EDITORIAL:

PRECISION NUTRITION IN THE ERA OF ARTIFICIAL INTELLIGENCE: FROM PERSONALIZED DIETS TO POPULATION HEALTH

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Nutrition science is moving towards a new era where traditional nutrition guidelines that are derived from population averages increasingly are complemented by those that incorporate individual biological, behavioral, environmental, and social differences. This growing field, often called precision nutrition 1**,** aims to uncover individual variation in response to dietary patterns and foods and to use this information to develop targeted nutrition interventions for preventing disease and promoting health. Precision nutrition (Shang et al., 2024) has been transformed by the rapid progress of artificial intelligence (AI), machine learning, wearable technology, digital health technologies, electronic health records, metabolomics, microbiome research and continuous physiological monitoring. National Institutes of Health (NIH) have recognized the field of precision nutrition as a key priority for nutrition research, highlighting the need for multidisciplinary research involving nutrition science, data science, systems science, and artificial intelligence **[2].** The core idea of precision nutrition is that a given food has many different biological effects on different people. The age, sex, genetic differences, metabolic characteristics, gut microbiota, physical activity, sleep, medication use, socioeconomic factors and dietary habits may affect how the body responds to foods and dietary patterns. Thus, an intervention that has a significant effect in one person might have a more muted effect in another person. Precision nutrition aims to shift the focus of the question of “What is a healthy diet?” to more personal ones: For whom are the effects of a certain nutritional intervention beneficial? When? How? Precision nutrition is about moving the focus of the question of “What is a healthy diet?” to more personal questions: For whom is a certain diet certain dietary intervention beneficial? When? How?

Population-Based Nutrition to Precision Nutrition.

Population-based dietary guidelines have been an appropriate approach for public health nutrition over the decades. These recommendations are still very much needed as they offer direction and general dietary guidelines for disease prevention for populations. However, averages of populations can mask significant biological and behavioral diversity. Precision nutrition aims to add to rather than take the place of population nutrition, and to identify meaningful sources of individual variation and map them onto more effective interventions. Precision nutrition is an emerging area of nutrition research that is highlighted in the NIH Strategic Plan for Nutrition Research 2020–2030, which includes the need to understand what people eat, how dietary patterns affect health, how nutritional exposures interact with biological characteristics, and the need to leverage nutrition more effectively in clinical settings [3]. Other critical aspects of this research agenda include data science, systems science, AI and health disparities, and workforce development. This is a paradigm change in nutrition research. Precision nutrition tends to focus more on inter-individual differences, whereas conventional studies focus more on the mean response of the study population. This heterogeneity may have the potential to be understood in the future so that dietary interventions can be better tailored to each person's circumstances and characteristics, ultimately leading to better adherence and health outcomes.

In this section, use AI to drive precision nutrition. Here, leverage AI to facilitate Precision Nutrition.

The potential of AI for precision nutrition is tremendous, as nutrition has a lot of interconnected and complex information to

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produce. Analytical systems could include dietary intake, food photographs, physical activity, sleep, anthropometric measurements, biochemical biomarkers, microbiome profiles, use of medications, clinical history and socioeconomic characteristics. Machine-learning methods can discover intricate relationships in vast amounts of data that might not be apparent through traditional statistical techniques. These techniques can be applied to identifying individuals at higher risk for nutrition-related disease, optimizing dietary interventions, predicting metabolic responses, and recognizing dietary patterns in nutrition research, as well as in monitoring dietary changes. Dietary assessment is another critical field of development that can benefit from AI. Traditional methods, such as 24-hour dietary recalls and food-frequency questionnaires, heavily rely on memory and self-report. Technologies that incorporate image recognition, natural-language processing, and automated food databases could alleviate some of the burden of dietary recording in digital applications. AI-powered systems might be able to identify food items by image, quantify food intake components, and help nutrition experts detect patterns that warrant more investigation [4].

But there is a difference between technical sophistication and nutritional validity. An algorithm can process information very quickly, but the results it produces depend on the quality, completeness, representativeness, and contextual relevance of the information it uses to draw those conclusions. AI is thus a supplement to nutrition expertise, not a substitute.

