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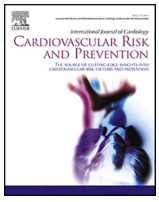

Evolving multimorbidity patterns among ageing adults with cardiovascular disease continuum in Southwest China: A longitudinal cohort study

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ABSTRACT

Background: The progression of multimorbidity in Chinese ageing adults with cardiovascular diseases remains inadequately understood. This study investigates the longitudinal evolution of cardiovascular disease continuum (CVDC)-related multimorbidity patterns in this population.

Methods: The observational study analyzed medical examination reports from individuals aged 65 and older who underwent regular physical examinations during January 1, 2010 to December 31, 2022 at the Second Affiliated Hospital of Chongqing Medical University. Multimorbidity patterns of CVDC were examined. The construction of the multimorbidity network was based on Spearman correlation analyses to visualize the evolution of gender differences. Odds ratios (ORs) for developing multimorbidity in CVDC in compared to non-CVDC were calculated. Survival analysis and multivariate cox proportional hazards regression were performed to estimate the cumulative probability and identify risk factors for multimorbidity.

Results: A total of 10,052 eligible individuals with 1835 (18.26 %) diagnosed with CVDC at baseline were included. The strongest positive correlation was observed between CVDC and obesity related diseases during both the initial ($r_{males} = 0.208$, $r_{females} = 0.244$) and final ($r_{males} = 0.312$, $r_{females} = 0.248$) examinations. Survival analysis revealed that the cumulative probability of multimorbidity of metabolic diseases in hypertension, dyslipidemia and atherosclerosis had increased over time; the corresponding adjusted HRs (95 % CIs) were 1.322 (1.219, 1.433), 1.553 (1.413, 1.706), and 1.460 (1.361, 1.567), respectively. The increasing risks of CVDC-related multimorbidity were primarily attributable to salty dietary habit (AHR = 1.336, 95 % CI: 1.239, 1.411).

Conclusions: Multimorbidity patterns and disease networks associated with CVDC have become more complex over time, especially with metabolic diseases. A high-salty diet significantly increased the risk of CVDC-related multimorbidity.

1. Introduction

Non-communicable diseases (NCDs) are chronic conditions that arise from a combination of genetic, physiological, environmental, and behavioral factors, often requiring long-term management [1]. Among NCDs, cardiovascular diseases (CVDs) are particularly prevalent in China, with an estimated 330 million individuals affected, including 11.39 million with coronary heart disease and 245 million with hypertension as of 2020 [2]. CVDs are responsible for nearly one-third of all deaths since 21st century, placing a substantial burden on individuals, families, and society [1]. Notably, many patients with CVDs also experience coexisting other NCDs, particularly in independent risk factors hypertension, and dyslipidemia. These conditions have been integrated into the concept of CVD continuum (CVDC) [3]. The co-occurrence of at least two chronic conditions in the same individual defined as multimorbidity [4], increases the complexity of care [5].

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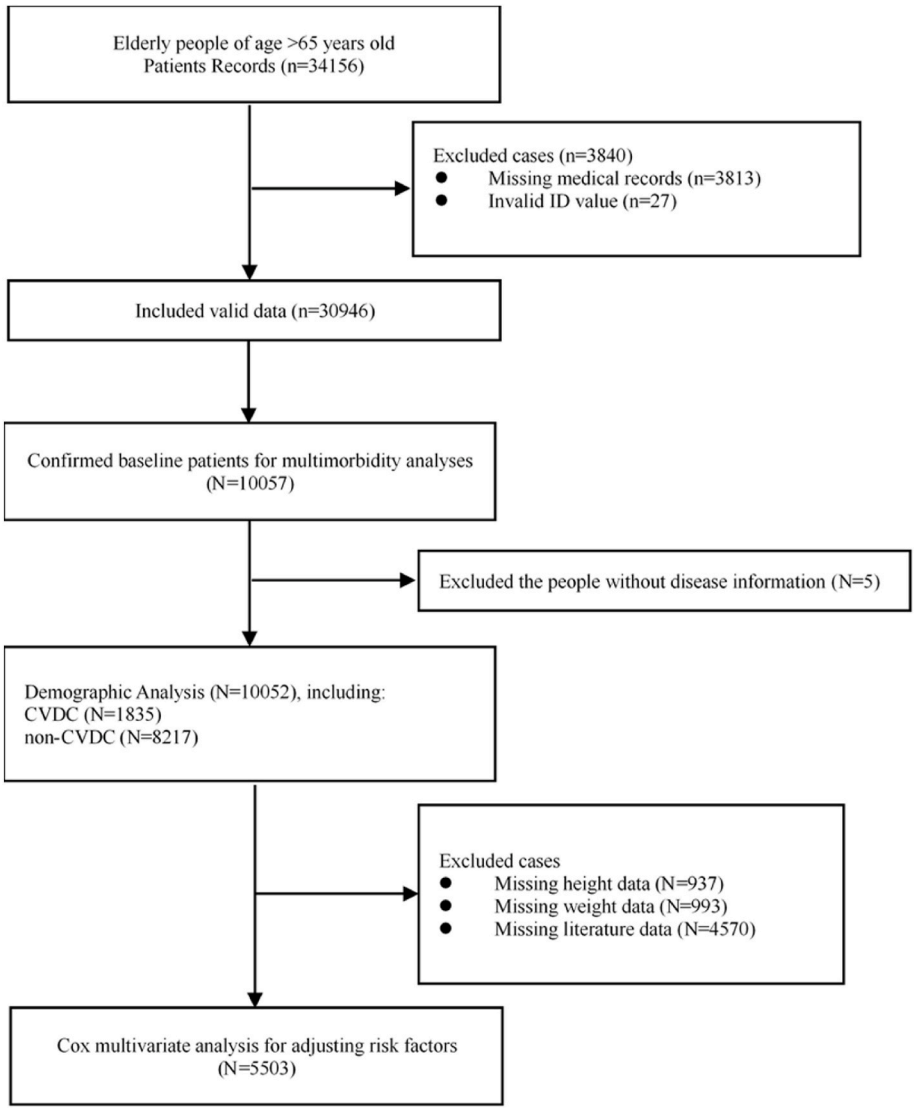

Fig. 1. Study flowchart.

