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Effect of Hypertension on Carotid Plaque Formation and Outcomes in High-Risk Cerebrovascular Population: A Community-Based Study in Guangzhou

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Abstract: Objective: This study investigates the effects of hypertension on carotid plaque formation and clinical outcomes in a high-risk population for cerebrovascular disease in the Guangzhou communities. Methods: Data from 322 high-risk individuals for cerebrovascular disease in the Guangzhou communities were consecutively collected between January 2018 to December 2023. These participants were hospitalized twice within one year at the Department of Neurology, the First Affiliated Hospital of Guangzhou Medical University, and underwent carotid ultrasound examinations during both admissions. Based on the carotid ultrasound results from the first hospitalization, participants were initially categorized into two groups (with or without plaque) to analyze the association between hypertension and carotid plaque formation using univariate and multivariate methods. Subsequently, the cohort was further divided into three groups according to hypertension control status across both admissions: a non-hypertensive group (n = 48), a hypertension controlled group (average blood pressure (BP) < 130/80 mmHg at both admission, n = 109), and a hypertension uncontrolled group (average BP ≥ 130/80 mmHg at either admission, n = 165). Differences in the variance of Crouse scores (ΔCrouse) between the two ultrasound examinations were analyzed among the three groups. Further stratification analysis was performed by dividing participants into two age subgroups (cutoff: 70 years) and three hypertension control subgroups (average BP < 130/80 mmHg at two-time admissions, one-time admission, or neither). The differences in ΔCrouse were then analyzed across these stratified subgroups. Results: Age (OR = 1.074, P = 0.000), gender (OR = 0.340, P = 0.000), SBP (OR = 1.039, P = 0.006), and DBP (OR = 0.932, P = 0.003) were significantly associated with carotid plaque formation. No statistically difference in ΔCrouse was observed between the hypertension controlled group and the non-hypertensive group; however, ΔCrouses in the above two groups showed significant differences from that in hypertension uncontrolled group (both, P < 0.01). Furthermore, similar trends were found in both age subgroups (≥ 70 years and < 70 years). The two-time controlled hypertension subgroup exhibited significantly smaller ΔCrouse value than the one-time and two-time uncontrolled subgroups (both, P < 0.05), while no significant difference was found between the one-time and two-time uncontrolled subgroups. Conclusions: Age, gender, SBP, and DBP were identified as influential factors for carotid plaque formation. In patients with well-controlled hypertension (average BP < 130/80 mmHg), the progression rate of carotid plaques showed no significant difference from that of non-hypertensive individuals. However, the progression of carotid plaques was significantly accelerated in patients with uncontrolled hypertension.

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1. Introduction

Hypertension is one of the main risk factors for atherosclerosis, which can promote the occurrence and development of atherosclerosis. Atherosclerosis can also lead to reduced elasticity of arterial walls, which in turn causes further increase in blood pressure [1,2]. Carotid plaque plays a key role in the study of systemic atherosclerosis, offering important clinical insights into the interplay between hypertension and this condition. Clinical studies have confirmed that controlling hypertension can significantly reduce the occurrence of cardiovascular and cerebrovascular events [3]. However, there are few literature reports specifically studying the relationship between hypertension and carotid atherosclerosis [4,5]. There are no definite reports at home and abroad on whether there is any difference in the outcome of carotid plaques in patients with well controlled hypertension compared with non-hypertensive patients. Community-based studies hold considerable clinical importance as the subjects share very similar environments and ways of life. The study reviews the clinical data of hypertensive and non-hypertensive patients in Guangzhou communities, exploring the prognosis of carotid plaques in patients with well hypertension control and non-hypertensive patients in order to provide more basis for guiding the prevention and treatment of clinical hypertension and atherosclerosis.

