scientific reports

OPEN

Effect of information motivation behavioral skills model based dietary patterns on carotid atherosclerosis in elderly hypertensive patients

Beiguang Yu[1]✉, Linlin Pu[2], Shuai Liu[3], Shanshan Lu[3], Guochao Han[3] & Dongruo He[3]

Since hypertension exacerbates carotid arteries atherosclerosis among the elderly, this study aimed to find whether dietary pattern alteration can alleviate this effect using the Information-Motivation-Behavioral (IMB) Skills Model. In a retrospective cohort study with a 3-month follow-up, 1000 elderly hypertensive patients admitted between June 2022 and June 2023 were categorized into two groups: a Non-IMB group (*n* = 480) following a standard low-salt, low-fat diet and an IMB model-based diet group (*n* = 520). Propensity score matching ensured comparable baseline characteristics. Over three months, the IMB group received comprehensive dietary education and support. Primary outcomes measured were changes in CIMT and plaque scores, assessed via carotid ultrasound. Secondary measures included motivation for health-related behaviors, cardiovascular health, and quality of life. The IMB group showed a significant reduction in CIMT (1.05 ± 0.30 mm) compared to the Non-IMB group (1.20 ± 0.35 mm, *P* < 0.001). Plaque scores decreased significantly in the IMB group (1.80 ± 0.32) versus the Non-IMB group (1.97 ± 0.41, *P* < 0.001). Multivariate analysis highlighted adherence to the IMB dietary pattern as the strongest predictor of improved CIMT and plaque scores, with an odds ratio of 7.807 (95% CI 5.851 to 10.417, *P* < 0.001). While significant improvements were noted in dietary intake patterns and blood pressure parameters, motivational and cardiovascular health metrics showed no statistically significant differences between groups. The potential applicability of the IMB dietary framework in clinical strategies aimed at mitigating atherosclerosis progression and managing cardiovascular risk in this demographic.

Keywords Dietary pattern, Information-motivation-behavioral model, Carotid artery atherosclerosis, Elderly hypertensive patients, Retrospective cohort study, Carotid vascular ultrasound

Carotid atherosclerosis significantly contributes to cardiovascular morbidity and mortality, accounting for approximately 20% of all stroke-related deaths globally[1]. This condition is particularly prevalent among elderly hypertensive patients, where the incidence rate reaches up to 75%, highlighting the urgent need for targeted interventions[2]. As the population ages, addressing carotid atherosclerosis becomes increasingly critical, given its role in increasing the risk of cerebrovascular events like strokes[3].

Hypertension is a well-documented risk factor for the progression of atherosclerotic disease, with elevated blood pressure contributing to endothelial damage and vascular inflammation[4]. By reducing blood pressure through dietary means, there is a plausible reduction in the progression of carotid intima-media thickness (CIMT) and plaque development[5]. This underscores the importance of exploring novel dietary strategies that are both evidence-based and psychologically informed to combat these pathophysiological processes[6].

Existing dietary interventions, such as the DASH diet, have demonstrated efficacy in lowering blood pressure and improving cardiovascular outcomes[7]. These diets typically emphasize reducing sodium intake and increasing

[1]Department of Electrophysiology, The First Hospital of Qiqihar, No. 30, Park Road, Longsha District, Qiqihar 161000, Heilongjiang, China. [2]Department of Respiratory Medicine I, The Second Affiliated Hospital of Qiqihar Medical University, Qiqihar, China. [3]Department of Electrophysiology, , The Second Affiliated Hospital of Qiqihar Medical University, Qiqihar, China. ✉email: yubeiguang@qmu.edu.cn

the consumption of fruits, vegetables, and whole grains, aligning with heart-healthy eating patterns[8,9]. Despite these benefits, the sustainability and adherence to such diets can be challenging without structured support[10].

The Information-Motivation-Behavioral Skills (IMB) model has emerged as a robust framework for promoting sustained lifestyle modifications in chronic diseases[11]. Originally developed to enhance adherence behaviors in HIV prevention, the IMB model is grounded in three core tenets: information provision, motivation enhancement, and behavioral skills development[12]. By leveraging these elements, the IMB model aids patients in adopting and maintaining health-promoting behaviors more effectively[13]. Studies have shown that interventions based on the IMB model can achieve adherence rates of over 80%, underscoring its potential in addressing complex health challenges such as carotid atherosclerosis[14]. The IMB model's integrative approach could potentially mitigate adherence issues by reinforcing motivation and enhancing self-efficacy through targeted behavioral strategies[15].

Given the physiological and psychosocial challenges often faced by the elderly demographic, including polypharmacy, cognitive changes, and motivational fluctuations, applying a model like the IMB can provide a personalized and comprehensive approach. Moreover, chronic disease management in elderly patients frequently requires multidisciplinary collaboration. An intervention rooted in the IMB model can leverage the diverse expertise of dietitians, psychologists, and other health professionals to craft an intervention tailored to the complex needs of this population.

The present study aims to evaluate the impact of an IMB skills model-based dietary intervention on carotid atherosclerosis in elderly hypertensive patients. By systematically assessing changes in vascular biomarkers and correlating them with dietary adherence and motivation, this research will provide critical insights into the utility of IMB-informed dietary patterns in clinical practice.

Materials and methods

Case selection

This study was designed as a retrospective cohort study aimed at evaluating the impact of dietary pattern, guided by the IMB model, on carotid atherosclerosis in elderly patients with hypertension using carotid ultrasound. The analysis includes elderly hypertensive patients admitted to our hospital between June 2022 and June 2023. Exclusion criteria included patients with diabetes, rheumatic diseases, or active inflammatory diseases. These conditions were excluded to ensure a homogeneous study population and minimize confounding factors that could affect the outcomes of carotid atherosclerosis. Propensity score matching (PSM) was performed based on baseline characteristics, and 1000 participants were selected. Participants were divided into two groups based on their dietary pattern: Non-IMB group ($n = 480$) and a diet group guided by the IMB model ($n = 520$).

To further elucidate the impact of a diet pattern guided by the Information-Motivation-Behavioral Skills (IMB) model on carotid atherosclerosis, we performed a secondary subgroup analysis based on the primary outcome measures (carotid intima-media thickness [CIMT] and plaque score). Patients were divided into two groups: the improvement group, which included patients who showed a reduction in CIMT of > 0.1 mm and/ or a reduction in plaque score of > 1 after three months, and the non-improvement group, which included patients with no significant changes in CIMT and/or plaque score. The distribution of patients in each group is summarized as follows: in the non-IMB group, the improvement group ($n = 100$) and the non-improvement group ($n = 380$); in the IMB group, the improvement group ($n = 350$) and the non-improvement group ($n = 170$). Given the retrospective nature of the study, randomization or blinding was not feasible. However, outcome assessors were blinded to group allocation when possible to minimize bias in the assessment of CIMT and plaque scores.

Demographic data, parameters of carotid atherosclerosis, medication use, and blood pressure measurements were gathered from the medical records system. Additionally, the study collected information on patients' motivation for health-related behaviors, quality of life, and cardiovascular health. The data were then analyzed to determine the effects of different dietary pattern on carotid atherosclerosis. The study received approval from the Institutional Review Board and Ethics Committee of our institution. All experiments were performed in accordance with relevant guidelines and regulations. For this retrospective study, informed consent was waived due to the use of de-identified patient data, which ensured no risk or impact on patient care. This waiver was granted in compliance with regulatory and ethical guidelines applicable to retrospective research.

Methods

Non-IMB group

Participants followed a low-salt, low-fat diet.

Diet group based on the IMB model

Establishment of a Dietary Pattern Team: A dietary pattern team was formed, consisting of four nurses from our department, organized by the head nurse. The team received professional training from the head nurse, a nutritionist, and a chief physician. Training sessions were conducted once a week, with four to five sessions covering the IMB model principles, nutritional requirements for hypertension, and effective nurse-patient communication. After passing assessments, the team collaborated in developing dietary plans with an emphasis on low salt and low fat. They also prepared a dietary pattern manual, recommending approximately ten cups (200 ml each) of plain or lightly brewed tea daily, to maintain continuous dietary pattern and promote patient health. Information: During the hospitalization period, a combination of group lectures and bedside education was employed. Group lectures were held twice a week, each lasting about 30 min, focusing on common dietary misconceptions and dietary principles. Bedside education concentrated on individual food choices, dietary precautions, and adequate hydration, using strategic segments to reinforce patient knowledge. Before discharge, patients received a dietary management manual. Communication continued outside the hospital through a WeChat platform, providing patients with information on gout, diabetes, and dietary recipes. Weekly quizzes with prizes were held to boost engagement, and the management team collected and addressed difficult questions to guide patients effectively. Motivation: Guided communication techniques were used to motivate patients. During the first interaction, patients provided a 3-day dietary intake record, which helped assess their understanding of dietary practices for hypertension. The second meeting analyzed barriers to scientific eating habits, allowing patients to express themselves while healthcare staff guided the conversation. Collaborative short-term goals tailored to individual patient needs were established with family members encouraged to supervise and motivate patients to adhere to the regimen outside the hospital. Behavior: One to 2 days prior to discharge, families were contacted to explain the importance of healthy dietary behaviors in disease management. Families were engaged to support and monitor the patient's dietary habits. Patients and family members were instructed to record daily dietary intake in the dietary management manual and submit photos every 3 days to the management team for analysis. The team provided scientific and targeted guidance to help establish healthy dietary habits. Additionally, patients who performed well were invited to share their experiences and insights on diet management in a WeChat group every two weeks, which was positively reinforced by team members to encourage others to learn from their examples.

