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Review

Neurodiversity-Informed Nutrition: Evaluating NutriSteppe-AI for Dietary Restriction and Metabolic Syndrome in Autism

Almaz Sharman

Professor, Academy of Preventive Medicine, Kazakhstan Academy of Nutrition, Almaty, Kazakhstan.
E-mail: Almaz@Sharman.pro

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Abstract

Individuals with autism spectrum disorder (ASD) experience a distinctive and clinically under-recognised form of dietary restriction that is driven not by preference but by the neurodevelopmental features of the condition — altered sensory gating, cognitive rigidity, and interoceptive dysfunction. The resulting narrowing of the food repertoire, frequently to fewer than twenty predominantly ultra-processed items, produces a pattern of hidden malnutrition that cascades over the lifespan into gut dysbiosis, chronic inflammation, metabolic syndrome, and elevated non-communicable disease risk. Standard nutrition counselling and mainstream digital health tools, designed around a neurotypical user model, are frequently inaccessible or actively harmful for this population, while the interdisciplinary specialist care that the evidence supports is structurally unavailable to most families, particularly in Central Asian and post-Soviet settings.

This narrative review synthesises current evidence on the neurodevelopmental origins of dietary restriction in ASD and its progression toward metabolic disease, and examines the design rationale and clinical architecture of NutriSteppe-AI, a neurodiversity-informed digital nutrition system.

Its separation of deterministic nutritional computation from language-model communication, its five sequential sensory-safety layers, its caregiver skill-building functions, and its culturally adapted Central Asian food database are described as mechanisms intended to deliver safe, continuous, and personalised dietary support without reliance on scarce specialist teams. A 12-week randomised controlled trial in Almaty is underway to evaluate clinical effectiveness.

Keywords: autism spectrum disorder, dietary restriction, food selectivity, hidden malnutrition, metabolic syndrome, neurodiversity, digital health, artificial intelligence, caregiver support, Central Asia.

1. Introduction

There is a nutritional emergency unfolding in plain sight inside the homes of families living with autism spectrum disorder (ASD), and it is almost entirely invisible to mainstream public health systems. It does not look like famine. Children are fed. Meals are served. Calories, in many cases, are adequate. Yet beneath this surface of apparent sufficiency lies a form of hidden malnutrition that is simultaneously driving a cascade of non-communicable diseases (NCDs), compounding the neurological challenges of ASD itself, and shortening life expectancy — all while receiving a fraction of the clinical and research attention it deserves.

The scale of the problem is not small. ASD affects approximately 1 in 36 children in high-income

countries, with prevalence estimates rising across Central Asia and the post-Soviet region as diagnostic capacity improves [1]. A conservative global figure places the number of individuals on the autism spectrum at over 75 million [2]. The majority of them — children and adults alike — face dietary restrictions not as a matter of preference or circumstance but as a direct and inescapable consequence of their neurology. They eat what their nervous system will permit, and often that permission covers fewer than 20 foods, most of them ultra-processed, nutritionally poor, and metabolically damaging [3,4].

The consequences compound over decades. A restricted dietary repertoire in childhood becomes metabolic syndrome in adulthood [5,6] Gut microbiome dysbiosis established in the first years of life becomes systemic inflammation by adolescence [7,8]. Micronutrient deficiencies that impair cognitive function and immune regulation in childhood translate into psychiatric comorbidities and cardiovascular risk in middle age [9,10]. And all of this happens in a population that already faces extraordinary barriers to healthcare access — a population for whom standard nutrition counselling is largely inaccessible, standard dietary advice is clinically inappropriate, and standard digital health tools are actively harmful.

This paper provides a comprehensive analysis of the mechanisms driving dietary restriction and nutritional failure in ASD, the pathways through which these failures cascade into NCDs and other serious health outcomes, and the design principles and clinical architecture of NutriSteppe-AI as a response — one built not merely to count nutrients, but to understand and accommodate the neurodevelopmental reality of autism at every level of its operation.

2. Materials and Methods

This work is a narrative review. Relevant literature was identified through searches of PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar, complemented by manual screening of the reference lists of key articles and of recent systematic reviews. Search terms combined concepts relating to autism spectrum disorder ("autism", "ASD", "autism spectrum disorder") with terms relating to nutrition and feeding ("food selectivity", "feeding problems", "dietary intake", "picky eating", "sensory processing", "interoception"), to nutritional and metabolic outcomes ("micronutrient deficiency", "malnutrition", "gut microbiota", "obesity", "metabolic syndrome", "non-communicable disease"), and to intervention approaches ("feeding therapy", "digital health", "artificial intelligence", "personalised nutrition"). Sources published in English and Russian were considered. Priority was given to peer-reviewed original research, systematic reviews, and meta-analyses, with clinical guidelines and authoritative reference sources included where appropriate.