2. Materials and Methods

2.1. Objects and Grouping

A total of 322 patients from the Guangzhou communities who were hospitalized and underwent carotid ultrasonography twice in the Department of Neurology of the First Affiliated Hospital of Guangzhou Medical University were consecutively between January 2018 to December 2023 collected, including 165 males and 157 females, aged from 44 to 92 (71.22 ± 10.87) years. According to the 2017 American College of Cardiology (ACC) Hypertension Management Guidelines, 274 cases were diagnosed with hypertension [6]. The target of blood pressure control was defined as achieving an average blood pressure (BP) below 130/80 mmHg [6]. The patients were divided into a hypertension controlled group (average BP < 130/80 mmHg at both admission, n = 109), a hypertension uncontrolled group (average BP ≥ 130/80 mmHg at either admission, n = 165) and a non-hypertension group (48 cases) for comparison. Differences of carotid plaque progression were analyzed among the three groups. To further explore the relationship between the rate of achieving BP control targets and the outcome of carotid plaques, the hypertensive patients were further subdivided into three subgroups: hypertension two-time controlled (107 cases), one-time controlled (62 cases) and two-time uncontrolled (105 cases) subgroups according to the average BP < 130/80 mmHg at two-time admissions, one-time admission, or neither.

1) Inclusion criteria:
    a) Residents of Guangzhou aged 40 years and above.
    b) Carotid ultrasound examinations were performed during both hospitalizations, with the procedures conducted one year apart.
    c) Patients with good adherence and able to complete follow-up.
2) Exclusion criteria:
    a) Patients who did not live in Guangzhou or lived there intermittently during the period between the two hospitalizations.
    b) Patients with malignant tumors, immune system diseases, infections, cardiomyopathy, and severe liver and kidney dysfunction.
    c) Patients who couldnot cooperate with timely examinations and follow-up, or patients with poor compliance.

2.2. Research Methods

2.2.1. Blood Pressure Measurement

Blood pressure was measured in the morning of the first 7 days after two admissions, and the average of systolic blood pressure (SBP) and diastolic blood pressure (DBP) for 7 days was calculated as blood pressure level.

2.2.2. Carotid Ultrasound Examination

Carotid ultrasound examination was performed with the patient lying in a supine position, and the plaques of the common carotid, internal carotid, and external carotid arteries were detected by transverse and longitudinal sections. Carotid plaque was defined as a focal structure that encroaches into the arterial lumen of at least 0.5 mm or 50% of the surrounding intima-media thickness value. In our study, the carotid plaque score was evaluated by Crouse method: The Crouse score measures the sum of the maximum thickness of isolated plaques in the carotid arteries [5,6].

2.2.3. Assessment of Biochemical Indicators

Fasting venous blood samples were collected in the next morning after two admissions, and serum levels of total cholesterol (TC), triglycerides (TG), high-density lipoprotein (HDL), and low-density lipoprotein (LDL) were determined using a Beckman fully automatic biochemical analyzer. Glycated hemoglobin (HbA1c) was detected by high performance liquid chromatography.

2.2.4. The Prognosis Evaluation

The carotid plaque scores at the 1st and 2nd hospitalization were Crouse1 and Crouse2, respectively. The difference between the 2nd and 1st plaque scores (△Crouse) was used as the standard for evaluating plaque prognosis.

2.3. Statistical Analysis

Normally distributed data were expressed as mean ± standard deviation ($\bar{x} \pm s$), non-normally distributed data as median (interquartile range) [M(Qn)], and categorical data as percentages (%). For multi-group comparisons, one-way ANOVA with post-hoc pairwise tests was applied to normally distributed variables, while the Kruskal-Wallis test followed by pairwise comparisons was used for non-normally distributed data; intergroup rate differences were assessed via the $\chi 2$ test. The ROC curve determined the age-group cutoff. First, the relationship between hypertension and carotid plaque formation was analyzed: participants were divided into two groups (presence/absence of plaque on initial carotid ultrasound) as the dependent variable, with age, gender, SBP, DBP, HbA1c, TC, TG, HDL, and LDL as independent variables in univariate and multivariate analyses. Subsequently, ΔCrouse was analyzed among the non-hypertension, hypertension controlled and uncontrolled groups. Further stratification analysis was performed by dividing participants into two age subgroups (cutoff: 70 years) and three hypertension control subgroups (average BP < 130/80 mmHg at two-time admissions, one-time admission, or neither). The differences in ΔCrouse were then analyzed across these stratified subgroups. Follow-up blood pressure measurements over one year between the two admissions were analyzed using repeated-measures ANOVA. Statistical significance was defined as $P < 0.05$, and all analyses were conducted in SPSS 25.0.