The management spanned a period of three months. This study adhered to ethical principles, with informed consent obtained from all participants. The study was approved by the Ethics Committee of the Second Affiliated Hospital of Qiqihar Medical University (No. 2024-01-23).

Assessment of health behavior motivation

Three months following the treatment, the Treatment Self-regulation Questionnaire (TSRQ) was utilized to assess participants' motivation for health-related behaviors. Developed in 1996 by British scholar Williams et al.[16], the questionnaire encompasses three domains: smoking cessation, physical activity, and healthy eating, each containing 14 items. Responses were measured on a 7-point Likert scale, ranging from 1 (not at all true) to 7 (very true), with total scores ranging from a minimum of 14 to a maximum of 98. Higher scores indicate a stronger level of motivation. The Cronbach's alpha for each of the three domains within the scale exceeds 0.8[17], indicating high internal consistency.

Cardiovascular health status

Cardiovascular health, a term encompassing cardiovascular-related behaviors and factors, was introduced by the American Heart Association (AHA) in 2010. It includes four health behaviors: smoking, body mass index, physical activity, and healthy diet; and three health factors: total cholesterol, blood pressure, and fasting blood glucose, totaling seven indicators[18]. Each indicator was scored on a scale ranging from 1 (poor) to 3 (ideal), resulting in a total score range of 0 to 14. Higher scores reflect better cardiovascular health, indicating lower progression of atherosclerosis and reduced incidence of cardiovascular events. Three months post-treatment, participants in both groups were surveyed to assess their cardiovascular health status.

Quality of life

The 36-item Short Form Health Survey (SF-36) was used to evaluate quality of life across several dimensions: physical pain, physical functioning, psychological health, social functioning, emotional functioning, and physiological functioning. This self-administered general health questionnaire assesses each domain on a scale from 0 to 100, with higher scores indicating a better quality of life. The scale demonstrates strong reliability, with a Cronbach's alpha coefficient of 0.800[19].

CIMT and plaque score measurement

CIMT and plaque scores were measured using high-resolution B-mode ultrasound imaging (Philips EPIQ 7G, Philips Medical Systems, Andover, MA, USA). All measurements were performed by two experienced sonographers who were blinded to the participants' group allocation to minimize bias.

Imaging protocol: Participants were examined in a supine position with slight neck extension. Longitudinal images of the common carotid artery (CCA), carotid bifurcation, and internal carotid artery (ICA) were obtained from both sides. CIMT was measured at the far wall of the CCA, approximately 1 cm proximal to the carotid bulb, using electronic calipers on a freeze-frame image. Three measurements were taken at each site, and the average value was used for analysis.

Plaque score: Plaques were defined as focal structures encroaching into the arterial lumen by at least 0.5 mm or 50% of the surrounding intima-media thickness. The plaque score was calculated based on the number and size of plaques, following the Mannheim Carotid Intima-Media Thickness and Plaque Consensus[20].

Inter- and Intra-observer variability: To assess inter- and intra-observer variability, 20 randomly selected cases were re-measured by both sonographers. The intra-class correlation coefficient (ICC) was calculated to quantify the consistency between measurements. The ICC values for CIMT measurements were 0.93 for intra-observer reliability and 0.89 for inter-observer reliability, indicating excellent agreement.

Quality control: Regular calibration and quality control checks were conducted on the ultrasound equipment to ensure consistent and accurate measurements. Sonographers underwent standardized training and certification to maintain high standards of data collection.

Additional physiological and biochemical indicators

Data on baseline blood pressure parameters, medication use, dietary intake, carotid artery atherosclerosis parameters (assessed via carotid ultrasound), and blood lipid profiles were collected and analyzed for both the Non-IMB group and the IMB model-based diet group before and three months after the treatment.

Statistical analysis

Given the retrospective nature of this study, the sample size was determined based on the availability of medical records. A total of 1000 participants were included after propensity score matching to ensure a balanced comparison between the Non-IMB and IMB-guided diet groups. To validate the adequacy of the sample size, a post-hoc power analysis was conducted. Based on our primary outcome measure (change in CIMT), with an expected mean difference of 0.1 mm and a standard deviation of 0.2 mm, a sample size of 1000 participants (480 in the Non-IMB group and 520 in the IMB-guided diet group) provides over 90% power to detect a significant difference at a two-sided alpha level of 0.05. This calculation was performed using G*Power software version 3.1.9.7.

The data were analyzed using SPSS 29.0 statistical software (SPSS Inc., Chicago, IL, USA). To address potential covariate bias, propensity score matching (PSM) was used to include all available baseline variables, including demographic characteristics, health status and history, blood pressure parameters, and medication use. Logistic regression analysis was employed to calculate the propensity scores, and a 1:1 nearest neighbor matching method without replacement was applied, with a caliper set at 20% of the standard deviation of the PSM scores between the two groups. To assess the impact of the IMB dietary pattern on the primary outcome, we conducted a multivariate logistic regression analysis. Additionally, we calculated the odds ratios (ORs) associated with the primary outcome to quantify the extent of the IMB dietary pattern's effect. Categorical data were represented as [n (%)] and the chi-square test was employed. Continuous variables were initially tested for normality using the Shapiro–Wilk method. For data following a normal distribution, results were presented as ($X \pm s$). A p-value of < 0.05 was considered statistically significant.

Results

Baseline characteristics of participants

The mean ages were 68.25 ± 3.21 years for the Non-IMB Group and 67.92 ± 3.51 years for the IMB group ($P = 0.116$) (Table 1). Both groups had similar body mass indices, with the Non-IMB Group at 26.18 ± 2.50 kg/m^2 and the IMB group at 25.97 ± 2.40 kg/m^2 ($P = 0.180$). Gender distribution, with males comprising 56.6% in the Non-IMB Group and 58.18% in the IMB group, was also not significantly different ($P = 0.652$). The duration of hypertension was reported as 5.87 ± 2.15 years in the Non-IMB Group and 6.02 ± 2.32 years in the IMB group ($P = 0.295$). Similar trends were observed for smoking status and drinking history, with both parameters showing no significant differences between the groups (smoking: $P = 0.094$; drinking: $P = 0.074$). Education levels and marital status were similarly balanced between the groups. For education level categories—illiterate, primary, secondary, and university degree—there were no significant disparities ($P = 0.849$). The proportion of patients using antihypertensive medication was 24.58% in the Non-IMB Group compared to 21.73% in the IMB group ($P = 0.285$). Statin use was reported in 20.63% of patients in the Non-IMB Group and 21.73% in the IMB group ($P = 0.669$). Similarly, aspirin use was observed in 15.00% of the Non-IMB Group and 16.35% of the IMB group ($P = 0.559$). These results indicate that medication usage patterns were comparable between the two groups at the start of the study. These findings suggest that both cohorts were comparable at baseline.

