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PRECISION NUTRITION IN THE PREVENTION AND MANAGEMENT OF METABOLIC SYNDROME: ROLE OF GUT MICROBIOTA, GENETICS AND DIETARY PATTERNS

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Abstract:

Metabolic syndrome is a multifactorial cardiometabolic condition characterized by central obesity, dysglycemia, hypertension, and dyslipidemia, substantially increasing the risk of type 2 diabetes and cardiovascular disease. Conventional dietary recommendations are valuable, but individuals may respond markedly differently to the same foods. Precision nutrition marks a major shift from uniform dietary advice to strategies that consider individual metabolic characteristics, gut microbiota, genetic variation, dietary patterns, and lifestyle and behavioural factors. This review examines the role of precision nutrition in the prevention and management of metabolic syndrome, with particular emphasis on gut microbial interactions, nutrigenetics, evidence-based dietary patterns and personalized dietary approaches. Recent research demonstrates substantial inter-individual variation in postprandial glucose, insulin and triglyceride responses, while microbiome characteristics may contribute to differences in metabolic response. Genetic factors may modify selected diet–metabolic syndrome associations, although current evidence remains insufficient for routine gene-based dietary prescriptions. Mediterranean-style and healthy plant-based dietary patterns continue to provide a strong foundation for cardiometabolic management and can potentially be adapted to individual metabolic responses and preferences. Randomized controlled trials and systematic reviews suggest that personalized nutrition may improve selected outcomes, including HbA1c, postprandial glucose, triglycerides, body weight and waist circumference; however, findings are heterogeneous and long-term evidence remains limited. Overall, precision nutrition represents a promising complement to established dietary management rather than a replacement for evidence-based nutrition counselling. Future research should establish standardized approaches, evaluate long-term clinical outcomes, improve affordability, and incorporate culturally appropriate strategies for diverse populations. Integration may strengthen individualized dietetic care and improve preventive strategies.

Keywords: Precision nutrition; metabolic syndrome; personalized nutrition; gut microbiota; nutrigenetics; dietary patterns; metabolic health.

Introduction:

Metabolic syndrome represents a major cardiometabolic challenge resulting from the interaction of obesity, impaired glucose regulation, abnormal lipid metabolism, and elevated blood pressure. Although conventional dietary management remains central to prevention and management, individuals may respond differently to the same foods and dietary patterns. This variation has encouraged the development of precision nutrition, which aims to move beyond generalized recommendations by considering

individual biological, dietary, and lifestyle characteristics. Recent research has strengthened the scientific basis for this approach, while also emphasizing that precision nutrition is still developing as a clinical field [1,2].

Role of Precision Nutrition:

Precision nutrition integrates information such as metabolic phenotype, dietary intake, physical activity, genetics, gut microbiota, and other individual characteristics to develop more suitable dietary recommendations. Rather than prescribing a completely different diet for every individual, its purpose is to identify factors that may influence dietary response and use them to improve nutritional decision-making. Recent scientific reviews describe precision nutrition as a promising framework for cardiometabolic disease prevention, while emphasizing the need for stronger clinical evidence and standardized approaches [2,3].

Individual Metabolic Response to Food:

One of the strongest arguments for precision nutrition comes from evidence showing considerable variation in individual responses to identical foods. Research from the PREDICT programme demonstrated substantial differences in postprandial glucose, insulin and triglyceride responses among individuals consuming similar meals. These findings indicate that food recommendations based only on population averages may not fully reflect individual metabolic responses. Such observations provide an important scientific foundation for developing more personalized dietary approaches [4].

Gut Microbiota and Metabolic Health:

The gut microbiota is increasingly recognized as an important link between diet and metabolic health. Differences in microbial composition and function may influence energy metabolism, glucose regulation, lipid metabolism, and inflammatory processes. Dietary macronutrients can alter microbial activity and metabolite production, while microbial metabolites may subsequently influence host metabolic pathways. Therefore, the gut microbiome has potential value as one component of precision nutrition, although its relationship with diet and host metabolism remains complex and requires further validation before routine clinical use [5,6]. Recent evidence also suggests that microbiome-informed nutrition may contribute to improved metabolic outcomes, but standardized microbiome assessment and long-term validation are still required [7].

Genetics and Nutrigenetics:

Genetic variation is another potential determinant of individual dietary response. Nutrigenetics examines how genetic differences influence responses to nutrients, foods and dietary patterns, while nutrigenomics investigates how dietary components influence gene-related biological pathways. Evidence indicates that selected gene–diet interactions may influence lipid metabolism and metabolic risk. However, metabolic syndrome results from multiple interacting genetic and environmental factors, and current evidence remains insufficient to recommend routine gene-based dietary prescriptions in clinical practice [8].