3. Results

3.1. Univariate Analysis of Factors Influencing Carotid Plaque Formation

The age ($t = -7.420$, $P = 0.000$), gender ($\chi^2 = 10.622$, $P = 0.001$), SBP ($Z = -2.849$, $P = 0.004$), DBP ($t = -3.033$, $P = 0.003$) and TC ($t = 2.004$, $P = 0.046$) of patients in the plaque group were

all significantly different from that in the non-plaque group. There was no statistical difference in the remaining parameters (Table 1).

Table 1. Univariate Analysis of Factors Influencing Carotid Plaque Formation.

Variables	Group without plaque (n = 90)	Group with plaque (n = 232)	Statistical Value	*P* Value
Age ($_{years}$)	64.54 ± 10.76	73.81 ± 9.77	t = -7.420	0.000
Male, n (%)	33 (36.7)	132 (56.9)	χ^2 = 10.622	0.001
SBP (mmHg)	125.45 (118.29, 132.71)	130.00 (123.25, 137.96)	Z = -2.849	0.004
DBP (mmHg)	75.50 ± 7.68	72.5 3 ± 7.96	t = -3.033	0.003
TC (mmol/L)	4.76 ± 1.33	4.45 ± 1.23	t = 2.004	0.046
TG (mmol/L)	1.58 (0.96, 2.07)	1.25 (0.92, 1.84)	Z = -1.918	0.055
HDL (mmol/L)	1.26 ± 0.33	1.25 ± 0.35	t = 0.180	0.857
LDL (mmol/L)	2.94 ± 0.95	2.73 ± 0.89	t = 1.919	0.056
HbA1c (%)	6.05 (5.60, 6.80)	6.10 (5.70, 7.28)	Z = -0.949	0.343

HbA1c, glycosylated hemoglobin; UA, uric acid; TC, total cholesterol; TG, triglycerides; LDL, low-density lipoprotein; HDL, high-density lipoprotein.

3.2. Multivariate Analysis of Factors Influencing Carotid Plaque Formation

Age (*OR* = 1.074, *P = 0.000*), gender (*OR* = 0.340, *P = 0.000*), SBP (*OR* = 1.039, *P = 0.006*), and DBP (*OR* = 0.932, *P = 0.003*) have an impact on carotid formation. The remaining parameters have all been eliminated (Table 2).

Table 2. Multivariate Analysis of Factors Influencing Carotid Plaque Formation.

Variables	B	*P*	OR Value	95% CI for OR
Age	0.072	0.000	1.074	1.044~1.105
Sex	-1.078	0.000	0.340	0.192~0.602
SBP	0.038	0.006	1.039	1.011~1.067
DBP	-0.070	0.003	0.932	0.890~0.977

Risk factors were analyzed by binary categorical variable logistic regression analysis.

3.3. Comparison of Clinical Parameters among the Hypertension Controlled, Uncontrolled, and Non-Hypertension Groups

There were statistically significant differences in age between the hypertension controlled, uncontrolled and non-hypertension groups (*P < 0.01* or *P < 0.05*). There was no statistical significance in gender among the above three groups. At the first admission, the Crouse1 in the non-hypertension group was significantly lower than that in both hypertension controlled and uncontrolled groups (*P < 0.01* and *P < 0.05*). At the second admission, Crouse2 in the non-hypertension group was also significantly lower than that in the hypertension controlled group and uncontrolled group (both, *P < 0.01*). Compared between the two hospitalizations, there was no statistically significant difference in △Crouse between the hypertension controlled group and the non-hypertension group. However, the △Crouse in the above two groups was both statistically significantly different from that in hypertension uncontrolled group (both, *P < 0.01*) (Table 3).

Table 3. Comparison of Clinical Parameters between Hypertension Controlled, Uncontrolled and Non-Hypertension Groups.