Blood pressure parameters

The mean systolic blood pressure was 138.07 ± 8.56 mmHg in the Non-IMB Group compared to 137.94 ± 7.92 mmHg in the IMB group ($P = 0.800$) (Table 2). Diastolic blood pressure averaged 85.45 ± 5.32 mmHg in the Non-

Parameters	Non-IMB group ($n = 480$)	IMB group ($n = 520$)	t/χ^2	*P*
Age (years)	68.25 ± 3.21	67.92 ± 3.51	1.572	0.116
BMI (kg/m^2)	26.18 ± 2.50	25.97 ± 2.40	1.341	0.180
Gender [n/(%)] (M/F)	272 (56.6%)	302 (58.18%)	0.203	0.652
Hypertension duration (years)	5.87 ± 2.15	6.02 ± 2.32	1.048	0.295
Smoking status [n/(%)] (Y/N)	127 (26.42%)	114 (21.82%)	2.807	0.094
Drinking history [n (%)] (Y/N)	289 (60.21%)	284 (54.62%)	3.191	0.074
Education level [n/(%)] (illiterate/ primary education/secondary education /university degree)			0.802	0.849
Illiterate	9 (1.88%)	9 (1.73%)		
Primary education	181 (37.71%)	198 (38.08%)		
Secondary education	263 (54.79%)	290 (55.77%)		
University degree	27 (5.63%)	23 (4.42%)		
Marital status (married with spouse/divorced or widowed)			0.243	0.622
Married with spouse	407 (84.79%)	435 (83.65%)		
Divorced or widowed	73 (15.21%)	85 (16.35%)		
Medication use				
Antihypertensive Medication [n/(%)]	118 (24.58%)	113 (21.73%)	1.143	0.285
Statin use [n/(%)]	99 (20.63%)	113 (21.73%)	0.183	0.669
Aspirin use [n/(%)]	72 (15.00%)	85 (16.35%)	0.342	0.559

Table 1. Baseline characteristics of participants. *BMI* body mass index.

	Parameters	Non-IMB group (n = 480)	IMB group (n = 520)	t/χ^2	P
Baseline	Systolic BP (mmHg)	138.07 ± 8.56	137.94 ± 7.92	0.254	0.800
	Diastolic BP (mmHg)	85.45 ± 5.32	84.91 ± 5.10	1.655	0.098
	Mean arterial pressure (mmHg)	102.13 ± 6.42	101.75 ± 6.10	0.967	0.334
	Pulse pressure (mmHg)	54.42 ± 7.23	53.89 ± 6.91	1.198	0.231
	Blood pressure control [n/ (%)]	380 (79.17%)	425 (81.73%)	1.045	0.307
After 3 months	Systolic BP (mmHg)	129.84 ± 9.86	126.25 ± 9.23	5.948	< 0.001
	Diastolic BP (mmHg)	80.13 ± 6.90	79.95 ± 6.57	2.767	0.006
	Mean arterial pressure (mmHg)	97.06 ± 5.99	95.94 ± 5.68	3.057	0.002
	Pulse pressure (mmHg)	50.12 ± 7.78	49.21 ± 7.35	1.900	0.058
	Blood pressure control [n/ (%)]	409(85.21%)	453(87.11%)	0.763	0.382

Table 2. Comparison of blood pressure parameters between two groups of patients (baseline and after 3 months). *BP* blood pressure.

IMB Group and 84.91 ± 5.10 mmHg in the IMB group (P = 0.098). The mean arterial pressure was 102.13 ± 6.42 mmHg for the Non-IMB Group and 101.75 ± 6.10 mmHg for the IMB group (P = 0.334). Pulse pressure showed similar trends with values of 54.42 ± 7.23 mmHg and 53.89 ± 6.91 mmHg in the Non-IMB and IMB groups, respectively (P = 0.231). Blood pressure control rates were comparable between the groups, with 79.17% in the Non-IMB Group and 81.73% in the IMB group achieving control (P = 0.307). These findings indicate that there were no significant differences in blood pressure parameters between the two groups at baseline.

However, after three months, significant reductions were noted in systolic BP (t = 5.948, P < 0.001), diastolic BP (t = 2.767, P = 0.006), and mean arterial pressure (t = 3.057, P = 0.002) in the IMB Group compared to the Non-IMB Group. These findings suggest that the IMB intervention was effective in lowering blood pressure over the 3-month period. Pulse pressure slightly decreased but did not reach statistical significance. Blood pressure control rates increased to 85.21% (409/480) in the Non-IMB Group and 87.11% (453/520) in the IMB group, although this increase was not statistically significant (P = 0.382).

Dietary intake

The IMB-based group showed a significantly higher fiber intake, averaging 33.07 ± 7.31 g/day, compared to 31.74 ± 7.09 g/day in the Non-IMB Group (P = 0.004) (Fig. 1). The sodium intake was significantly lower in the IMB group, with 2383.86 ± 281.33 mg/day versus 2508.19 ± 304.26 mg/day in the Non-IMB group (P < 0.001). Additionally, the IMB-based group consumed more servings of fruits and vegetables per day, averaging 6.04 ± 1.38 servings/day compared to 5.79 ± 1.07 servings/day in the Non-IMB Group (P = 0.001). There were no significant differences between the groups regarding total calorie intake per day (P = 0.906), saturated fat intake (P = 0.942), or potassium intake (P = 0.935). These findings suggest that the IMB-based dietary pattern led to healthier eating patterns in terms of fiber, sodium, and fruit and vegetable consumption.

Carotid artery atherosclerosis parameters

After three months, the carotid intima-media thickness (CIMT) decreased significantly in the IMB group to 1.05 ± 0.30 mm compared to the Non-IMB Group's measurement of 1.20 ± 0.35 mm (P < 0.001) (Fig. 2). Similarly, the plaque score showed a significant reduction in the IMB-based group to 1.80 ± 0.32 after three months, compared to 1.97 ± 0.41 in the Non-IMB Group (P < 0.001). At baseline, there were no significant differences between the groups for CIMT (P = 0.415) or plaque score (P = 0.223). Both groups demonstrated no significant differences in blood flow velocity at baseline (P = 0.490) and after three months (P = 0.450), indicating that this parameter was not influenced by the dietary intervention. Regarding carotid artery stenosis percentage, there was a slight improvement noted in both groups over the study period, with the IMB group starting from 20.45% ± 5.12% and ending at 18.70% ± 4.90%, and the Non-IMB group moving from 20.89% ± 5.09% to 19.08% ± 5.10%, but these changes did not reach statistical significance (P = 0.231). Additionally, the resistive index exhibited no significant change throughout the study, with P values of 0.151 at baseline and 0.657 at the end of the study. These findings indicate that the IMB-based dietary pattern effectively decreased CIMT and plaque scores, suggesting an improvement in carotid artery atherosclerosis in elderly hypertensive patients.

Lipid profile

Low-density lipoprotein (LDL) cholesterol levels showed a slight decrease in both groups after three months, with the Non-IMB Group reducing from 122.09 ± 13.11 mg/dL at baseline to 120.25 ± 13.20 mg/dL and the IMB-based group from 120.51 ± 13.09 mg/dL to 118.86 ± 11.90 mg/dL (Fig. 3). However, these changes were not statistically significant (baseline P = 0.058; after 3 months P = 0.082). High-density lipoprotein (HDL) cholesterol increased slightly in both groups over the study period, with the Non-IMB Group increasing from 42.56 ± 5.08 mg/dL to 46.63 ± 4.78 mg/dL and the IMB group from 43.11 ± 4.98 mg/dL to 47.20 ± 4.80 mg/dL. Although there was a trend towards improvement in HDL cholesterol levels, especially in the IMB group, this did not reach statistical significance (baseline P = 0.081; after 3 months P = 0.060). Total cholesterol levels decreased in both groups after 3 months, from 208.35 ± 21.11 mg/dL to 199.27 ± 21.68 mg/dL in the Non-IMB Group and from 206.27 ± 21.57 mg/dL to 196.85 ± 19.97 mg/dL in the IMB group, but these reductions were also not statistically significant (baseline P = 0.124; after 3 months P = 0.067). Triglyceride levels showed similar patterns, decreasing