Previous researches [6,7] have indicated that a substantial proportion of CVDC-related death were due to comorbid conditions like diabetes and chronic obstructive pulmonary disease (COPD), underscoring the need for a deeper understanding of CVDC in the context of multimorbidity [8].

While several studies have focused on multimorbidity management, most are limited to specific diseases and are based on cross-sectional [9] or short-term observations [10,11]. These studies often lack a longitudinal perspective and few explore how the risk of multimorbidity evolves over time. Additionally, most clinical guidelines emphasize the management of individual diseases, overlooking potential interactions between diseases [12]. Furthermore, existing multimorbidity research predominantly involves Caucasian populations from high-income countries, limiting the relevance of these findings to the Chinese population due to differences in lifestyle and ethnicity. [13]. In China, research on multimorbidity is still in its early stages, with cutting-edge articles mainly describing multimorbidity status [14], the risk factors and pathogenesis of two specific diseases [15,16]. However, there is a need for further exploration to inform dynamic NCDs management in a long-term real-world study [4].

China possesses the largest ageing population globally, with a rapidly accelerating rate of demographic ageing [17]. This trend is further compounded by a declining birth rate, resulting in a higher social dependency ratio and increasing demands on elderly care. In alignment with the Healthy China 2030, this study aims to evaluate the patterns of multimorbidity and identify factors that influence the risk of developing additional conditions over time in patients with CVDC. The findings will inform evidence-based recommendations for both clinical management and personal prevention strategies.

2. Methods

2.1. Study design and participants

This retrospective longitudinal cohort study aimed to identify trends in multimorbidity patterns among older adults with common CVDC in Southwest China. Data was collected from medical examination reports at the Health Management Center of the Second Affiliated Hospital of Chongqing Medical University between January 1, 2010, and December 31, 2022. The examination records were drawn from two independent databases: 1) demographic characteristics and lifestyle behaviors, and 2) diagnostic conclusions. Demographic characteristics and lifestyle behaviors included height, weight, education, smoking status, drinking habits, dietary patterns, exercise frequency, and disease history. Among them, lifestyles behavioral such as smoking status, drinking habits, dietary patterns, and exercise frequency were obtained in the form of

Table 1
Demographic and clinical characteristics of participants with and without CVDC.

	CVDC (N = 1835)	Non-CVDC (N = 8217)
Age, mean±SD(N), years	68.24 ± 6.28 (1835)	70.09 ± 7.10(8217)
Height, mean±SD(N), meters	160.73 ± 8.15 (1744)	159.63 ± 8.46 (8091)
Weight, mean±SD(N), kilograms	61.10 ± 9.62 (1744)	62.31 ± 10.32 (8091)
Literature, N	993	4677
College or above, N (%)	581(58.51)	2571(54.97)
High school or technical school, N (%)	196(19.74)	1078(23.05)
Junior high school or below, N (%)	216(21.75)	1028(21.98)
Dietary habit, N	1580	7333
Unbiased, N (%)	1269(80.32)	6010(81.96)
Mild, N (%)	217(13.73)	899(12.26)
Salty, N (%)	94(5.95)	424(5.78)
Smoking history, N	1587	7350
Never or quit smoking, N (%)	1364(85.95)	6300(85.71)
Occasional, N (%)	38(2.39)	155(2.11)
Less than one pack, N (%)	159(10.02)	766(10.42)
One pack or above, N (%)	26(1.64)	129(1.76)
Drinking history, N	1587	7350
Never, N (%)	1306(82.29)	5881(80.01)
Occasional, N (%)	214(13.49)	981(13.35)
Regular but moderate, N (%)	47(2.96)	347(4.72)
Regular and heavy, N (%)	20(1.26)	141(1.92)
Exercise habits, N	1579	7324
Never, N (%)	501(31.73)	2388(32.61)
One to two times a week, N (%)	474(30.02)	2220(30.31)
Three or more times a week, N (%)	604(38.25)	2716(37.08)
Disease history, N	403	2378
Hypertension related disease, N (%)	54(13.40)	859(36.12)
Coronary heart disease, N (%)	18(4.47)	144(6.06)
Dyslipidemia, N (%)	0	0
Atherosclerosis, N (%)	0	0

questionnaires, which were self-reported by patients. To mitigate the unavoidable recall bias, the structured interviews were conducted by trained clinical professionals to collect data on demographic characteristics and behavioral habits. Diagnostic conclusions were based on physicians' diagnoses, derived from medical history, physical examinations, laboratory tests, and radiological imaging. And the selection of all diseases was based on the frequency of their classification or subtypes in the dataset, with a threshold of >0.1 % of total records (≥30/30,052) to ensure sufficient representation.

Participants aged 65 or older with at least two physical examination reports were included in the study. Exclusion criteria were: (1) incomplete records of demographic characteristics and lifestyle behaviors, (2) missing diagnostic conclusions, and (3) missing medical ID that could not be linked with each database.

CVDC was defined as either (1) clinically confirmed diagnosis of CVDs, including coronary heart disease or atherosclerosis, or (2) independent high-risk factors of CVDs, specifically hypertension-related diseases or dyslipidemia. Other diseases were defined based on the medical history recorded in the physical examination report and corresponding health standards (Supplementary Table S1) [1,18–23].

2.2. Ethical considerations

The Ethical Review Committee of The Second Affiliated Hospital of Chongqing Medical University granted approval for this study (Approval No. 2024IIT046).

2.3. Procedures and outcomes

We conducted data cleaning of demographic characteristics and lifestyle behaviors. For categorical variables, entries were standardized. To simplify analysis and facilitate comparison, categorical variables with more than four levels, such as education, smoking history, and exercise habits, were reduced to three or four categories. For diagnostic conclusions, we extracted, separated, and integrated all disease information. A total of 26 NCDs were included in the analysis, covering four cardiovascular diseases, three chronic respiratory diseases, seven other metabolic disease continuum, and 12 other conditions, such as hepatic cysts, renal cysts, thyroid disorders (e.g. thyroid cysts, thyroid nodules), prostate-related diseases (e.g. prostate calcification, enlargement, cysts), gallbladder polyps, intrahepatic calcification, cervical gland cysts, cholecystolithiasis, sinus bradycardia, and pulmonary nodules (Supplementary Table S1). Finally, the two cleaned databases were matched and merged by medical ID and the physical examination code. The number of individuals was determined by their medical ID, and the frequency of physical examinations for each person was calculated based on the number of physical examination codes linked to their medical ID.

