mental State Examination (MMSE) and Clinical Dementia Rating (CDR) scales. We also explored the diagnostic value of carotid ultrasonographic indices for AD. The findings of this study may provide new evidence in support of the use of non-invasive vascular imaging biomarkers for the supplementary assessment and clinical management of AD.

Patients and methods

Study subjects

This retrospective observational study was conducted at The Third People's Hospital of Ganzhou and was approved by the Ethics Committee of The Third People's Hospital of Ganzhou.

300 participants were included in this study between January 2024 and December 2025. The study population consisted of 150 patients diagnosed with Alzheimer's disease (AD) and

150 cognitively normal individuals who underwent routine health examinations during the same period.

The AD group included patients who met the clinical diagnostic criteria for Alzheimer's disease and underwent cognitive assessment and carotid Doppler ultrasonography during hospitalization. Patients were eligible if they were aged 50-85 years and had a Clinical Dementia Rating (CDR) score ranging from 0.5 to 2. According to age distribution, participants were further classified into different age categories (50-64 years, 65-74 years, and ≥ 75 years) for baseline assessment because AD is an age-related progressive neurodegenerative disorder.

The exclusion criteria for the AD group were as follows: (1) cognitive impairment caused by other neurological or psychiatric disorders, including vascular dementia, dementia with Lewy bodies, frontotemporal dementia, or severe psychiatric diseases; (2) symptomatic severe carotid artery stenosis ($> 70\%$) or a history of carotid endarterectomy or carotid artery stent implantation; (3) severe cardiac, pulmonary, hepatic, or renal dysfunction, malignant tumors, severe arrhythmia, significant valvular heart disease, arteritis, or other diseases that could substantially influence cerebral blood flow; and (4) poor-quality carotid ultrasound images unsuitable for quantitative analysis.

The control group consisted of 150 cognitively normal individuals recruited from the hospital health examination center during the same period. Participants in the control group were matched with the AD group at a 1:1 ratio according to age, sex, and years of education. Cognitive normality was confirmed by normal Mini-Mental State Examination (MMSE) and Montreal Cognitive Assessment-Basic (MoCA-B) scores, absence of subjective cognitive complaints, and a CDR score of 0.

The exclusion criteria for the control group were similar to those of the AD group and included symptomatic severe carotid artery stenosis ($> 70\%$) or previous carotid intervention, severe systemic diseases, cardiovascular conditions that could affect cerebral hemodynamics, history of stroke or transient ischemic attack (TIA), and inadequate ultrasound image quality.

Table 1. Comparison of general characteristics between the two groups

Variable	Observation group (n = 150)	Control group (n = 150)	Statistical value	P value
Age (years)	72.34 ± 6.85	71.89 ± 7.12	t = 0.567	0.571
Age group, n (%)			$\chi^2 = 0.326$	0.850
50-64 years	18 (12.00)	20 (13.33)		
65-74 years	82 (54.67)	79 (52.67)		
≥ 75 years	50 (33.33)	51 (34.00)		
Male, n (%)	78 (52.00)	75 (50.00)	$\chi^2 = 0.120$	0.729
BMI (kg/m ²)	23.56 ± 2.78	23.89 ± 2.94	t = 1.019	0.309
Years of education	9.45 ± 3.21	9.82 ± 3.05	t = 1.042	0.298
Hypertension, n (%)	85 (56.67)	78 (52.00)	$\chi^2 = 0.655$	0.418
Diabetes mellitus, n (%)	36 (24.00)	32 (21.33)	$\chi^2 = 0.306$	0.580
Hyperlipidemia, n (%)	62 (41.33)	58 (38.67)	$\chi^2 = 0.225$	0.635

Baseline demographic and clinical characteristics, including age, sex, body mass index (BMI), years of education, and medical history of hypertension, diabetes mellitus, hyperlipidemia, and coronary heart disease, were collected for all participants.

There were no statistically significant differences in the general baseline characteristics between the two groups ($P > 0.05$, **Table 1**).