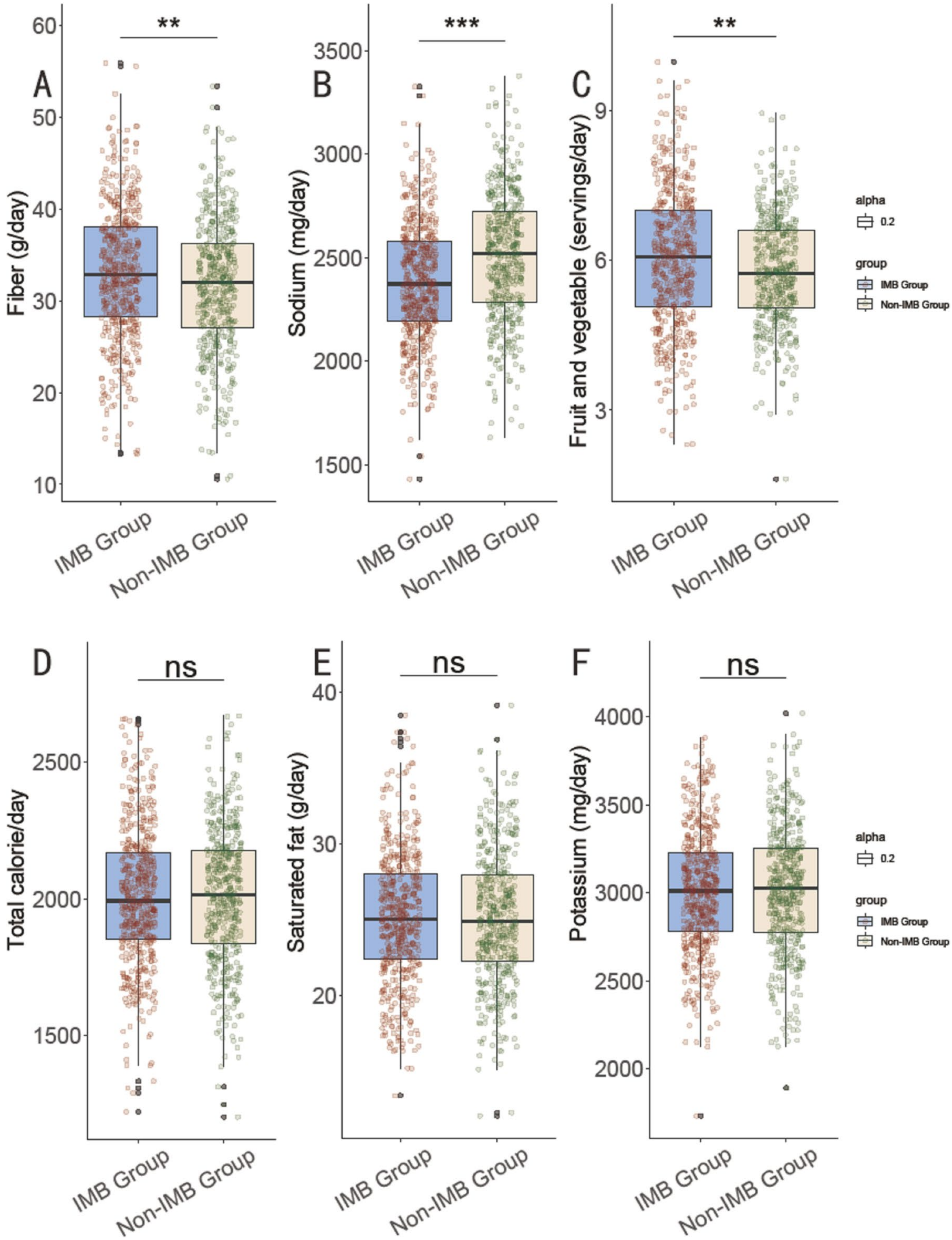

Fig. 1. Comparison of dietary intake between two groups of patients. (**A**) Fiber (g/day); (**B**) Sodium (mg/day); (**C**) Fruits and vegetables (servings/day); (**D**) Total calories/day; (**E**) Saturated fat (g/day); (**F**) Potassium (mg/day). *ns* not significant; $^{**}P<0.01$; $^{***}P<0.001$.

from 161.11 ± 10.21 mg/dL to 150.05 ± 12.70 mg/dL in the Non-IMB Group and from 161.21 ± 10.34 mg/dL to 148.90 ± 10.50 mg/dL in the IMB group, without reaching statistical significance (baseline $P=0.883$; after 3 months $P=0.122$)(Fig. 3). Overall, while trends towards improvement were noted, especially in HDL cholesterol levels, these changes were not statistically significant.

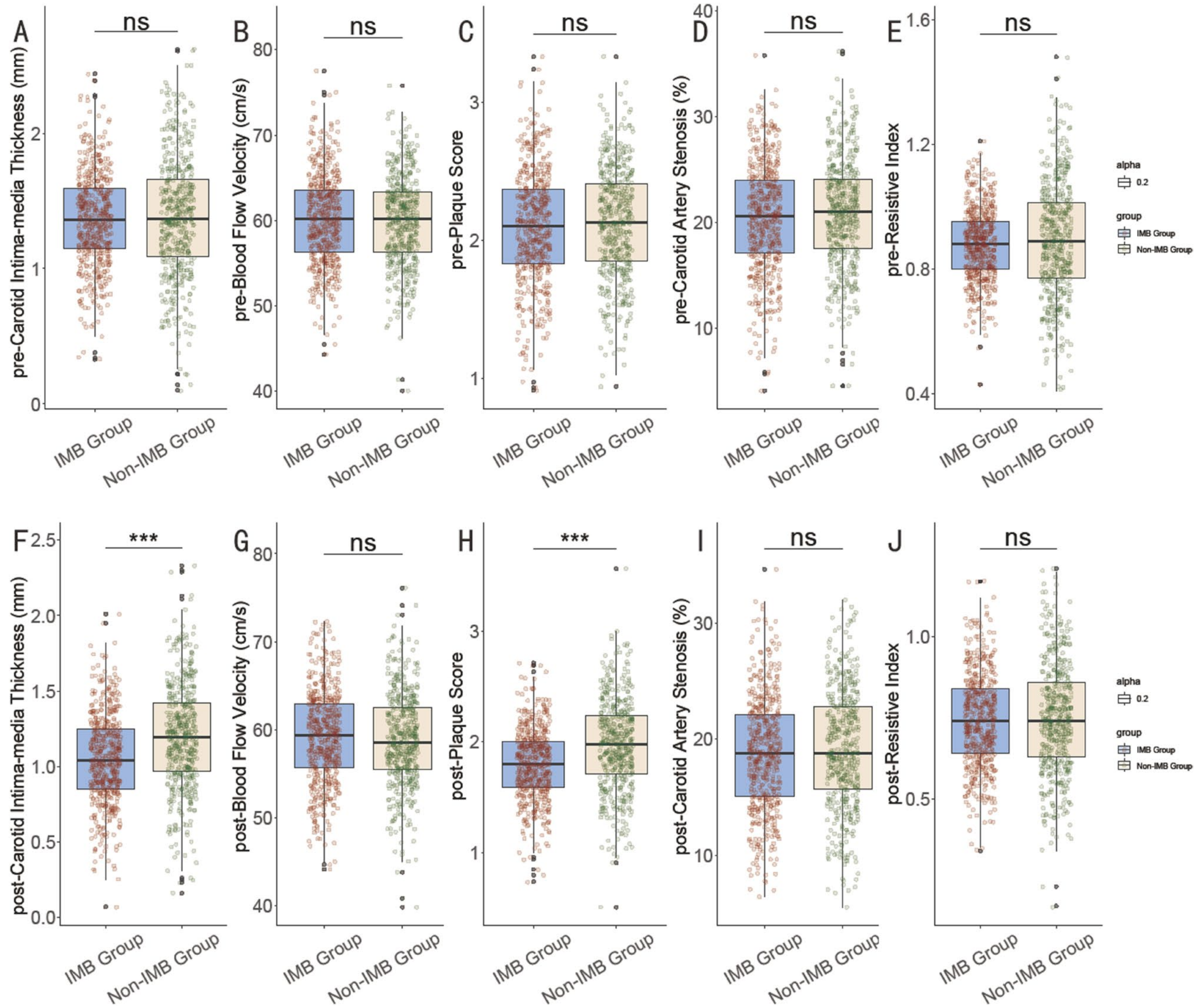

Fig. 2. Carotid artery atherosclerosis parameters (carotid vascular ultrasound). (**A**) Carotid intima-media thickness (mm) at baseline; (**B**) Blood flow velocity (cm/s) at baseline; (**C**) Plaque score at baseline; (**D**) Carotid artery stenosis (%) at baseline; (**E**) Resistive index at baseline; (**F**) Carotid intima-media thickness (mm) after 3 M; (**G**) Blood flow velocity (cm/s) after 3 M; (**H**) Plaque score after 3 M; (**I**) Carotid artery stenosis (%) after 3 M; (**J**) Resistive index after 3 M. *ns* not significant; ***$P < 0.001$.

Follow-up health behavior motivation levels, cardiovascular health and quality of life

The total score for smoking cessation motivation was 45.36 ± 5.22 in the Non-IMB group and 45.77 ± 5.34 in the IMB group ($P = 0.22$) (Table 3). Physical activity motivation scores were almost identical between the groups, with the Non-IMB group scoring 43.27 ± 4.51 and the IMB group scoring 43.29 ± 3.77 ($P = 0.942$). Similarly, healthy eating motivation scores showed slight variation but no significant difference, with scores of 34.89 ± 3.01 in the Non-IMB group compared to 35.07 ± 2.88 in the IMB group ($P = 0.319$). These results suggest that the dietary pattern based on the IMB Model did not significantly alter health behavior motivation levels compared to the regular diet.