As a narrative review intended to trace the evolution of the underlying concepts, strict chronological limits were not imposed: foundational and historically significant studies were retained where they remain conceptually relevant, while preference was given to more recent evidence wherever comparable current data were available. Of the sources ultimately cited, 19 were published within the preceding five years (since 2020) and 43 within the preceding ten years (since 2015); the remainder comprise established works that document the origins and development of the field. The final selection reflects the authors' judgement of relevance, methodological quality, and contribution to a coherent account of the topic rather than the application of predefined systematic-review inclusion criteria.

3. The Neurodevelopmental Roots of Dietary Restriction in ASD

3.1. Why ASD Food Refusal Is Not Picky Eating

The most persistent and damaging misconception about food restriction in autism is that it represents an extreme version of typical childhood picky eating — a preference-based behaviour that will resolve with time, firmness, or sufficient hunger. This misconception is not merely incorrect; it is clinically dangerous [3,11]. It delays intervention, generates guilt and shame in caregivers, and leads to therapeutic approaches (pressure, exposure without preparation, food refusal consequences) that actively worsen the child's relationship with food and intensify the anxiety cycle.

ASD-related food restriction differs from typical picky eating across every clinically relevant dimension. In typical picky eating, food avoidance is driven by preference and mood, the child has a repertoire of 20 to 30 or more foods, avoidance tends to resolve by age 5 or 6 as the child's dietary range naturally expands, and hunger reliably overrides refusal when the child is sufficiently hungry [12]. In ASD food restriction, avoidance is driven by neurological stress — a genuine physiological threat response mediated by altered sensory processing, cognitive rigidity, and interoceptive dysfunction. The repertoire is often below 20 foods and sometimes as narrow as 5 to 8 [3,4,13]. The

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restriction does not resolve with age without targeted intervention; in many cases it becomes more entrenched as the anxiety around food deepens [14]. And critically, hunger does not reliably override refusal — a child with severe ASD food restriction will remain hungry rather than eat a food that triggers sensory distress. This is not a failure of willpower or parenting. It is a neurological phenomenon [11].

3.2. Sensory Processing Differences: The Neurological Gating Failure

The brainstem and its ascending sensory relay systems perform a crucial function in typical neurodevelopment: they gate, filter, and modulate sensory input so that the cortex receives a manageable, appropriately weighted signal. In ASD, this sensory gating process is fundamentally altered [15,16]. The result is that sensory stimuli — including the sensory properties of food — arrive at conscious awareness with aberrant intensity, timing, and emotional valence [17].

For food, this means that a texture perceived by a neurotypical individual as unremarkable — the slight softness of a cooked vegetable, the mixed consistency of a stew, the sliminess of certain fruits — is experienced by a person with ASD as genuinely aversive, sometimes to the point of triggering a gag reflex or acute distress [11,15]. The brainstem's altered gating is not a psychological preference; it is a structural neurological difference that cannot be overridden by willpower, hunger, or parental encouragement [17,18].

Texture is the most commonly reported sensory barrier. Children with ASD frequently reject soft, mushy, slimy, or mixed-texture foods — the very texture profile that characterises most fruits, cooked vegetables, legumes, and many protein-rich foods [11,13]. Foods that pass the texture test tend to be uniformly crunchy (crisps, crackers, dry cereals) or uniformly smooth (certain purées, specific yogurts). Mixed textures — a food with both soft and chewy elements, or a dish where textures vary — are particularly aversive. The clinical consequence is that the foods most likely to survive the texture filter are overwhelmingly ultra-processed [9].

Colour functions as a powerful visual gating mechanism. Many children with ASD show strong preferences for foods within a narrow colour range — typically beige and white — and systematic refusal of foods in unfamiliar or complex colour bands, particularly green [13]. This preference is not aesthetic; it reflects the fact that visual processing in ASD is often characterised by heightened sensitivity to colour contrast and novelty, making unfamiliar food colours a potential trigger for the threat-detection system [19].

Smell operates through hyperosmia, an abnormally heightened sensitivity to olfactory stimuli that is reported in a substantial proportion of individuals with ASD [20,21]. Cooked vegetables, fish, eggs, spiced foods, and many fermented products produce olfactory signatures that, for a hypersensitive nose, are overwhelming at distances that neurotypical individuals would not even detect [22,23]. Hyperosmia thus removes from the acceptable food set not only specific foods but entire food categories based on cooking method and preparation.

Temperature represents a further filtering layer. Many children with ASD will only accept foods within a very narrow temperature range — often room temperature, sometimes only specific temperatures associated with particular familiar foods [13,24].

Brand and packaging constitute perhaps the most underappreciated dimension of ASD food selectivity. A child who has been eating a specific brand of crackers may refuse the identical product when it appears in new packaging — the visual cues of the familiar package have become part of the food's identity, and their absence triggers the threat response [25,26]. This is not defiance; it is an expression of the same neurological inflexibility that governs all aspects of ASD food restriction.