Based on preliminary data showing a mean difference of approximately 10 cm/s in ICA PSV between AD and control subjects, a sample size calculation was performed using GPower 3.1. Assuming $\alpha = 0.05$, power = 0.90, and effect size $d = 0.50$, at least 134 participants per group were required. Considering a potential 10% dropout rate, 150 participants were ultimately recruited in each group.

Collection of clinical data and cognitive assessment

The age, sex, height, weight (for calculation of body mass index, BMI), years of education, and medical history including hypertension, diabetes mellitus, hyperlipidemia, and coronary heart disease were recorded for all participants. Cognitive function was evaluated in a quiet and independent environment by professionally trained neuropsychological assessors using the standardized Mini-Mental State Examination (MMSE) scale and Clinical Dementia Rating (CDR) scale.

Carotid color Doppler ultrasonography examination

The neck was checked with a special machine called a Siemens ACUSON Juniper and Sequoia

Silver color Doppler ultrasound diagnostic system (made in Germany). This machine has a special part that can be moved back and forth and can make pictures of the neck. All examinations were conducted by an experienced sonographer with over 5 years' experience in vascular ultrasound, who was blinded to the participants' group allocation.

Participants were placed in the supine position with the neck relaxed and slightly extended to fully expose the cervical region. The probe was moved along the course of the carotid artery to perform longitudinal and transverse scans sequentially.

Two-dimensional structures were observed in the form of the bilateral common, carotid and extracranial internal cervical arteries within the 1.5-2.0 cm range distal to the carotid bifurcation. Vessel inner diameter and intima-media thickness (IMT) were measured, and the average of three consecutive cardiac cycles was recorded.

Under quiet breathing conditions, the pulsed Doppler sample volume was positioned at the center of the target vessel lumen, with the insonation angle maintained at $\leq 60^\circ$. Stable flow spectra were obtained from the mid-CCA (> 2 cm proximal to the bifurcation) and the extracranial ICA (1-1.5 cm distal to the origin).

After freezing the image, peak systolic velocity (PSV) and end-diastolic velocity (EDV) were measured. The built-in software automatically calculated mean velocity (MV), pulsatility index (PI), and resistance index (RI). Each index was measured over three consecutive clear cardiac

Table 2. Comparison of cognitive function scores between the two groups

Group	MMSE Score	CDR Score
Observation group (n = 150)	18.62 ± 4.37	1.0 (0.5, 1.0)
Control group (n = 150)	28.45 ± 1.52	0.0 (0.0, 0.0)
t value	25.781	-
P value	< 0.001	< 0.001

cycle spectra, and the mean value was used for analysis.

Observation indicators

(1) The differences in the general clinical characteristics, IMT and haemodynamic indices of the common carotid artery (CCA) and internal carotid artery (ICA) were compared between the observation group and the control group. (2) Correlations between hemodynamic indices and cognitive scores were analyzed. (3) Differences in hemodynamic indices among Alzheimer's disease patients with different CDR grades were compared. (4) Receiver operating characteristic (ROC) curves were plotted in order to evaluate the diagnostic value of carotid ultrasonographic indices in discriminating between Alzheimer's disease and other conditions.

Statistical analysis

Analyses were done using SPSS version 26.0. Continuous variables were presented as the mean ± standard deviation ($\bar{x} \pm s$), or the median with the interquartile range (IQR), depending on the distribution of the data. Between-group comparisons were performed using an independent-samples t-test or a Mann-Whitney U-test, as appropriate. Categorical variables were reported as frequencies and percentages, and comparisons were made using the chi-square test or Fisher's exact test.

Univariate and multivariate binary logistic regression analyses. Odds ratios (ORs) with their respective 95% confidence intervals (CIs) were estimated. Variables with a P value of less than 0.1 in the univariate analysis were entered into the multivariate model.

The predictive performance of each independent factor, as well as the combined model generated from logistic regression probabilities, was assessed using receiver operating charac-

teristic (ROC) curve analysis. The area under the ROC curve (AUC) was calculated. Comparisons between AUC values were conducted. The DeLong test was used. A two-sided P value < 0.05 was considered significant.