Smoking scores were similar between the Non-IMB group (1.34 ± 0.57) and the IMB group (1.32 ± 0.56, $P = 0.581$). Body mass index showed negligible variation (1.11 ± 0.26 for the Non-IMB group vs. 1.12 ± 0.15 for the IMB group, $P = 0.537$). Physical exercise scores were also comparable, with values of 1.05 ± 0.28 for the Non-IMB group and 1.07 ± 0.33 for the IMB group ($P = 0.404$). Additionally, salt intake showed a non-significant trend toward reduction in the IMB group (0.67 ± 0.22) compared to the Non-IMB group (0.65 ± 0.20, $P = 0.156$). Total cholesterol levels were closely aligned between the groups, with the Non-IMB group at 1.27 ± 0.33 and the IMB group at 1.25 ± 0.16 ($P = 0.281$). Blood sugar levels were also similar, with the Non-IMB group at 1.52 ± 0.50 and the IMB group at 1.50 ± 0.48 ($P = 0.470$). These findings suggest that the IMB-based dietary pattern did not result in significant changes in cardiovascular health status compared to the regular diet.

Physical pain scores were comparable, with the Non-IMB group scoring 70.76 ± 7.35 and the IMB group scoring 71.45 ± 7.71 ($P = 0.153$). Physiological function was nearly identical between the groups, scoring

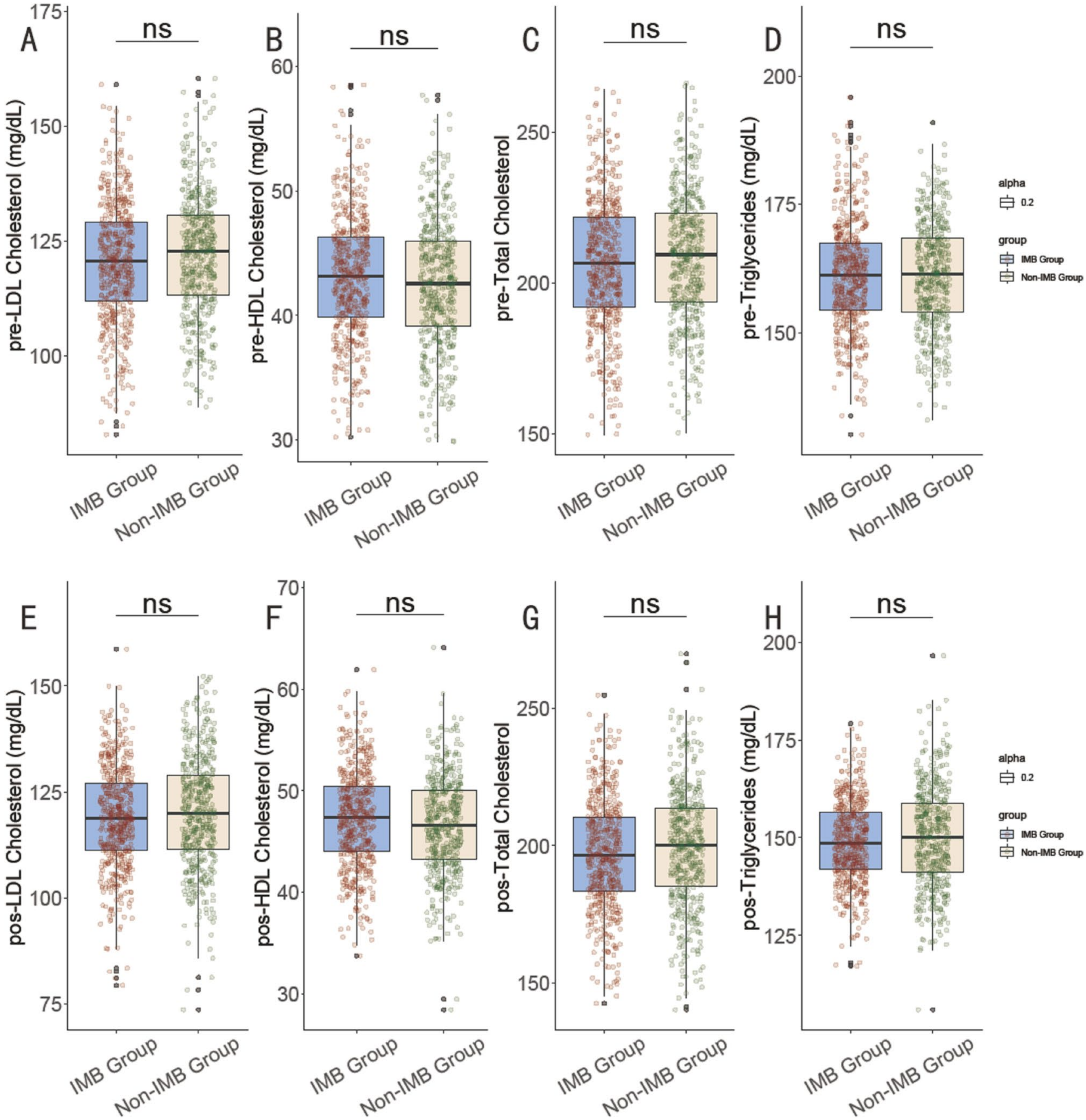

Fig. 3. Lipid profile of non-IMB group and IMB model diet. (**A**) LDL cholesterol (mg/dL) at baseline; (**B**) HDL cholesterol (mg/dL) at baseline; (**C**) Total cholesterol at baseline; (**D**) Triglycerides (mg/dL) at baseline; (**E**) LDL cholesterol (mg/dL) after 3 M; (**F**) HDL cholesterol (mg/dL) after 3 M; (**G**) Total cholesterol after 3 M; (**H**) Triglycerides (mg/dL) after 3 M. *LDL* low density lipoprotein, *HDL* high density lipoprotein, *ns* not significant.

78.26 ± 3.17 for the Non-IMB group and 78.33 ± 3.56 for the IMB group ($P = 0.740$). Mental health scores were similar, at 69.34 ± 8.32 for the Non-IMB group and 68.48 ± 8.29 for the IMB group ($P = 0.102$). Social function showed minimal variance, with scores of 76.95 ± 7.66 for the Non-IMB group and 76.77 ± 7.28 for the IMB group ($P = 0.860$). Emotional function also demonstrated no significant difference, scoring 79.68 ± 8.24 in the Non-IMB group and 79.33 ± 8.57 in the IMB group ($P = 0.516$). Thus, the dietary pattern based on the IMB Model did not considerably affect the quality of life metrics when compared with the regular diet.

Multivariate logistic regression analysis

The multivariate logistic regression analysis revealed significant associations between several parameters and the outcome. Specifically, negative correlations were observed for post-systolic blood pressure (OR 0.954, 95%

Parameters	Non-IMB group (n = 480)	IMB group (n = 520)	t	P
Health behavior motivation levels				
SS motivation total score	45.36 ± 5.22	45.77 ± 5.34	1.228	0.22
PA motivation total score	43.27 ± 4.51	43.29 ± 3.77	0.073	0.942
HE motivation total score	34.89 ± 3.01	35.07 ± 2.88	0.997	0.319
Cardiovascular health status				
Smoking	1.34 ± 0.57	1.32 ± 0.56	0.552	0.581
Body Mass Index	1.11 ± 0.26	1.12 ± 0.15	0.617	0.537
Physical exercise	1.05 ± 0.28	1.07 ± 0.33	0.835	0.404
Salt intake	0.65 ± 0.20	0.67 ± 0.22	1.421	0.156
Total cholesterol	1.27 ± 0.33	1.25 ± 0.16	1.078	0.281
Blood sugar	1.52 ± 0.50	1.50 ± 0.48	0.724	0.470
Quality of life				
Physical pain	70.76 ± 7.35	71.45 ± 7.71	1.431	0.153
Physiological -function	78.26 ± 3.17	78.33 ± 3.56	0.333	0.740
Mental health	69.34 ± 8.32	68.48 ± 8.29	1.637	0.102
Social function	76.95 ± 7.66	76.77 ± 7.28	0.176	0.860
Emotional function	79.68 ± 8.24	79.33 ± 8.57	0.649	0.516

Table 3. Comparison of follow-up health behavior motivation levels, cardiovascular health status and quality of life between two groups of patients.

Parameters	OR	95% CI lower	95% CI upper	P-value
Post-Systolic BP (mmHg)	0.954	0.940	0.969	< 0.001
Post-Diastolic BP (mmHg)	0.979	0.959	0.999	0.039
Post-Mean arterial pressure (mmHg)	0.963	0.940	0.986	0.002
Fiber (g/day)	1.024	1.004	1.044	0.017
Sodium (mg/day)	0.999	0.998	0.999	< 0.001
Fruits and vegetables servings/day	1.190	1.062	1.333	0.003
Post-carotid intima-media thickness (mm)	0.204	0.131	0.317	< 0.001
Post-plaque score	0.298	0.201	0.441	< 0.001

Table 4. Multivariate logistic regression analysis. *BP* blood pressure.

