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Mechanisms of Nutritional Factors in Chronic Disease Risk and a Comprehensive Intervention Framework

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Abstract. Currently, the global burden of chronic diseases continues to grow and has become a major challenge facing the field of public health. Against this background, nutritional factors, as a key modifiable component, play a core driving role in the development of chronic diseases. Although extensive research has been conducted on the association between nutrition and chronic diseases and a large body of relevant evidence has been accumulated, how to systematically explain the specific mechanisms by which nutritional factors drive chronic disease risk through complex biological pathways, and on this basis build a cross-level and operable comprehensive intervention framework, remains a prominent challenge in current research and practice. To address this issue, this paper adopts systematic review and multidisciplinary integrated analysis methods to sort out existing evidence in the fields of molecular nutrition, epidemiology and public health policy, and analyze the biological mechanisms through which macronutrients, micronutrients and dietary patterns affect chronic disease risk via pathways such as oxidative stress, inflammatory response, metabolic regulation and gut microbiota. Based on the social ecological model and life cycle perspective, this paper analyzes the social determinants affecting dietary choices from multiple dimensions including individual behavior, family environment, community support and policy environment. On this basis, this study focuses on integrating mechanistic understanding and social determinants to build a multi-dimensional comprehensive intervention framework covering biological mechanism-targeted intervention, individualized nutritional guidance, community environment optimization and macro-policy support, so as to transform basic scientific research into systematic prevention and control strategies. This study organically integrates mechanism analysis and framework construction, which not only deepens the scientific understanding of nutrition-driven chronic disease risk, but also provides theoretical basis and practical approaches for designing integrated public health interventions. It has important theoretical and practical value for promoting the transformation of chronic disease prevention and control from single treatment to comprehensive prevention.

Keywords: Nutritional factors, Chronic disease risk, Biological mechanisms, Social determinants, Comprehensive intervention framework, Public health strategies

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1. Introduction

1.1 Research background: current status of chronic diseases globally and in China

Chronic diseases are a focal point of social health and security at present, and their occurrence is closely related to nutritional factors. Changes in lifestyle and dietary structure have affected various aspects of the development of chronic diseases. Chronic diseases can be influenced through different pathways such as metabolic disorder, oxidative stress and inflammatory response [1, 2]. For example, a high-sodium and low-potassium diet can lead to hypertension, and insufficient dietary fiber intake increases the risk of diabetes and cardiovascular diseases [3]. Such chronic diseases caused by nutritional factors are not only related to individual metabolism, but also associated with new mechanisms such as gut microbiota dysbiosis and epigenetic modification [4]. Therefore, medical development has driven the shift of nutritional intervention from population-based proposals to individualized solutions, opening up new scientific ideas for chronic disease prevention and control [5].

Current research on nutrition and chronic diseases is multi-dimensional. Globally, malnutrition and overnutrition have brought difficulties to the prevention and treatment of chronic diseases, but from this perspective we can also derive approaches to manage chronic diseases through nutrition. Epidemiological data report that there is a certain correlation between nutritional risk and the comorbidity rate of chronic diseases in the elderly population, and sarcopenia and obesity are important manifestations of malnutrition and metabolic abnormalities [6, 7]. In terms of molecular mechanisms, nutritional factors participate in chronic disease research by regulating molecular mechanisms such as cell signaling pathways, mitochondria and epigenetic modification [8]. Gut microbiota serves as an "intermediary" of nutrient metabolism; its structure, function and activity can directly affect the host's energy metabolism and immune level, representing a new mechanism of diet-microbiota-host interaction. Meanwhile, clinical evidence also directly shows that MNT-based individualized intervention can reduce the risk of chronic diseases such as diabetes and hypertension and their complications [9].

Nutritional intervention has made breakthroughs in chronic disease management, but it also faces dual challenges in theory and practice. Theoretically, there are large differences in the dose-effect relationship between nutrition and chronic diseases, and simple "one-size-fits-all" dietary guidelines can hardly meet the demand for precise prevention and control [10, 11]. Existing studies only focus on a single nutrient or disease, lacking a systematic analysis of the overall relationship between the nutrition network and multimorbidity [12]. In practice, insufficient nutritional literacy, inadequate health information and social determinants (such as income, living environment, etc.) hinder the effect of nutritional intervention [13, 14]. A study on the relationship between chronic diseases and nutritional indicators among the elderly in rural areas of China found that the detection rate of nutritional risk was significantly higher in groups with lower socioeconomic status [15]. The uneven distribution of nutritional service resources in the medical system, low coverage of registered dietitians and insufficient accessibility of nutritional intervention [16] all call for the construction of a comprehensive and multi-level intervention framework.

From my perspective, exploring the mechanisms of nutritional factors in managing chronic diseases needs to be based on practical evidence. The use of multi-modal data such as nutritional epidemiology, metabolomics and microbiomics can better explain the relationship spectrum between different nutritional patterns and chronic disease risk. Meanwhile, exploring personalized nutritional intervention models based on digital technology, such as big data-based dietary management and intelligent decision support systems, can evaluate the feasibility of nutritional intervention models

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under the social ecological model, provide reference for policy making, fill the knowledge gap in nutrition and chronic disease research, promote the transformation from disease treatment to health management mode, and is of great significance for the realization of the "Healthy China 2030" strategy [17].