Values	non-hypertension group (n = 48)	hypertension controlled group (n = 109)	hypertension uncontrolled group (n = 165)	*P* Value
Age (years)	66.21 ± 12.89■▩	70.09 ± 10.97▲	73.42 ± 9.55	0.000
Male (%)	25 (52.1)	54 (49.5)	86 (52.1)	0.909
Crouse1	1.950 (0.000, 3.700)▼▲	3.600 (1.450, 5.700)	3.200 (0.000, 4.650)	0.005
Crouse2	2.200 (0.000, 3.600)★	3.700 (1.450, 5.400)	4.100 (1.700, 5.550)	0.000
△Course	0.000 (-0.200, 0.175)■	0.000 (-0.600, 0.450)■	0.300 (0.000, 1.550)	0.000

Crouse1 and Crouse2 respectively represent the Crouse scores of carotid plaques at the 1st and 2nd admissions; △Course represents the difference between Crouse2 and Crouse1; ▼, Compared with hypertension controlled group, P < 0.01; ▲, Compared with hypertension uncontrolled group, P < 0.05; ★, Compared with hypertension controlled and uncontrolled group, P < 0.01; ■, Compared with hypertension uncontrolled group, P < 0.01; ▩, Compared with hypertension controlled group, P < 0.05.

3.4. Determination of Age Stratification Cut-off Points cause age is one of the independent risk factors affecting carotid plaque formation, and there are significant differences between the hypertension controlled, uncontrolled and non-hypertension groups, the data were stratified and analyzed by age. Taking the presence or absence of carotid plaques as the state variable, and the age as the test variable, the ROC curve was plotted (AUC = 0.741, P = 0.032). Taking the maximum sum of sensitivity and specificity as the optimal cut-off point, which was 69.5 years old. Therefore, 70 years old was taken as the optimal cut-off value, and the data were stratified into two levels: < 70 years old and ≧70 years old (Table 4). On this basis, the Crouse scores were once more compared among the above three groups.

Table 4. Coordinates of the Roc Curve of Age and Carotid Plaque.

Age	Sensitivity	1-specificity	Sensitivity + specificity
43.00	1.000	1.000	1.000
...	...	...	...
68.50	0.728	0.333	1.395
69.50	0.703	0.300	1.430
70.50	0.629	0.278	1.351
...	...	...	...
93.00	0.000	0.000	1.000

3.5. Comparison of Carotid Plaque Outcomes among the Hypertension Controlled, Uncontrolled and Non-Hypertension Groups in Different Age Patients

In the patients aged < 70 years, at the first and second admissions, there was no statistical significance of Crouse1 and Crouse2 among the three groups. There was no statistical significance of △Crouse between the hypertension controlled group and non-hypertension group; moreover, the △Crouse in either the hypertension controlled group or the non-hypertension group was respectively significantly lower than that in hypertension uncontrolled group (*P < 0.05* and *P < 0.01*) (Table 5).

Table 5. Comparison of Crouse Scores between Hypertension Controlled, Uncontrolled and Non-hypertension Groups in Different Age Patients.

		Crouse1	Crouse2	△Course
<70 (years)	Non-hypertension group (n = 29)	0.000 (0.000, 3.050)	0.000 (0.000, 3.20)	0.000 (-0.050, 0.000)▲
	Hypertension controlled group (n = 52)	1.800 (0.000, 4.325)	1.750 (0.000, 4.500)	0.000 (-0.250, 0.250)▼
	Hypertension uncontrolled group (n = 51)	0.000 (0.000, 3.700)	1.600 (0.000, 4.900)	0.000 (0.000, 1.300)
≧70 (years)	Non-hypertension group (n = 19)	2.500 (2.400, 4.100)	2.500 (2.200, 4.300)■	0.000 (-0.700, 0.500)▲
	Hypertension controlled group (n = 57)	4.900 (2.050, 6.250)▩	4.600 (3.350, 5.650)	0.000 (-1.350, 0.700)▼
	Hypertension uncontrolled group (n = 114)	3.800 (2.075, 4.800)	4.550 (3.175, 5.700)	0.400 (0.000, 1.600)