3.3. Cognitive Rigidity and Executive Function: Routine as Neurological Necessity

The restricted and repetitive behavioural patterns that characterise ASD are not confined to motor behaviours and special interests; they extend fully into the domain of food and mealtimes [25,27]. The same prefrontal cortex and basal ganglia circuits that support cognitive flexibility — the ability to shift attention, update expectations, tolerate uncertainty, and adapt to change — show structural and functional differences in ASD that make behavioural flexibility genuinely difficult at a neurological level [25].

In the context of eating, cognitive rigidity manifests as an intense need for sameness and predictability. The same food must be served on the same plate, with the same utensils, at the same time, in the same arrangement [13,26]. Foods must not touch each other on the plate. The sequence of eating may be fixed and non-negotiable. Any deviation — a different fork, a slightly different arrangement, the wrong bowl — can be sufficient to trigger refusal and distress that is entirely disproportionate to the magnitude of the change as perceived by a neurotypical observer [12].

This is not stubbornness. The prefrontal cortex-based flexibility required to process and accommodate unexpected change draws on executive function resources that are structurally compromised in ASD [27]. When change occurs unexpectedly, the default

response is not adaptation but threat activation. The amygdala — the brain's threat-detection centre — registers the unexpected change as a potential danger, triggering a stress response that makes eating impossible [17,28]. The behavioural cascade that follows — refusal, crying, screaming, leaving the table, meltdown — is not manipulation; it is the visible expression of a genuine physiological stress response.

The mealtime anxiety cycle that this creates is self-reinforcing in ways that are particularly resistant to standard behavioural intervention [29,30]. Without external support and evidence-based techniques, this cycle is essentially self-perpetuating [31].

3.4. Interoceptive Anomalies: When the Body Cannot Signal Itself

Interoception — the brain's capacity to perceive and process signals from the body's internal state — is a fundamental biological function that most people take entirely for granted [32,33]. In ASD, interoceptive processing is significantly altered. Neuroimaging studies consistently demonstrate reduced functional connectivity of the insula and anterior cingulate cortex — two key nodes of the interoceptive network — in individuals with ASD compared to neurotypical controls [34,35]. The practical consequences of this for eating behaviour are profound and appear in two opposite directions simultaneously.

The under-eating pattern emerges when hunger signals fail to reach conscious awareness with normal intensity and timing. An individual with severely impaired interoception may go four, five, or six hours without eating without experiencing subjective hunger — not because they are not in a state of caloric deficit but because the internal signal that should register as hunger never achieves conscious salience [32,33].

The over-eating pattern emerges when satiety signals fail to register appropriately. When the vagal afferent signal of gastric fullness and the hormonal signal of satiety are not processed normally by the insula and hypothalamus, the individual continues eating past the point of fullness without awareness [33,36]. When this pattern is combined with a dietary repertoire dominated by ultra-processed, calorie-dense, low-fibre foods, the result is rapid and sustained weight gain [5,37].

Both patterns — under-eating and over-eating — can coexist in the same individual at different times or in different contexts, making nutritional management extraordinarily complex [32].

4. The Nutritional Consequences — From Restricted Repertoire to Hidden Malnutrition

4.1. The Structural Exclusion of Entire Nutrient Groups

When the sensory filtering, cognitive rigidity, and mealtime anxiety described above interact over months and years, the result is a dietary repertoire that is not merely narrow but structurally skewed in ways that create severe and predictable micronutrient deficiencies [4,9,38]. The foods that survive the sensory and cognitive filters — crisps, crackers, white bread, biscuits, chips, certain processed meats, a very small number of specific branded products — share a common nutritional profile: they are high in refined carbohydrates, saturated fat, and sodium, and extremely low in fibre, vitamins, minerals, and phytonutrients [10,39].

The foods that are systematically excluded by ASD dietary barriers — vegetables (colour + texture + smell barriers), fruits (texture + temperature barriers), legumes (texture + smell barriers), fish (smell + texture barriers), eggs (smell + texture barriers), most whole grains (texture barriers) — represent the primary dietary sources of the micronutrients most critical to child development, neurological function, and metabolic health [9,11,40].

4.2. Critical Micronutrient Deficiencies and Their Consequences

Fibre deficiency is perhaps the most prevalent and clinically consequential nutritional problem in ASD, affecting the majority of children on the spectrum [41]. The consequences operate through multiple pathways. Chronic constipation — already one of the most common medical comorbidities in ASD, affecting 50 to 85% of the population compared to approximately 10% of neurotypical children — is significantly worsened by low fibre intake [42-46]. The gut microbiome, which requires dietary fibre to maintain its diversity and function, is profoundly disrupted in a low-fibre state [7,8,47]. This dysbiosis — an imbalance in the composition and function of gut microbiota — has been demonstrated to influence the gut-brain axis in ways that worsen the behavioural and neurological features of ASD itself [48,49].

Iron deficiency affects 30 to 52% of children with ASD, compared to 8 to 12% of the general paediatric population — a prevalence three to six times higher [7,50]. The primary mechanism is dietary: the foods highest in bioavailable haem iron (red meat, poultry, fish) are frequently rejected on sensory grounds, while plant-based iron sources (legumes, dark leafy vegetables) are also largely excluded [10,40]. Iron deficiency in children produces fatigue, impaired cognitive function, attention deficits, and immune suppression — all of which directly worsen the core

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symptoms of ASD and significantly impair educational function [51].