1.2. Research significance: importance and necessity of nutrition for chronic disease prevention and control

Chronic diseases have become one of the most prominent public health problems worldwide, with expanding scope and annual growth, which seriously affects social and economic development and people's health. Data from the World Health Organization has continuously confirmed that unreasonable diet and nutritional imbalance are important risk factors for the occurrence and development of chronic diseases, and this relationship is more prominent in chronic diseases such as cardiovascular diseases, type 2 diabetes, some cancers and obesity. At present, the mission of nutrition science is changing. Early research and practice mainly aimed to prevent and reduce nutritional deficiency diseases, while current nutritional science faces more complex challenges, namely the coexistence of "hidden hunger" and "overnutrition" (excessive intake of energy and macronutrients). This change in dietary structure is closely related to industrialization, urbanization and changes in lifestyle. In China, the "Healthy China 2030" strategy puts chronic disease prevention and control at the core, and nutritional intervention is a necessary prerequisite for achieving this strategic goal.

The impact of nutritional factors on chronic disease risk is complex and cannot be summarized by the simple balance formula of "energy intake and expenditure". Its pathophysiological pathways cover multiple levels, which are interconnected to form a complex network. At the cellular and molecular levels, long-term intake of nutrients can cause adverse outcomes such as chronic low-grade inflammation, oxidative stress, insulin resistance and gut microbiota ecological imbalance, thereby directly affecting tissues and organs. For example, a high-fat, high-sugar and low-fiber diet will alter the composition and metabolic function of gut microbiota, reduce the production of beneficial short-chain fatty acids, and may increase the entry of pro-inflammatory substances such as endotoxin into the bloodstream, leading to systemic metabolic disorders and immune abnormalities. At the individual level, nutrition and chronic disease risk show a "U-shaped" or "J-shaped" curve, and both malnutrition and overnutrition pose threats. A large number of epidemiological studies have shown that certain nutrient patterns are significantly associated with the risk of multiple chronic diseases. The elderly are a high-incidence group of chronic diseases. Surveys show that among elderly patients with chronic diseases in communities, the detection rates of malnutrition risk, overweight/obesity and sarcopenia are all high, and nutritional status is significantly correlated with the prevalence of chronic diseases such as hypertension and diabetes. Elderly inpatients with chronic diseases have high nutritional risk and common frailty, which are related to decreased appetite and reduced clinical physiological resilience [18]. It can be seen that a vicious cycle often forms between chronic diseases and malnutrition: the disease itself and its treatment may affect appetite, digestion, absorption and metabolism, leading to deterioration of nutritional status; while the deterioration of nutritional status will weaken the body's resistance and repair ability, accelerating disease progression and the occurrence of complications.

Although the necessity of nutritional intervention has been widely recognized, its effective application is still limited by many factors. First of all, traditional "one-size-fits-all" dietary advice cannot meet the needs of highly heterogeneous populations. Differences in genetics, metabolic phenotypes, gut microbiota, lifestyle, social culture and other factors make different groups respond

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differently to the same dietary pattern. Secondly, some patients lack understanding of nutrition, and lack the ability to acquire, understand, evaluate and use nutritional information to make reasonable dietary decisions. Studies have shown that nutritional literacy level is associated with the risk of obesity and nutrition-related chronic diseases, and low nutritional literacy may be the most important factor affecting health behaviors. Thirdly, the integration and accessibility of nutritional intervention in clinical and public health systems need to be improved. In many places, related services still face problems such as insufficient professionals, incomplete medical insurance coverage and poor referral. In addition, how to effectively carry out accurate nutritional risk assessment and monitoring for a large number of people with chronic diseases is also worth considering.

Therefore, we need a comprehensive intervention framework to integrate existing knowledge and bridge the gap between research and practice. In recent years, scientific and technological development has also provided conditions. For example, the malnutrition-based chronic disease model divides the period from nutritional risk to nutritional complications into four stages, emphasizing the influence of low-level driving factors such as genetics, environment and behavior, as well as social structural determinants, providing conceptual support for phased precise intervention. Behavior change theories such as the Health Belief Model also found that effective nutrition education requires understanding and intervening in individuals' cognition, perception and motivation to make them accept and maintain healthy dietary behaviors [19]. Meanwhile, the rapid development of digital technology provides opportunities for the innovation of nutritional intervention. Big data and artificial intelligence help to comprehensively analyze multi-dimensional health information (dietary records, biomarkers, genomics, microbiomics), laying the foundation for establishing individual nutritional profiles and truly achieving "precision nutrition". The dietary management system for patients with chronic diseases developed based on these technologies can realize the formulation of personalized dietary plans and provide dynamic adjustment, and can also improve management efficiency and compliance. Of course, front-of-pack labeling, as an important environmental strategy, can help consumers identify the nutritional properties of food and guide consumers to make healthy choices, and its application in patients with chronic diseases has also been verified [20].

1.3. Research progress at home and abroad: a brief review of research progress on dietary nutrition and chronic diseases and summary of methods

Chronic non-communicable diseases are the main cause of death and disability worldwide, and the continuous spread of their high incidence has also brought serious public health problems to social health. Cardiovascular diseases, diabetes, obesity and some cancers have long courses and complex etiologies, which increase the social medical burden and reduce personal quality of life. Therefore, exploring effective prevention and management plans is very important. However, although factors such as genetic susceptibility and environmental exposure are important risk factors affecting the onset of chronic diseases, a large amount of epidemiological data has confirmed that unreasonable dietary structure and nutritional disorders are modifiable risk factors affecting the occurrence and development of chronic diseases [21]. Shifting from simply preventing nutritional deficiencies to focusing nutritional intervention on the comprehensive prevention and control of chronic diseases marks a major change in the practical goals of nutritional science [22]. As a management path based on scientific evidence, food nutrition intervention has been proven to effectively reduce the incidence of chronic diseases, alleviate the clinical manifestations of diseases and improve the quality of life of patients [23]. Therefore, systematically expounding how nutritional factors affect

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chronic disease risk and putting forward a feasible comprehensive intervention framework on this basis is an important key to realizing the transformation of public health strategy from "disease treatment" to "health maintenance".