Crouse1 and Crouse2 respectively represent the Crouse scores of carotid plaques at the 1st and 2nd admissions; △Course represents the difference between Crouse2 and Crouse1; ▩, Compared with non-hypertension and hypertension uncontrolled groups, $P < 0.05$; ■, Compared with hypertension controlled and uncontrolled group, $P < 0.05$; ▲, Compared with hypertension uncontrolled group, $P < 0.05$; ▼, Compared with hypertension uncontrolled group, $P < 0.01$.

In the patients aged ≧ 70 years, at the first admission, there was no statistically significant difference of Crouse1 between the non-hypertensive group and the hypertensive uncontrolled group; however, the Crouse scores in the above two groups were both significantly lower than that in hypertension controlled group (both, $P < 0.05$). at the second admission, the Crouse2 of the patients in non-hypertension group was significantly lower than that in both hypertension controlled and uncontrolled groups (both, $P < 0.05$). The △Crouse was similar between the hypertension controlled group and non-hypertension group; moreover, the △Crouse in each of the above two groups was both significantly lower than that in hypertension uncontrolled group ($P < 0.05$ and $P < 0.01$) (Table 5).

3.6. Comparison of Clinical Parameters among the Three Subgroups of Hypertension

Hypertensive patients were further subdivided into three subgroups: two-time controlled, one-time controlled, and two-time uncontrolled subgroups. The clinical parameters were compared among them. There was a significant difference in age between the hypertension two-time controlled and the two-time uncontrolled subgroups ($P < 0.05$), while there was no statistical difference among the other subgroups. There was no statistical significance in gender among the three subgroups (Table 6).

Table 6. Comparison of Clinical Parameters between Three Subgroups of Hypertension Control.

	Two-time controlled subgroup (n = 107)	One-time controlled subgroup (n = 62)	Two-time uncontrolled subgroup (n = 105)	*P* Value
Age (years)	70.19 ± 10.91▲	73.24 ± 10.16	73.37 ± 9.38	0.047
Male (%)	53 (49.5)	29 (46.8)	58 (55.2)	0.525
Crouse1	3.600 (1.500, 5.700)	2.050 (0.000, 4.625)	3.600 (1.650, 4.650)	0.067
Crouse2	3.700 (1.500, 5400)	3.150 (0.000, 5.350)	4.500 (2.400, 5.600)	0.066
△Course	0.000 (-0.600, 0.500)■	0.100 (0.000, 1.325)	0.300 (0.000, 1.600)	0.000

Crouse1 and Crouse2 respectively represent the Crouse scores of carotid plaques at the 1st and 2nd admissions; △Course represents the difference between Crouse2 and Crouse1; ▲, Compared with two-time uncontrolled subgroup, P < 0.05; ■, Compared with one-time and two-time uncontrolled subgroups, P < 0.01.

At the first and second admissions, there was no statistically significant difference of the Crouse1 and Crouse2 among the three subgroups. The △Crouse in the hypertension two-time controlled subgroup was significantly lower than those in the two-time and one-time uncontrolled subgroups (both, *P < 0.01*), however there was no statistically significant difference between the two-time and one-time uncontrolled subgroups (Table 6).

3.7. Comparison of Crouse Scores among the Three Subgroups of Hypertension at Different Age Patients

In the patients aged < 70 years, at the first and second admissions, the Crouse1 and Crouse2 in hypertension one-time controlled subgroup was significantly lower than those in both two-time controlled and two-time uncontrolled subgroups (both, *P < 0.05*). The △Crouse of the patients in two-time controlled subgroup was significantly lower than that in two-time uncontrolled subgroup (*P < 0.01*). There was no statistical significance of △Crouse among the remaining subgroups (Table 7).

Table 7. Comparison of Crouse Scores between Three Subgroups of Hypertension Control in Different Age Patients.