Calcium deficiency affects more than 70% of children with severely restricted diets. The primary calcium sources — dairy products — are accepted by some children with ASD but rejected by many on the grounds of texture, smell, or food rigidity [12,52]. The consequences include compromise of bone mineral density during the critical growth years, with increased fracture risk — a risk compounded by the low vitamin D levels and reduced physical activity that also characterise this population [51,52].

Vitamin D deficiency is classified as a critical concern, with deficiency rates of 40 to 65% in the ASD population and the highest rates among those with the most severely restricted dietary repertoires [53,54]. The dietary sources of vitamin D are narrow even in a healthy diet (fatty fish, egg yolks, fortified foods), and most of these sources are precisely the ones most commonly excluded by ASD dietary barriers. The consequences of vitamin D deficiency in ASD extend beyond bone health: vitamin D plays significant roles in immune regulation, inflammatory signalling, and neurological development [54]. Deficiency is associated with amplification of psychiatric comorbidities including anxiety and depression — both of which are already highly prevalent in ASD — and with impairment of insulin sensitivity, adding to the metabolic disease burden [53,55].

Zinc deficiency affects 35 to 48% of children with ASD [56,57]. Zinc's role in taste perception makes its deficiency particularly self-reinforcing: zinc deficiency impairs the ability to taste, which makes food less sensory-distinct and less engaging, which can worsen food refusal and dietary restriction, further depleting zinc. Beyond taste, zinc is required for immune function, wound healing, and growth — all of which are compromised in a zinc-deficient state [56].

Omega-3 fatty acid deficiency is severely prevalent in children with ASD who avoid fish and nuts — the primary dietary sources — with more than 60% of those with restricted repertoires showing critically low levels [58-60]. Omega-3 fatty acids, particularly DHA and EPA, are essential for neurological function, inflammatory regulation, and emotional regulation. Their deficiency is associated with neuro-inflammation, cognitive decline, worsened emotional dysregulation, and heightened severity of ASD core symptoms [61,62]. This creates another bidirectional self-reinforcing loop: ASD drives avoidance of omega-3 sources; omega-3 deficiency worsens the neurological and behavioural features of ASD; worsened ASD deepens dietary restriction [58,62].

4.3. The ASD → NCD Cascade: A Longitudinal Perspective

The cumulative effect of chronic dietary restriction in ASD is not simply current malnutrition but a trajectory of accelerating non-communicable disease risk that unfolds across the lifespan [5,6,37]. The cascade begins with the restricted food repertoire of fewer than 20 foods, structurally dominated by ultra-processed products. This drives reduced dietary diversity and fibre intake, which leads to gut microbiome dysbiosis [7,8]. Dysbiosis drives increased intestinal permeability (the "leaky gut" phenomenon) and activation of the mucosal immune system, generating systemic low-grade inflammation characterised by elevated circulating concentrations of pro-inflammatory cytokines including interleukin-6, tumour necrosis factor alpha, and C-reactive protein [48,63].

Chronic systemic inflammation impairs insulin signalling at the cellular level, driving insulin resistance. Insulin resistance, combined with the high glycaemic load of an ultra-processed diet and the physical inactivity that characterises much of the ASD population, drives progressive weight gain and adipose tissue accumulation — particularly visceral adipose tissue, which is metabolically active and itself a source of inflammatory cytokines, further deepening the inflammatory cycle [6,64]. The result is a phenotype of obesity and metabolic syndrome that emerges in adolescence or early adulthood and progresses with accelerating momentum thereafter [5,37].

The endpoint of this cascade is a substantially elevated risk of cardiovascular disease, type 2 diabetes, hypertension, and dyslipidaemia — risks estimated at three to five times the general population rate for type 2 diabetes, with corresponding elevations in cardiovascular mortality risk [6,63]. Life expectancy projections for individuals with ASD and comorbid metabolic syndrome are substantially reduced compared to both the neurotypical population and individuals with ASD without metabolic complications [63].

4.4. Gastrointestinal Comorbidity: The Compounding Burden

Gastrointestinal distress is among the most prevalent and impactful medical comorbidities in ASD, affecting an estimated 50 to 85% of the population compared to approximately 10% of neurotypical children [42-44]. Constipation is the most common presentation, but the GI burden extends to include chronic abdominal pain, bloating, reflux, diarrhoea, and functional gut dysmotility [46,65].

The clinical management of GI comorbidity in ASD faces a unique and largely under-recognised

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challenge: communication. The sensory processing differences and communication impairments that characterise ASD mean that GI symptoms are frequently not reported, not described accurately, or expressed only through behavioural change — increased irritability, self-injurious behaviour, worsened food refusal, aggression — that may not be recognised by caregivers or clinicians as signs of somatic distress [46,65].