The risk of chronic diseases induced by nutritional factors is a joint network of multiple levels and systems. From a macro perspective, sustained overloaded energy supply is the main inducement of obesity and obesity-related metabolic syndrome, and obesity itself is the primary risk point for various chronic diseases: type 2 diabetes, hypertension and fatty liver. From a micro perspective, specific nutrients directly or indirectly participate in the formation of diseases by affecting cell signal transmission, gene expression regulation, oxidative stress level and chronic low-grade inflammation state. For example, excessive saturated fatty acids and trans fatty acids promote the formation of atherosclerosis and diabetes by activating inflammatory pathways and inducing insulin resistance; dietary fiber, polyunsaturated fatty acids and various phytochemicals have various anti-inflammatory, antioxidant and improving effects on immunity and metabolism. The balance between pathogenic factors and protective factors shows strong individual differences and life cycle characteristics for individual health. For the elderly, their physiological functions gradually decline, social roles change, and comorbidity is common, making them a population with high nutritional vulnerability and high incidence of chronic diseases. Studies have shown that the prevalence of malnutrition is high among elderly patients with chronic comorbidities and is related to various factors such as body mass index, comorbidity severity, depression status and serum albumin level. Nutritional risk assessment and intervention must be combined with the physiological and pathological characteristics of specific populations to better assess and intervene in the chronic disease risk of nutritional factors for individuals.

Although nutritional intervention has become a consensus, there are still many problems in practice. On the one hand, people and even some doctors have insufficient understanding of the importance of nutrition in the prevention and treatment of chronic diseases, and the popularization of scientific nutrition knowledge needs to be strengthened. On the other hand, the current intervention measures are mostly scattered and not systematic and personalized enough. For example, a clinical study on elderly patients with chronic diseases found that systematic nutritional care can more effectively improve patients' blood glucose and blood pressure levels than ordinary care, thereby further promoting patients' health behaviors [24], which shows that structured and professional nutritional support is of great significance. However, how to transform such effective clinical nursing methods into promotable public health measures and implement different dietary guidance for individuals with different health conditions and living environments is a difficult problem that has not been solved yet. There is still a certain disconnect between research and practice, and theoretical nutrition principles need to be transformed into operable and culturally adaptive action plans.

Therefore, it is very necessary to construct a mechanism analysis and comprehensive intervention framework for chronic disease risk driven by nutritional factors. It should not be a simple abstract induction of nutrition principles, but a multidisciplinary system combining mechanism science, preventive medicine, clinical nutrition and health behavior science. First of all, there should be basic knowledge based on the mechanism of nutrition-disease association. This framework needs to be multi-level and comprehensive, such as society-wide dietary guidelines and policies, community health education and environment, as well as screening, assessment and management of high-risk groups and patients. Alternatively, using risk management ideas to construct a risk prediction model for malnutrition in elderly patients with chronic comorbidities. At the same time, multi-departmental coordination and cooperation are also required, including health departments, food industry,

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education, communities and families. Transforming the ideas of mechanism research into comprehensive intervention actions can truly give play to the role of nutrition in the process of chronic disease prevention and control, so as to reduce the disease burden and improve the national health level.

2. Biological mechanisms of nutritional imbalance driving chronic diseases

The biological mechanism of chronic diseases caused by nutritional imbalance is that long-term dietary abnormalities damage the body's metabolic homeostasis and internal environment balance through different molecular and cellular pathways, resulting in organ function damage and the establishment of pathological states. Chronic diseases caused by nutritional imbalance are not a linear process of a single factor, but the result of the interaction of multiple factors. It is the combined effect of network factors such as energy metabolism disorder, the vicious cycle of oxidative stress and inflammatory response, intestinal microecological disorder and epigenetic modification changes. Long-term imbalance between energy intake and expenditure is the fuse of metabolic chronic diseases. Excessive energy intake, especially energy from refined carbohydrates and saturated fat, causes excessive expansion of adipose tissue and ectopic lipid deposition. In non-adipose tissues such as the liver, skeletal muscle and pancreas, lipid accumulation will produce lipotoxicity, interfere with insulin signal transduction and cause insulin resistance. Insulin resistance is also one of the causes of type 2 diabetes. The resulting hyperinsulinemia, metabolic abnormalities and vascular endothelial damage will further promote the occurrence and development of atherosclerosis, linking nutritional imbalance with cardiovascular diseases. This series of metabolic disorders will self-reinforce, and the body gradually progresses from compensatory high insulin secretion to pancreatic β-cell function failure and irreversible metabolic syndrome.

Parallel to and mutually reinforcing with energy metabolism disorder are systemic low-grade inflammation and oxidative stress. Excessive dietary intake, especially high-fat and high-sugar foods, can promote the activation of the innate immune system. Adipose tissue macrophages also produce pro-inflammatory cytokines, such as tumor necrosis factor-α and interleukin-6, which enter the circulation and cause systemic chronic low-grade inflammation. At the same time, when mitochondria metabolize excess substrates and produce excessive reactive oxygen species that exceed the clearance capacity of the endogenous antioxidant defense system, oxidative stress will occur. Oxidative stress not only directly damages proteins, lipids and DNA, but also further activates inflammatory pathways, such as nuclear factor-κB. The interaction between oxidation and inflammation continuously damages cell function and accelerates cell senescence and apoptosis, which is the molecular basis for the formation of atherosclerotic plaques, non-alcoholic fatty liver disease and some cancers. In recent years, the key mediating role of gut microbiota between nutrition and host health has begun to emerge. An unbalanced diet, such as insufficient dietary fiber, excessive animal protein and excessive fat, will lead to changes in the structure and type of gut microbiota. The metabolic profile of dysregulated gut microbiota changes, such as decreased short-chain fatty acids, increased endotoxin (lipopolysaccharide) and harmful metabolites (trimethylamine N-oxide). Intestinal permeability increases, and endotoxin translocates into the portal vein, causing liver and systemic inflammation. These microbiota-derived metabolites directly or indirectly affect the host's energy supply, insulin sensitivity, bile acid metabolism and immune system, and play an important role in obesity, diabetes, cardiovascular diseases and nervous system diseases.