		Two-time controlled subgroup (n = 51)	**One-time controlled subgroup (n = 19)**	**Two-time uncontrolled subgroup (n = 33)**	***P* Value**
<70 (years)	Crouse1	1.9000 (0.000, 4.400)▲	0.000 (0.000, 1.500)★	1.700 (0.000, 4.600)	0.034
	Crouse2	1.800 (0.000, 4.600)▲	0.000 (0.000, 1.600)▼	2.700 (0.000, 5.400)	0.018
	△Course	0.000 (-0.300, 0.300)▼	0.000 (0.000, 0.100)	0.300 (0.000, 1.550)	0.003
		two-time controlled subgroup (n = 56)	one-time controlled subgroup (n = 43)	two-time uncontrolled subgroup (n = 72)	*P* Value
≧70 (years)	Crouse1	4.900 (2.025, 6.275)▲	3.500 (1.400, 5.100)	3.950 (2.500, 4.675)	0.033
	Crouse2	4.600 (3.325, 5.675)	4.200 (2.200, 5.700)	4.700 (3.525, 5.675)	0.631
	△Course	0.000 (-1.375, 0.700)■	0.500 (0.000, 1.600)	0.300 (0.000, 1.750)	0.000

Crouse1 and Crouse2 respectively represent the Crouse scores of carotid plaques at the 1st and 2nd admissions; △Course represents the difference between Crouse2 and Crouse1; ▲, Compared with one-time uncontrolled subgroup, P < 0.05; ▼, Compared with two-time uncontrolled subgroup, P < 0.01; ★, Compared with two-time uncontrolled subgroup, P < 0.05; ■, Compared with one-time and two-time uncontrolled subgroups, P < 0.01.

Among patients aged ≧ 70 years, at the first admission, Crouse1 of the patients in the hypertension two-time controlled subgroup was statistically different from that in the one-time controlled subgroup (*P < 0.05*), while there was no statistical difference among the remaining subgroups. At the second admission, there was no statistically significant difference of the Crouse2 among the three subgroups of hypertension. The △Crouse in the hypertension two-time controlled subgroup was significantly lower than those in the two-time and one-time uncontrolled subgroups (both, *P < 0.01*), however there was no

statistically significant difference between the two-time and one-time uncontrolled subgroups (Table 7).

3.8. Follow-Up SBP and DBP in the Three Hypertension Subgroups and the Non-Hypertension Group

During 12 months of follow-up, the mean SBP and DBP of the non-hypertension group were 119.66 ± 10.79 mmHg and 71.58 ± 9.81 mmHg, of the hypertension two-time controlled subgroup were 120.39 ± 13.01 mmHg and 71.49 ± 9.62 mmHg, of the one-time controlled subgroup were 131.44 ± 11.59 mmHg and 73.85 ± 11.42 mmHg, of the two-time uncontrolled subgroup were 141.74 ± 12.70 mmHg and 76.32 ± 8.93 mmHg, respectively (Figure 1).