CI 0.940–0.969, $P < 0.001$), post-diastolic blood pressure (OR 0.979, 95% CI 0.959–0.999, $P = 0.039$), post-mean arterial pressure (OR 0.963, 95% CI 0.940–0.986, $P = 0.002$), sodium intake (OR 0.999, 95% CI 0.998–0.999, $P < 0.001$), post-carotid intima-media thickness (CIMT) (adjusted OR 0.204, 95% CI 0.131–0.317, $P < 0.001$), and post-plaque score (adjusted OR 0.298, 95% CI 0.201–0.441, $P < 0.001$). These indicate that decreases in these parameters are associated with a decreased likelihood of adverse outcomes. Conversely, positive correlations were found for fiber intake (OR 1.024, 95% CI 1.004–1.044, $P = 0.017$) and servings of fruits and vegetables per day (OR 1.190, 95% CI 1.062–1.333, $P = 0.003$), suggesting that higher consumption of these nutrients is linked to an increased likelihood of achieving favorable outcomes (Table 4). Therefore, managing blood pressure, reducing sodium intake, increasing fiber, fruit, and vegetable consumption, and promoting carotid health are crucial for achieving better outcomes.

Factors influencing CIMT and plaque scores

Table 5 illustrates that among factors influencing CIMT and plaque scores, only systolic blood pressure (138.49 ± 8.36 mmHg vs. 137.24 ± 7.62 mmHg, $P = 0.014$), mean arterial pressure (103.03 ± 6.52 mmHg vs. 101.95 ± 6.11 mmHg, $P = 0.007$), and adherence to the IMB dietary pattern (30.91% vs. 77.78%, $P < 0.001$) showed significant differences between the Non-Improvement Group ($n = 550$) and the Improvement Group ($n = 450$). There were no significant differences in age, BMI, gender, hypertension duration, smoking status, drinking history, education level, marital status, blood pressure control, antihypertensive medication use, statin use, or aspirin use. These findings suggest that lower systolic blood pressure and mean arterial pressure, coupled with adherence to the IMB dietary pattern, are associated with improvements in CIMT and plaque scores, highlighting the potential benefits of integrating such dietary interventions into the management of hypertensive patients to mitigate atherosclerosis progression.

Multivariate analysis of factors influencing CIMT and plaque scores

Table 6 presents the results of a multivariate analysis identifying key factors influencing carotid intima-media thickness (CIMT) and plaque scores. Adherence to the IMB dietary pattern emerges as the most significant

Parameters	Non-improvement group (*n* = 550)	Improvement group (*n* = 450)	t/χ2	*P*
Age (years)	68.37 ± 3.32	68.02 ± 3.37	1.656	0.098
BMI (kg/m²)	26.07 ± 2.31	25.85 ± 2.42	1.512	0.131
Gender [n/(%)] (M/F)	310 (56.36%)	262 (58.22%)	0.349	0.555
Hypertension duration (years)	6.07 ± 2.25	5.82 ± 2.30	1.746	0.081
Smoking status [n/(%)] (Y/N)	146 (26.55%)	97 (21.56%)	3.35	0.067
Drinking history [n (%)] (Y/N)	331 (60.18%)	245 (54.44%)	3.336	0.068
Education Level [n/(%)] (illiterate/ primary education/secondary education /university degree)			1.543	0.672
Illiterate	10 (1.82%)	8 (1.78%)		
Primary education	207 (37.64%)	154 (34.22%)		
Secondary education	305 (55.45%)	267 (59.33%)		
University degree	28 (5.09%)	21 (4.67%)		
Marital status (married with spouse/divorced or widowed)			0.169	0.681
Married with spouse	466 (84.73%)	377 (83.78%)		
Divorced or widowed	84 (15.27%)	73 (16.22%)		
Systolic BP (mmHg)	138.49 ± 8.36	137.24 ± 7.62	2.464	0.014
Diastolic BP (mmHg)	85.35 ± 5.37	84.87 ± 5.14	1.444	0.149
Mean arterial pressure (mmHg)	103.03 ± 6.52	101.95 ± 6.11	2.68	0.007
Pulse pressure (mmHg)	54.62 ± 7.21	53.79 ± 6.93	1.844	0.066
Blood pressure control [n/(%)]	433 (78.72%)	367 (81.56%)	1.237	0.266
Antihypertensive medication [n/(%)]	114 (20.73%)	107 (23.78%)	1.338	0.247
Statin use [n/(%)]	113 (20.55%)	98 (21.78%)	0.226	0.635
Aspirin use [n/(%)]	83 (15.09%)	74 (16.44%)	0.343	0.558
IMB dietary pattern [n/(%)]	170 (30.91%)	350 (77.78%)	217.819	< 0.001

Table 5. Factors influencing CIMT and plaque scores. *BMI* body mass index, *BP* blood pressure.

Parameters	OR	95% CI lower	95% CI upper	*P*-value
Systolic BP (mmHg)	0.979	0.961	0.996	0.017
Mean arterial pressure (mmHg)	0.977	0.955	0.999	0.041
IMB dietary pattern [n/(%)]	7.807	5.851	10.417	< 0.001

Table 6. Multivariate analysis of factors influencing CIMT and plaque scores. *BP* blood pressure.

determinant, with an odds ratio (OR) of 7.807 (95% CI 5.851 to 10.417, $P < 0.001$), indicating a markedly higher likelihood of CIMT and plaque score improvements compared to those not following this diet. In contrast, systolic blood pressure and mean arterial pressure showed less pronounced but still significant associations, with ORs of 0.979 (95% CI 0.961 to 0.996, $P = 0.017$) and 0.977 (95% CI 0.955 to 0.999, $P = 0.041$) respectively, suggesting that increases in these pressures are associated with decreased odds of improvement.

These findings highlight the critical role of the IMB dietary pattern as the most influential factor in improving CIMT and reducing plaque scores, with its high OR indicating substantial impact. Integrating this dietary intervention into routine care could offer significant benefits in managing cardiovascular risk factors among elderly hypertensive patients. The results emphasize the importance of incorporating the IMB diet into therapeutic strategies for better management of atherosclerosis progression.

Discussion

Previous studies have demonstrated that the IMB model not only performs well in cardiovascular disease management but also shows potential advantages in other chronic disease management. For example, Arsan et al.[21] found that interventions based on the IMB model significantly improved dietary therapy and fluid restriction adherence in hemodialysis patients. They noted that the IMB model effectively addresses patient behavior change challenges in resource-limited settings. Jeon et al.[22] reported the development of a mobile application for diabetes self-management based on the IMB model. The application significantly enhanced self-management abilities and blood glucose control in diabetic patients, further validating the effectiveness of the IMB model in chronic disease management. Taştekin Ouyaba et al.[23] investigated the influence of IMB model variables on orthorexia nervosa behaviors in pregnant women. Their study found that the IMB model helped improve dietary habits and mental health in pregnant women, suggesting the broad applicability of the IMB model in various health behavior domains.

These studies indicate that the IMB model, as a behavioral science tool, can effectively promote the management and prevention of various chronic diseases. Our study further extends this field by focusing on the management of carotid atherosclerosis in elderly hypertensive patients, supplementing and validating the widespread applicability of the IMB model across different health conditions.

In the current study, we investigated the effects of dietary patterns guided by the Information-Motivation-Behavioral Skills (IMB) model on carotid atherosclerosis among elderly hypertensive patients. The results indicated that implementing an IMB model-based dietary intervention led to significant improvements in certain cardiovascular parameters, notably carotid intima-media thickness (CIMT) and plaque scores. These findings[24,25] suggest that a structured dietary regimen rooted in behavioral science concepts can have substantial clinical benefits for managing atherosclerotic progression in this high-risk population.

CIMT and plaque are established markers of subclinical atherosclerosis and are predictive of future cardiovascular events such as myocardial infarction (MI), ischemic stroke, and major adverse cardiovascular and cerebrovascular events (MACCEs). Previous research has shown that the reduction in CIMT and plaque is associated with a decreased risk of these events. In the context of our dietary intervention guided by the IMB model, the observed reductions in CIMT and plaque scores suggest that targeted dietary modifications can effectively mitigate the progression of atherosclerosis. The IMB model's emphasis on providing patients with accurate information, enhancing their motivation, and improving their behavioral skills appears to be particularly effective in promoting adherence to heart-healthy diets. This approach not only reduces key cardiovascular risk factors such as blood pressure but also directly impacts vascular health through mechanisms like reduced sodium intake and increased consumption of fiber, fruits, and vegetables. These dietary changes may help stabilize or even reverse early stages of atherosclerosis, thereby reducing the risk of future cardiovascular events. Moreover, our findings highlight the potential of integrating the IMB model into routine clinical practice for managing carotid atherosclerosis in elderly hypertensive patients. By addressing both informational and motivational barriers, this model offers a comprehensive strategy to support sustained lifestyle modifications, ultimately contributing to improved cardiovascular outcomes[26].