This diagnostic obscuring creates a clinical trap: GI distress worsens behavioural presentations; worsened behavioural presentations lead to medication adjustments and diagnostic reattribution; the underlying GI pathology remains unaddressed; the child continues to suffer. And the dietary implications are direct: GI discomfort associated with specific foods drives further narrowing of the already restricted repertoire [40,65].

5. The Caregiver Crisis — Why Families Cannot Bridge This Gap Alone

5.1. The Knowledge-Practice Gap

It is tempting — and wrong — to assume that better nutrition information would solve the ASD dietary problem. Most caregivers of children with ASD are well-informed about the importance of dietary quality [26,66]. The problem is not information; it is implementation. There is a profound and underappreciated gap between knowing what a healthy diet consists of and knowing how to introduce even a single new food to a child who will refuse it with genuine and intense distress [67,68].

The step from "broccoli is nutritious and my child should eat it" to "my child is able to tolerate broccoli without a meltdown" is not a knowledge gap; it is a skill gap requiring specialised training in neurodiversity-informed feeding therapy, applied behaviour analysis, sensory integration principles, and graduated exposure protocols [29-31]. These skills are not available from standard nutrition information sources, not modelled in standard parenting resources, and not routinely taught to caregivers even by specialist teams [69].

5.2. The Capacity Gap

Managing ASD is, for most families, a full-time occupation embedded within the demands of a full-time life [26]. In this context, the additional cognitive and physical load required to research, plan, prepare, and introduce varied foods to a child who will likely refuse them is often simply not available. This is not a failure of parental commitment or knowledge. It is a rational response to resource scarcity.

5.3. The Access Gap: Structural Inaccessibility in the Post-Soviet Context

Effective evidence-based nutrition management for ASD requires a coordinated interdisciplinary team: a paediatrician with understanding of ASD nutritional needs, a dietitian specifically trained in neurodiversity-sensitive practice and feeding therapy, and a behavioural therapist qualified in applied behaviour analysis with a feeding specialisation [52,69]. This team is rare in high-income English-speaking countries; it is essentially absent in Central Asian, post-Soviet, and most low- and middle-income contexts.

In Kazakhstan, for a population of 20 million, there are fewer than 30 registered dietitians with any meaningful ASD training. Waiting lists for multidisciplinary ASD teams stretch from 12 to 24 months. Costs are prohibitive for the majority of families. Geographic barriers exclude most families outside of Almaty and Astana entirely. The model of care that evidence supports — sustained, intensive, interdisciplinary, and family-centred — is structurally inaccessible to the vast majority of families who need it [52,70].

6. NutriSteppe-AI — A System Designed for the Neurological Reality of Autism

6.1. Design Philosophy: Why Standard Digital Health Fails This Population

The proliferation of digital health applications in nutrition and wellness has not benefited individuals with ASD and their families proportionally. Most existing platforms — even those of clinical quality — are designed around a neurotypical user model that assumes the following: the user has access to a wide range of acceptable foods; the user can reliably perceive and report their hunger and satiety; the user is comfortable with variable and gamified interfaces featuring notifications, streaks, social comparisons, and surprise rewards [32,33]. Every one of these assumptions is wrong for a significant proportion of users with ASD. Standard digital health tools are not merely unhelpful for ASD users; they are often actively harmful [15,17].

6.2. The Three-Layer Architecture: Deterministic Safety Under LLM Orchestration

The clinical safety of NutriSteppe-AI is grounded in a fundamental architectural principle that distinguishes it from most AI-powered health applications: the separation of computation from communication. In most LLM-based health applications, the language model both interprets user input and generates nutritional recommendations, performing nutrient calculations and optimisation as part of the same generative process. This architecture

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creates an irreducible risk of hallucination — confident, fluent, plausible-sounding but factually incorrect outputs — that is clinically unacceptable in a population where dietary miscalculation can have serious consequences.

Layer 1 — The Food Database is the foundation of the system's nutritional intelligence. It contains 27,000 food items and dishes, each tagged against BLS, NHS, and USDA nutritional standards across 135 nutrients per item [71]. The database includes 7,000 dishes formatted specifically for menu generation, enabling the system to operate at the level of real meals rather than abstract nutrient targets. Every item also carries Health Food Index (HFI) scores and NOVA ultra-processing classification, enabling quality-weighted recommendation alongside raw nutritional content.

Layer 2 — The Deterministic Algorithm performs all nutritional computation using mathematically defined, reproducible, and auditable methods. Energy requirements are calculated using the Harris-Benedict equation to determine total energy expenditure [71]. A linear programming (LP) optimiser then solves simultaneously for maximisation of multiple nutritional targets within a constrained solution space. Crucially, the sensory constraint layer — the user's exclusion list — is enforced before the LP optimiser is run, not after.

Layer 3 — LLM Orchestration handles all natural language interpretation and user-facing communication. The LLM receives the user's or caregiver's input, interprets their intent, calls the deterministic API to obtain nutritionally optimised, sensory-safe menu recommendations, and communicates these recommendations in appropriate language. In ASD mode, this communication follows strict protocols: literal language only, no idioms or metaphors, no figurative phrasing, no emotional urgency or pressure [72].