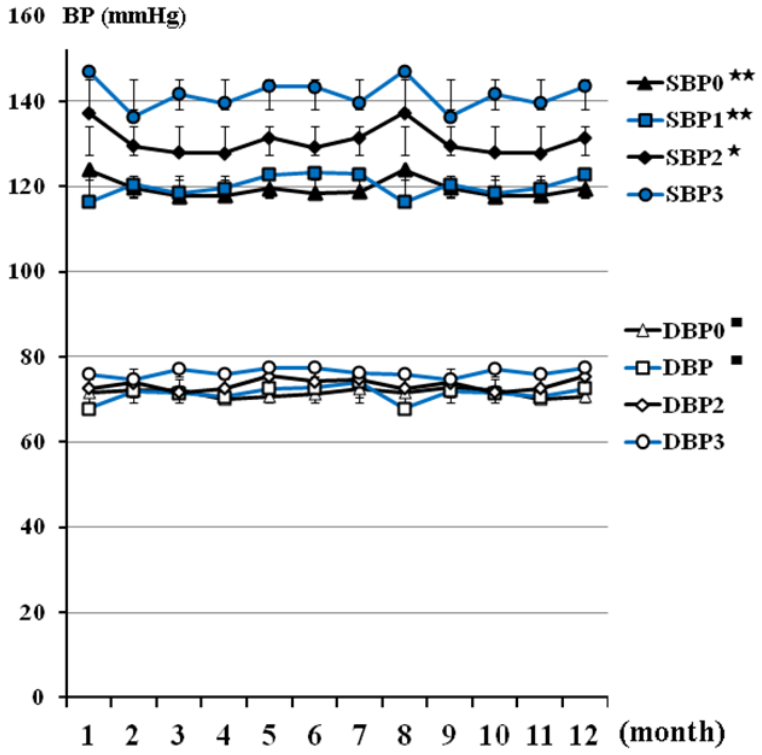

Figure 1. SBP and DBP of Non-Hypertension Group as Well as the Hypertension Two-Time Controlled, One-Time Controlled and Two-Time Uncontrolled Subgroups during the 12-Month Follow-up between the 1st and 2nd Admissions. (SBP0, SBP1, SBP2 and SBP3 represent the SBP in non-hypertension group, and the SBP in hypertension two-time controlled, one-time controlled and two-time uncontrolled subgroups, respectively. DBP0, DBP1, DBP2 and DBP3 represent the DBP in non-hypertension group, and the DBP in hypertension two-time controlled, one-time controlled and two-time uncontrolled subgroups, respectively. ★★, Compared with SBP2 and SBP3, P < 0.01; ★, Compared with SBP3, P < 0.01; ■, Compared with DBP3, P < 0.01.).

The mean SBP in the patients with two-time controlled hypertension and without hypertension was similar; however, the mean SBP of both of them was lower than that of patients in both hypertension one-time and two-time uncontrolled subgroups (all, $P < 0.01$); and that also showed a statistical difference between the patients in one-time controlled and the patients in two-time uncontrolled subgroups ($P < 0.01$). The mean DBP in the patients with two-time controlled hypertension and without hypertension was similar as well. The mean DBP in the patients with two-time uncontrolled hypertension was significantly higher than that in the patients with two-time controlled hypertension and without hypertension (both, $P < 0.01$), and also exhibited an increasing trend compared with that of the patients with one-time controlled hypertension ($P = 0.05$) (Figure 1).

4. Discussion

The primary pathophysiological basis of cerebrovascular disease is atherosclerosis; carotid atherosclerosis and plaque formation represent an integral component of systemic atherosclerosis. The development of carotid atherosclerotic plaque occurs gradually and is influenced by various risk factors, with hypertension being a significant one [7-11]. Therefore, controlling hypertension is an important method to prevent and treat atherosclerosis [12,13]. However, current evidence from both domestic and international studies remains limited regarding whether there is a significant difference in the progression of carotid atherosclerosis between patients achieving target blood pressure control and non-hypertensive individuals. Investigating this question holds substantial clinical value.