The IMB model, utilized to guide the dietary patterns in this study, emphasizes the synergy between knowledge dissemination (Information), boosting individuals' motivation, and enhancing behavioral skills to facilitate engagement in health-positive behaviors. This comprehensive approach is particularly suited to elderly hypertensive patients, who may face multiple barriers to adopting and maintaining lifestyle modifications. Our results demonstrated that the IMB model can successfully shift dietary habits towards healthier patterns, such as increased fiber intake and reduced sodium consumption, without adversely impacting overall caloric intake or medication compliance.

One primary mechanism through which the IMB-based diet presumably impacted carotid atherosclerosis is via blood pressure reduction. After three months, the diet group exhibited significant decreases in both systolic and diastolic blood pressure, which is well-aligned with existing literature on the benefits of dietary modifications, such as the Dietary Approaches to Stop Hypertension (DASH) diet, known for its effects on hypertension and cardiovascular health. The IMB model's focus on information and motivation could enhance patients' adherence to a low-sodium, low-fat diet, integral to controlling blood pressure levels. Notably, the process of actively involving family members and using continuous digital communication (via platforms like WeChat) could substantially bolster the patients' motivation and adherence, creating a supportive environment conducive to sustained dietary adherence.

Beyond blood pressure management, the significant changes observed in CIMT and plaque scores also suggest that the intervention had a direct positive effect on vascular health. One potential explanation is the significant reduction in sodium intake in the IMB group, as excessive sodium consumption has been consistently linked to adverse vascular changes, including endothelial dysfunction and increased arterial stiffness[27,28]. Additionally, the increased intake of dietary fiber, fruits, and vegetables characteristic of the IMB-guided dietary patterns could confer protective effects against atherosclerosis. These components are rich in antioxidants, vitamins, and minerals essential for maintaining vascular integrity and function. They potentially mitigate oxidative stress and inflammation—both critical pathways in atherogenesis. The multivariate logistic regression analysis elucidated that fiber intake and servings of fruits and vegetables were positively correlated with better carotid outcomes, highlighting these dietary factors as pivotal contributors to improvements in vascular health[29,30].

In the multivariate logistic regression analysis, we found that the IMB dietary pattern significantly reduced the risk of carotid intima-media thickness (CIMT) and plaque scores. Specifically, the adjusted odds ratios (ORs) were 0.128 (95% CI 0.096–0.171, $P<0.001$) for CIMT and 0.340 (95% CI 0.250–0.463, $P<0.001$) for plaque scores. These ORs were calculated as the inverse of the IMB dietary pattern OR (7.807). This not only confirms the critical role of the IMB dietary pattern in improving carotid atherosclerosis but also quantifies its relative impact compared to other factors. Further analysis of the primary outcomes across the total sample size revealed that the IMB dietary pattern was the most influential factor, with the highest odds ratio (OR) among all considered variables. Systolic blood pressure (OR 0.979, 95% CI 0.961–0.996, $P=0.017$) and mean arterial pressure (OR 0.977, 95% CI 0.955–0.999, $P=0.041$) also showed significant but weaker impacts, indicating that higher levels of these blood pressure measures were associated with lower odds of improvement. However, the high OR of the IMB dietary pattern suggests it is the most effective intervention for reducing carotid atherosclerosis. These results underscore the importance of incorporating the IMB dietary pattern into routine care for managing cardiovascular risk factors in elderly hypertensive patients and highlight its critical significance in treatment strategies aimed at better managing the progression of atherosclerosis.

Despite the small reductions in LDL cholesterol levels observed in both groups, no significant correlations were found between LDL cholesterol and CIMT or plaque scores. This observation underscores the complex interplay between different atherosclerosis risk factors and their impact on various arterial territories. For instance, smoking and hyperlipidemia are most strongly associated with PAOD and coronary arteries, whereas hypertension has a more significant impact on carotid and cerebral arteries. The role of LDL cholesterol in carotid atherosclerosis appears to be less prominent compared to its influence on other vascular beds. In our study, the significant reductions in CIMT and plaque scores were more closely related to improvements in blood pressure and dietary patterns, particularly reduced sodium intake and increased consumption of fiber, fruits, and vegetables. These dietary changes may help stabilize or even reverse early stages of atherosclerosis, thereby reducing the risk of future cardiovascular events. This highlights the importance of tailoring interventions to specific risk factors and arterial territories. While managing LDL cholesterol remains crucial for overall cardiovascular health, our findings suggest that targeting hypertension and promoting heart-healthy diets may be particularly effective strategies for mitigating carotid atherosclerosis in elderly hypertensive patients[31].

The clinical context of our study population further underscores the value of the IMB intervention. The relatively low baseline use of antihypertensive medications highlights a potential reliance on non-pharmacological management or undertreatment in this cohort. Furthermore, elderly patients often face challenges such as polypharmacy and depression, which can severely impair medication adherence and motivation for lifestyle change[32,33]. In this complex scenario, the IMB model, by strengthening intrinsic motivation and self-efficacy through a structured dietary approach, offers a viable non-pharmacological strategy. It can help mitigate the reliance on complex drug regimens and address motivational barriers, providing a patient-centered complement to standard care.

Another critical observation was that despite significant improvements in dietary habits and vascular markers, the quality of life indicators and motivation levels in health-related behaviors, such as smoking cessation and physical activity, did not change significantly[34,35]. This suggests that while the IMB-model was effective for dietary modifications, it might require further adaptation or reinforcement to influence a broader range of lifestyle behaviors comprehensively. Nevertheless, the successful dietary changes underline the potential of the IMB model to create specific, targeted behavioral interventions that efficiently address particular health challenges, such as hypertension and atherosclerosis[36,37].

Our study's outcomes highlighted the IMB model's practical application in real-world clinical settings, enhancing the relevance and potential utility of behavioral interventions in managing chronic diseases among older adults. These findings also underscore the importance of an interdisciplinary approach, combining dietary advice with consistent behavioral support to achieve significant health improvements. By addressing the motivational and informational barriers head-on, the IMB model can empower patients to make and maintain heart-healthy dietary changes.

However, it is important to acknowledge that the study's scope was limited to a single health behavior—dietary patterns—while other lifestyle factors were not extensively targeted. For comprehensive cardiovascular risk reduction, future interventions could explore integrating additional lifestyle modification components, such as structured exercise programs, into the IMB framework. Limitations of this study also include the relatively short follow-up duration, which may limit the generalizability of our findings regarding long-term outcomes. Additionally, potential selection bias cannot be ruled out, as participants were recruited from a specific geographic region. Future studies with longer follow-up periods and more diverse populations are needed to validate these findings. Given that our study focused on elderly hypertensive individuals from a specific geographic region, the applicability of these findings to other populations may be limited. Future research should aim to replicate these results in different demographic and geographic settings to determine their broader relevance.

Conclusion

In conclusion, this study provides compelling evidence that dietary interventions based on the IMB skills model can significantly benefit carotid atherosclerosis in elderly hypertensive patients. By effectively reducing key markers such as CIMT and plaque scores through improved dietary practices, the IMB-model offers a valuable strategy to ameliorate cardiovascular risk factors holistically. Future studies could delve deeper into expanding this model's scope, improving intervention adherence, and examining the long-term sustainability of behavioral modifications to further harness the potential of behavioral science in preventive cardiovascular care.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Received: 10 April 2025; Accepted: 3 November 2025
Published online: 08 December 2025

References

1. Sharifi, M. A. et al. ADAMTS-7 modulates atherosclerotic plaque formation by degradation of TIMP-1. *Circ. Res.* **133** (8), 674–686 (2023).
2. Cuciureanu, T. et al. Improvement of carotid atherosclerosis and peripheral artery disease after hepatitis C virus eradication by direct-acting antivirals. *Roman. J. Morphol. Embryol. Revue Roumaine De Morphologie Et Embryologie*. **64** (4), 483–491 (2023).
3. Tan, J. et al. Single-cell transcriptomics reveals crucial cell subsets and functional heterogeneity associated with carotid atherosclerosis and cerebrovascular events. *Arterioscler. Thromb. Vasc. Biol.* **43** (12), 2312–2332 (2023).
4. Huang, X. C. et al. Effect of acupuncture and moxibustion on artery elasticity for early carotid atherosclerosis. *Zhen Ci Yan jiu = Acupunct. Res.* **49** (6), 611–617 (2024).
5. Puig, N. et al. Novel therapeutic approaches to prevent atherothrombotic ischemic stroke in patients with carotid atherosclerosis. *Int. J. Mol. Sci.* **24**(18). (2023).
6. Bashore, A. C. et al. High-dimensional single-cell multimodal landscape of human carotid atherosclerosis. *Arterioscler. Thromb. Vasc. Biol.* **44** (4), 930–945 (2024).