6.3. The Five Sensitivity Layers: Protection by Architecture

Beyond the three-layer computational architecture, NutriSteppe-AI implements five sequential protection layers that every recommendation must pass through before reaching the individual or caregiver.

Layer 1 — Sensory Profile Enforcement is classified as critical. At onboarding, caregivers map the child's sensory profile across texture, colour, smell, and temperature dimensions, constructing an exclusion list that is stored as hard constraints in the system [11,19]. This exclusion list is enforced architecturally — the LP engine and menu generator never see an excluded food. The rule is absolute: no menu recommendation can contain any food in the exclusion list under any circumstances.

Layer 2 — Routine and Predictability is also classified as critical. The system maintains fixed meal schedules with minimal week-to-week variation. Menus are repeated consistently for two to three weeks before any change is introduced. New foods are introduced at a maximum rate of one item per week, always with 48 hours of advance notice to the caregiver and visual pre-introduction to the individual before the food appears on a plate [29,30]. This design reflects the fundamental insight that predictability is not a preference for people with ASD — it is a neurological requirement [25].

Layer 3 — Nutritional Safety Guarantee is classified as high priority. The LP engine's protein floor and micronutrient tracking ensure that the menu recommendations generated within the sensory-safe food set achieve minimum safe nutritional standards [24,71]. When nutritional threshold breaches persist for more than three days, clinician-level flagging is automatic.

Layer 4 — Communication Adaptation is classified as critical. The LLM's ASD mode prompt prohibits all figurative language, metaphor, idiom, and ambiguous phrasing throughout all user-facing output [72]. Emotional user inputs are met with validation and calm redirection — never with urgency, never with performance pressure, never with any implication that the user or caregiver is failing.

Layer 5 — Caregiver Integration is classified as high priority. A parallel caregiver dashboard provides structured daily guidance, progress visualisation across multiple nutritional and behavioural dimensions, and alert management. Threshold alerts for nutritional risk are generated within 24 hours of detection [52,68].

6.4. Caregiver Skill Training: The Home as the Primary Therapeutic Environment

Micro-Step Goal Personalisation acknowledges that the distance from "does not tolerate broccoli" to "eats broccoli regularly" is not covered in a single step, or a week, or typically even a month [29,31]. The system allows caregivers to set hyper-specific, individually calibrated micro-goals. The typical timeline for advancing through all steps with a new food is four to eight weeks [30,31,73].

Stimulus Fading and Systematic Desensitisation protocols guide caregivers in the gradual modification of food properties across sensory dimensions in a way that never crosses the threshold that triggers the stress response [29,31]. The system tracks mixing ratios and sends caregiver reminders according to the fading schedule.

Visual Schedules and Predictive Preparation use digital social stories and mealtime countdowns to systematically remove unpredictability from the mealtime experience. The system provides advance information about what the meal will contain with sufficient lead time for the child to prepare cognitively for the experience [73].

The NutriToken Economy applies the behavioural science of positive reinforcement through a token system specifically redesigned for ASD. Standard gamification reward systems use variable ratio reinforcement schedules — the slot-machine model where the timing and size of rewards is unpredictable. For individuals with ASD, this is the most anxiety-generating paradigm precisely because of unpredictability [18,25]. NutriSteppe-AI replaces variable ratio reinforcement with fixed, fully predictable, pre-announced reinforcement. The child is told in advance exactly what behaviour will earn exactly what reward at exactly what time.

6.5. Gamification Redesigned for Sensory Safety

Standard gamification mechanics — developed for neurotypical users who respond well to novelty, surprise, social comparison, and variable reward schedules — are not merely neutral for ASD users; they are often actively counterproductive [15,18]. Social comparison features — leaderboards, peer rankings, community challenges — are eliminated entirely in ASD mode. These features generate anxiety and distress in individuals with ASD for whom social performance pressure is experienced as threat rather than challenge [55].

The Body Balance System replaces the weight-centric metrics that dominate most nutrition and wellness applications with a multidimensional functional health representation: Energy, Hydration, Recovery, Concentration, Stress, and Food Balance. This design decision is particularly important for a population with high rates of weight stigma sensitivity and for whom weight-focused feedback can trigger anxiety, shame, and avoidance [5,56].

6.6. The Agentic AI Model: 24/7 Support Without Waiting Lists

NutriSteppe-AI operates as an agentic AI system — an autonomous agent that continuously perceives the user's health data, reasons over it to produce optimal dietary recommendations, acts by generating personalised menus and guidance, and learns from feedback to refine future recommendations. This agentic architecture is particularly well-matched to the needs of the ASD population for two reasons.

First, ASD nutritional management is not episodic; it is continuous. The dietary challenges of ASD do not resolve between appointments and do not wait for the next scheduled dietitian consultation [69]. Second, the pace of food acceptance in ASD is too slow for episodic management. If the realistic timeline for a child to accept a new food is four to eight weeks of graduated, daily micro-step work, then a monthly dietitian appointment captures only one data point in a process that requires weekly monitoring and adjustment [29,30].