The primary outcome was to identify multimorbidity patterns associated with CVDC and their evolutionary trends. The secondary outcome was to determine the lifestyle-related risk factors linked to these common chronic CVDC-related multimorbidity patterns.

2.4. Statistical analysis

2.4.1. Multimorbidity network construction

The multimorbidity networks illustrated the relationships between CVDC and non-CVDC in the elder, comprising nodes (representing diseases) and edges (indicating disease correlations). Spearman correlation analyses were conducted using R software (v4.2.1) to calculate intra-group correlations and filter significantly correlated disease pairs ($p < 0.05$). The diameter of the nodes represented the degree, while the color indicated the disease type. These attributes were determined through clustering analysis of node subsets using Cytoscape software (v3.7.2), which revealed the number of associated nodes. The CVDC were extracted based on these measurements, and the multimorbidity networks were visualized using Gephi software (v0.1.0).

2.4.2. Risk Determinations of CVDC-related multimorbidity patterns

The risks of developing multimorbidity of CVDC in compared to non-CVDC were calaulated by Odds Ratio (OR) and its 95 % confidence interval (CI). Specifically, patients diagnosed with a specific non-CVDC were defined as the case group, and when this non-CVDC co-occurred with any CVDC (i.e., CVDC-related multimorbidity), it was considered an exposure factor. Exposure groups were recognized as risk factors if the OR value and its 95 % CI exceeded 1 during both the first and last medical examinations.

To assess changes in the risks of each CVDC-related multimorbidity pattern, the OR and 95 % CI for the last medical examination compared to the first was also calculated.

2.4.3. Survival analysis of CVDC-related multimorbidity burdens

Cox proportional hazards regression was used to estimate the adjusted hazard ratio (AHR) ($p < 0.05$) and 95 % CIs for the risk of cardiovascular patients developing other diseases during follow-up, thereby assessing the risk of multimorbidity progression in CVDC patients. Kaplan-Meier curves were fitted to show the cumulative hazard of survival and the occurrence of outcome events at each follow-up time for patients with or without each CVDC. To explore the influence of various factors on the development of multimorbidity in CVDC patients, we adjusted the Cox survival analysis for confounding factors identified in the univariate analysis and calculated AHR values for each major category according to demographic statistical categories.

3. Results

We selected 34,156 eligible medical reports, of which 30,496

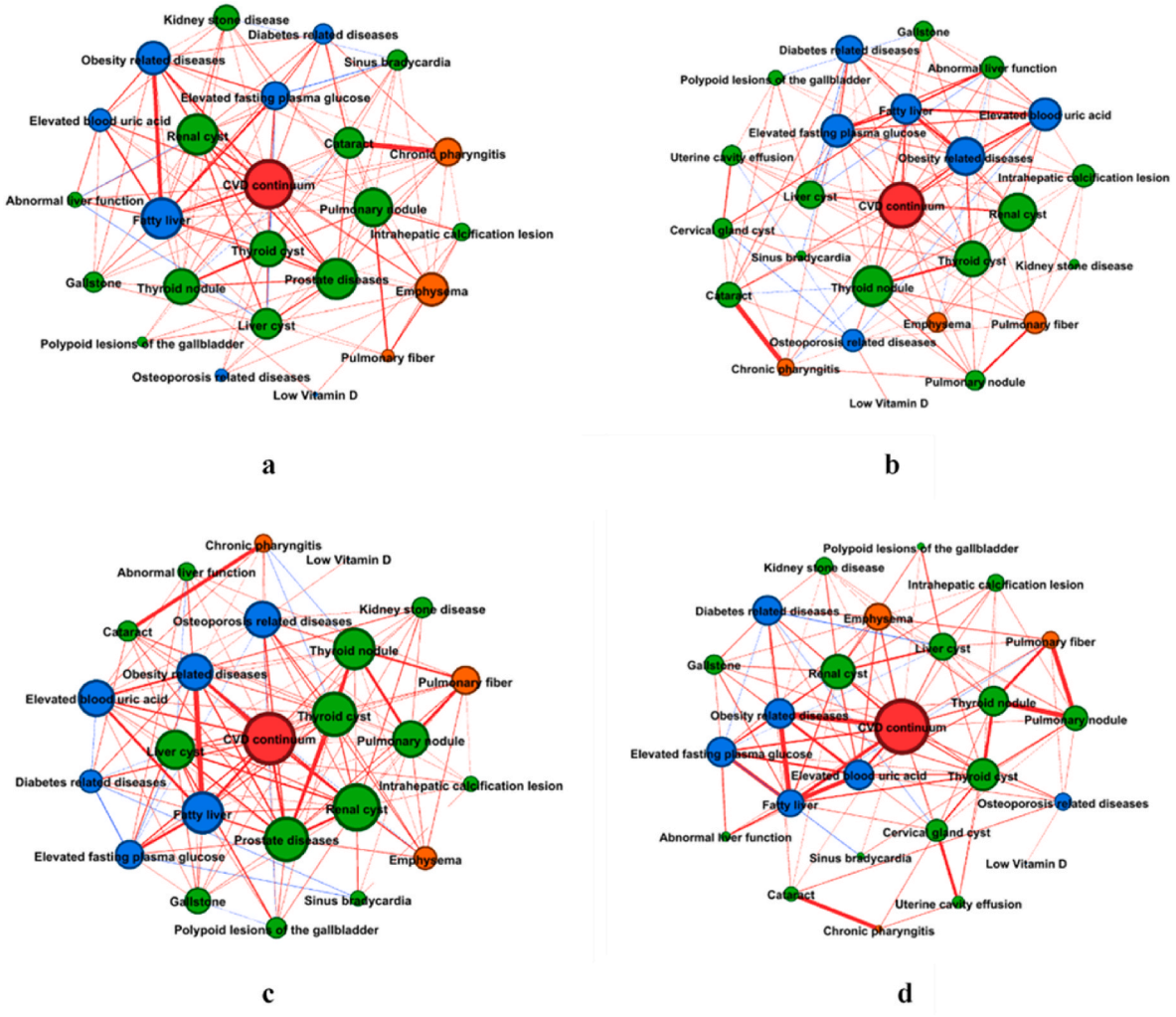

Fig. 2. * Network analysis of CVDC, chronic respiratory diseases, metabolic disease continuum and other NCDs across physical examinations.
a. Male-First physical examination; b. Female-First physical examination;
c. Male-Last physical examination; d. Female-Last physical examination.

contained valid data for the study in Fig. 1. A final analytic 10,052 people were included in the final analytic cohort via grouping by ID and excluding individuals without disease information (n = 5). The demographics and clinical characteristics of the study population are summarized in Table 1. Among the 10,052 participants, 1835 had CVDC with a mean age of 68.24 years (SD = 6.28), while 8217 without CVDC. More than half of the respondents with CVDC have attended college or had a higher degree, and 54.97 % without CVDC. Most participants reported rarely smoking (85.95 % with CVDC, 85.71 % without CVDC). Patients with CVDC showed a relatively higher proportion of salty dietary habits (5.95 %), and a lower proportion of regular exercise (31.73 %). Only hypertension-related conditions and coronary heart disease were reported among those with a history of CVDC.