7. Schulz, K. et al. Complement C1q and von Willebrand factor interaction in atherosclerosis of human carotid artery. *Front. Immunol.* **14**, 1265387 (2023).
8. Xie, W. et al. Association between triglyceride-glucose index and carotid atherosclerosis in patients with psoriatic arthritis. *Rheumatol. (Oxford England)*. **62** (11), 3584–3591 (2023).
9. Zhu, N. et al. Epigenetic regulation of vascular smooth muscle cell phenotypic switch and neointimal formation by PRMT5. *Cardiovasc. Res.* **119** (12), 2244–2255 (2023).
10. Chen, Q. S. et al. A machine learning based approach to identify carotid subclinical atherosclerosis endotypes. *Cardiovasc. Res.* **119** (16), 2594–2606 (2023).
11. Mocci, G. et al. Single-cell gene-regulatory networks of advanced symptomatic atherosclerosis. *Circ. Res.* **134** (11), 1405–1423 (2024).
12. Grech, J., Norman, I. J. & Sammut, R. Exploring the smoking cessation needs of individuals with diabetes using the Information-Motivation-Behavior skills model. *Tobacco Prev. Cessation*. **10**. (2024).
13. Prakot, S., Fink, A. M., Culbert, G. & Visudtibhan, P. J. An analysis and evaluation of the Information-Motivation-Behavioral skills (IMB) model for antiretroviral therapy. *ANS Adv. Nurs. Sci.* **47** (1), 73–88 (2024).
14. Peng, X., Ni, H. Q., Liu, Y. M., Zhu, J. L. & Bai, Y. T. Information-motivation-behavioral guided nursing for stroke patients with pulmonary dysfunction: A randomized controlled trial. *World J. Clin. Cases*. **12** (24), 5549–5557 (2024).
15. Musharaf, I. & Nashwan, A. J. Health education intervention and its impact on patients with unilateral vestibular dysfunction: an information-motivation-behavioral model approach. *World J. Clin. Cases*. **12** (20), 4031–4033 (2024).
16. Levesque, C. S. et al. Validating the theoretical structure of the treatment Self-Regulation questionnaire (TSRQ) across three different health behaviors. *Health Educ. Res.* **22** (5), 691–702 (2007).
17. Ishii, K., Morita, K. & Sumita, H. Reliability and validity of the Japanese treatment self-regulation questionnaire for Japanese workers. *BMC Public. Health*. **22** (1), 1892 (2022).
18. Ross, M. D., Malone, E. & Florida-James, G. Vascular ageing and exercise: Focus on cellular reparative processes. *Oxid. Med. Cell. Longevity* **2016**, 3583956 (2016).
19. Lyons, R. A., Perry, H. M. & Littlepage, B. N. Evidence for the validity of the Short-form 36 questionnaire (SF-36) in an elderly population. *Age Ageing*. **23** (3), 182–184 (1994).
20. Touboul, P. J. et al. Mannheim carotid intima-media thickness consensus (2004–2006). An update on behalf of the Advisory Board of the 3rd and 4th Watching the Risk Symposium, 13th and 15th European Stroke Conferences, Mannheim, Germany, 2004, and Brussels, Belgium, 2006. *Cerebrovasc. Dis. (Basel, Switzerland)* **23**(1), 75–80 (2007).
21. Arsan, Z. S. H. & Sjattar, E. L. Arafat RJHiL-rS: enhancing adherence to diet therapy and fluid restrictions in Hemodialysis patients: a study using the information-motivation-behavioral skills model (2025).
22. Jeon, E. & Park, H.-A.-J.-H. Development of the IMB model and an evidence-based diabetes self-management mobile application. **24**(2), 125–138 (2018).
23. Taştekin Ouyaba, A. & Çiçekoğlu Öztürk, P. J. E. Weight disorders-studies on anorexia B, obesity: the effect of the information-motivation-behavioral skills (IMB) model variables on orthorexia nervosa behaviors of pregnant women. **27**(1), 361–372 (2022).
24. Shamloo, A. et al. In-silico study of drug delivery to atherosclerosis in the human carotid artery using metal-organic frameworks based on adhesion of nanocarriers. *Sci. Rep.* **13** (1), 21481 (2023).
25. Saba, L. et al. Carotid plaque-RADS: A novel stroke risk classification system. *JACC Cardiovasc. Imaging*. **17** (1), 62–75 (2024).
26. Gacoń, J. et al. Prospective study on the prognostic value of repeated carotid intima-media thickness assessment in patients with coronary and extra coronary steno-occlusive arterial disease. *Pol. Arch. Intern. Med.* **129** (1), 12–21 (2019).
27. Wang, Q. et al. Sublingual immunotherapy adherence in patients with allergic rhinitis: effects of an intervention based on the information-motivation-behavioral skills model. *Heliyon* **9** (12), e22929 (2023).
28. Mohamed, A. A. E., ElKholy, S. E. A., Eweida, R. S. & AbdElsalam, R. M. M. Using the information-motivation-behavioral skills model for targeting older adults' climate change management practices: in the road of COP27. *Geriatric Nurs. (New York NY)*. **55**, 52–63 (2024).
29. Wan Mohamad Darani, W. N. S., Mat Ruzlin, A. N., Azhar, Z. I. & Chen, X. W. Development and validation of the information-motivation-behavioural skills model-based human immunodeficiency virus education kit for adolescents in Malaysia. *Sci. Rep.* **14** (1), 6890 (2024).
30. Newsome, A. M., Kilpatrick, M. & Dedrick, R. F. Exercise prescription practices among mental health professionals on college campuses: testing the Information-Motivation-Behavioral skills model. *Int. J. Behav. Med.* (2024).
31. Atkins, P. W. et al. Increased carotid plaque burden in patients with family medical history of premature cardiovascular events in the absence of classical risk factors. *Arch. Med. Sci. AMS*. **15** (6), 1388–1396 (2019).
32. Podolec, J. et al. Depression in cardiac patients is a major cardiovascular event risk factor: A 12-month observational study. *J. Clin. Med.* **13**(22). (2024).
33. Piechocki, M. et al. A Non-Coronary, peripheral arterial atherosclerotic disease (Carotid, Renal, lower Limb) in elderly patients-A review PART II-Pharmacological approach for management of elderly patients with peripheral atherosclerotic lesions outside coronary territory. *J. Clin. Med.* **13**(5). (2024).
34. Amani, A. & Farajollahi, A. H. Drug delivery angle for various atherosclerosis and aneurysm percentages of the carotid artery. *Mol. Pharm.* **21** (4), 1777–1793 (2024).
35. Abbott, A., Schott, L., Gao, L., Budincevic, H. & Ricco, J. B. Carotid artery overtreatment in the USA. *Lancet Neurol.* **22** (12), 1102–1103 (2023).
36. Zhao, Z., Xu, W., Wang, S., Zhang, D. & Wang, Y. Application of continuous care pattern based on Information-Motivation-Behavioral skills model in out-of-Hospital rehabilitation of diabetic foot ulceration patients: A randomized controlled trial. *Int. J. Lower Extremity Wounds*. **2024**, 15347346241275243 (2024).
37. Xu, H. & Wang, J. An information-motivation-behavioral skills model-based intervention for patients with epilepsy. *Epilepsy Behav. E&B* **147**, 109408 (2023).

Author contributions

B.Y. designed the manuscript. G.H. provided the administrative support. L.P. provided the materials. S.L., S.L. collected the data. S.L., D.H. analyzed the data. All authors wrote the manuscript. All authors reviewed the manuscript.

Funding

Qiqihar Science and Technology Program Joint Guidance Project (LSFGG-2024064).

Declarations

Competing interests

The authors declare no competing interests.

Ethical statement

This study adhered to ethical principles, with informed consent obtained from all participants. The study was approved by the Ethics Committee of the Second Affiliated Hospital of Qiqihar Medical University (No. 2024-01-23).

Additional information

Correspondence and requests for materials should be addressed to B.Y.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.