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AI-Driven holistic health medicine: Integrating nutrition, exercise and industrial implementation for personalized healthcare

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Abstract
Global population ageing has escalated the burden of chronic diseases, driving a paradigm shift from treatment-centered medicine toward preventive, personalised health management. Artificial intelligence, wearable sensing, and big-data analytics offer unprecedented opportunities to integrate nutrition, exercise physiology, gut-microbiome science and real-world service delivery. This study synthesises multidisciplinary evidence to construct a holistic AI-driven personalised health-management framework covering nutritional metabolism, gut-brain-axis mechanisms, evidence-based dietary patterns, exercise physiology for healthy ageing, and digital-health industrial practices. We systematically reviewed the performance of image-based dietary assessment, personalised nutrition-recommendation algorithms, AI posture-recognition for physical training, and closed-loop monitoring via wearable physiological data. Key findings indicate that gut microbiota acts as a critical biological mediator linking diet, lifestyle and chronic-disease risk. Customised multimodal AI models achieve acceptable accuracy for dietary evaluation, while AI virtual-coaching systems enable safe home-based exercise, particularly for older-adult populations. Nevertheless, critical gaps remain, including insufficient long-term user retention mechanisms, safety risks for AI-generated exercise advice, and misalignment between regulatory frameworks and fast-evolving digital-health technologies. Furthermore, this work proposes multi-category business models and a cross-sector health ecosystem spanning consumers, healthcare providers, food-supplement industries and technology vendors. The framework provides technical, clinical and industrial references for advancing preventive personalised healthcare and healthy-ageing interventions.

Keywords: Holistic health, artificial intelligence, nutrition, exercise, preventive medicine, personalized healthcare, digital health

Introduction

Since the twenty-first century, global healthcare systems have been undergoing structural transformation. According to the United Nations World Population Prospects report, the proportion of the global population aged 65 years and above will rise from 9 % in 2019 to 16 % by 2050. Population ageing has brought a growing burden of chronic diseases including cardiovascular disorders, type 2 diabetes, obesity and neurodegenerative diseases, which have become the leading contributors to global disease burden. Meanwhile, information technology and biomedicine are rapidly converging. The maturation of artificial intelligence (AI), wearable devices and big-data analytics has created transformative opportunities for health-management paradigms. Traditional health management centres on disease treatment and emphasises passive medical intervention, which entails high medical costs and limited prognostic outcomes. By contrast, preventive-medicine-oriented personalised health management highlights active monitoring, early-warning alerts and behavioural modification. It generates tailored health-promotion programmes by evaluating individuals' genetic backgrounds, physiological statuses, lifestyles and environmental factors. Such paradigm shift from a treatment-oriented to a prevention-oriented framework has become a core trend in global health policy. In nutritional health, conventional dietary assessment relies heavily on self-reporting and recall-based methods, which suffer from recall bias, heavy respondent burden and insufficient accuracy. Advances in computer vision and deep learning have rendered image-based food recognition and nutritional estimation practically viable. Customised multimodal AI models can achieve accuracy comparable to the weighed-food-record method for dietary assessment (Chen *et al.*, 2025) [5]. Meanwhile, personalised nutrition-recommendation algorithms integrating machine-learning techniques and domain expertise generate optimised dietary plans according to individual health metrics, food preferences and disease-related constraints, outperforming generic dietary guidelines substantially in precision (Papastratis *et al.*, 2024) [17]. In exercise health, wearable devices enable continuous 24-hour monitoring of physiological parameters such as heart rate, heart-rate variability (HRV), physical-activity volume and sleep architecture. Large-sample studies confirm that such data reflect physiological trajectories across age and sex groups and correlate strongly with healthy ageing (Alikhani *et al.*, 2025) [2]. AI posture-recognition technology detects human-skeleton key points to evaluate movement execution in real time and deliver feedback, substantially lowering the risk of sports-related injuries and making home-based independent exercise a safe and feasible health-promotion strategy (Marusic *et al.*, 2025) [13]. Despite rapid technological progress, three major gaps persist in contemporary health-management research and practice. First, nutrition- and exercise-related research have largely developed in isolation, lacking integrated frameworks for personalised health management. Second, existing AI applications focus predominantly on technical performance, with insufficient exploration of user behavioural change,

long-term participation and retention mechanisms. Third, business models and regulatory frameworks for health-food and fitness-service industries have not kept pace with AI-driven technological innovation.

Human Metabolism, Nutrition and Gut Microbiome

The human metabolic system constitutes a core biochemical network sustaining life, encompassing thousands of enzyme-catalysed chemical reactions that convert food-derived nutrients into energy, construct bodily tissues and regulate diverse physiological functions. Metabolic processes are divided into anabolism and catabolism. Anabolism refers to energy-consuming pathways that assemble complex macromolecules from small molecular substrates, such as protein synthesis and glycogenogenesis. Catabolism breaks down macromolecules to release energy, exemplified by glycolysis, β-oxidation and the tricarboxylic-acid cycle. Energy balance represents the cornerstone of weight management and metabolic health, denoting the dynamic equilibrium between energy intake and energy expenditure. When energy intake exceeds expenditure, surplus energy is primarily stored as triglycerides in adipose tissue; chronic positive energy balance induces weight gain and obesity, whereas negative energy balance triggers mobilisation of stored fat and muscle tissues. Contemporary research has moved beyond simplistic calorie-balance models and recognises the complex influences of differential nutrient metabolic effects, hormonal regulation and inter-individual variability on energy homeostasis. Basal Metabolic Rate (BMR), accounting for 60 %-75 % of total daily energy expenditure, denotes the minimum energy required to sustain fundamental life functions including respiration, circulation, cellular repair and thermoregulation. BMR is modulated by age, sex, body composition, thyroid function and genetics. Generally, men exhibit higher BMR than women owing to greater muscle mass. After age 30, BMR declines by approximately 2 %-3 % per decade, mainly attributable to sarcopenia and reduced organ metabolic activity.

Human nutrients are categorised into macronutrients and micronutrients. Although dietary fibre and phytochemicals provide no caloric value, they exert vital health-protective effects. Carbohydrates serve as the primary human energy source; upon digestion they are hydrolysed into glucose entering systemic circulation. Blood-glucose homeostasis is precisely regulated by insulin and glucagon. Insulin facilitates cellular glucose uptake and promotes glycogen and lipid synthesis; glucagon stimulates glycogenolysis and gluconeogenesis during fasting to stabilise blood-glucose concentrations. Proteins consist of 20 amino acids, among which nine are essential amino acids that cannot be endogenously synthesised. Proteins exert multifaceted physiological roles: tissue construction, enzymatic catalysis, hormone production, antibody formation and energy provision. Muscle protein undergoes constant dynamic turnover between synthesis and degradation. Resistance training combined with protein supplementation enhances anabolic processes and augments muscle mass. Lipids function not only as concentrated energy substrates but also as key building blocks for cell membranes, steroid hormones, bile acids and prostaglandins. Omega-3 and omega-6 fatty acids are essential fatty acids requiring dietary supply. Omega-3 fatty acids (EPA, DHA) exert anti-inflammatory, lipid-lowering and cardioprotective properties; excessive omega-6 fatty-acid intake may promote inflammatory responses. Micronutrients are required in small quantities yet participate in numerous enzymatic reactions and physiological modulations. Vitamins are classified as water-soluble (B-complex, vitamin C) and fat-soluble (A, D, E, K). Among minerals, calcium, phosphorus and magnesium are pivotal for skeletal health; iron mediates oxygen transport; zinc participates in immune responses and wound healing. Complex interactions exist among micronutrients: for instance, vitamin C enhances iron absorption, while excessive zinc inhibits copper uptake. Accordingly, balanced diets remain the optimal nutritional strategy.

Trillions of microorganisms colonise the human gastrointestinal tract, whose collective gene pool is approximately 150-fold larger than the human genome and is termed the human “second genome”. In healthy adults, Firmicutes and Bacteroidetes dominate gut microbiota, jointly constituting roughly 90 % of total microbial abundance, followed by Actinobacteria, Proteobacteria and Verrucomicrobia. Gut-microbiota profiles are highly individual-specific and shaped by mode of birth, feeding patterns, age, diet, medication and living environments. Gut microbiota fulfils multiple indispensable physiological roles. First, metabolic nutrition: gut microbes decompose complex indigestible carbohydrates to produce short-chain fatty acids (SCFAs), namely acetate, propionate and butyrate. Butyrate acts as the primary energy source for colonocytes, reinforces intestinal-barrier integrity, suppresses inflammation and modulates gene expression via epigenetic mechanisms. Second, intestinal-barrier and immune functions: the gastrointestinal tract constitutes the largest human immune organ, harbouring approximately 70 % of immune cells within gut-associated lymphoid tissues. Gut microbiota co-develop with the immune system to maintain equilibrium between immune tolerance and host defence. Third, biosynthesis of neuroactive substances: gut microbes synthesise diverse neurotransmitters, including approximately 90 % of peripheral serotonin, γ-aminobutyric acid (GABA) and dopamine precursors. Although most gut-derived serotonin cannot cross the blood-brain barrier, it influences brain function via the enteric nervous system, vagus nerve and metabolic signalling cascades.