3.1. Multimorbidity network analysis

Fig. 2 illustrates the network structure of CVDC, chronic respiratory diseases, metabolic disease continuum and other conditions during the first and last physical examinations, stratified by sex. Comparing the first and last exams, the degree of CVDC increased for both men (first degree = 19, last degree = 20) and women (first degree = 18, last degree = 22). Additionally, the network from the last examination shows a greater number of edges and stronger degrees compared to the first, indicating that the multimorbidity correlations between various diseases have become more complex over time. For instance, the correlation between CVDC and obesity-related diseases in men (r = 0.208) was notably higher in the last exam compared to the first (r = 0.164), while in women, the correlation rose even more sharply (first r = 0.156, last r = 0.244).

In the multimorbidity network, the strongest positive correlation related to CVDC was generally with obesity (r = 0.208), except in the first physical examination of women, where fatty liver showed the highest correlation (r = 0.167). It was worth noting that the three strongest connections with CVDC in men's first physical examination were emphysema (r = 0.164), chronic pharyngitis (r = 0.160) and diabetes related diseases (r = 0.125). While in the last physical examination were obesity (r = 0.208), fatty liver (r = 0.176) and prostate diseases (r = 0.152). For women, the top three connections in the first physical examination were CVDC-fatty liver (r = 0.167), CVDC-obesity (r = 0.156) and CVDC-elevated blood uric acid (r = 0.118), with CVDC-obesity (r = 0.244), CVDC-fatty liver (r = 0.167) and CVDC-elevated blood uric acid (r = 0.132) in the last. Other specific multimorbidity network data are listed in Supplementary Table S2.

*In each wave and sex subgroup, edge colors indicate correlations between diseases: pink edges represent positive correlations, while green edges represent negative correlations. Disease categories are distinguished by color, with CVDC in red, metabolic disease continuum in blue, chronic respiratory diseases in green, and other diseases in

Table 2
Odds ratios (OR) for multimorbidity risk of CVDC and major NCDs at first and last physical examinations.

Variables	N	Other CVDC		Chronic respiratory diseases		Metabolic disease continuum		Other diseases	
		N	OR(95 %CI)	N	OR(95 %CI)	N	OR(95 %CI)	N	OR(95 %CI)
First Physical Examination									
Hypertension related diseases	4033	3152	1.569(1.430,1.722)	823	1.344(1.213,1.490)	3539	2.708(2.426,3.022)	3384	1.490(1.344,1.653)
No-hypertension related diseases	6019	4184	Ref	964	Ref	4368	Ref	4681	Ref
Coronary heart disease	133	125	3.547(1.732,7.262)	49	2.746(1.923,3.920)	118	2.151(1.254,3.689)	113	1.398(0.867,2.254)
No-coronary heart disease	9919	8084	Ref	1738	Ref	7789	Ref	7952	Ref
Dyslipidemia	5677	3630	1.281(1.182,1.389)	967	0.890(0.803,0.986)	4712	1.803(1.638,1.985)	4715	1.500(1.359,1.655)
No-Dyslipidemia	4375	2540	Ref	820	Ref	3195	Ref	3350	Ref
Atherosclerosis	3961	3097	1.545(1.408,1.696)	983	2.171(1.957,2.407)	3357	1.882(1.696,2.089)	3454	2.187(1.959,2.441)
No-Atherosclerosis	6091	4256	Ref	804	Ref	4550	Ref	4611	Ref
Last Physical Examination									
Hypertension related diseases	4981	3747	1.647(1.510,1.795)	1133	1.212(1.101,1.334)	4500	3.302(2.950,3.697)	4211	1.818(1.645,2.008)
No-hypertension related diseases	5071	3288	Ref	991	Ref	3748	Ref	3806	Ref
Coronary heart disease	401	365	2.298(1.625,3.248)	99	1.235(0.979,1.557)	374	3.126(2.108,4.635)	342	1.492(1.127,1.976)
No-coronary heart disease	9651	7868	Ref	2025	Ref	7874	Ref	7675	Ref
Dyslipidemia	5457	3963	1.682(1.546,1.829)	1158	1.012(0.919,1.114)	4768	2.217(1.997,2.462)	4647	2.085(1.888,2.303)
No-Dyslipidemia	4595	2812	Ref	966	Ref	3480	Ref	3370	Ref
Atherosclerosis	3418	2834	1.784(1.607,1.980)	1010	2.078(1.885,2.292)	3022	2.056(1.823,2.319)	2976	2.128(1.897,2.386)
No-Atherosclerosis	6634	4851	Ref	1114	Ref	5226	Ref	5041	Ref
Last physical Examination/First physical examination									
Last hypertension related diseases	4033	3152	0.849(0.769,0.937)	823	1.148(1.038,1.271)	3539	1.306(1.143,1.492)	3384	1.049(0.936,1.175)
First hypertension related diseases	4981	3747	Ref	1133	Ref	4500	Ref	4211	Ref
Last coronary heart disease	133	125	0.649(0.294,1.433)	49	0.562(0.370,0.855)	118	1.761(0.906,3.421)	113	1.026(0.592,1.778)
First coronary heart disease	401	365	Ref	99	Ref	374	Ref	342	Ref
Last dyslipidemia	5677	3630	1.496(1.380,1.621)	967	1.312(1.193,1.443)	4712	1.417(1.275,1.575)	4715	1.171(1.057,1.296)
First dyslipidemia	5457	3963	Ref	1158	Ref	4768	Ref	4647	Ref
Last atherosclerosis	3961	3097	1.354(1.205,1.521)	983	1.271(1.146,1.408)	3357	1.373(1.199,1.573)	3454	0.988(0.862,1.133)
First atherosclerosis	3418	2834	Ref	1010	Ref	3022	Ref	2976	Ref

orange. The thickness of the edges reflects the strength of the correlation between diseases.