Results

Comparison of cognitive function scores between the two groups

The MMSE score in the observation group was significantly lower than that of the control group, $P < 0.05$. The CDR score was significantly higher than that of the control group, $P < 0.05$, **Table 2**.

Comparison of intima-media thickness (IMT) between the two groups

There was a significant difference between the IMT of the bilateral common carotid arteries (CCA) in the observation group and the control group ($P < 0.05$). No significant difference was found in the IMT of the bilateral internal carotid arteries (ICA) between the two groups, $P > 0.05$. See **Table 3** and **Figure 1**.

Comparison of hemodynamic indices of the CCA between the two groups

Peak systolic velocity (PSV), end-diastolic velocity (EDV), and mean velocity (MV) of the bilateral CCA were significantly lower in the observation group than in the control group ($P < 0.05$), whereas pulsatility index (PI) and resistance index (RI) were significantly higher ($P < 0.05$). See **Table 4**.

Comparison of hemodynamic indices of the ICA between the two groups

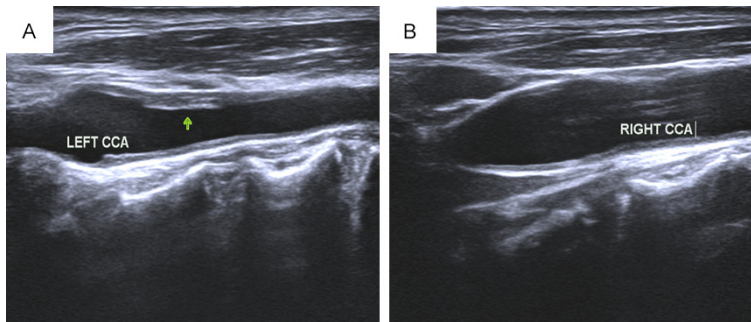
PSV, EDV, and MV of the bilateral ICA were significantly lower in the observation group than in the control group ($P < 0.05$), whereas PI and RI were significantly higher ($P < 0.05$). See **Table 5**.

Correlation analysis between hemodynamic indices and cognitive scores

Correlation analysis showed that carotid hemodynamic $P < 0.05$. were significantly associated

Table 3. Comparison of IMT between the two groups

Group	Left CCA IMT	Right CCA IMT	Left ICA IMT	Right ICA IMT
Observation group (n = 150)	0.89 ± 0.16	0.88 ± 0.15	0.73 ± 0.14	0.72 ± 0.13
Control group (n = 150)	0.81 ± 0.12	0.80 ± 0.13	0.71 ± 0.11	0.70 ± 0.12
t value	4.873	4.933	1.367	1.378
P value	< 0.001	< 0.001	0.173	0.169

**Figure 1.** Longitudinal B-mode ultrasound images of the right CCA (A) and left CCA (B), showing clear visualization of the arterial lumen and intima-media complex. The green arrow indicates focal intima-media thickening in the left CCA. CCA: common carotid arteries.**Table 4.** Comparison of hemodynamic indices of CCA between the two groups

Index	Observation group (n = 150)	Control group (n = 150)	t value	P value
PSV (cm/s)				
Left CCA	65.34 ± 11.25	78.91 ± 12.47	-9.865	< 0.001
Right CCA	66.02 ± 10.98	79.56 ± 13.02	-9.632	< 0.001
EDV (cm/s)				
Left CCA	18.56 ± 4.32	24.89 ± 5.01	-11.789	< 0.001
Right CCA	19.01 ± 4.45	25.12 ± 5.11	-11.345	< 0.001
MV (cm/s)				
Left CCA	35.45 ± 6.78	44.12 ± 7.89	-10.123	< 0.001
Right CCA	36.01 ± 6.91	44.89 ± 7.95	-10.456	< 0.001
PI				
Left CCA	1.35 ± 0.23	1.22 ± 0.18	5.456	< 0.001
Right CCA	1.33 ± 0.22	1.21 ± 0.19	5.234	< 0.001
RI				
Left CCA	0.72 ± 0.06	0.68 ± 0.05	6.345	< 0.001
Right CCA	0.71 ± 0.05	0.68 ± 0.05	5.789	< 0.001