In addition to classical metabolic and inflammatory pathways, nutritional factors can also affect chronic disease risk through epigenetic mechanisms. Nutrients and their metabolites can directly control epigenetic regulation processes such as DNA methylation, histone modification and non-

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coding RNA expression as substrates or co-products of enzymatic reactions. Nutritional status in early or critical periods can affect the long-term gene expression state of individuals through epigenetic programming, establishing the basis of susceptibility to chronic diseases in adulthood. For example, malnutrition during pregnancy may increase the risk of obesity or cardiovascular diseases in offspring by changing the methylation status of metabolism-related genes. This mechanism explains why nutritional intervention needs to focus on specific life cycles and provides a biological explanation for "metabolic memory". In summary, nutritional imbalance constitutes a complex biological mechanism driving the occurrence and development of chronic diseases by disrupting energy metabolism, triggering oxidative inflammation, destroying intestinal ecology and rewriting epigenetic codes. Therefore, understanding these mechanisms helps to formulate nutritional intervention measures from the root, thereby breaking the vicious cycle between nutrition and chronic diseases.

3. Major dietary risk factors and disease associations

High-salt, high-oil and high-sugar dietary patterns are core risk factors driving the occurrence and development of various chronic non-communicable diseases. This dietary structure has a profound impact on the cardiovascular system, metabolic homeostasis and tissue and organ functions through direct or indirect pathophysiological pathways, constituting an important modifiable part of the global disease burden. In-depth analysis of its mechanism is the cornerstone of constructing effective public health intervention strategies.

Excessive sodium intake is an established independent risk factor for hypertension and cardiovascular and cerebrovascular diseases. Its mechanism mainly involves body fluid volume expansion and vascular function disorder. Sodium retention in the body directly increases extracellular fluid volume, leading to increased cardiac output. In the early stage, blood pressure stability is maintained through autoregulation mechanisms, but long-term volume load will cause vascular structural changes and increased resistance. More critically, a high-sodium environment can damage vascular endothelial function, reduce the bioavailability of nitric oxide, and activate the renin-angiotensin-aldosterone system (RAAS) and sympathetic nervous system, jointly leading to enhanced vasoconstriction and continuous increase in peripheral resistance [25]. Sodium ions may also enhance the sensitivity of vascular smooth muscle to contractile stimuli by affecting intracellular calcium transport. These processes are intertwined, eventually leading to persistent hypertension and significantly increasing the risk of stroke, coronary heart disease and heart failure.

Dietary fat, especially excessive intake of saturated fatty acids and trans fatty acids, plays a key role in atherosclerotic cardiovascular disease (ASCVD) and metabolic disorders. Its pathogenic pathway is complex, and the core lies in promoting the formation of atherogenic lipoprotein profile and systemic inflammation. A high-saturated fat diet increases the synthesis and secretion of very low-density lipoprotein (VLDL) in the liver, leading to an increase in circulating low-density lipoprotein cholesterol (LDL-C) levels. Small and dense LDL particles are more susceptible to oxidative modification and are phagocytosed by macrophages to form foam cells, which deposit in the arterial intima. This is the initial event of atherosclerotic plaques. Trans fatty acids not only increase LDL-C, but also reduce protective high-density lipoprotein cholesterol (HDL-C), and induce endothelial dysfunction and systemic low-grade inflammatory response. In addition, energy excess caused by excessive fat intake will promote ectopic deposition of fat in non-adipose tissues such as the liver and muscle, leading to insulin resistance, which is an important inducement for type 2 diabetes and non-alcoholic fatty liver disease.

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The association between excessive consumption of free sugars, especially added sugars and fructose in sugary beverages, and obesity, type 2 diabetes and cardiovascular diseases is increasingly clear. The metabolic pathway of fructose is different from that of glucose; it is mainly metabolized in the liver. When ingested in large quantities, it is rapidly converted into fatty acids, promoting hepatic de novo lipogenesis (DNL), leading to intrahepatic triglyceride accumulation and insulin resistance. This process not only directly contributes to non-alcoholic fatty liver disease, but also affects systemic lipid metabolism by increasing VLDL secretion. Sharp fluctuations in postprandial blood glucose and repeated surges in insulin levels caused by high sugar intake can lead to pancreatic β-cell function exhaustion in the long term. At the same time, fructose metabolism consumes intracellular phosphate and adenosine triphosphate (ATP), promotes uric acid production, and may activate inflammatory pathways. Sugary beverages have high energy density but weak satiety, which can easily lead to excessive total energy intake, making them an important dietary factor driving the obesity epidemic.

To clearly compare the core pathological mechanisms and major health outcomes of the three dietary risk factors, Table 1 provides a systematic summary.