The gut-brain axis (GBA) represents a bidirectional communication network linking the gastrointestinal tract and central nervous system, integrating neural, endocrine, immune and metabolic pathways. Neural signalling constitutes the most direct communication route. The enteric nervous system embedded within the gut wall contains approximately 500 million neurons, independently regulating gut motility, secretion and perfusion, hence nicknamed the “second brain”. Studies using germ-free mice demonstrate reduced anxiety-like behaviours yet impaired spatial memory. Supplementation with specific probiotic strains alleviates anxiety- and depression-related phenotypes via vagal pathways; such beneficial effects vanish upon vagotomy, confirming the mediating role of the vagus nerve (Suganya & Koo, 2022) [19]. Endocrine signalling operates primarily through the hypothalamic-pituitary-adrenal (HPA) axis. Stress activates the HPA axis and elevates cortisol secretion, which alters intestinal permeability, mucosal immunity and microbiota composition. Conversely, gut microbiota modulates HPA-axis reactivity: germ-free mice exhibit exaggerated

HPA-axis responses, which can be normalised by specific probiotic interventions. Furthermore, gut hormones such as GLP-1 and PYY regulate appetite and glycaemia and exert central-nervous-system effects to modulate feeding behaviours and mood (Fried *et al*., 2021) [9]. Accumulating evidence links gut-brain-axis dysregulation to multiple neuropsychiatric disorders. Depressive patients commonly display reduced gut-microbiota diversity and elevated inflammatory biomarkers. Clinical trials of probiotic interventions report improvements in depressive symptoms, giving rise to the concept of "psychobiotics". Dysbiosis is also associated with neurodegenerative conditions including Alzheimer's and Parkinson's diseases. The gut-origin hypothesis for Parkinson's disease posits that Lewy-body pathology may initially emerge within the enteric nervous system and propagate upwards to the brain via the vagus nerve. Gut-microbiota composition correlates with memory and executive functions; reduced microbiota diversity in mid-life may predict late-life cognitive-decline risk

Gut dysbiosis refers to states characterised by reduced microbial diversity, depleted beneficial taxa and overgrowth of pathobionts, closely implicated in the onset and progression of multiple chronic diseases. In metabolic-syndrome and obesity research, early studies demonstrated that gut microbiota from obese mice extract energy more efficiently from food; faecal-microbiota transplantation from obese donors induces greater adiposity in germ-free recipients. In type 2 diabetes, gut dysbiosis not only disturbs energy metabolism but also contributes directly to insulin resistance. Diabetic patients exhibit depleted butyrate-producing taxa and increased pro-inflammatory Gram-negative bacteria. Regarding autoimmune diseases, gut microbiota is essential for establishing and sustaining immune tolerance. Germ-free animals are more susceptible to autoimmune disorders; specific bacterial strains promote regulatory T-cell (Treg) differentiation and restrain excessive immune activation. For cancers, gut microbiota influences not only colorectal carcinogenesis but also distal-tumour progression and therapeutic responses. Certain gut microbes metabolise dietary substrates into carcinogenic metabolites or trigger chronic inflammation to facilitate tumour advancement. Collectively, gut microbiota acts as a critical mediator connecting diet, lifestyle and health. Personalised gut-microbiota profiling and modulation — including precision probiotics, prebiotics, dietary adjustments and faecal-microbiota transplantation — represent promising directions for future precision nutrition and precision medicine.

Dietary Patterns, Functional Foods and Chronic-Disease Prevention

Plant-based diets centre on plant-sourced foods, encompassing flexible vegetarianism, lacto-ovo vegetarianism and veganism. Their core features include high intakes of whole grains, vegetables, fruits, legumes, nuts and seeds, accompanied by reduced or eliminated animal-product consumption. Substantial epidemiological studies and intervention trials have documented multiple chronic-disease-preventive benefits of plant-based diets. For cardiovascular-disease prevention, a meta-analysis synthesising 86 cross-sectional and 10 cohort studies reported 25 % lower incidence and mortality of ischaemic heart disease among vegetarians relative to omnivores, attributable to lower body-mass index, total cholesterol and low-density-lipoprotein-cholesterol concentrations (Dinu *et al*., 2017) [6]. Another meta-analysis covering nine cohorts and nearly 700 000 participants found that individuals with highest adherence to plant-based diets exhibited 16 % lower cardiovascular-disease risk and 12 % lower coronary-heart-disease risk. Health-oriented plant-based diets emphasising whole foods and limited refined carbohydrates confer more pronounced protective effects (Gan *et al*., 2021) [10]. For type-2-diabetes prevention, a large-scale meta-analysis of 67 studies involving over 3.8 million participants demonstrated 20 % reduced diabetes risk among subjects with high plant-based-diet adherence; protective associations became more robust for health-focused plant-based diets, displaying dose-response relationships between dietary-pattern improvement and risk reduction (Wang *et al*., 2021) [21]. High dietary-fibre contents in plant-based diets slow carbohydrate digestion, blunt postprandial glycaemic excursions, enhance insulin sensitivity, boost intestinal SCFA production and modulate gut-hormone secretion. For cancer prevention, the aforementioned meta-analysis reported 8 % lower overall cancer incidence among vegetarians and 15 % among vegans. Although statistical significance was not achieved for certain cancer subtypes, aggregate trends support protective effects of plant-based diets. Reports from the World Cancer Research Fund also highlight that increased consumption of whole grains, vegetables, fruits and legumes mitigates multiple cancer risks. In terms of inflammatory status, a meta-analysis of 29 intervention trials revealed that plant-based diets significantly lower inflammatory biomarkers including C-reactive protein (CRP) and interleukin-6 (IL-6), with average CRP reductions of 0.55 mg/L, indicating amelioration of obesity-related chronic low-grade inflammation (Eichelmann *et al*., 2016) [7]. Nevertheless, plant-based diets are not inherently healthy and vary substantially in quality. Unhealthy plant-based diets dominated by refined grains, sugary beverages and fried foods elevate metabolic-disease risk. Therefore contemporary research adopts the "Healthy Plant-Based Diet Index" to distinguish health-promoting versus detrimental plant-derived foods for improved disease-risk prediction. Vegans require special attention to adequate intakes of vitamin B12, vitamin D, calcium, iron, zinc, omega-3 fatty acids and iodine, with nutritional supplements recommended when necessary to avert nutrient deficiencies.

Beyond plant-based diets, the Mediterranean diet and the Dietary Approaches to Stop Hypertension (DASH) diet represent two evidence-supported healthy dietary patterns built upon plant-food foundations yet possessing distinct characteristics and target populations. The Mediterranean diet originates from traditional eating habits of Mediterranean-basin populations, characterised by abundant olive-oil intake as primary fat sources, plentiful vegetables, fruits, whole grains, legumes and nuts, moderate fish and dairy consumption, limited red and processed meats, and moderate wine intake with meals. The DASH diet was originally developed for blood-pressure reduction, advocating high potassium, magnesium, calcium and dietary-fibre intake alongside low sodium consumption. Practical recommendations encourage ample vegetables, fruits, low-fat dairy, whole grains, poultry, fish and nuts, while restricting sodium, saturated fat, sweets and sugary beverages.

Comparative studies show that despite disparate origins, Mediterranean, DASH and healthy plant-based diets share overlapping core components: whole-food emphasis, high plant-food proportions, minimal processing, low refined-sugar and low saturated-fat contents. Meta-analyses indicate that these healthy dietary patterns correlate with diminished oxidative stress and inflammatory markers, supporting shared pathological pathways underlying chronic-disease prevention (Aleksandrova *et al*., 2021) [1].

Broadly defined, functional foods deliver specific physiological benefits for health promotion or disease-risk reduction beyond basic nutritional value. This category encompasses fortified foods, natural foods containing bioactive components, probiotic- and prebiotic-containing foods, and plant-sterol-fortified products. "Health supplements" serves as a broader term referring to food-related products claiming health benefits. Functional foods fall into three product formats: first, conventional-food formats such as yoghurt, functional beverages and fortified cereals for incorporation into regular diets; second, supplement-type formulations including tablets, capsules and powders administered similarly to pharmaceuticals for precise dosage control; third, special-purpose nutritional foods formulated for specific populations or disease states, e.g. diabetic formulas and sports-nutrition supplements. Common functional-food claims cover gastrointestinal health, cardiovascular health, immune modulation, bone health, weight management, visual care, cognitive support and anti-fatigue effects. The global functional-food market continues expanding, driven by population ageing, rising health consciousness, growing chronic-disease prevalence, strengthened preventive-health concepts and technological innovation.