Note: CCA: common carotid arteries.

with cognitive scores in patients with Alzheimer's disease (AD). The peak systolic velocity (PSV), end-diastolic velocity (EDV), and mean velocity (MV) of the bilateral common carotid arteries (CCA) and internal carotid arteries (ICA) were positively correlated with Mini-Mental State Examination (MMSE) scores and neg-

atively correlated with Clinical Dementia Rating (CDR) scores ($P < 0.05$). In contrast, the pulsatility index (PI) and resistance index (RI) of the bilateral CCA and ICA showed negative correlations with MMSE scores and positive correlations with CDR scores ($P < 0.05$). These findings indicated that lower carotid blood flow velocity and increased vascular resistance were associated with poorer cognitive performance and greater dementia severity in AD patients (Table 6).

A comparison of the hemodynamic indices of patients in the observation group with different CDR grades who have Alzheimer's disease is presented here

Patients in the observation group were categorised by CDR score into the following groups: CDR 0.5 (n = 48), CDR 1 (n = 72) and CDR 2 (n = 30). As CDR scores increased, the PSV, EDV and MV of the bilateral CCA and ICA decreased ($P < 0.05$), while the PI and RI increased ($P < 0.05$). See Table 7.

Diagnostic value of carotid ultrasonographic indices for Alzheimer's disease

Binary logistic regression analysis (forward LR method) was performed using an Alzheimer's disease diagnosis as the dependent variable and ultrasonographic parameters showing significant differences in univariate analyses (bilateral common carotid artery (CCA) and internal carotid artery (ICA) peak systolic velocity (PSV), end-diastolic velocity (EDV), mean velocity (MV), pulsatility

Table 5. Comparison of hemodynamic indices of ICA between the two groups

Index	Observation group (n = 150)	Control group (n = 150)	t value	P value
PSV (cm/s)				
Left ICA	52.34 ± 9.87	63.45 ± 10.56	-9.342	< 0.001
Right ICA	53.12 ± 9.45	64.01 ± 11.02	-9.123	< 0.001
EDV (cm/s)				
Left ICA	15.89 ± 3.78	21.34 ± 4.56	-11.234	< 0.001
Right ICA	16.23 ± 3.91	21.78 ± 4.67	-11.567	< 0.001
MV (cm/s)				
Left ICA	28.45 ± 5.67	36.78 ± 6.89	-11.890	< 0.001
Right ICA	29.01 ± 5.89	37.12 ± 7.01	-11.345	< 0.001
PI				
Left ICA	1.29 ± 0.21	1.15 ± 0.16	6.567	< 0.001
Right ICA	1.28 ± 0.20	1.14 ± 0.17	6.789	< 0.001
RI				
Left ICA	0.70 ± 0.05	0.66 ± 0.05	7.012	< 0.001
Right ICA	0.69 ± 0.05	0.66 ± 0.04	6.456	< 0.001

Note: CCA: internal carotid arteries.

index (PI), resistance index (RI), and CCA intima-media thickness (IMT)) as the independent variables. The final regression model included the following variables: left ICA PSV, left ICA RI and right CCA IMT. The construction of a combined predictive factor (Logit P) and the generation of an ROC curve were based on this model. The results showed that the combined predictive factor had an area under the curve (AUC) of 0.873. This was 95% CI: 0.832-0.914. The results also showed that the combined predictive factor had a sensitivity of 81.33% and a specificity of 80.00%. This was superior to any single index for differential diagnosis. See **Table 8**.

Discussion

The global population is ageing rapidly, and this has made AD one of the major neurodegenerative disorders that are a serious threat to the health of older adults [9, 10]. While not all of the pathologic mechanisms of AD are clear, evidence indicates that cerebrovascular dysfunction plays a pivotal role in the onset and progression of the disease [11, 12]. As the carotid arteries are the main pathways supplying cerebral blood flow, their hemodynamic status can directly reflect cerebral perfusion [13, 14]. Therefore, evaluating carotid hemodynamic indices

using Doppler ultrasonography is of great significance for understanding the pathophysiologic processes of AD.