This study identified SBP and DBP as independent risk factors for carotid plaque formation through univariate and multivariate analyses. While no statistically significant difference in carotid plaque burden progression was observed between hypertensive patients achieving target blood pressure control and normotensive individuals, those with suboptimal blood pressure control exhibited significantly accelerated plaque progression compared to both normotensive subjects and well-controlled hypertensive patients [14,15]. Comparative analysis of blood pressure measurements during the 12-month follow-up period between two hospitalizations revealed consistent levels of mean SBP and DBP across the normotensive group and three hypertensive subgroups. Previous studies have demonstrated a higher prevalence of carotid plaques in hypertensive populations [16]. Hypertension plays a critical role in both the initiation and progression of carotid plaques. When blood pressure is controlled up to standard, the progression of carotid plaque shows no significant difference compared to that in normotensive populations. Conversely, failure to achieve well blood pressure control is associated with a markedly accelerated progression of carotid plaque pathology [17-19]. Within the hypertensive subgroups of this study, statistically significant differences were observed between the subgroup achieving well controlled blood pressure at both timepoints and the subgroup failing to meet control targets during both hospitalizations. These findings suggest that sustained blood pressure management serves as a critical intervention for mitigating carotid plaque progression, with a clear gradient of control efficacy: poorer blood pressure control correlates with greater plaque advancement. This further underscores the prognostic significance of achieving blood pressure targets in modulating the trajectory of carotid atherosclerosis [17]. Hypertension can cause increased shear stress in the blood vessel wall, which in turn causes varying degrees of damage to the structure and function of vascular endothelial cells [9,10]. Subsequently, the endothelial cell-mediated inflammatory response presents a cascade reaction event, causing lipid infiltration of the blood vessel wall, leading to changes in vascular structure and function, and ultimately atherosclerosis [11,20]. Following endothelial injury, platelets adhere to the damaged site, undergo activation and aggregation, subsequently release proinflammatory mediators that orchestrate the recruitment and activation of immune cells [21]. This cascade triggers a self-amplifying inflammatory response, thereby serving as a pivotal driver in the pathogenesis and progression of atherosclerotic lesions [22-24]. With aging, persistent elevated blood pressure will exacerbate the progression of atherosclerosis at all levels of blood vessels, turning early lipid streaks into fibrous plaques, reducing the elasticity of arterial walls, and leading to further increases in blood pressure, which results in a vicious circle [1]. However, the clinical correlation between gradations of blood pressure control and carotid plaque progression remains underexplored, with no definitive studies previously establishing this mechanistic link in human populations.

Research indicates that age serves as the primary risk factor to the formation of carotid atherosclerotic plaques [14,15]. This study demonstrated no statistically significant difference in carotid plaque progression between normotensive patients and hypertensive patients achieving blood pressure control targets, regardless of age stratification (≥70

years vs. <70 years), however, the patients with suboptimal blood pressure control demonstrated significantly accelerated progression of carotid plaque compared to the normotensive group, with this intergroup difference reaching statistical significance. Advancing age potentiates atherosclerotic plaque formation through a pathological cascade mediated by age-related degenerative vascular remodeling and cumulative exposure to risk factors. This process heightens hemodynamic stress on the arterial intima, precipitating endothelial injury that disrupts vascular homeostasis. Concomitant subintimal lipid deposition is facilitated by progressive alterations in endothelial permeability and lipoprotein metabolism, ultimately culminating in plaque development [25]. The progressive vascular dysfunction associated with aging is driven by age-related biomechanical deterioration, cumulative oxidative stress from heightened reactive oxygen species production, accelerated nitric oxide inactivation, and prolonged exposure to risk factors, all of which collectively compromise arterial elasticity and structural integrity [26-28]. This process is characterized by aortic stiffening with increased pulse wave velocity, premature return of reflected pressure waves during systole rather than diastole, and pathological systolic pressure augmentation, which elevates hemodynamic stress on the arterial wall. Sustained hypertension exacerbates endothelial shear stress gradients [9,10,29-31], inducing focal endothelial denudation and subintimal matrix exposure, thereby initiating a self-perpetuating cycle of oxidized LDL retention, monocyte adhesion, foam cell formation, and chronic vascular inflammation — key pathological hallmarks of atherosclerotic plaque development [30-32]. Advancing age significantly elevates the risk profile for both the de novo formation and accelerated progression of atherosclerotic plaques, attributable to synergistic interactions between age-dependent vascular senescence mechanisms and cumulative exposure to atherogenic stimuli.

5. Conclusion

In conclusion, there is no significant difference in the progression of carotid plaques between patients with well controlled hypertension and non-hypertensive patients, and the progression of carotid plaques in patients with uncontrolled hypertension is significantly accelerated. Patients of all ages will gain from satisfactory control of hypertension. Strict control of blood pressure has important clinical value in delaying the progression of carotid plaques. This study also has some limitations. Gender was also identified as a risk factor for the formation of carotid plaque in this study. However, no significant uneven distribution was observed between groups in subsequent analyses, and no further in-depth research was conducted on this aspect. In addition, since the retrospective nature of the clinical data analysis and the absence of a prospective study, there was a deficiency in monitoring of cardiovascular and cerebrovascular endpoint events, which needs to be further explored in future studies.

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