Role of Dietary Patterns:

Dietary patterns continue to form the foundation of metabolic syndrome management. Among established approaches, the Mediterranean dietary pattern has considerable evidence supporting its association with improved cardiometabolic health. Its emphasis on vegetables, fruits, legumes, whole grains, nuts, seeds and unsaturated fats provides a nutritionally balanced framework that can be adapted to individual requirements and food preferences [9]. Healthy plant-based dietary patterns have also demonstrated favourable effects on several cardiometabolic indicators. However, the quality of the plant-based diet is important because diets dominated by refined carbohydrates, added sugars and highly processed foods may not provide the same benefits as diets rich in minimally processed plant foods [10].

Personalized Dietary Approach:

A personalized dietary approach combines established dietary principles with information specific to the individual. Depending on the clinical setting, personalization may involve consideration of metabolic markers, dietary intake, body composition, food preferences, lifestyle, glucose responses and, where appropriate, microbiome or genetic information. The approach should remain practical and culturally appropriate so that recommendations can be followed over the long term [3,11]. For example, carbohydrate quality and meal distribution may be modified according to glycemic response, while dietary fat quality may be adjusted according to lipid profile and cardiovascular risk.

Scientific Evidence:

A randomized controlled trial evaluating a personalized nutrition programme reported improvements in triglycerides, body weight, waist circumference and HbA1c compared with general dietary advice [12]. A systematic review of randomized controlled trials in adults with prediabetes or metabolic syndrome found relatively consistent improvements in HbA1c, postprandial glucose and waist circumference, although findings for fasting glucose, insulin resistance, blood lipids and blood pressure were inconsistent [13]. Another systematic review reported potential improvements in dietary and health-related outcomes but highlighted differences in study design and personalization methods [14]. A further systematic review focusing on personalized nutrition in prediabetes and type 2 diabetes found promising effects while noting concerns regarding study quality and risk of bias [15].

Emerging Technologies and Future Potential:

Advances in continuous glucose monitoring, metabolomics, microbiome analysis, genomics, and artificial intelligence have expanded the possibilities for precision nutrition. These technologies may allow biological and dietary information to be integrated to predict individual responses and support targeted recommendations. However, technological advancement alone does not establish clinical effectiveness. Reproducibility, standardization, cost, data interpretation, accessibility, and long-term clinical outcomes remain important challenges [3,16].

Relevance to Metabolic Syndrome Management:

The potential value of precision nutrition in metabolic syndrome lies in combining biological information with established dietary principles. Instead of replacing Mediterranean-style, plant-based or other evidence-based approaches, precision nutrition can help adapt them to an individual's metabolic characteristics, preferences, and circumstances. This may improve the practicality

and acceptability of dietary interventions. Microbiome-informed personalization remains promising but requires external validation and standardized measurement before widespread clinical implementation [7].

Methodology:

The present study was conducted as a narrative evidence review to examine the emerging role of precision nutrition in the prevention and management of metabolic syndrome. Literature was searched using PubMed/MEDLINE, Scopus, Web of Science, ScienceDirect, Cochrane Library, and Google Scholar. Articles published primarily between 2020 and 2026 were considered, with priority given to peer-reviewed publications from established and indexed scientific journals.

The search was performed using combinations of keywords including "precision nutrition," "metabolic syndrome," "personalized nutrition," "gut microbiota," "gut microbiome," "nutrigenetics," "gene–diet interaction," "Mediterranean diet," "plant-based diet," "personalized dietary intervention," and "continuous glucose monitoring." Human studies, randomized controlled trials, systematic reviews, meta-analyses and high-quality scientific reviews relevant to metabolic syndrome, prediabetes, obesity and cardiometabolic health were prioritized.

Duplicate publications, animal-only studies, conference abstracts, non-peer-reviewed material and articles unrelated to the objectives of the review were excluded. The selected literature was critically examined and thematically synthesized according to precision nutrition, gut microbiota, genetics and nutrigenetics, dietary patterns, personalized dietary approach and emerging technologies. Particular attention was given to study design, consistency of findings, clinically relevant metabolic outcomes and limitations of the available evidence.

Summary and Conclusion:

Precision nutrition provides a promising framework for addressing the considerable variation in individual responses to food. It integrates metabolic characteristics, gut microbiota, genetics, dietary patterns and lifestyle factors to support more individualized dietary care. Current evidence suggests potential improvements in HbA1c, postprandial glucose, triglycerides, body weight and waist circumference, particularly in some personalized intervention studies [12–15]. However, evidence remains heterogeneous and long-term clinical benefits are not yet firmly established. Mediterranean-style and healthy plant-based dietary patterns continue to provide a strong evidence-based foundation and can be adapted through personalized dietary approaches. Gut microbiome and genetic information may further improve personalization, but routine clinical application requires stronger validation. Therefore, precision nutrition should currently complement rather than replace conventional evidence-based nutrition counselling. Future research should focus on larger and longer studies, standardized personalization methods, affordability, cultural adaptability, and clinically meaningful outcomes.

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