The present study showed that MMSE scores in the observation group were lower than those of the control group ($P < 0.05$), whereas CDR scores were higher ($P < 0.05$). These findings are consistent with the clinical characteristics of cognitive impairment in patients with AD [15, 16], indicating that the enrolled patients indeed had significant cognitive dysfunction, thus providing a reasonable clinical basis for subsequent hemodynamic analyses. Further analyses demonstrated that the bilateral CCA IMT was significantly greater in

the observation group than in the control group ($P < 0.05$). In addition, PSV, EDV, and MV of the bilateral CCA and ICA were significantly lower than those of the control group ($P < 0.05$), whereas PI and RI were significantly higher ($P < 0.05$). Increased IMT suggests that the inner wall of the carotid artery has changed shape. This may be related to a build-up of fat and inflammation, which can narrow the inside of the artery or reduce its flexibility. This can affect how fast blood flows and is considered an early marker of atherosclerosis [17, 18]. Our findings are largely consistent with those of Williams et al. [19], who also reported that carotid stiffness and structural changes were closely associated with cognitive decline and AD-related brain structural abnormalities [20, 21].

In addition, correlation analyses in the observation group showed that PSV, MV, and EDV of the bilateral CCA and ICA were positively correlated with MMSE scores ($P < 0.05$) and negatively correlated with CDR scores ($P < 0.05$), whereas PI and RI were negatively correlated with MMSE scores ($P < 0.05$) and positively correlated with CDR scores ($P < 0.05$). These findings suggest that hemodynamic abnormalities are continuously and progressively associated with the severity of cognitive impairment [22]. They may be not only a concomitant phenomenon of AD,

Table 6. Correlation analysis between hemodynamic indices and cognitive scores

item	MMSE		CDR	
	r	P	r	P
Left CCA				
PSV	0.435	< 0.001	-0.421	< 0.001
EDV	0.365	< 0.001	-0.356	< 0.001
MV	0.452	< 0.001	-0.438	< 0.001
PI	-0.412	< 0.001	0.403	< 0.001
RI	-0.423	< 0.001	0.415	< 0.001
Right CCA				
PSV	0.427	< 0.001	-0.412	< 0.001
EDV	0.358	< 0.001	-0.345	< 0.001
MV	0.446	< 0.001	-0.432	< 0.001
PI	-0.405	< 0.001	0.396	< 0.001
RI	-0.418	< 0.001	0.410	< 0.001
Left ICA				
PSV	0.468	< 0.001	-0.452	< 0.001
EDV	0.389	< 0.001	-0.378	< 0.001
MV	0.486	< 0.001	-0.468	< 0.001
PI	-0.498	< 0.001	0.482	< 0.001
RI	-0.523	< 0.001	0.507	< 0.001
Right ICA				
PSV	0.456	< 0.001	-0.441	< 0.001
EDV	0.375	< 0.001	-0.364	< 0.001
MV	0.473	< 0.001	-0.456	< 0.001
PI	-0.487	< 0.001	0.471	< 0.001
RI	-0.512	< 0.001	0.495	< 0.001

Note: PSV: peak systolic velocity; EDV: end-diastolic velocity; MV: mean velocity; PI: pulsatility index; RI: resistance index.

but also a key contributor to the pathologic process of cognitive decline [23, 24]. Furthermore, as CDR scores increased, peak blood flow velocity, end-diastolic volume, and mean blood flow velocity in the bilateral common carotid and internal carotid arteries showed a downward trend ($P < 0.05$), while the pulse index and resistance index showed an upward trend ($P < 0.05$). This indicates a positive correlation between the deterioration of hemodynamic indices and the progression of cognitive impairment. These changes provide enhanced clinical evidence to explain the pathophysiologic basis of the progressive cognitive decline observed in AD [25]. Furthermore, previous studies have demonstrated that persistent hemodynamic abnormalities in AD patients may lead to insuff-

icient cerebral perfusion, thereby exacerbating cognitive impairment and creating a vicious cycle [26, 27]. Gareau et al. [28] also observed abnormal cerebral vascular reactivity in mouse models of AD, supporting the critical role of vascular dysfunction in disease progression.