7. The Central Asian Context — Cultural Specificity as Clinical Necessity

7.1. Why Cultural Adaptation Is Not Optional

Dietary management platforms that are designed for Western food environments and then localised through translation fail to serve Central Asian populations for reasons that go beyond language. The food database must contain the actual foods that families eat — not approximations of those foods or Western analogues. The cultural context of food — its role in family ritual, social obligation, religious practice, and ethnic identity — must be understood and accommodated rather than overridden by generic healthy eating guidance [74].

7.2. The Central Asian Food Database and NutriSteppe-AI

NutriSteppe-AI's food database has been built with explicit attention to Central Asian and Western food culture, incorporating the regional food diversity that is entirely absent from Western-centred nutritional databases. Its integration into NutriSteppe-AI's food database ensures that recommendations are drawn from foods that are actually available, culturally familiar, and economically accessible in the Kazakhstani context [9,74].

For ASD management specifically, this cultural depth is clinically necessary. A child with ASD in Almaty who accepts only a small set of familiar Kazakhstani foods cannot be served by a recommendation system that offers quinoa bowls and avocado toast as nutritional solutions. Cultural specificity is not a localisation feature; it is a clinical requirement [70,74].

8. Discussion: Towards a New Standard of Care

The dietary crisis in autism spectrum disorder is a clinical emergency that has been largely invisible to mainstream healthcare systems precisely because it does not present as starvation or obvious acute illness.

It presents instead as a quiet, progressive, nutritionally mediated deterioration in metabolic health that unfolds over decades, driven not by neglect or ignorance but by the neurological reality of a condition that makes standard dietary advice inapplicable and standard healthcare access structurally impossible for the majority of affected families [4,6,69].

NutriSteppe-AI represents a comprehensive clinical response to this emergency — one that acknowledges the neurodevelopmental roots of dietary restriction, addresses the sensory, cognitive, interoceptive, and communication dimensions of ASD that make standard nutritional tools harmful rather than helpful, builds caregiver capacity as the primary therapeutic lever in the home environment, and delivers continuous, personalised, culturally appropriate support without requiring the interdisciplinary specialist team that is structurally inaccessible to most families [52,69,74].

Its deterministic architecture guarantees clinical safety in an AI domain where hallucination risk is real and clinically unacceptable. Its five sensitivity layers constitute a protective architecture that places sensory safety above all other considerations. Its caregiver training functions address the knowledge-practice gap that prevents even highly motivated families from translating nutritional knowledge into accepted foods [29,67,68].

The 12-week RCT underway in Almaty will generate the clinical evidence needed to move NutriSteppe-AI from innovation to standard of care. But the scale of the problem and the quality of the solution argue for urgency. Seventy-five million people with ASD worldwide are facing a nutritional emergency that is silently driving a non-communicable disease epidemic within an already vulnerable population. They are not picky eaters. They are not failing to try hard enough. Their nervous systems are operating under constraints that standard nutrition systems were never designed to accommodate [1,2,4,6].

9. Conclusions

Dietary restriction in autism spectrum disorder is a neurodevelopmental phenomenon with lifelong nutritional and metabolic consequences, yet it remains poorly served by conventional nutrition care and by digital health tools built for neurotypical users. The evidence reviewed here indicates that meaningful improvement depends less on the transfer of nutritional information than on tools that accommodate the sensory, cognitive, interoceptive, and communication realities of autism, that build the capacity of caregivers as the primary agents of change in the home, and that remain continuously available in settings where specialist teams are scarce.

NutriSteppe-AI has been designed around these principles, combining a deterministic and auditable computational core with adaptive, neurodiversity-informed communication, layered sensory-safety safeguards, and a culturally grounded food database appropriate to the Kazakhstani and wider Central Asian context. Whether this design translates into measurable clinical benefit remains to be demonstrated, and the outcome of the ongoing randomised controlled trial in Almaty will be decisive. Nevertheless, the approach illustrates how nutrition technology can be reconceived to serve a neurologically distinct and historically underserved population, and it offers a template for equitable, scalable dietary support that merits further development and independent evaluation.

Conflicts of Interest. The authors declare that they have no conflict of interest.

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AI Declaration. Claude Opus 4.8 was used solely to edit the completed manuscript.

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Нейроәртүрлілікке негізделген тамақтану: Аутизм кезіндегі тағамдық шектеулер мен зат алмасу синдромын емдеудегі NutriSteppe-AI жүйесін бағалау

Шарман А.Т.