Personalized Dietary Recommendations: Promise and Caution

A prominent use case for AI in nutrition is creating personalized meal plans and recommendations. Dietary intake, anthropometric data, physical activity, metabolic markers, health history, preferences, and behavioral patterns could all be considered within the scope of an AI system to deliver personalized recommendations. Personalization can enhance the 'real-world' effectiveness of nutrition recommendations. An AI-powered system would not offer a one-size-fits-all diet plan, but rather could suggest suitable food substitutions, depending on the individual's eating preferences, cultural habits, financial constraints, access to food, and health goals. The latter may be especially applicable to long-term adherence to a diet, given that the success of nutrition interventions is also dependent upon the biological efficacy as well as acceptability and feasibility. However, individual nutrition is not on the same level as automated meal planning. Personalized nutrition must be validated, have the right clinical context, be transparent, and be professionally monitored to be scientifically credible. World Health Organization (WHO) has highlighted the importance of ensuring the safety, transparency, accountability, equity, privacy, and human rights of AI applications in health [5]. These principles are further highlighted by the development of generative AI. AI systems can produce nutrition information that may seem authoritative even when there are incomplete or inappropriate nutrition recommendations. WHO is therefore stressing the need for expert supervision, strict evaluation, transparency, and safeguarding of sensitive health information when using generative AI for health [6].

As AI technologies advance, what about the future of population nutrition? What about the future of population nutrition in the age of AI?

Precision nutrition shouldn't be thought of as a one-person approach. AI could also play a significant role in the nutrition and health of populations. On the population level, AI could be used to incorporate food environments, nutritional surveys, food prices, agricultural production, health records, demographic data, climate data, and other indicators. This translation could be used to help identify communities with higher food insecurity, micronutrient deficiency, overweight and obesity, and diet-related non-communicable diseases (NCDs) [7]. The use of predictive models may also help policymakers to investigate the possible impacts of food price fluctuations, climate events, shifts in agricultural production and food availability on nutrition outcomes. AI-based systems can assist in mapping geographic areas to target interventions and in nutrition program monitoring. The broader application is especially relevant in LMIC countries where multiple malnutrition types might occur. Child undernutrition, micronutrient deficiency, overweight/obesity, and diet-related non-communicable diseases (NCDs) may coexist in the same population and often in the same household [8]. An AI-informed population approach can assist policymakers to create more context-specific strategies rather than blanket interventions. WHO's recommendations on AI and evidence-informed policy underscore the potential benefits of AI in areas such as problem identification, data integration, predictive analysis, policy development, implementation, and monitoring. Meanwhile, AI must be used to complement, not supplant, human decision-making in health policy and decision-making **[9].**

The risk of a new Digital nutrition divide.

While precision nutrition promises that nutrition science could equalize access to the therapy, there is a possibility for it to inadvertently exacerbate health disparities depending on who has access to advanced technologies. Many precision nutrition apps need smartphones, the Internet, wearable devices, lab testing, digital skills, and trained experts. It can be challenging to meet these requirements in low-resource and underserved rural and low-resource communities. Precision nutrition, if it becomes a "high cost" service, may exacerbate, rather than narrow, prevailing nutrition inequalities. The nutrition equity gap is thus another digital divide issue **[10].** AI systems should be designed with a wide range of representative datasets that capture the socioeconomic, geographic, cultural, and dietary diversity of populations. Algorithms developed primarily from data from wealthy populations may not be as effective in populations that have unique foods, eating habits, environmental exposures, and disease patterns. It should therefore be equity by default in precision nutrition. Those most at risk of nutrition issues mustn't be denied access to technology gains due to a lack of digital infrastructure.

Data Privacy, Bias and Ethical Responsibility

Data is crucial to precision nutrition, yet nutrition-related information is very personal. Food consumption, body proportions, lab tests, medications, activity level, health history, and behaviour can provide personal, private details about people. As these data are increasingly embedded within AI systems, privacy and governance are crucial issues. Another important point to take into account is algorithmic bias. An AI system that is created with incomplete or unrepresentative data may systematically exclude or marginalize certain groups. For instance, a system that is built primarily from Western food databases may struggle to recognise traditional South Asian foods or foods from other parts of the world with a different culture. The same applies to nutrition, which is clearly affected by socioeconomic and environmental factors. A personalized algorithm for a low-income family with a high cost of food items may not actually be personalized, but rather inappropriate. Social determinants, affordability, food availability, culture, and household circumstances [11] therefore need to be part of true precision nutrition. WHO calls for autonomy and human well-being and safety as well as transparency, accountability, inclusiveness, equity and sustainability to be chief principles of responsible AI in health. These principles should be applied to nutrition research and practice from the very beginning of the development of AI.