Health-supplement research-and-development constitutes interdisciplinary work integrating food science, nutrition, biochemistry, microbiology, clinical medicine and regulatory science. Standard development workflows comprise target-function and target-population definition, bioactive-ingredient screening and validation, formula design and manufacturing-process development, stability testing, safety evaluation, efficacy trials, regulatory submission and post-market surveillance. Bioactive ingredients are sourced from plant extracts, microbial fermentation, marine organisms, animal materials and chemical synthesis. Advanced separation-and-purification technologies such as supercritical-fluid extraction, membrane filtration and chromatography enhance ingredient purity and bioactivity. Supply-chain management is critical for supplement quality. Raw-material-sector challenges include heterogeneous sourcing, geographical variability, unstable bioactive-ingredient concentrations, potential pesticide-residue and heavy-metal contamination, and adulteration risks. Consequently, rigorous supplier screening, vendor auditing, establishment of raw-material specifications and traceability systems are indispensable. Quality-management systems include Quality Assurance (QA) and Quality Control (QC). QC covers raw-material, semi-finished-product and finished-product testing, assaying ingredient concentrations, microbial indicators, heavy metals, pesticide residues and dissolution profiles. QA establishes comprehensive documentation, standard-operating procedures, non-conformity-handling protocols and internal-audit frameworks. Internationally recognised quality certifications include ISO 22000 food-safety-management systems, Hazard Analysis and Critical Control Points (HACCP), and current Good Manufacturing Practices (cGMP). Driven by advances in genomics, metabolomics and microbiomics, health-supplement R&D is progressing towards personalised precision nutrition.

Regulatory governance for functional foods and health supplements safeguards consumer rights and facilitates sound industrial development. Regulatory systems in Taiwan and the United States reflect distinct supervisory philosophies and market environments. In Taiwan, health-food regulation is governed by the *Health Food Act*, administered by the Food and Drug Administration (TFDA), Ministry of Health and Welfare. Products must undergo scientific safety-and-efficacy verification and obtain official health-food permits from TFDA before labelling as "health food" and making authorised health-benefit claims. In the United States, dietary supplements are regulated by the Food and Drug Administration (FDA) under the Dietary Supplement Health and Education Act of 1994 (DSHEA). Adopting a post-market-surveillance framework, dietary supplements enter commerce without pre-market FDA approval. Manufacturers bear responsibility for product safety and truthful benefit claims. Manufacturers may use "structure-function claims" describing effects on bodily structures or functions, yet are prohibited from claiming treatment, prevention or cure of diseases, and must display mandatory disclaimers (Taylor, 2004) [20]. FDA conducts post-market safety monitoring and enforcement via adverse-event-reporting systems and market sampling. The US-FDA regulatory framework offers low market-entry barriers and substantial industrial-innovation flexibility but receives criticism for inconsistent product quality, insufficient evidence supporting efficacy claims and recurring safety incidents. Research documents wide quality variability among dietary supplements, with some products deviating from labelled ingredient contents or containing adulterated prescription-drug components that endanger consumers (Lewis & Strom, 2002) [11]. For industry stakeholders, regulatory compliance constitutes an operational foundation; dedicated regulatory-affairs teams must track regulatory updates to ensure full compliance across R&D and marketing workflows.

AI-Nutrition Technology and Personalised Dietary Management

AI applications in nutrition are expanding rapidly across nutritional-data analytics, dietary assessment, personalised recommendation and public-health surveillance, transforming nutritional-science research and nutrition-service delivery. Conventional nutritional-data analysis relies heavily on manual processing including food coding, nutrient calculation and dietary-pattern analysis, which is labour-intensive and constrained by practitioner expertise. AI improves processing efficiency and accuracy considerably. Machine-learning algorithms extract hidden patterns from large-scale dietary datasets. In nutritional epidemiology, traditional approaches mostly investigate isolated nutrient-disease or food-disease associations, whereas real-world diets represent complex combinations with nutrient-nutrient interactions. AI-dimensionality-reduction, clustering and deep-learning models effectively analyse high-dimensional dietary-pattern datasets to identify meaningful eating patterns and evaluate

their associations with health outcomes. For public-health nutrition surveillance, AI analyses social-media, search-engine and sales data to monitor population-level dietary trends and nutritional status in a timelier and cost-effective manner compared with conventional nutrition surveys. For nutritional diagnosis, AI integrates multi-dimensional information including blood biochemistry, body composition, dietary records and lifestyle factors to assess nutritional status and detect early nutritional imbalances with higher sensitivity and specificity than single-indicator-based conventional evaluation.

Image-based automated dietary-assessment technology leverages computer vision and deep learning to identify food items, estimate portion sizes and compute nutrient intakes directly from food photographs, lowering respondent burden and enhancing assessment accuracy and representing one of the most promising AI-nutrition innovations. Technical workflows for food-image recognition generally encompass four stages: food detection and localisation, food classification, portion-size estimation and nutritional calculation. Food detection locates food regions within images employing object-detection architectures such as YOLO and Faster R-CNN. Food classification identifies food species using convolutional-neural-network (CNN) and Vision-Transformer models. Portion-size estimation constitutes the most technically challenging step, utilising depth information, reference objects or three-dimensional reconstruction. Nutritional calculation multiplies estimated portion weights by nutrient-database values to yield total nutrient-intake estimates. Recent advances in Vision-Language Models (VLMs) such as GPT-4o and Gemini create new opportunities for dietary assessment. Combining visual comprehension and linguistic reasoning, VLMs recognise food items and additionally interpret cooking methods, ingredient compositions and contextual information. Evaluations across six VLMs report >90 % single-food-recognition accuracy for closed-source models, yet performance degrades for fine-grained classification and mixed-food scenarios (Romero-Tapiador *et al*., 2025) [18]. A custom-developed Taiwanese Diabot-GPT-4o system achieved 74 % food-item-recognition accuracy across 714 food images in validation datasets, outperforming vanilla GPT-4o (59 %). Energy and carbohydrate estimates deviated by 10 %-20 % relative to weighed-food-record references, demonstrating satisfactory concordance. Primary error sources include inaccurate portion estimation, food occlusion, suboptimal shooting angles, inadequate prompt engineering and model hallucinations, highlighting the necessity of standardised input protocols and expert supervision (Chen *et al*., 2025) [5]. Monocular three-dimensional-reconstruction techniques generate three-dimensional point-cloud representations from single images to estimate food volume and energy without physical reference objects, improving usability for mobile phones and smart glasses with limited computational resources.

Personalised nutritional recommendation constitutes a core precision-nutrition application. It aims to deliver dietary guidance tailored to individual physiological conditions, health goals, disease risks, genetic backgrounds, gut-microbiota profiles, food preferences, cultural customs and lifestyles, instead of universal one-size-fits-all guidelines. Personal-health-need modelling underpins recommendation systems by integrating multi-dimensional user data: demographic-physiological variables, biochemical-laboratory results, medical history and medication records, genetic profiles, gut-microbiota data, dietary preferences and restrictions, sleep-activity patterns and health objectives. These datasets construct individual health profiles for recommendation inputs. Nutrition-recommendation algorithms fall into four categories: rule-based, collaborative-filtering, content-based and hybrid-recommendation systems. Rule-based systems build explicit logical frameworks grounded in domain expertise and nutritional guidelines; they offer interpretability and professional compliance yet exhibit limited flexibility for complex inter-individual differences. Collaborative-filtering approaches identify dietary patterns of demographically similar users; they handle taste-preference modelling yet suffer from cold-start limitations and cannot guarantee nutritional adequacy. Content-based recommendations suggest foods matching user-defined requirements according to food-composition attributes. Machine-learning models learn preference patterns from historical records and predict acceptability of novel foods. Recent deep-learning and generative-model advances enable systems to generate complete daily or weekly menus satisfying multiple nutritional constraints (Papastratis *et al*., 2024) [17]. Reinforcement learning represents another important technical paradigm especially suited for dynamic personal-need adaptation and long-term behavioural modification. Reinforcement-learning models iteratively adjust recommendation strategies through user feedback to optimise long-term health outcomes and user satisfaction (Tragos *et al*., 2023) [21]. Applied to nutrition, reinforcement-learning systems dynamically revise dietary advice according to adherence, body-weight fluctuations and glycaemic responses.