Профессор, Профилактикалық медицина академиясы; Қазақстан тамақтану академиясы, Алматы, Қазақстан.
E-mail: Almaz@Sharman.pro

https://doi.org/10.53498/rw6jqz83

Түйіндеме

Аутизм спектрі бұзылыстары (АСБ) бар адамдар тамақтанудың ерекше әрі клиникалық тұрғыдан жеткілікті бағаланбайтын шектеулерімен бетпе-бет келеді. Аталған шектеулер қалау-таңдаумен емес, жағдайдың нейродамулық ерекшеліктерімен — сенсорлық сүзгілеудің бұзылуымен, когнитивті ригидтілікпен және интероцепция дисфункциясымен байланысты. Тамақ рационының тарылуы, жиі жиырмадан аз, көбіне ультраөңделген өнімдерге дейін, өмір бойы ішек дисбиозына, созылмалы қабынуға, метаболикалық синдромға және жұқпалы емес аурулар қаупінің артуына сатылап әкелетін жасырын тамақтану жеткіліксіздігінің көрінісін қалыптастырады. Нейротиптік пайдаланушыға бағдарланған стандартты диеталық кеңес беру мен кең таралған цифрлық денсаулық құралдары бұл топ үшін көбіне қолжетімсіз немесе тікелей зиянды болып келеді. Ол дәлелдемелі медицина ұсынатын пәнаралық мамандандырылған көмек отбасылардың басым бөлігіне, әсіресе Орталық Азия мен посткеңестік елдерінде, құрылымдық тұрғыдан қолжетімсіз.

Бұл нарративтік шолуда АСБ кезіндегі тамақтану шектеулерінің нейродамулық бастаулары және олардың метаболикалық ауруларға қарай үдеуі туралы заманауи деректер жинақталып, нейроәртүрлілікті ескеретін NutriSteppe-AI цифрлық тамақтану жүйесінің тұжырымдамалық негіздері мен клиникалық архитектурасы қарастырылады.

Анықтаушы тамақтану есептеулері мен тілге негізделген қарым-қатынасты бөлу, сенсорлық қауіпсіздіктің бес тізбекті деңгейі, күтушілерге арналған дағдыларды дамыту қызметтері және мәдени бейімделген Орталық Азия тағамдарының дерекқоры шектеулі мамандандырылған топтарға сүйенбей қауіпсіз, үздіксіз және жекелендірілген тамақтануды қолдауды қамтамасыз ету механизмдері ретінде сипатталады. Клиникалық тиімділікті бағалау үшін Алматыда 12 апталық рандомизацияланған бақыланатын сынақ жүргізілуде.

Түйін сөздер: аутизм спектрі бұзылыстары, тамақтану шектеулері, тағам таңдаудағы талғампаздық, жасырын тамақтану жеткіліксіздігі, метаболикалық синдром, нейроәртүрлілік, цифрлық денсаулық сақтау, жасанды интеллект, күтім жасаушыларды қолдау, Орталық Азия.

Нутрициология с учетом нейроразнообразия: Оценка системы NutriSteppe-AI в управлении диетическими ограничениями и метаболическим синдромом при аутизме

Шарман А.Т.

Профессор, Академия профилактической медицины; Казахстанская академия питания, Алматы, Казахстан.
E-mail: Almaz@Sharman.pro

Резюме

Лица с расстройством аутистического спектра (РАС) сталкиваются с особой и клинически недооцениваемой формой пищевых ограничений, обусловленной не предпочтениями, а нейроонтогенетическими особенностями состояния — нарушением сенсорной фильтрации, когнитивной ригидностью и дисфункцией интероцепции. Возникающее сужение пищевого рациона, нередко до менее чем двадцати преимущественно ультрапереработанных продуктов, формирует картину скрытой недостаточности питания, которая на протяжении жизни каскадно приводит к дисбиозу кишечника, хроническому воспалению, метаболическому синдрому и повышенному риску неинфекционных заболеваний. Стандартное диетологическое консультирование и распространенные цифровые инструменты для здоровья, ориентированные на нейротипичного пользователя, для этой группы зачастую недоступны или прямо вредны, а рекомендуемая доказательной медициной междисциплинарная специализированная помощь структурно недоступна большинству семей, особенно в странах Центральной Азии и постсоветского пространства.

В настоящем нарративном обзоре обобщаются современные данные о нейроонтогенетических истоках пищевых ограничений при РАС и их прогрессировании в сторону метаболических заболеваний, а также рассматриваются концептуальные основы и клиническая архитектура системы NutriSteppe-AI — цифровой системы питания, учитывающей нейроразнообразие.

Описываются разделение детерминированных нутрициологических расчетов и коммуникации на основе языковой модели, пять последовательных уровней сенсорной безопасности, функции формирования навыков у лиц, осуществляющих уход, и культурно адаптированная база данных продуктов Центральной Азии как механизмы обеспечения безопасной, непрерывной и персонализированной нутритивной

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поддержки без опоры на дефицитные команды специалистов. Для оценки клинической эффективности в Алматы проводится 12-недельное рандомизированное контролируемое исследование.

Ключевые слова: расстройство аутистического спектра, пищевые ограничения, избирательность в еде, скрытая недостаточность питания, метаболический синдром, нейроразнообразие, цифровое здравоохранение, искусственный интеллект; поддержка лиц, осуществляющих уход; Центральная Азия.

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