3.2. Risk Determinations of CVDC related multimorbidity patterns

Table 2 depicted the risks of CVDC related multimorbidity patterns with ORs which demonstrated that, for both men and women, having CVDC is associated with a greater risk of having other NCDs than those without CVDC. In the first physical examination, compared with participants without the history of hypertension related diseases, patients who had hypertension related diseases (OR = 2.708, 95 %CI: 2.426, 3.022) was independently associated with higher risk of metabolic diseases, significantly. However, dyslipidemia have reduced risk of respiratory disease (OR = 0.890, 95 %CI: 0.803, 0.986).

In the last physical examination, the risk of CVDC related multimorbidity has increased. For instance, the risks of hypertension related diseases with chronic respiratory diseases (OR = 1.148, 95 %Cl: 1.038, 1.271) and metabolic diseases (OR = 1.306, 95 %Cl: 1.143, 1.492) were increased. The multimorbidity risk of dyslipidemia and atherosclerosis with other NCDs (OR>1, 95 %Cl lower limit>1) was significant during follow-up except atherosclerosis-other diseases (OR = 0.988, 95 %Cl: 0.862, 1.133). Additionally, the risk of hypertension related diseases-other CVDC (OR = 0.849, 95 %Cl: 0.769, 0.937) and coronary heart disease-chronic respiratory diseases (OR = 0.562, 95 %Cl: 0.370, 0.855) were decreased following time.

3.3. Survival analysis of CVDC related multimorbidity burdens

Cox proportional hazards regression analysis indicated that the presence of certain CVDC increased the risk of developing other NCDs. In addition to coronary heart disease, the risk of developing multimorbidity with hypertension related diseases (AHR = 1.322, 95 %CI: 1.219, 1.433, $p < 0.001$), dyslipidemia (AHR = 1.553, 95 %CI: 1.413, 1.706, $p < 0.001$) and atherosclerosis (AHR = 1.460, 95 %CI: 1.361, 1.567, $p < 0.001$) were time dependent and significantly correlated (Fig. 3). And all the AHR values and 95 %CIs are listed in Supplementary Table S3. Additionally, hypertension related diseases (HR = 1.529, 95 % CI: 1.407, 1.662, $p < 0.001$) and dyslipidemia (HR = 1.640, 95 %CI: 1.490, 1.805, $p < 0.001$) had relatively high cumulative hazard in developing metabolic multimorbidity, while coronary heart disease (HR = 1.379, 95 %CI: 1.192, 1.596, $p < 0.001$) and atherosclerosis (HR = 2.515, 95 %CI: 2.302, 2.747, $p < 0.001$) were closely related to chronic respiratory diseases (Supplementary Fig. S1).

Multivariate cox regression analysis showed that advanced age (AHR = 1.013, 95 %Cl: 1.007, 1.019, $p < 0.001$) and salty dietary habit (AHR = 1.336, 95 %Cl: 1.239, 1.411, $p < 0.001$) were significantly associated with CVDC related multimorbidity outcomes (Table 3)

4. Discussion

Our study revealed that the multimorbidity network related to CVDC has become increasingly complex over time, with significant clustering observed in conditions such as obesity, diabetes, and other metabolic diseases. Additionally, older age and a high-salt diet were associated with an elevated multimorbidity risk in individuals with CVDC.

In our network analysis, metabolic diseases emerged as the most frequent comorbidities with CVDC, with obesity showing the strongest correlation, followed by diabetes, elevated blood uric acid, and high fasting plasma glucose. Obesity is frequently linked to hypertension and dyslipidemia, which are prevalent drivers of cardiovascular risk and can be targeted through pharmacotherapy [24]. Current studies have explored the connections between CVDC and endocrine disorders. Eckel et al. [25] have shown that cardiovascular multimorbidity are related to abnormalities in various components of the body, which was consistent with the dyslipidemia, abnormal blood sugar, and abnormal uric acid included in this study. In addition, the multimorbidity pattern of abnormal endocrine indicators with CVDC has been extensively studied with the concept of metabolic syndrome [26,27], which supports better coordination of multimorbidity management.

Furthermore, our research found that there was not overall difference in the likelihood of developing CVDC-related multimorbidities between men and women, while the multimorbidity patterns were different. But overall, women were more vulnerable to develop multimorbidities between non-CVDC compared with men. This gender