Wearable-device proliferation introduces novel dimensions for dietary-behaviour monitoring. Whereas traditional dietary tracking merely records food ingestion, wearables continuously capture physiological responses to eating behaviours, enabling "intake-response" closed-loop feedback cycles. Wearables monitor heart rate, HRV, physical-activity volume, step counts, energy expenditure, sleep architecture, body temperature, blood oxygen saturation and stress indices, all of which correlate with dietary behaviours. For example, postprandial thermogenesis slightly elevates heart rate; high-calorie high-fat meals may reduce postprandial HRV reflecting autonomic dysregulation; sustained poor dietary patterns raise resting heart rate and diminish HRV as markers of deteriorating metabolic health. Large-scale wearable-device datasets provide unprecedented sample sizes to characterise age- and sex-stratified physiological trajectories. One study of 25 757 Oura-ring users mapped age-sex trajectories of sleep-related heart rate and HRV. Women displayed higher heart rates across the lifespan; HRV followed an asymmetric U-shaped curve. Sleep deprivation and low physical-activity levels correlated with higher heart rates and lower HRV in dose-response fashions. These normative datasets improve personal-assessment precision (Alikhani *et al*., 2025) [2]. Bidirectional sleep-diet interactions merit attention. Sleep-wake disturbances alter ghrelin-leptin homeostasis, increasing appetite and cravings for high-calorie foods and degrading dietary quality; conversely, suboptimal diets impair sleep quality. Wearables simultaneously monitor sleep and physical

activity; combined with dietary logs, they quantify three-way interactions and deliver holistic lifestyle advice. Research among older adults demonstrates positive correlations between physical-activity volume and sleep duration with threshold effects: health benefits plateau beyond certain activity thresholds, while excessive activity may yield adverse consequences, highlighting requirements for individualised exercise prescriptions (Cai *et al*., 2025) [4].

Built upon preceding technical foundations, this section outlines a complete service loop for personalised AI-dietary-analysis workflows spanning onboarding through long-term follow-up.

Stage 1: Personal-health profiling and baseline assessment

Upon initial registration, users complete questionnaires covering age, sex, height, weight, activity levels, medical history, medication use, dietary preferences and food allergies. Systems may integrate health-check-up or blood-biochemistry reports to construct comprehensive health profiles. Daily energy requirements, macronutrient-proportion targets and micronutrient recommendations are computed and adjusted according to health objectives. Baseline dietary-pattern questionnaires identify habitual eating behaviours and generate preliminary dietary-improvement suggestions.

Stage 2: AI-food-image recognition and dietary logging

Users upload food photographs captured by smartphones during meals. Systems perform food detection, classification, portion-size estimation and nutritional calculation. User-verification interfaces enable manual correction of misclassified entries, and corrected data feed back into model optimisation. Supplementary logging modalities including voice input, barcode scanning and frequent-meal quick-entry options enhance usability. Cumulated dietary records build individual food-intake databases.

Stage 3: Dietary-quality analysis and problem diagnosis

Systems generate dietary-analysis reports periodically (weekly or monthly). Analytical dimensions include alignment of caloric and macronutrient distributions with targets, achievement benchmarks for dietary fibre, sodium and added sugars, dietary-diversity scoring, meal-distribution balance and adherence to food-group recommendations. AI-diagnostic modules automatically flag dietary-pattern deficiencies and explain corresponding health impacts. Integrating wearable physiological data establishes associations between dietary exposures and physiological responses.

Stage 4: Personalised-nutrition-advice generation

Recommendation engines produce dietary-improvement outputs stratified into three tiers: general-principle guidance, concrete food-substitution suggestions and complete meal-plan recommendations. Recommendation generation balances nutritional validity, practical feasibility and user preferences to reconcile health objectives and quality of life. Each suggestion includes explanatory rationales and anticipated health benefits to enhance comprehension and adherence.

Stage 5: Adherence tracking and dynamic adjustmen

Continuous dietary logging enables systems to track indicator trends and evaluate intervention effectiveness. When body weight, body-fat percentage or biochemical-lab values change, nutritional-demand calculations are refreshed and recommendations updated. Behavioural-science-informed reminder systems, achievement incentives and progress feedback sustain user motivation. Over time, accumulating individual-specific data refine recommendation accuracy, establishing a positive "record-analyse-recommend-execute-feedback" loop.

This workflow automates and democratises professional nutritional assessment. Rather than replacing human dietitians, AI serves as an auxiliary tool handling standardised assessment and tracking workflows, freeing nutrition specialists for complex-case counselling and behavioural-change facilitation.

Exercise Physiology and Older-Adult Health Management

Exercise physiology investigates bodily responses and adaptations to physical-activity stimuli, forming theoretical underpinnings for exercise prescription and physical training. Cardiorespiratory fitness represents core physical capacity, denoting the capacity of the heart, lungs and vasculature to deliver oxygen to muscle mitochondria and for skeletal-muscle utilisation of oxygen for energy production. Cardiorespiratory fitness declines markedly with age. Maximal oxygen uptake (VO_2max) decreases by 5 %-15 % per decade after age 30; decline rates are heavily modulated by physical-activity status, with sedentary individuals experiencing steeper deterioration and regular exercisers exhibiting attenuated loss. Acute cardiovascular responses to exercise include elevated heart rate, increased stroke volume, higher cardiac output, blood redistribution and elevated blood pressure. Chronic adaptations induced by sustained aerobic exercise comprise reduced resting heart rate, enlarged left-ventricular volume, enhanced myocardial contractility, elevated stroke volume, increased capillary density, and greater mitochondrial density and enzymatic activity. These adaptations improve cardiorespiratory efficiency, lowering heart-rate and blood-lactate concentrations under equivalent exercise intensities and delaying fatigue onset. Scientific statements from the American Heart Association designate functional fitness as a core health metric for older adults. Cardiorespiratory fitness exhibits strong inverse correlations with all-cause mortality; individuals with low cardiorespiratory fitness possess several-fold higher mortality risk relative to high-fitness counterparts, predictive power exceeding traditional risk factors including smoking, hypertension and diabetes (Forman *et al*., 2017). Beyond cardiorespiratory capacity, muscular strength, balance and flexibility maintain activities-of-daily-living independence and constitute physical-fitness dimensions highly susceptible to age-related deterioration. Muscle mass begins gradual attrition around age 40, accelerates after age 50, declining by 1 %-2 % annually after age 60 and potentially diminishing by 40 %-50 % by age 80 — a phenomenon termed sarcopenia. Muscle loss not only diminishes physical strength but also correlates with reduced metabolic rate, insulin resistance, elevated fall risk and disability. Research indicates that reduced muscular strength quadruples fall risk and serves as

a powerful disability predictor among older adults. Resistance training represents the most effective intervention to augment muscle mass and strength. Even frail older adults demonstrate favourable physiological adaptations to resistance training. Eight-to-twelve-week resistance-training interventions increase muscle cross-sectional area, neural-drive efficiency, muscular strength and power by 20 %-40 %, alongside measurable improvements in gait speed and functional performance (Cadore *et al*., 2014) [3]. Balance capacity stabilises body centre-of-gravity within supporting surfaces, relying on integrated vestibular, visual, proprioceptive and muscular-reflex systems. Tai-chi constitutes one of the most well-documented balance-training modalities, reducing fall risk by approximately 30 %. Flexibility denotes joint range-of-motion modulated by muscle length, connective-tissue elasticity, joint architecture and neural tone. Functional fitness emphasises links between physical capacity and real-world daily performance rather than athletic achievements. American Heart Association guidelines recommend older-adult exercise regimens integrating aerobic, resistance, balance and flexibility components: at least 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity aerobic activity weekly; resistance training targeting major muscle groups two-to-three days weekly; balance training two-to-three days weekly; flexibility-stretching exercises minimum two days weekly. Multimodal combined training yields optimal functional-improvement outcomes and represents mainstream intervention approaches for older-adult populations.

Sleep mediates physiological repair and restoration and occupies pivotal roles in healthy ageing. Ageing alters sleep architecture: slight reductions in total sleep duration, substantial declines in slow-wave-sleep proportions, increased sleep fragmentation, greater difficulty initiating sleep, frequent early-morning awakening and elevated daytime-sleepiness prevalence. Sleep insufficiency and sleep disorders impose multi-faceted adverse-health consequences. Metabolically, sleep deprivation reduces insulin sensitivity, disrupts ghrelin-leptin signalling, amplifies appetite and high-calorie-food cravings, raising obesity and diabetes risk. Cardiovascularly, sleep loss and obstructive-sleep-apnoea elevate blood pressure, augment sympathetic-nervous-system activity and promote inflammation, increasing risks for hypertension, coronary-artery disease and heart failure. Cognitively, cerebrospinal-fluid clearance of β-amyloid during slow-wave sleep is impaired under sleep-deprivation conditions, potentially increasing long-term Alzheimer's-disease susceptibility.