Table 1. Core pathophysiological mechanisms and associated diseases of three major dietary risk factors

Risk Factor	Core Pathophysiological Mechanisms	Major Associated Diseases
High salt	1. Sodium retention causes extracellular fluid volume expansion and increased cardiac output 2. Impairs endothelial function, reduces nitric oxide, and activates RAAS and sympathetic nerves 3. Enhances the contractile sensitivity of vascular smooth muscle	Primary hypertension, hemorrhagic and ischemic stroke, coronary heart disease, heart failure, chronic kidney disease
High oil	1. Increases LDL-C, promotes oxidative modification and foam cell formation, and initiates atherosclerosis 2. Induces endothelial dysfunction and systemic inflammation 3. Causes energy excess and ectopic fat deposition, leading to insulin resistance	Atherosclerotic cardiovascular diseases (myocardial infarction, cerebral infarction), type 2 diabetes, non-alcoholic fatty liver disease
High sugar	1. Fructose promotes hepatic de novo lipogenesis, leading to hepatic steatosis and insulin resistance 2. Causes drastic fluctuations in blood glucose and insulin, accelerating β-cell function exhaustion 3. High energy and low satiety, promoting total energy excess	Obesity, type 2 diabetes, non-alcoholic fatty liver disease, hyperuricemia and gout, cardiovascular diseases

In general, the intake of high salt, high oil and high sugar does not act in isolation; they have extensive interactive and synergistic effects at the metabolic level. For example, insulin resistance induced by high sugar can aggravate hypertension, while the inflammatory state caused by a high-fat diet will amplify the damage of high salt to the endothelium. This synergistic effect makes the harm of the "three-high" dietary pattern far greater than the simple superposition of single factor effects, jointly shaping a metabolic and vascular internal environment that promotes the occurrence and development of chronic diseases. Understanding these intertwined mechanism networks is crucial for designing integrated nutritional intervention policies and personal dietary guidance. The goal is

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not only to reduce the intake of a single nutrient, but also to promote the fundamental transformation of the overall dietary pattern towards balance and diversity.

4. Chronic disease risk assessment methods

4.1 Dietary assessment

Dietary assessment is an indispensable and important part of chronic disease risk assessment. It not only includes the total intake of macronutrients and energy, but also focuses on dietary patterns, dietary diversity, dietary nutrient density and the long-term cumulative effects of certain specific food components. Through dietary assessment, dietary behaviors leading to nutritional imbalance can be identified, so as to further clarify prediction results and carry out relevant intervention measures (Table 2).

The more scientific and applicable the dietary assessment method is, the more conducive it is to guiding disease risk prediction work, and the easier it is to formulate a good intervention plan. At present, three types of methods can be adopted: retrospective assessment, prospective recording and biomarker verification. The 24-hour dietary recall method and food frequency questionnaire refer to targeted assessments based on people's memory and reports of food intake over a past period of time. The 24-hour recall method can provide a detailed snapshot of dietary intake in the short term and is often included in individualized counseling and clinical research, but it is greatly affected by factors such as recall bias and daily dietary fluctuations. The food frequency questionnaire is designed to capture long-term, habitual dietary patterns. It assesses long-term nutritional exposure related to the development of chronic diseases by asking about the consumption frequency and usual portion sizes of certain foods at a certain time point. This method is often used in large epidemiological cohorts. Its advantage is that it can quickly and effectively link dietary factors with disease outcomes, but it is limited by questionnaire design, completeness of food lists and respondents' cognitive level. Prospective recording methods, such as dietary diaries or dietary records, record all ingested foods and beverages immediately during and after eating, generally lasting 3 to 7 days. This method can more truly reflect daily intake, and is very suitable for studies that require accurate quantification of nutrient intake, as well as for clinical nutritional assessment. However, it has high requirements for participants' educational level and cooperation degree. To increase objectivity, biomarker detection has received widespread attention as a supplementary verification method. By detecting specific nutrients or metabolites in biological samples such as blood and urine, the body's nutritional status can be objectively reflected, making up for the shortcomings of subjective reporting methods. For example, biomarkers of certain fatty acids, vitamins or phytochemicals can better indicate long-term intake levels. Combining subjective reporting methods with objective biomarkers is the current trend in the development of dietary assessment methodology, in order to obtain more robust risk assessment results.

The results of dietary assessment need to be compared with scientific reference standards to be transformed into meaningful risk information. These standards include dietary reference intakes, dietary guidelines issued by various countries, and chronic disease dietary risk thresholds established based on evidence-based evidence. For example, comparing an individual's intake of sodium, saturated fat and added sugar with the recommended upper limit can assess their risk of hypertension and cardiovascular diseases; while whether the intake of dietary fiber, whole grains, vegetables and fruits reaches the recommended level is related to the protective effect of intestinal health and various chronic diseases. The malnutrition-based chronic disease model emphasizes the continuous process from nutritional risk to nutritional imbalance, and then to nutritional diseases

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and complications. Dietary assessment is exactly the key tool to identify the early "nutritional imbalance" stage.

With the development of digital technology, dietary assessment tools are also gradually undergoing transformation. The dietary management system for patients with chronic diseases based on big data management includes a localized food database, nutrition calculation algorithms and a personalized recommendation engine. The intervention of artificial intelligence technology makes it possible to identify food types and predict portion sizes through image recognition, which greatly reduces the recording burden and improves the objectivity of data. These technology-driven food health assessments not only make collection fast and convenient, but also enable more continuous and dynamic monitoring and risk warning.

The ultimate result of assessment is to guide practice, and the risk information revealed by dietary assessment is the beginning of medical nutrition therapy and personalized nutritional intervention. Studies have shown that medical nutrition therapy provided by registered dietitians based on individual assessment results has significant effects on improving the clinical outcomes of various chronic diseases such as diabetes, hypertension and dyslipidemia. Good nutrition education, such as interventions based on the Health Belief Model, can affect individuals' cognition and beliefs, and encourage them to adopt the dietary behavior changes recommended after assessment, thereby reducing chronic disease risk. Therefore, dietary assessment is by no means a simple measurement, but a bridge connecting "risk identification" and "effective intervention", and its quality is directly related to the efficiency of the entire chronic disease prevention and control chain.