The Evolving Role of Nutrition Professionals

While AI has emerged, it's not taking the place of nutrition professionals, but rather changing their job description. The knowledge and skills of dietitians, nutritionists, doctors, researchers, and public health practitioners will continue to grow in the knowledge of AI-generated recommendations, how they are created, validated, interpreted and communicated. While AI can detect patterns statistically, it is the trained experts who will decide whether the patterns are scientifically meaningful and suitable for a person or population. Where cultural preferences, food insecurity, medical complexity, family context, behavioral barriers and multiple health priorities co-exist, human judgment is essential to dietary recommendations [12]. This new generation of nutrition professionals will thus need to be equipped with a blend of traditional nutrition knowledge and digital skills. Existing nutrition education should be complemented by the education of data interpretation, artificial intelligence, research methodology, ethics, digital health and communication of science, which should be increasingly part of the education to be offered. The best approach is thus not between AI and the nutrition professional, but rather between AI and the nutrition professional. This partnership might enable professionals to focus more on interpretation, counseling, behavior change, empathy, and complex decision-making, while AI takes on the role of data processing and pattern recognition.

Evidence generation could be the biggest hurdle to overcome in precision nutrition, not technology. While the development of AI applications can be very fast, they need to be carefully studied to demonstrate their clinical and public health value. Further research is needed to determine if AI nutrition interventions are effective at changing dietary behaviors, nutrition status, clinical outcomes, quality of life, adherence, and cost-effectiveness [13]. Algorithmic correctness is not enough. Even if the model is technically accurate, it has little or no public health value unless it is associated with improvements in health. Longitudinal research is of particular importance as dietary behavior and metabolic health status change over time. The effects of AI-based intervention compared to traditional professional nutrition counseling should also be assessed by studies [14]. Implementation research is thus a key factor of precision nutrition. Lab studies need to determine if an algorithm works in real life, in low-income and high-income populations, in different health care systems, and in populations with varying food habits.

A vision for precision nutrition that shapes the future.

There are several priorities that need to be considered in developing precision nutrition going forward. First, the validity of science has to be kept as a key element. Recommendations provided by AI must be grounded in good nutrition evidence and properly tested in different populations. Secondly, there should still be a human element in place. The use of AI should empower nutrition professionals and decision makers, not replace their professional judgment. Third, equity needs to be considered in technology development from the outset. Precision nutrition should not be a service for those who are technologically advanced but rather populations where there are major nutrition issues. Fourth, dietary databases and algorithms need to be made culturally and contextually relevant. Fourth, cultural and contextual relevance should be taken up in dietary databases and algorithms. Any approach to personalized nutrition that does not consider local foods, cultural food preferences and dietary habits, affordability, food availability, and household context is not truly personalized. Lastly, governance and accountability need to evolve with technological innovation. Nutrition AI systems need to be transparent, privacy protecting, auditable, scientifically assessed and properly regulated.

Conclusion

Precision nutrition is an important step forward in nutrition science and a chance to shift away from blanket dietary advice to more individualized, context-specific interventions. AI can help speed up the journey by utilizing complex datasets, aiding dietary assessment, detecting patterns, forecasting responses, and empowering personalized nutrition care and population-level decisions. But the future of nutrition isn't all about technology. The problems stemming from poor quality evidence, a selection of biased data, socioeconomic inequality, poor dietary assessment, and the absence of professional oversight are not solvable by sophisticated algorithms. It is therefore important to build a partnership between nutrition science and intelligent technologies – not replace nutrition professionals. Precise nutrition is not about how sophisticated and individualized an algorithm gets, it's about whether these advances make any difference in nutritional health and equity, are viable for sustainability, and can be measured. With proper and responsible development, AI can contribute to a future where nutrition science is able to identify a person's nutritional risk earlier, implement more targeted interventions, and evaluate the dietary and health outcomes on an ongoing basis. The future should thus be seen as “AI enriching nutrition science and empowering nutrition professionals” rather than “AI replacing nutritionists.” This vision will need to be achieved through the work of nutrition scientists, dietitians, clinicians, data scientists, computer scientists, policy makers, ethicists, and communities. This interdisciplinary work will be vital to making precision nutrition a scientifically sound, ethical, and equitable approach to population health.

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