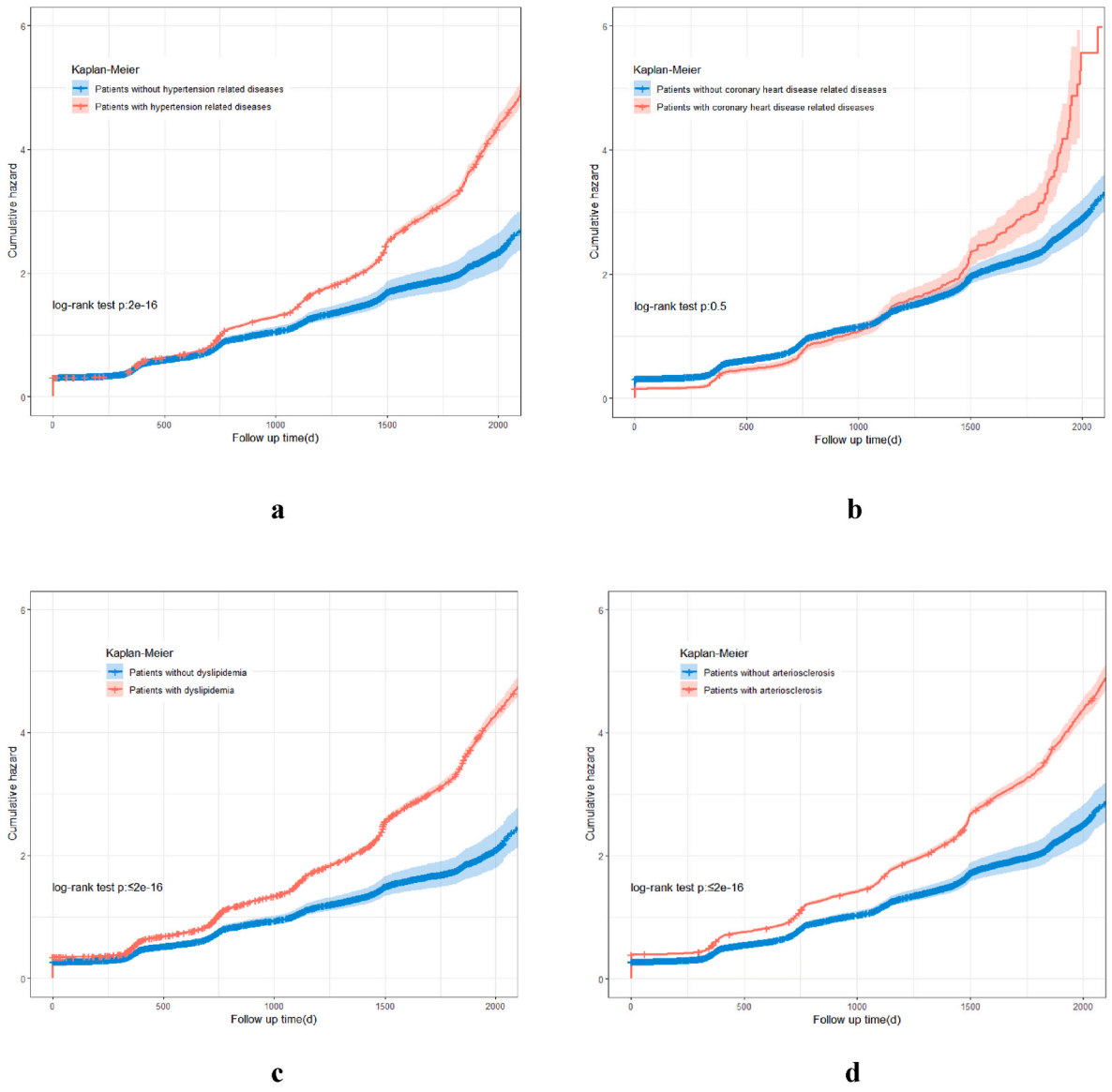

Fig. 3. Kaplan-Meier (KM) curves of cumulative hazard over follow-up time
a.KM curve of hypertension related diseases; b.KM curve of coronary heart diseases; c. KM curve of dyslipidemia; d. KM curve of arteriosclerosis.

difference may be explained by female longer life expectancy [28], greater health awareness [29] and especially hormonal changes during menopause and postmenopause. Estrogen prevents vascular aging and reduces the risk of cardiovascular diseases by reducing cellular autophagy and increasing telomerase activity. In addition, it promotes the breakdown of adipose tissue and reduces the occurrence of metabolic diseases. And in postmenopausal women, the decrease in estradiol levels is closely related to the reduction of bone mineral density and the occurrence of related diseases [30]. Meanwhile, COPD is the most common multimorbidity with CVDC in male patients at a relatively young age, due to the generally higher smoking rate among man. Long term smoking directly damages the airway and vascular endothelium, while increasing blood viscosity and promoting thrombus formation [31]. However, as men age, there was an increase in multimorbidities with metabolic diseases and a decrease in COPD, which may be due to the high mortality rate of elderly patients with COPD [32] or metabolic disorders caused by other reasons, leading to a surge in multimorbidities of metabolic diseases.

The identification of CVDC related multimorbidity patterns further highlighted the association between CVDC and other NCDs. Comparing the relationships between multimorbidity risk of CVDC and time, patients diagnosed with dyslipidemia and atherosclerosis exhibited significantly higher risks of multimorbidity. Elevated plasma LDL-cholesterol levels and atherosclerosis are major risk factors for CVDC [33]. Individuals with higher socioeconomic status and dietary habits influenced by Southwest China are more likely to avoid physical labor and consume high-calorie foods, potentially leading to an increased prevalence of NCDs such as hypertension, obesity, fatty liver, and dyslipidemia [34]. Unhealthy lifestyle and diets account for excessive fat accumulation, which not only lead to obesity, but also generate dyslipidemia and atherosclerosis in cardiovascular system [35].Beyond that, fat accumulation is a contributing factor to insulin resistance, which enhance the possibility of other CVDC like atherosclerosis and more metabolic diseases including diabetes [36]. On the foundation of the comparative study of the first and last physical examination data, we utilized cox regression analysis to compensate for eliminating interference, inferring that the multimorbidity risk of hypertension related diseases, dyslipidemia, and atherosclerosis gradually increased over

Table 3
Impact of demographic characteristics and lifestyle behaviors on outcomes of CVDC-multimorbidity.

Factors	Hazard Ratio (HR)	95 % CI lower limit	95 % CI upper limit	*p-value*
Sex				
Male	Ref			
Female	0.988	0.906	1.077	0.781
Age	1.013	1.007	1.019	<0.001
Hight	0.990	0.980	0.999	0.037
Weight	1.009	1.003	1.014	0.001
Literature				
Junior high school or below	Ref			
High school or technical school	0.879	0.831	0.930	<0.001
College or above	0.960	0.890	1.036	0.291
Dietary habit				
Unbiased	Ref			
Salt	1.336	1.239	1.411	<0.001
Mild	0.793	0.743	0.845	<0.001
Smoking history				
No or stopped smoking	Ref			
Occasional	0.804	0.517	1.252	0.334
Less than 1 pack	0.765	0.545	1.074	0.122
One pack or above	0.991	0.812	1.208	0.925
Drinking history				
No drinking	Ref			
Occasional	1.158	1.055	1.272	0.002
Regular but moderate	1.012	0.852	1.203	0.889
Regular and heavy	0.996	0.823	1.206	0.970
Exercise habits				
No	Ref			
One to two times a week	1.107	1.014	1.209	0.023
Three or more times a week	0.941	0.861	1.029	0.179
Disease history	1.100	0.941	1.286	0.230

time. Unlike previous cross-sectional or time node comparison studies [37,38],we dynamically tracked and extrapolated developmental risks with the data of 13 years. The multimorbidity risk of other NCDs was higher in individuals with CVDC than in those without, and the difference became more pronounced over time. From a pathological and physiological perspective, mechanisms can be categorized three areas: ageing and inflammation; socioeconomic, psychosocial and behavioral determinants of health; and medication use [39]. There is an undeniable relationship between age, behavior, lifestyle, and the occurrence of diseases. Additionally, individuals who have already experienced illnesses not only face a decline in bodily functions [40], but may also develop other NCDs as consequence of medication use. For instance, the administration of oral corticosteroids for polymyalgia rheumatica may end up diseases such as diabetes, cataracts, and osteoporosis [36].