Circadian rhythms are approximately 24-hour physiological cycles governed by the suprachiasmatic nucleus in the hypothalamus and synchronised by photic environmental cues. Circadian rhythms regulate sleep-wake cycles, body temperature, hormone secretion, metabolism, immunity and gene expression. Physical activity serves as a non-pharmacological strategy to enhance sleep quality and stabilise circadian rhythms. Nevertheless, exercise-sleep relationships are non-linear and subject to dose- and timing-dependent effects. Moderate physical activity facilitates sleep, whereas overtraining may induce sympathetic-nervous-system hyper-arousal and disturb sleep. Timing matters: late-evening vigorous exercise may delay sleep onset, while mild-intensity evening exercise exerts minimal interference. Older-adult studies document positive yet threshold-limited associations between physical-activity volume and sleep quality; excessive physical activity may produce adverse outcomes, reinforcing demands for personalised exercise prescriptions (Cai *et al*., 2025) [4]. Isotemporal-substitution-model analyses reveal that replacing 30 minutes of sedentary time with physical activity mitigates age-related functional-decline accumulation. Conversely, increased physical activity yields limited benefits under sleep-deprivation conditions, highlighting the necessity of balancing sleep, sedentary behaviour and physical-activity exposures rather than evaluating each factor in isolation (Ortolá *et al*., 2021) [15].

Global population ageing fuels expansion of older-adult-health markets. Distinct from conventional geriatric medical care, longevity management prioritises proactive prevention, ageing-process retardation and extension of healthy-life expectancy rather than merely prolonging chronological lifespan. Health check-ups constitute mature market entry points for longevity management. Conventional health screening focuses primarily on disease detection; modern longevity-oriented health assessments incorporate ageing-related functional biomarkers including body-composition analysis, cardiorespiratory-fitness testing, arterial-stiffness measurement, bone-mineral-density scanning, cognitive-function evaluation, genetic testing, metabolomics profiling and gut-microbiota analysis. These indicators enable early detection of functional deterioration and ageing signatures before clinical-disease onset, supporting timely interventions. Longevity clinics represent emerging service models integrating health screening, counselling and intervention under membership-based personalised longevity-management programmes structured across diagnostic, clinical-intervention and lifestyle-support tiers that combine medical expertise and everyday-life services (Mironov *et al*., 2024) [14]. Another older-adult-market trend centres on "ageing-in-place". Most older adults prefer ageing within familiar home environments, generating rising demand for home-based health monitoring, telehealth, domiciliary services and assistive-device technologies. Wearables and home-based sensors continuously monitor older adults' activity patterns, sleep metrics, physiological signals and safety conditions, triggering automatic alerts to family members or caregivers upon anomaly detection. AI-image analytics detect falls, abnormal behaviours and health-deterioration signals for early-warning purposes. Economic benefits of preventive healthcare receive increasing recognition. The "longevity dividend" concept posits that investment in healthy ageing improves older-adult quality of life and autonomy while reducing medical expenditures, prolonging productive working-life periods and fostering social participation to yield substantial socioeconomic returns. Taiwan has entered an ageing society and is projected to become a super-ageing society by 2025, creating vast older-adult-health-market potential. Market stakeholders include hospital-based health-check-up centres, commercial screening chains, senior-living communities, fitness facilities, nutrition-consulting services, digital-health start-ups, biotechnology enterprises and health-supplement manufacturers. Current markets remain fragmented, lacking integrated service platforms. Future

development directions emphasise cross-sector integration uniting medicine, exercise science, nutrition science, digital-technology and lifestyle services to deliver one-stop older-adult-health-management solutions.

Fitness-industry business models continuously evolve from traditional membership schemes toward diversified, digital-enabled and personalised formats. Conventional fitness-centre revenue models rely on monthly or annual membership subscriptions granting facility-and-equipment access alongside group classes and personal-training services. This model generates predictable stable revenue yet suffers from high churn rates, uneven facility utilisation and service homogenisation. Industry data report average annual membership churn rates of 30 %-50 %; many paying members rarely utilise facilities, representing major vulnerabilities for traditional business models.

Subscription-based business models have gained traction across health-service sectors beyond fitness. Subscription frameworks emphasise recurring billing, continuous service provision and long-term customer relationships. Compared with conventional membership systems, subscription-oriented operations prioritise iterative content updates and routine user interactions. Member-relationship management forms core competitive advantage within fitness industries. Key retention strategies include comprehensive onboarding workflows lowering entry barriers; progress-tracking and achievement-feedback mechanisms sustaining motivation; community-building and peer-support systems fostering sense of belonging; personalised services and empathetic engagement strengthening emotional connections; and continuously refreshed classes and activities maintaining novelty. Data-driven member management analyses usage frequency, class preferences, consumption patterns and physiological metrics to predict churn risks and deploy proactive retention interventions. Cross-brand collaboration constitutes vital growth strategy for fitness enterprises. Partnerships with athletic-apparel brands, nutrition-supplement suppliers, health-catering businesses, medical institutions, corporations, hospitality operators and technology firms expand customer bases, enrich service portfolios and elevate brand positioning. Personal-training services represent high-margin high-value offerings enhancing member satisfaction and retention. One-on-one coaching delivers customised training regimens, movement correction and motivational support superior to independent workouts. New modalities including small-group coaching and remote-online coaching lower price barriers and expand service reach. AI virtual-coaching systems represent technology-enabled innovations handling standardised training guidance and progress tracking, freeing human coaches for high-level counselling and complex-problem resolution. Market segmentation differentiates fitness providers into categories: large-scale low-cost clubs, boutique fitness studios, women-exclusive gyms, senior-friendly fitness centres and medically oriented rehabilitative-exercise facilities. Collectively, fitness industries are transitioning from “selling physical space” toward “selling services, outcomes and health”. Future-market winners will integrate professional expertise, digital-technology tools and community-building mechanisms to deliver quantifiable health benefits. Integration of AI and wearable-device ecosystems accelerate this shift toward personalised, efficient and outcome-driven service provision.

AI-Exercise Technology and Virtual-Fitness-Coach Systems

AI-posture-recognition represents a computer-vision sub-discipline detecting human-joint key-points from images or videos to reconstruct human-skeleton models and analyse movement kinematics. It underpins AI virtual-fitness-coach applications spanning fitness training, rehabilitation medicine, competitive sports and interactive entertainment. Standard exercise-movement-analysis workflows contain six sequential steps: image acquisition, posture detection, motion segmentation, movement-quality evaluation, error diagnosis and feedback generation. For rehabilitative-exercise assessment, Transformer-based deep-learning architectures deliver robust performance. The PhysioFormer model leverages skeleton-sequence self-attention mechanisms, outperforming traditional convolutional-neural-network benchmarks on standard datasets including KIMORE and UI-PRMD. Advanced error-classification models not only judge movement correctness but also identify specific error categories and quantify joint-level contributions, delivering concrete corrective guidance and overcoming limitations of simplistic binary pass-fail feedback (Marusic *et al*., 2025) [13]. Home-rehabilitation applications constitute important development directions. Conventional motion-capture rehabilitation requires costly depth-camera equipment and lacks scalability. RGB-camera-only skeleton-feedback systems incorporating three-dimensional-pose-estimation models enable correctness evaluation and fault-diagnosis for common rehabilitative exercises, validated against physiotherapist-annotated datasets, lowering accessibility barriers for remote rehabilitation. For general-fitness contexts, hybrid physical-model-driven frameworks combining MediaPipe posture-detection and peak-valley counting diagnose six upper-and-lower-limb exercises in real-time, issuing corrective alerts upon deviations from standard movement patterns. Low-latency on-device smartphone execution provides coaching-like real-time feedback for home-exercisers and mitigates sports-injury risks.

Wearable devices constitute primary sources of exercise-and-health data, embedding accelerometers, gyroscopes, heart-rate sensors, blood-oxygen sensors and thermometers to collect 24-hour physiological and activity signals. Raw sensor measurements are processed via AI algorithms into actionable health indicators and insights. Activity-level analysis represents foundational wearable-device functionality. Accelerometer data compute step counts, stratify activity intensities (sedentary, light, moderate, vigorous) and estimate activity-related energy expenditure. Advanced algorithms additionally classify activity types including walking, running, cycling and stair climbing. High-precision wearable-research datasets illuminate fine-grained ageing-related activity-pattern shifts. Comparisons of three-day continuous activity records between younger and older cohorts reveal not only reduced overall activity volume among older adults but also diminished movement frequency, fewer sleep-period body turns and smaller-amplitude nocturnal movements. These subtle signatures reflect neuromuscular ageing and serve as potential early-functional-decline biomarkers. Sleep analysis

forms another core wearable-device capability. Accelerometer and HRV-derived signals enable algorithmic differentiation of wakefulness, light sleep, deep sleep and REM-sleep stages, computing total-sleep duration, sleep efficiency, sleep-onset latency and awakening frequency. Large-scale wearable databases advance granular sleep-physiology understanding. A dataset of 25 757 users mapped age-sex trajectories of sleep-related heart rate and HRV: women's average heart rates were 7.5 bpm higher across the lifespan; HRV exhibited an asymmetric U-shaped curve reaching nadir during middle-age. Sleep deprivation and low physical-activity levels correlated with elevated heart rates and diminished HRV following dose-response patterns. These normative distributions support personalised assessments benchmarking individual metrics against age-sex-matched reference populations (Alikhani *et al*., 2025) [2]. Heart-rate variability constitutes a prominent contemporary health biomarker reflecting autonomic-nervous-system equilibrium. Higher HRV indicates robust parasympathetic-nervous-system activity and bodily-recovery capacity; reduced HRV signals stress, fatigue or systemic inflammation. Integrating activity, sleep and HRV data facilitates physical-recovery-status evaluation, enabling adjustment of daily-exercise intensity and overtraining prevention. AI models learn individual HRV baselines and response patterns to predict optimal training loads and deliver personalised-recovery recommendations. Explainable-machine-learning techniques further analyse activity-sleep associations. Gradient-boosting models combined with SHAP-value analysis among older-adult cohorts demonstrate non-linear positive relationships between physical-activity volume and sleep duration with threshold effects; approximately 15 000 MIMS represents critical cut-off values. Researchers recommend minimum 12 000 MIMS daily activity for older adults while cautioning against excessive-exercise hazards (Cai *et al*., 2025) [4]. Ultimately, wearable-data value resides not merely within raw measurements but within long-term tracking and intra-individual comparisons. Changes relative to personal baselines carry greater clinical significance than generic population-wide reference values and enable early anomaly detection. AI transforms massive wearable-sensor datasets into actionable health insights, forming indispensable infrastructure for personalised health management.