Table 2. Dietary assessment

Type of Assessment Method	Specific Method	Main Characteristics	Applicable Scenarios	Limitations
Retrospective assessment	24-hour dietary recall method	Relies on memory, obtains short-term detailed data, and is relatively quick to operate	Clinical outpatient assessment, cross-sectional surveys	Recall bias, large intra-day/inter-day variation
	Food frequency questionnaire (FFQ)	Assesses long-term habitual dietary patterns, suitable for large sample studies	Large epidemiological cohort studies, exploring the association between diet and chronic diseases	Memory error, imprecise quantification, greatly affected by questionnaire design
Prospective recording	Dietary diary/record	Real-time recording, reduces recall bias, relatively accurate data	Studies requiring precise quantification of intake, individualized nutritional counseling	May change dietary behavior, heavy burden on participants, depends on cooperation degree
Biomarker method	Blood/urine nutrient testing	Objectively reflects the body's nutritional status and verifies subjective report data	Supplementary verification of subjective methods, precision nutrition research	High cost, only applicable to some nutrients, reflects status at a specific time point
Technology integration method	Mobile app + image recognition + AI analysis	Convenient and highly interactive, capable of dynamic monitoring and real-time feedback	Long-term health management, patient self-monitoring, big data collection	Depends on equipment and network, accuracy of database needs to be guaranteed, user stickiness issues exist

In the practice of chronic disease risk assessment, the choice of dietary assessment method needs to comprehensively consider the research purpose, target population, resource conditions and the

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required data accuracy. For population risk screening and macro policy formulation, standardized food frequency questionnaires combined with sampled 24-hour recall surveys may be more cost-effective. In clinical scenarios, to formulate individualized medical nutrition therapy plans, it may be necessary to combine multi-dimensional information such as dietary records, biomarker testing and even gut microbiota analysis to achieve a comprehensive assessment from macro nutrition to micro metabolism. In the future, with the in-depth integration of multi-omics technology and artificial intelligence, dietary assessment will become more dynamic, precise and predictive, thereby providing more powerful tool support for the early prevention and personalized management of chronic diseases.

4.2. Biomarkers

Chronic disease risk assessment is an important link connecting nutritional factors and disease outcomes. Its main goal is to assess the probability, or risk, of specific chronic diseases occurring in certain individuals or groups under specific nutritional exposure. Modern risk assessment of chronic diseases has gradually shifted from simple biomarker detection to prediction and intervention by comprehensively considering various information, striving for early identification, stratification and precise intervention of chronic diseases. In the past, risk assessment mainly relied on clinical diagnostic indicators, such as blood pressure, blood glucose and blood lipids. Although these diagnostic indicators can clarify the patient's disease status, they often lag behind changes in their pathological and physiological processes. Therefore, current research and practice pay more attention to finding prospective risk markers that can reflect subclinical status and are sensitive to nutritional intervention. For example, body composition, especially distinguishing fat mass from fat-free mass, is crucial for assessing the metabolic risk caused by obesity. Sarcopenia, that is, age-related muscle loss and functional decline, is a strong predictor of frailty, disability and poor prognosis of various chronic diseases in the elderly. Meanwhile, nutritional risk screening, as a method to assess adverse clinical outcomes caused by nutrition in individuals, has a high detection rate in the elderly chronic disease population, and is closely related to advanced age, number of comorbidities, socioeconomic factors and so on. All these mean that the outcome of any development is abnormal: on the one hand, both malnutrition and overnutrition are important basic risks leading to the occurrence or development of chronic diseases.

At present, risk assessment methodology pays more and more attention to the integration of multi-dimensional data and model construction. A single indicator can no longer comprehensively reflect the complexity of chronic disease risk. Therefore, finding a comprehensive risk prediction model has become one of the research hotspots. Usually, statistical methods such as logistic regression and machine learning are used to incorporate demographic characteristics, clinical indicators, lifestyle and nutrition-related variables into risk analysis, so as to obtain an individualized risk score. For example, through multi-factor analysis, a risk prediction model for malnutrition in elderly patients with chronic comorbidities can be established. Variables such as body mass index, comorbidity severity, history of nutrition education, depression status, activities of daily living and serum albumin are considered to distinguish and calibrate various risks, providing a quantitative basis for early identification of high-risk groups. In addition to objective physiological data, subjective perception and behavioral factors have also begun to be investigated. Subjective cognitive decline and decreased appetite have been found to be significantly associated with frailty in elderly inpatients with chronic diseases, indicating that cognitive function and appetite are not negligible when assessing overall health risk. Clinical physiological resilience, that is, the body's ability to maintain homeostasis under pressures such as disease, has also been proven to be a

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protective factor against frailty, all of which add a new perspective of physiological resilience to risk assessment. These models have the same value: they are not limited to the impact of a certain disease, but can also assess and predict the overall health risk of multiple diseases in the presence of multimorbidity.

At the population level, epidemiological studies have revealed a wide range of associations between nutritional status indicators and the risk of chronic diseases through cross-sectional or longitudinal designs. Surveys of the community elderly population show that overweight or obesity, sarcopenia risk and malnutrition risk often coexist, and are significantly correlated with the prevalence of various chronic diseases such as hypertension and diabetes. For example, sarcopenia risk has been identified as an independent risk factor for malnutrition, while overweight or obesity status shows a protective effect against malnutrition, which highlights the complex and non-linear relationship between different nutritional imbalance patterns and disease risk. Trend analysis further points out that in some rural elderly populations, the prevalence of chronic diseases such as diabetes and hypertension is on the rise, and has specific associations with nutrition and health-related indicators, emphasizing the necessity of continuous monitoring and risk assessment based on population characteristics. These population-level data provide empirical evidence for formulating public health strategies and identifying high-risk groups, and also indicate that risk assessment needs to consider social determinants such as region, economy and culture. For example, factors such as living alone and low income have been proven to significantly increase the nutritional risk of elderly patients with chronic diseases.