Our multi-factor analysis highlighted the significant impact of dietary habits on multimorbidity risk. Previous studies [41–43] have consistently shown that diet influences physical health, with high salt intake particularly increasing the risk of CVDC. Building on this foundation, our research found that patients with CVDC who consumed a salty diet had an elevated risk of developing other NCDs. Evidence indicates that excessive salt intake can lead to higher sugar consumption by stimulating energy intake [44]. Over time, a high-salt diet may contribute to metabolic disorders by disrupting the secretion of hormones like fructose and insulin, subsequently affecting other metabolism-related hormones. These findings emphasize the importance for patients with a history of CVDC to adopt behavioral and lifestyle modifications, which may help reduce the risk of multimorbidity and prevent more severe health complications.

This study has several limitations. First, the quality and consistency of the available data were affected by the heterogeneity of the included datasets. For instance, some cohorts with CVDC were selected based on abnormal indicators rather than confirmed diagnoses, which may not accurately represent the general population of patients with CVDC. Additionally, variability in the selection of control populations could influence the associations related to multimorbidity outcomes in CVDC. Meanwhile, the inevitable recall bias in retrospective dietary assessment precluded precise effect quantification, and our bias mitigation measures (e.g., guiding inquiry from clinical doctors) may inadvertently introduce selection bias. Second, the large time span of the screened data means that the changes observed in the study may not fully reflect shifts in disease risk. For example, ongoing advancements in China's healthcare system and public health awareness have led to increased participation in physical examinations [45,46], potentially resulting in the detection of more cardiovascular patients and impacting research on multimorbidity. Another limitation is the potential influence of unmeasured confounding factors, such as genetic predispositions or environmental exposures (e.g., air pollution) prevalent in Southwest China. These factors could affect both CVDC and multimorbidity risk but were not included in our dataset, which may have impacted the accuracy of the associations observed between dietary habits, lifestyle factors, and disease outcomes. Nonetheless, our study collected long-term observational data and innovatively explored changes in multimorbidity patterns of CVDC over time, helping to fill a research gap regarding the longitudinal development of these patterns.

5. Conclusions

In summary, the multimorbidity patterns and disease networks associated with CVDC have become increasingly complex over time, particularly with the inclusion of metabolic diseases. Our study provides compelling evidence linking the multimorbidity risk of CVDC to lifestyle behaviors, with a high-salt diet having the most significant impact. This research underscores the critical need to manage the progression of NCDs through both clinical practice and personal health care measures. Future research should focus on evaluating targeted interventions and developing guidelines to effectively mitigate these risks.

CRediT authorship contribution statement

Xiaoya Qi: Writing – review & editing, Supervision, Resources, Project administration, Formal analysis, Conceptualization. **Ziyue Zhang:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Meng Jia:** Writing – review & editing, Visualization, Software, Methodology, Data curation, Conceptualization. **Yangping Zhang:** Investigation, Data curation. **Shuang Feng:** Investigation, Data curation. **Ruixue Bai:** Investigation, Data curation. **Siyao Wang:** Investigation, Data curation. **Jinning Mao:** Writing – review & editing, Resources, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Shu Su:** Writing – review & editing, Resources, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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Declaration of competinfg interest

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcrp.2025.200417.