Personalised exercise prescription represents an ultimate objective of exercise science. Conventional exercise guidance provides generic recommendations such as "150 minutes of moderate-intensity aerobic exercise weekly", disregarding inter-individual variability in physical-fitness baselines, disease status, injury histories, preferences and goals. AI facilitates highly individualised exercise-plan generation. Personalised-exercise-recommendation systems incorporate age, sex, physical-fitness levels, medical-history and medication records, injury-related physical limitations, exercise preferences and accessibility constraints, available time allocations, health objectives and physiological-recovery status. AI systems synthesise these variables to optimise exercise regimens dynamically. Exercise-recommendation algorithms share conceptual similarities with nutrition-recommendation systems yet possess domain-specific characteristics. Contextual multi-armed-bandit and reinforcement-learning frameworks address cold-start challenges: models are initially trained on synthetic-user profiles derived from clinical guidelines and subsequently refined through real-world user feedback. Explanatory outputs enhance user acceptance. Home-fitness intervention studies demonstrate that reinforcement-learning-based recommendation frameworks outperform baseline algorithms in boosting user engagement and retention. Systems learn individual-user preferences and physiological responses to dynamically modulate exercise-sequence difficulty and content, balancing challenge and achievement to sustain long-term motivation (Tragos *et al*., 2023) [21]. Safety-risk management constitutes paramount priority for exercise recommendations targeting older adults and chronic-disease populations. Improper physical exertion may induce sports-related injuries, cardiovascular events or clinical deterioration, rendering safety paramount. AI-exercise-recommendation systems possess inherent limitations and cannot fully substitute clinical-professional judgement, especially for complex chronic-disease or rehabilitative cases. Research warns that AI-generated advice requires rigorous validation; erroneous rehabilitative-exercise suggestions may exacerbate injuries, underscoring irreplaceable value of clinical-and-exercise-specialist expertise. Optimal implementation adopts human-AI collaboration: AI handles standardised assessment, monitoring and baseline recommendations, while human professionals manage complex-case evaluation, problem-solving and high-level coaching.

Integrated-Business-Model for AI-Powered Personalised -Health Management

1. Nutritional-Demand and Health-Supplement-Recommendation Logic

Drawing upon foregoing personalised-nutrition-assessment frameworks and health-supplement domain knowledge, this paper establishes systematic nutritional-demand-and-health-supplement-recommendation logic serving as core decision-making frameworks for AI-nutrition services. Four hierarchical recommendation tiers are defined: baseline-nutritional-demand evaluation, dietary-gap diagnosis, supplement-indication matching and product-filtering recommendation.

Tier 1: Baseline-nutritional-demand calculation

Daily recommended intakes for macro- and micronutrients are computed according to user age, sex, height, weight, physical-activity levels and physiological states, referencing national dietary guidelines and adjusted for individual conditions. For instance, older-adult protein recommendations increase to 1.2-1.5 g per kilogram body weight; post-menopausal women receive elevated calcium and vitamin-D recommendations; physically-active populations require higher protein and B-complex-vitamin intakes.

Tier 2: Dietary-gap analysis

Actual nutrient-intake estimates derived from dietary logs or dietary-pattern questionnaires are compared against recommended intakes to identify nutrient-insufficiency profiles. Blood-biochemical-laboratory results enable objective nutritional-status verification. Cross-validation between dietary and biochemical data improves diagnostic accuracy. Beyond nutrient-intake shortfalls, functional-level

issues are analysed including dietary-fibre inadequacy, perturbed omega-3/omega-6 fatty-acid ratios and gut-microbiota dysbiosis.

Tier 3: Supplement-indication matching
Identified nutritional gaps and health conditions are matched against eligible functional ingredients and product categories. Matching principles include dietary-source priority: dietary-modification interventions precede supplementation for nutrient-deficiency scenarios; functional-claim alignment selecting evidence-based bioactive ingredients targeting specific health concerns; population-specific requirements for vulnerable subgroups such as older adults; disease-medication-interaction contraindications eliminating hazardous ingredients; and evidence-grade prioritisation favouring well-researched high-safety ingredients.

Tier 4: Product-filtering and recommendation
Within eligible-product categories, candidate offerings are screened according to efficacy-dosage thresholds, governmental health-food certifications, third-party-verification credentials, cGMP-manufacturing compliance, ingredient purity, dosage-form suitability, cost-effectiveness, brand credibility and user preferences, yielding 3-5 final recommendations.
Recommendations include detailed documentation of rationales, suggested dosages, optimal administration timing, precautions, potential adverse effects and expected outcomes. The core principle "dietary modification first, supplements as adjuvants" is consistently emphasised: dietary-improvement strategies are prioritised, with supplements treated as secondary adjunctive measures. This recommendation logic integrates expert-rule systems and machine-learning approaches, preserving professional grounding while supporting iterative optimisation through accumulating real-world data. AI models learn from user feedback and subsequent health-metric changes to validate real-world recommendation effectiveness and enhance predictive precision. Decision-making traceability is maintained for every recommendation to build user trust.

2. Business-Models for AI-Personalised-Nutrition Services

Based on foregoing technical architectures and recommendation frameworks, AI-personalised-nutrition services can deploy multiple business-models targeting diverse customer segments and market positioning.

Model 1: Business-to-Consumer (B2C) subscription-based mobile applications
End-users pay recurring subscription fees to access AI-driven dietary analysis, personalised-nutrition guidance and health-supplement recommendations. Revenue streams derive primarily from subscription fees supplemented by affiliate commissions on recommended products. Premium tiers add on-demand remote consultations with human dietitians.

Model 2: Business-to-Business-to-Consumer (B2B2C) value-added services for health-food brands
AI-nutrition-assessment systems are embedded within brand websites or member portals in collaboration with health-supplement manufacturers. Consumers purchasing products receive personalised-nutrition-assessment and recommendation services. This business-model enhances product-added value, strengthens customer loyalty and enables precision marketing and cross-selling. Brand clients pay system-licensing fees or usage-based charges.

Model 3: Business-to-Business (B2B) corporate-employee-wellness programmes
AI-nutrition services are deployed as employee-welfare benefits for corporate clients, delivering population-wide nutrition assessments, personalised dietary advice, health-education lectures and group-health-challenge activities. Enterprises pay per-employee annual licensing fees. This model improves employee health outcomes, reduces sick-leave rates, enhances workforce productivity and strengthens employer branding.

Model 4: B2B auxiliary-systems for clinical-nutrition outpatient clinics
AI-nutrition-assessment platforms are supplied to hospital-and-clinic nutrition departments to support dietitians. Systems automate dietary-record analysis, nutritional-computation workflows and report generation, freeing clinical-nutrition specialists for deep-dive counselling and behavioural-change facilitation. Companion patient-facing mobile applications extend home-based monitoring and health-education functionalities.

Model 5: B2B2C value-add-on services for health-check-up centres
AI-nutrition-analysis and personalised-dietary-recommendation modules are integrated into health-check-up reports. After completing physical examinations, clients receive actionable dietary guidance alongside abnormal-laboratory-result notifications. Health-check-up centres offer these services as premium add-ons or bundle them within high-end-screening packages. This model leverages high-health-awareness health-check-up customer bases, with laboratory-test data enhancing recommendation accuracy.
Across all business-models, core-value propositions centre on precision, convenience and personalisation. Critical success factors include AI-algorithm accuracy and user-experience quality, depth and credibility of nutritional-expertise underpinnings, data-privacy-and-cybersecurity safeguards, continuous-content updating and optimisation, and measurable real-world-health-outcome delivery.