As the focus of health management shifts forward to prevention, the assessment of risk-related "soft skills" has received increasing attention, among which nutritional literacy has become a key concept. Nutritional literacy refers to an individual's knowledge, motivation and ability to acquire, understand, evaluate and apply nutritional information to make reasonable dietary decisions. Studies have shown that there is a complex association between nutritional literacy level and chronic disease status. A study of outpatients found that the overall nutritional literacy score of the chronic disease patient group may be higher than that of the healthy control group, but the scores are lower in specific sub-dimensions such as general nutrition knowledge and food label reading. More in-depth model analysis reveals that higher overall nutritional literacy scores and specific sub-dimensional abilities (such as reading comprehension and numerical interpretation of food labels) are negatively correlated with the likelihood of suffering from nutrition-related chronic diseases. This suggests that improving specific nutritional literacy skills of the public, especially patients with chronic diseases, such as interpreting food labels and applying nutrition knowledge, may be an effective primary prevention strategy. The effectiveness assessment of front-of-pack labeling systems, as tools to assist consumers in making healthy choices, also falls into the category of behavioral risk assessment. Studies have confirmed that systems such as nutrition scores and warning labels can significantly change adults' perception of food nutritional quality, including patients with chronic diseases, thereby potentially affecting their purchase choices, which provides a methodological basis for intervening in dietary risks through environmental strategies.

In summary, chronic disease risk assessment methods are evolving towards integration, individualization, prospectiveness and behavior orientation. From assessing body composition, screening nutritional risk, constructing prediction models, to analyzing population epidemiological associations, and then to measuring nutritional literacy and evaluating the information environment, multiple methods complement each other and jointly build a three-dimensional risk assessment network. Future research needs to further explore the effectiveness of different assessment tools in predicting intervention effects and guiding the formulation of personalized nutrition plans, and

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devote itself to developing more convenient, more accurate and culturally adaptive risk assessment systems, so as to provide a solid methodological foundation for the mechanism explanation of the proposition of "nutritional factors driving chronic disease risk" and the construction of intervention frameworks.

5. Construction of a comprehensive intervention framework for chronic diseases

The core of constructing a comprehensive intervention framework for chronic diseases lies in establishing a multi-level, multi-dimensional and dynamically adjusted intervention model, and formulating specific implementable and evaluable strategies accordingly. This model should not be limited to a single medical or nutritional perspective, but should integrate multiple levels such as individual behavior, social environment, medical system and policy support to form a synergistic system. Its fundamental goal is to break the traditional passive model of "treatment-oriented" and shift to an active health management model integrating "prevention-intervention-management", so as to curb the chronic disease risk driven by nutritional factors at the source. This framework emphasizes that nutritional intervention is not an isolated behavior, but a continuous process embedded in individuals' daily lives, community support networks and macro health policies (Table 3).

In the construction of the intervention model, the individual is the core, and the social ecological background in which the individual is located should also be considered. Generally, health models usually include three parts: core intervention layer, support system layer and macro policy layer. For individuals, the core refers to aspects such as dietary structure adjustment, precise application of nutritional supplements, and promotion of physical activity that are needed for their intervention; families, communities, workplaces and medical and health institutions provide necessary knowledge, skills, environment and social support for individuals to implement these intervention programs; the macro policy layer refers to a large environment conducive to healthy choices composed of main factors such as laws and regulations, industry standards, public health education, and social and economic levers. Due to the interconnection among the three, for example, the macro government promotes the establishment of community health canteens to make it easier for residents to adopt a balanced diet. The integrated model can better achieve and maintain healthy behavior changes, and its effect far exceeds the results of any single effort.

In terms of core intervention measures, it is particularly important to formulate personalized plans targeted at individuals' specific nutritional conditions. That is, personalized intervention measures should comprehensively consider individuals' genetic background, physiological status (metabolic indicators), disease history, lifestyle, dietary preferences and socioeconomic conditions. For example, for the elderly with hypertension, their dietary plan should not only limit sodium intake, but also ensure adequate potassium, calcium, magnesium and high-quality protein, and take into account their masticatory function, economic conditions and convenience of food access. The use of nutritional supplements should also be based on scientific assessment to avoid blind following. According to a cross-sectional study on the elderly in China, the use of nutritional supplements may be associated with certain chronic diseases, and the utilization rate of nutritional supplements is relatively low, which suggests that we should pay attention to seeking help from professionals.

Accordingly, with detailed assessment, the strategy at the support system level is to create an "empowering" environment for individuals. Community-based comprehensive health management programs can be developed in communities, including professional teams such as dietitians, general practitioners, health managers and social workers providing dietary guidance, cooking courses,

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group support and health screening services. In the entire medical and health field, the "nutritional care" pathway should be vigorously promoted as part of the standard diagnosis and treatment of chronic diseases. Clinical evidence shows that systematic nutritional care for elderly patients with chronic diseases is conducive to improving blood glucose and blood pressure control levels, and improving their health behaviors and quality of life; improving the "nutritional literacy" of patients and their caregivers is a key step, which requires not only acquiring and understanding nutritional information, but more importantly, using this information to make reasonable dietary decisions and put them into practice.