References

[1] WHO, Global Status Report on Noncommunicable Diseases, 2010.
[2] T.W.C.O. China, Report on cardiovascular health and diseases in China 2022: an Updated summary, Biomed. Environ. Sci. (2023) 699–701.
[3] D.E. Forman, M.S. Maurer, C. Boyd, et al., Multimorbidity in older adults with cardiovascular disease, J. Am. Coll. Cardiol. 71 (19) (2018) 2149–2161.
[4] S.T. Skou, F.S. Mair, M. Fortin, et al., Multimorbidity, Nat. Rev. Dis. Primers 8 (1) (2022) 48.
[5] WHO. Primary Health Care-Now More than Ever[Z]. .
[6] F. Bragg, L. Li, L. Yang, et al., Risks and population burden of cardiovascular diseases associated with diabetes in China: a prospective study of 0.5 million adults, PLoS Med. 13 (7) (2016) e1002026.
[7] A.A. Damluji, D.E. Forman, T.Y. Wang, et al., Management of acute coronary syndrome in the older adult population: a scientific statement from the American heart association, Circulation 147 (3) (2023) e32–e62.
[8] W. Chen, J. Thomas, M Sadatsafavi, J.M. FitzGerald, Risk of cardiovascular comorbidity in patients with chronic obstructive pulmonary disease: a systematic review and meta-analysis, Lancet Respir Med 3 (8) (2015 Aug) 631, 9.
[9] A. Dekamin, M. Wahab, K. Keshavjee, et al., High cardiovascular disease risk-associated with the incidence of Type 2 diabetes among prediabetics, Eur. J. Intern. Med. 106 (2022) 56–62.
[10] Y. Han, Y. Hu, C. Yu, et al., Lifestyle, cardiometabolic disease, and multimorbidity in a prospective Chinese study, Eur. Heart J. 42 (34) (2021) 3374–3384.
[11] S. Gupta, Z. Syrimi, D.M. Hughes, et al., Comorbidities in psoriatic arthritis: a systematic review and meta-analysis, Rheumatol. Int. 41 (2) (2021) 275–284.
[12] C.M. Boyd, D.M. Kent, Evidence-based medicine and the hard problem of multimorbidity, J. Gen. Intern. Med. 29 (4) (2014) 552–553.
[13] D. Tomic, E.S.A.D. Jonathan, The burden and risks of emerging complications of diabetes mellitus, Nature (2022) 525–539.
[14] H. Qianqian, Z. Tong, L. Zhihui, et al., Research progress of multimorbidity and its management in the elderly, Chinese Journal of General Practitioners 22 (7) (2023) 754–758.
[15] L. Hongru, W. Dongmin, L. Na, et al., Research progress on comorbidity of chronic obstructive pulmonary disease and coronary heart disease, Practical Journal of Cardiac Cerebral Pneumal and Vascular Disease 31 (4) (2023) 126–131.
[16] Y.C.L.X. Liang Dong, L.X. Ou Yangjiang, Burden of cardiovascular diseases attributable to diabetes in among Chinese adults from 1990 to 2019. GENERAL PRACTICE IN CHINA, 2023.
[17] L. The, Population ageing in China: crisis or opportunity? Lancet 400 (2022) 1821, 10366.
[18] J. Beulens, F. Rutters, L. Rydén, et al., Risk and management of pre-diabetes, Eur. J. Prev. Cardiol. 26 (2_suppl) (2019) 47–54.
[19] K.D. Cashman, Vitamin D deficiency: defining, prevalence, causes, and strategies of addressing, Calcif. Tissue Int. 106 (1) (2020) 14–29.
[20] C. Borghi, D. Agnoletti, A. Cicero, et al., Uric acid and hypertension: a review of evidence and future perspectives for the management of cardiovascular risk, Hypertension 79 (9) (2022) 1927–1936.
[21] P.Y. Kwo, S.M. Cohen, J.K. Lim, ACG clinical guideline: evaluation of abnormal liver chemistries, Am. J. Gastroenterol. 112 (1) (2017) 18–35.
[22] L. Du, Y. Zong, H. Li, et al., Hyperuricemia and its related diseases: mechanisms and advances in therapy, Signal Transduct. Target. Ther. 9 (1) (2024) 212.
[23] L. Salmón-Gómez, V. Catalán, G. Frühbeck, et al., Relevance of body composition in phenotyping the obesities, Rev. Endocr. Metab. Disord. 24 (5) (2023) 809–823.
[24] A.T.J.D. Marie-Eve Piché, Obesity phenotypes, diabetes, and CVDs, Circ. Res. (2020) 1477–1500.
[25] Y. Yuhuan, W. Jun, Association of serum uric acid with carotid atherosclerotic plaque and 10-year risk of cardiovascular disease in the people undergoing health examinations: a follow-up study, Practical Journal of Cardiac Cerebral Pneumal and Vascular Disease 31 (12) (2023).
[26] P.L. Huang, A comprehensive definition for metabolic syndrome, Dis. Model. Mech. 2 (5–6) (2009) 231–237.
[27] R.H. Eckel, S.M. Grundy, P.Z. Zimmet, The metabolic syndrome, Lancet 365 (9468) (2005) 1415–1428.
[28] Y. Zhong, H. Xi, X. Guo, et al., Gender and socioeconomic differences in the prevalence and patterns of multimorbidity among middle-aged and older adults in China, Int J Environ Res Public Health 19 (24) (2022).
[29] S.S. Yao, G.Y. Cao, L. Han, et al., Prevalence and patterns of multimorbidity in a nationally representative sample of older Chinese: results from the China health and retirement longitudinal study, J Gerontol A Biol Sci Med Sci 75 (10) (2020) 1974–1980.
[30] J. Jiao, X. Feng, A. Gong, et al., Association between reproductive lifespan and multimorbidity among Chinese postmenopausal women, Menopause 31 (11) (2024) 945–951.
[31] P. Lin, C. Shen, Q. Li, et al., A systematic review and meta-analysis of chronic obstructive pulmonary disease in asia: risk factors for readmission and readmission rate, BMC Pulm. Med. 24 (1) (2024) 388.
[32] WHO. TOBACCO AND CHRONIC OBSTRUCTIVE, PULMONARY DISEASE (COPD), 2023.
[33] A. Pirillo, M. Casula, E. Olmastroni, et al., Global epidemiology of dyslipidaemias, Nat. Rev. Cardiol. 18 (10) (2021) 689–700.
[34] W. Ni, X. Yuan, Y. Zhang, et al., Sociodemographic and lifestyle determinants of multimorbidity among community-dwelling older adults: findings from 346,760 SHARE participants, BMC Geriatr. 23 (1) (2023) 419.
[35] J. Zhu, Y. Zhang, Y. Wu, et al., Obesity and dyslipidemia in Chinese adults: a cross-sectional study in Shanghai, China, Nutrients 14 (11) (2022).
[36] X. Su, X. Chen, B. Wang, Pathology of metabolically-related dyslipidemia, Clin. Chim. Acta 521 (2021) 107–115.
[37] S. Cheng, C. Ming-sheng, Prevalence and control multimorbidity of non-communicable chronic diseases in the communities, in: Jiangsu Province Based on Network Analysis, Chinese Health Economics, 2021, pp. 52–55.
[38] C.W. Duarte, V. Lindner, S.A. Francis, et al., Visualization of cancer and cardiovascular disease Co-occurrence with network methods, JCO Clin Cancer Inform 1 (2017) 1–12.
[39] S.T. Skou, F.S. Mair, M. Fortin, et al., Multimorbidity, Nat. Rev. Dis. Primers 8 (1) (2022) 48.
[40] M. Kordalewska, M.J. Markuszewski, Metabolomics in cardiovascular diseases, J. Pharm. Biomed. Anal. 113 (2015) 121–136.
[41] D. Mozaffarian, The microbiome, plasma metabolites, dietary habits, and cardiovascular risk unravelling their interplay, Circ. Res. 124 (12) (2019) 1695–1696.
[42] M. Ezzati, S.J. Henley, M.J. Thun, et al., Role of smoking in global and regional cardiovascular mortality, Circulation 112 (4) (2005) 489–497.
[43] H.R. Middlekauff, J. Park, R.S. Moheimani, Adverse effects of cigarette and noncigarette smoke exposure on the autonomic nervous system: mechanisms and implications for cardiovascular risk, J. Am. Coll. Cardiol. 64 (16) (2014) 1740–1750.
[44] Q. Wu, G. Burley, L.C. Li, et al., The role of dietary salt in metabolism and energy balance: insights beyond cardiovascular disease, Diabetes Obes Metab 25 (5) (2023) 1147–1161.
[45] L. Quan, P. Xueying, C. Jing, Construction of the knowledge service system for major chronic disease prevention from the perspective of Healthy China strategy, Inf. Sci. 41 (6) (2023) 1–8, 28.
[46] D. Shen'Gen, W. Mengxue, W. Qianqian, et al., Analysis of health resource allocation efficiency and medical level in China's megapolis in 2020, Chinese Hospitals 27 (11) (2023) 25–28.