3. Service Design for Healthy-Ageing and Exercise-Management Interventions

Services addressing older-adult healthy-ageing and exercise management require special design considerations balancing safety, professionalism, human-centred empathy and accessibility. Five core service principles are established: safety as overriding priority with gradual-intensity progression commencing from low-threshold exercise; functionality-orientation prioritising preservation of activities-of-daily-living performance over athletic-performance benchmarks; multi-modal integration combining aerobic, resistance, balance and flexibility training components; social-connection mechanisms embedding group-activity and social-interaction elements to mitigate loneliness and boost participation motivation; and

professional safeguards requiring instructors specialised in geriatric-exercise science with competence in chronic-disease-management and emergency-response protocols.

Six service-content modules are defined:

1. **Physical-fitness-assessment module:** periodic functional-fitness evaluations establishing individual baseline physical capacity and tracking long-term trajectories.

2. **Group-exercise curricula:** stratified-intensity group classes including senior-adapted fitness routines, chair-based yoga and tai-chi.

3. **Personalised-exercise-prescription services:** one-on-one or small-group coaching for older adults with special-condition requirements.

4. **AI-virtual-coach home-based programmes:** tablet-optimised AI-virtual-fitness-coach platforms housing senior-adapted exercise classes; family-member portals enable remote monitoring of older-adult exercise adherence.

5. **Health-education seminars:** regular lectures covering exercise-nutrition interactions, chronic-disease self-management, sleep hygiene and fall-prevention knowledge.

6. **Social-and-outdoor-recreational activities:** scheduled hiking excursions, seasonal events combining physical activity and social engagement to fulfil older-adult social-participation needs.

Seven-step service workflows: initial intake interviews investigating health conditions, exercise backgrounds and personal objectives; baseline functional-fitness testing; tailored curriculum-and-exercise-frequency recommendations; structured onboarding with heightened instructor attention during early sessions to familiarise participants with environments and movement patterns; tri-annual physical-fitness reassessment to review progress and adjust intervention plans; proactive outreach mechanisms for absent participants to identify barriers and deliver support; regular caregiver-family-member communication reporting participant engagement and health-status changes. Revenue-generation approaches include per-session fees, monthly-quarterly-annual membership passes, personal-training hourly rates, AI-home-programme subscription fees and health-seminar registration fees. Additional funding sources encompass government-community-health-programme grants, corporate sponsorships and philanthropic-foundation support to lower financial barriers and expand service reach. Successful older-adult-exercise-service performance depends less on luxurious hardware infrastructure and more on service empathy, professional competence and community cohesion. Older-adult populations rely heavily on interpersonal relationships; staff compassion and care outweigh equipment quality. Trust-building and fostering sense of community represent core operational imperatives for geriatric-focused services.

4. **Cross-Sector Integration and Health-Ecosystem Construction**

Future-health-management-industry competition will shift from isolated product-and-service rivalry toward ecosystem-level competition. Holistic personal-health-solution delivery requires cross-domain resource integration spanning nutrition, exercise, sleep, medical care and digital-technology sectors to satisfy comprehensive consumer-health demands. Seven core stakeholder categories constitute ecosystem participants:

1. **Technology platforms:** providing AI algorithms, data infrastructure, mobile applications and wearable-device hardware as foundational technical infrastructure.

2. **Professional-service providers:** dietitians, fitness coaches, physiotherapists, physicians and psychologists.

3. **Health-product enterprises:** health-supplement manufacturers, health-catering operators, sports-equipment and assistive-device suppliers.

4. **Medical-and-care-delivery institutions:** hospitals, clinics, health-check-up centres and long-term-care facilities.

5. **Insurance-and-financial-industry participants:** health-insurance, life-insurance and pension providers offering financial safeguards and incentive mechanisms.

6. **Corporations and employers:** key business-sector customers procuring employee-wellness solutions.

7. **Governmental-and-public-health agencies:** responsible for policy formulation, resource subsidies and public-health promotion.

Four layers of integration generate incremental value:

1. **Data integration:** aggregation of dietary, exercise, sleep, physiological and laboratory-test datasets within unified platforms to construct complete personal-health records. Inter-service data interoperability enables more accurate recommendations grounded in comprehensive individual-health-profiling.

2. **Service orchestration:** seamless cross-service user journeys with single-point onboarding across ecosystem offerings. For example, health-check-up outputs auto-generate exercise-and-nutrition recommendations; abnormal wearable-device physiological readings trigger medical-evaluation referrals.

3. **Incentive-mechanism design:** linkage with insurance-and-financial instruments to reward health-achievement milestones.

Key challenges and considerations:

1. **Data-privacy-and-cybersecurity:** highly sensitive health data necessitate strict personal-data-protection-regulation compliance, high-grade cybersecurity standards, transparent privacy policies and end-user data-ownership control to sustain public trust.

2. **Professional-quality-control mechanisms:** consistent quality benchmarks for ecosystem-hosted professional services and commercial-product offerings must prevent adverse market-selection dynamics.

3. **Cross-sector-collaboration obstacles:** divergent organisational cultures, regulatory regimes and operational logics across industries raise communication-and-coordination costs. Neutral platform-orchestrator roles are required to align stakeholder interests and establish mutually-beneficial business-models

Collectively, AI-powered personalised-health-management industries are undergoing rapid expansion driven by intertwined technological-innovation and business-model-innovation cycles. Over the coming decade, intensifying population ageing, rising public-health awareness and sustained technological advancement will transform personalised-health management from niche premium offerings into mainstream necessities, profoundly reshaping individual-lifestyle-health-practices and healthcare-system architectures.

Conclusions

This study systematically investigates two core pillars of physical-health management — nutritional-metabolic science and exercise physiology — and integrates AI-technology perspectives and industrial-sector insights to construct integrated personalised-health-management frameworks. Major findings are summarised below: First, for nutritional-metabolic science: gut microbiota functions as a critical mediator connecting diet and health. Through multi-modal gut-brain-axis signalling pathways encompassing neural, immune and metabolic routes, gut microbiota influences gastrointestinal homeostasis and exerts far-reaching impacts on metabolic disorders, immune competence, mood, cognition and neurodegenerative-disease risk. Evidence-supported healthy dietary patterns including plant-based and Mediterranean diets confer protection against cardiovascular disease, type 2 diabetes and cancer via anti-inflammatory, antioxidant and gut-microbiota-modulating mechanisms, forming cornerstones for chronic-disease prevention. Second, for functional-food industries: global-market expansion continues. Product development evolves from basic nutritional supplementation toward functional-specialisation and precision-oriented innovation. R&D pipelines incorporate biotechnology and AI to accelerate innovation; supply-chain-and-quality-management standards become increasingly rigorous. Regulatory frameworks contrast pre-market-approval governance (Taiwan TFDA) versus post-market-surveillance oversight (United States FDA), reflecting trade-offs between consumer-protection priorities and industrial-innovation flexibility. Third, for AI-nutrition-technology applications: image-recognition technologies achieve practical-use maturity; customised multimodal-model food-recognition accuracy surpasses 70 %, with acceptable nutrient-estimation error margins. Personalised-nutrition-recommendation algorithms incorporating generative-AI and reinforcement-learning capabilities generate menus satisfying multi-dimensional nutritional constraints while accommodating user preferences. Wearable-device physiological-sensor outputs furnish objective feedback on dietary-metabolic responses, enabling “intake-response” closed-loop monitoring cycles. Fourth, for exercise-physiology and older-adult-health research: ageing induces comprehensive deterioration of cardiorespiratory fitness, muscular strength, balance and flexibility, constituting major risk factors for disability and chronic disease. Regular physical-activity interventions effectively retard ageing-related functional decline; older-adult populations demonstrate favourable physiological adaptations to both aerobic and resistance training. Sleep and circadian-rhythm homeostasis represents pivotal healthy-ageing pillars exhibiting complex reciprocal interactions with exercise and metabolism. Older-adult-health-market growth proceeds, with longevity-management paradigms shifting from disease-screening-oriented workflows toward functional-assessment-driven proactive-prevention frameworks. Fifth, for AI-exercise-technology developments: posture-recognition capabilities advance rapidly from two-dimensional skeleton-detection to three-dimensional kinematic analysis, extending functionality from movement-quality scoring to specific-fault diagnosis. Transformer architectures deliver superior rehabilitative-exercise-evaluation performance, and few-shot-learning techniques enhance clinical practicality. Wearable-device-captured physical-activity-and-sleep-data provide objective long-term-monitoring metrics. AI-virtual-fitness-coaching systems integrate real-time feedback, adaptive-difficulty adjustment and motivational-engagement mechanisms to support home-based independent exercise. Safety-risk-management constitutes central consideration for AI-exercise-recommendation-system design, requiring complete protection workflows covering risk screening, intensity surveillance, movement-quality assessment and emergency-response protocols. Sixth, for business-model innovation: AI-personalised-nutrition services support diverse commercial-formats including B2C subscription-based applications, B2B2C brand-value-added services, corporate-employee-wellness solutions, clinical-auxiliary-systems and health-check-up-centre add-on offerings. Older-adult-exercise-service delivery prioritises safety, functionality-orientation and social-connectedness, with particular emphasis on human-centred empathy and professional competence. Long-term-industry trajectories point toward cross-sector-integrated health-ecosystem development, delivering one-stop-health-solutions via data interoperability, service-orchestration and incentive-mechanism deployment.