The shaping of macro policies and environment is the guarantee for the wide implementation and sustainable development of the intervention framework. It requires the collaboration of various departments to integrate chronic disease prevention and control goals into policies such as agriculture, food industry, education, urban planning and social security. For example, promoting the standardization of food nutrition labeling, restricting the marketing of unhealthy foods, providing subsidies or tax incentives for healthy foods, and adding fitness facilities and green spaces in urban planning. In addition, building a team of nutritional professionals, especially training skilled talents in non-medical health services, to meet the growing social demand.

Table 3. Synergistic relationship and key action points of strategies at all levels

Intervention Level	Core Goal	Key Strategies and Action Examples
Core intervention layer (individual)	Promote and maintain individual healthy behavior change	1. Implement personalized dietary plans based on precise assessment (e.g., adaptation of DASH diet and Mediterranean diet patterns) 2. Targeted use of nutrient supplements under the guidance of professionals 3. Formulate individualized physical activity plans 4. Carry out self-health management skills training (e.g., food diaries, blood glucose monitoring)
Support system layer (community/medical care)	Create a supportive environment and provide professional services	1. Communities carry out "health canteen", "nutrition corner" and peer support group activities 2. Medical institutions incorporate standardized nutritional screening and care pathways into routine chronic disease diagnosis and treatment 3. Use digital health tools (APPs, wearable devices) for remote monitoring and guidance 4. Develop and apply nutritional literacy assessment tools and carry out targeted health education
Macro policy layer (society)	Create a social and policy environment where health is the first choice	1. Formulate and implement food processing standards and labeling regulations for salt reduction, oil reduction and sugar reduction 2. Include nutritional intervention in the basic public health service package and medical insurance payment scope 3. Support the development of the nutrition and health industry, and encourage the research and development of formula foods suitable for people with chronic diseases 4. Strengthen the construction of nutrition and health courses in universities, primary and secondary schools and vocational colleges

Ultimately, the successful implementation of the comprehensive chronic disease intervention framework requires the establishment of a multi-dimensional evaluation system. Through data collection and analysis, obstacles and advantages in the operation of the framework can be continuously identified, so as to optimize and adjust the intervention model and strategies, ensure

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that they are always scientific and effective, and truly achieve the goal of managing nutrition-related chronic disease risks from the source.

6. Conclusion and prospect

Although the role of nutritional factors in the occurrence and development of chronic diseases has been fully confirmed, the mechanism research is not deep enough, intervention strategies need to be enriched, and the adaptability for specific populations still needs to be explored in the future. At present, most explanations of the mechanism of nutrition-driven chronic disease risk focus on the impact of a single nutrient or isolated metabolic pathway, lacking an integrated elaboration of multi-level and multi-system interactions. For example, the process by which the interaction between dietary patterns and gut microbiota affects the immune-metabolic axis and causes systemic inflammation and insulin resistance is still a very complex process and causal chain. Most studies adopt cross-sectional observations or short-term interventions, making it difficult to distinguish the long-term cumulative effect of nutritional exposure from the critical window effect in certain life stages. This leads to fragmented understanding of the association mechanism and hinders the search for accurate targets. In the future, systems biology should continue to be applied, such as comprehensive multi-omics analysis methods, to longitudinally explore the covariation relationship between dietary intake, metabolite profiles, microbiome and host phenotypes from population cohorts, and depict the dynamic network map from diet to disease; strengthen experiments such as organoids or animal models to verify key nodes, and clarify specific molecular pathways such as how certain dietary fibers shape the microbiota structure and produce short-chain fatty acids to regulate host epigenetic modification and immune homeostasis, so as to transform mechanistic cognition into practical results.

In terms of intervention, most existing intervention strategies are scattered, isolated or carry out nutrition education for individual characteristics, or only focus on the supplementation of a single dietary component, without fully considering the impact of individual differences, behavioral science and environmental factors. For example, when intervening in the elderly, the complexity of various dietary behaviors such as physiological function decline, comorbidity status, dysphagia and psychosocial factors is often ignored. Future intervention research needs to take the road of "precision" and "integration". On the one hand, explore different nutritional response differences based on individual genotypes, metabolic phenotypes and gut microbiota characteristics, so as to help provide scientific and appropriate nutritional advice; on the other hand, it is necessary to break through the boundaries of simple nutrition knowledge and design and evaluate a series of intervention models at different levels. For example, develop personalized dietary monitoring and feedback tools based on digital health, embed nutritional guidance into primary health care and chronic disease management, and explore the use of policy and environmental adjustments (such as food labels, provision of healthy foods) to promote healthy choices. Special attention should be paid to how to transform scientific nutrition knowledge into sustainable daily dietary behaviors, especially family care, which requires learning from experience in other fields including pet health management and attaching importance to the knowledge and skills training of caregivers.

On the other hand, the limitations of research perspectives are also worthy of attention. Most scholars focus on mainstream human populations, and lack in-depth discussion and understanding of nutritional programming effects in important transition stages such as early life and old age; there are few studies on subgroups with unique metabolic characteristics or cultural dietary customs. For example, the mechanisms and intervention strategies of new food environments (such as the popularization of ultra-processed foods) that affect chronic disease risk with social changes still

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need to be further explored; in the future, the life course perspective can be expanded to strengthen longitudinal cohort studies from pregnancy, childhood to old age, and find the window period for nutritional intervention; encourage cross-species comparative research, find mechanistic inspiration and intervention ideas from nutrition and disease models of model organisms or companion animals, and actively integrate multiple disciplinary factors such as food science, social science and data science to deal with the non-linear relationship between complex food systems and health outcomes. Ultimately, nutritional factors will be upgraded from general health promotion means to a quantifiable, predictable and precisely regulated core pillar of chronic disease prevention and control, so that public health practice will gradually bid farewell to "one-size-fits-all" advice and turn to evidence-based personalized solutions.

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