Logical analysis and mathematical modelling showed that left ICA PSV, left ICA RI and right CCA IMT were all important in predicting AD. ROC curve analysis revealed that the combined predictive factor exhibited an area under the curve (AUC) of 0.873, indicating its effectiveness in distinguishing between cases. This indicates that merging CCA IMT, which mirrors vascular structure, with ICA PSV and RI, which mirror haemodynamic status, furnishes a more exhaustive documentation of carotid pathophysiologic alterations in AD patients, thus enhancing disease identification. This combination of indices could provide a non-invasive, reproducible set of imaging biomarkers for early screening and auxiliary diagnosis of AD, with promising clinical application prospects [29, 30]. In clinical practice, these indices, obtained via carotid Doppler ultrasonography, could be useful tools. They can be used to evaluate the risk of cognitive decline and to monitor disease progression. This is particularly beneficial for individuals at risk of cognitive impairment. These are individuals who have not yet developed obvious clinical symptoms.

In summary, people with Alzheimer's disease exhibit distinct alterations in carotid blood flow, including reduced blood velocity, increased vascular resistance, and elevated intima-media thickness (IMT). The severity of these changes is closely linked to the extent of impairment to patients' cognitive abilities. The findings suggest that carotid Doppler ultrasonography can serve as an additional diagnostic tool in clinical practice. However, this study had certain limitations, including a relatively small sample size and the fact that a cross-sectional design cannot establish causation. Further investigation into the causal relationship between carotid haemodynamic indices and the occurrence, progression and prognosis of Alzheimer's disease is warranted in future multicentre prospective cohort studies with larger sample sizes.

Table 7. Comparison of blood flow indices in Alzheimer's disease patients with different cdr grades in the observation group

Index	CDR 0.5 (n = 48)	CDR 1 (n = 72)	CDR 2 (n = 30)	F	P
PSV (cm/s)	58.34 ± 8.45	51.23 ± 9.12	45.67 ± 8.89	18.234	< 0.001
EDV (cm/s)	18.56 ± 3.23	15.12 ± 3.45	12.34 ± 2.98	25.678	< 0.001
MV (cm/s)	32.45 ± 4.98	27.89 ± 5.12	23.45 ± 4.56	29.012	< 0.001
PI	1.21 ± 0.18	1.30 ± 0.20	1.42 ± 0.22	10.456	< 0.001
RI	0.68 ± 0.04	0.71 ± 0.05	0.73 ± 0.05	12.345	< 0.001

Note: PSV: peak systolic velocity; EDV: end-diastolic velocity; MV: mean velocity; PI: pulsatility index; RI: resistance index.

Table 8. Diagnostic value of carotid ultrasound indices for Alzheimer's disease

Index	AUC	95% CI	Optimal cutoff value	Sensitivity (%)	Specificity (%)	Youden index
Left ICA PSV	0.798	0.748-0.849	≤ 56.5 cm/s	76.00	72.67	0.4867
Left ICA RI	0.765	0.711-0.819	> 0.685	70.67	69.33	0.4000
Right CCA IMT	0.702	0.643-0.761	> 0.85 mm	65.33	68.67	0.3400
Combined predictor	0.873	0.832-0.914	-0.352	81.33	80.00	0.6133

Note: ICA: internal carotid arteries; CCA: common carotid arteries; PSV: peak systolic velocity; EDV: end-diastolic velocity; IMT: intima-media thickness; RI: resistance index.

Disclosure of conflict of interest

None.

Abbreviations

AD, Alzheimer's disease; MMSE, Mini-Mental State Examination; CDR, Clinical Dementia Rating; CCA, Common carotid artery; ICA, Internal carotid artery; IMT, Intima-media thickness; PSV, Peak systolic velocity; EDV, End-diastolic velocity; MV, Mean velocity; PI, Pulsatility index; RI, Resistance index; ROC, Receiver operating characteristic; AUC, Area under the curve.

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