Derived from study findings, actionable recommendations are presented for different stakeholder groups. First, for consumers, Adopt prevention-first health philosophies and prioritise investments in diet, physical-activity and sleep-related lifestyle modifications as cost-effective health-preservation strategies. Adopt whole-food-oriented plant-based dietary patterns, maximise dietary diversity and minimise processed-food, refined-sugar and excessive-saturated-fat intakes. Integrate aerobic, resistance, balance and flexibility training components to meet public-health-exercise guidelines; older-adult populations should emphasise resistance-and-balance-training practice. Leverage digital-health tools to support self-management

without over-reliance on sensor-derived metrics. Treat health supplements as secondary adjunctive interventions behind dietary-pattern optimisation; select evidence-backed certified-products from reputable brands matching individual-specific requirements (Lu, 2026). Second, for industry stakeholders, Health-food enterprises should strengthen scientific-evidence foundations and quality-control systems, invest in clinical-research validating product efficacy and pursue precision-nutrition innovation combined with digital-service offerings to enhance product-value propositions. Fitness-industry operators should shift business emphasis from facility rental toward outcome-oriented service delivery, elevate coach-professional-competence standards, incorporate AI-technology-assisted workflows, develop subscription-based-member-management frameworks and target underserved-niche-markets including older adults and chronic-disease patients. Digital-health-start-ups must deepen domain-expertise collaborations with medical-and-health-professional teams to guarantee safety and validity of health-related outputs, prioritise user-retention metrics and real-world-health-outcome performance. Industrial actors should actively pursue cross-sector-collaborative opportunities to build shared-health-ecosystems and expand overall-market boundaries (OpenAI, 2026) [16]. Third, for policy-makers, Augment preventive-medicine resource allocation and explore health-insurance-coverage expansions for health-management services to facilitate paradigm shifts from treatment-centric toward prevention-oriented healthcare systems. Update health-food-and-digital-health-service-regulatory frameworks in step with technological progress, balancing consumer-safety safeguards and reasonable industrial-innovation-space. Promote community-based older-adult-health-programmes expanding access to community-exercise stations and nutrition-promotion services to mitigate urban-rural health disparities. Establish health-data-governance specifications enabling responsible health-data utilisation and cross-institutional-data-sharing under robust-privacy-protection constraints.

References

1. Aleksandrova K, Koelman L, Rodrigues CE. Dietary patterns and biomarkers of oxidative stress and inflammation: A systematic review of observational and intervention studies. Redox Biology,2021:42:101910. https://doi.org/10.1016/j.redox.2021.101910
2. Alikhani I, Karsikas M, de Zambotti M. Age & sex trajectories in heart rate & variability: Links to sleep & activity from large-scale wearable data. Sleep,2025:48(Suppl_1):A133. https://doi.org/10.1093/sleep/zsae076.0305
3. Cadore EL, Pinto RS, Bottaro M, Izquierdo M. Strength and endurance training prescription in healthy and frail elderly. Aging and Disease,2014:5(6):410–422. https://doi.org/10.14336/AD.2014.0500410
4. Cai X, Xian Y, Zhou Y, Liu T, Zhang X, Chen Q. Association between accelerometer-measured physical activity volume and sleep duration in older adults: A cross-sectional interpretable machine learning analysis. Frontiers in Public Health,2025:13:1635020. https://doi.org/10.3389/fpubh.2025.1635020
5. Chen YJ, Chang CC, Hoang YN, Lin AW, Lin WL, Lin CY, *et al*. Customized multimodal Diabot-GPT-4o enhances accuracy of image-based dietary assessments in dietetic trainees in Taiwan: Validation against weighed food records. The American Journal of Clinical Nutrition,2025:122(6):1836–1849. https://doi.org/10.1016/j.ajcnut.2025.06.017
6. Dinu M, Abbate R, Gensini GF, Casini A, Sofi F. Vegetarian, vegan diets and multiple health outcomes: A systematic review with meta-analysis of observational studies. Critical Reviews in Food Science and Nutrition,2017:57(17):3640–3649. https://doi.org/10.1080/10408398.2016.1138447
7. Eichelmann F, Schwingshackl L, Fedirko V, Aleksandrova K. Effect of plant-based diets on obesity-related inflammatory profiles: A systematic review and meta-analysis of intervention trials. Obesity Reviews,2016:17(11):1067–1079. https://doi.org/10.1111/obr.12435
8. Forman DE, Arena R, Boxer R, Dolansky MA, Eng JJ, Fleg JL, *et al*. Prioritizing functional capacity as a principal end point for therapies oriented to older adults with cardiovascular disease: A scientific statement for healthcare professionals from the American Heart Association. Circulation,2017:135(16):e894–e912. https://doi.org/10.1161/CIR.0000000000000484
9. Fried S, Wemelle E, Cani PD, Knauf C. Interactions between the microbiota and enteric nervous system during gut-brain disorders. Neuropharmacology,2021:198:108766. https://doi.org/10.1016/j.neuropharm.2021.108766
10. Gan ZH, Cheong HC, Tu YK, Kuo PH. Association between plant-based dietary patterns and risk of cardiovascular disease: A systematic review and meta-analysis of prospective cohort studies. Nutrients,2021:13(11):4072. https://doi.org/10.3390/nu13114072
11. Lewis JD, Strom BL. Balancing safety of dietary supplements with the free market. Annals of Internal Medicine,2002:136(7):546–548. https://doi.org/10.7326/0003-4819-136-7-200204020-00014
12. Lu L. The history of Western holistic health development. AkiNik Publications, 2026.
13. Marusic A, Nguyen SM, Tapus A. Skeleton-based transformer for classification of errors and better feedback in low back pain physical rehabilitation exercises. arXiv preprint arXiv:2504.13866, 2025. https://doi.org/10.48550/arXiv.2504.13866
14. Mironov S, Borysova O, Morgunov I, Zhou Z, Moskalev A. A framework for an effective healthy longevity clinic. Aging and Disease,2024:16(4):1971–1986. https://doi.org/10.14336/AD.2024.0328-1
15. Ortolá R, García-Esquinas E, Cabanillas-Sánchez V, Migueles JH, Martínez-Gómez D, Rodríguez-Artalejo F. Association of physical activity, sedentary behavior, and sleep with unhealthy aging: Consistent results for device-measured and self-reported behaviors using isotemporal substitution models. The Journals of Gerontology: Series A,2021:76(1):85–93. https://doi.org/10.1093/gerona/glaa177
16. OpenAI. ChatGPT (GPT 5.6) [Large language model], 2026. https://chatgpt.com/

17. Papastratis I, Konstantinidis D, Daras P, Dimitropoulos K. AI nutrition recommendation using a deep generative model and ChatGPT. Scientific Reports,2024:14(1):15621. https://doi.org/10.1038/s41598-024-65438-x
18. Romero-Tapiador S, Tolosana R, Lacruz-Pleguezuelos B, Marcos-Zambrano LJ, Bazán GX, Espinosa-Salinas I, *et al*. Are vision-language models ready for dietary assessment? Exploring the next frontier in AI-powered food image recognition. Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops, 2025, 1–10. https://doi.org/10.1109/CVPRW67362.2025.00047
19. Suganya K, Koo B. Gut–brain axis: Role of gut microbiota on neurological disorders and how probiotics/prebiotics beneficially modulate microbial and immune pathways to improve brain functions. International Journal of Molecular Sciences,2022:23(20):12093. https://doi.org/10.3390/ijms232012093
20. Taylor CL. Regulatory frameworks for functional foods and dietary supplements. Nutrition Reviews,2004:62(2):55–59. https://doi.org/10.1111/j.1753-4887.2004.tb00042.x
21. Tragos E, O'Reilly-Morgan D, Geraci J, Shi B, Smyth B, Doherty C, *et al*. Keeping people active and healthy at home using a reinforcement learning-based fitness recommendation framework. Proceedings of the Thirty-Second International Joint Conference on Artificial Intelligence (IJCAI-23), 2023, 6246–6254. https://doi.org/10.24963/ijcai.2023/692
22. Wang Y, Hu Y, Zhu L, Sun Q. Associations between plant-based dietary patterns and risks of type 2 diabetes, cardiovascular disease, cancer, and mortality - A systematic review and meta-analysis. Circulation,2021:144(Suppl_1):A13268. https://doi.org/10.1161/circ.144.suppl_1.13268