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From Rations to Reactions: A Narrative Review of Precision Nutrigenomics in Emergency, Disaster, and Critical Care Medicine

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Abstract

Background: Traditional nutritional support in emergency and disaster medicine operates on a one-size-fits-all paradigm, often delayed until the hospital phase of care. This approach fails to address the profound metabolic heterogeneity of critically ill or traumatized individuals, potentially compromising recovery.
Aim: This narrative review aims to synthesize current evidence and propose an integrated framework for implementing precision nutrigenomics across the continuum of crisis care, from pre-hospital settings through to rehabilitation.
Methods: A systematic search of PubMed, Scopus, Web of Science, and CINAHL was conducted for literature published between 2010 and 2024.
Results: The review identifies a viable pathway for personalized nutrition in crisis response, reliant on: 1) Point-of-Injury Metabolic Phenotyping via portable lab devices; 2) Genetically-Informed Formulary Development for enteral/parenteral nutrition; 3) Informatics-Enabled Dietary Data Integration into emergency protocols; and 4) Logistical Frameworks for delivering precision diets in austere or high-security environments. Key barriers include the validation of field-deployable biomarkers, cost, data interoperability, and the need for cross-disciplinary training.
Conclusion: Precision nutrigenomics represents a transformative frontier in crisis medicine, with the potential to modulate immune response, reduce complications, and improve survival. Its realization requires dismantling silos between emergency responders, laboratory scientists, dietitians, and hospital logisticians to create a seamless, data-driven nutritional care pathway that begins at the moment of crisis intervention.
Keywords: Precision Nutrition; Nutrigenomics; Critical Care Nutrition; Disaster Medicine; Point-of-Care Testing.

Introduction

The physiological insult of major trauma, severe sepsis, or extensive burns triggers a hypermetabolic and catabolic state that can rapidly deplete nutritional reserves, impair immune function, and jeopardize recovery (Casaer & Van den Berghe, 2014). In disaster scenarios, where populations may be already nutritionally vulnerable, this metabolic crisis is compounded by food insecurity and infrastructure collapse (Wischmeyer et al., 2023). Historically, nutritional intervention in these settings has been reactive, standardized, and delayed—often initiated days into an intensive care unit (ICU) stay with formulaic enteral or parenteral feeds (Taylor et al., 2016). This "late and generic" model ignores a fundamental tenet of modern medicine: individual variation. Patients differ drastically in their baseline nutritional status, metabolic capacity, inflammatory response, and genetic predispositions affecting nutrient metabolism and drug-nutrient interactions (Ferguson et al., 2016).

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The emerging field of precision nutrigenomics—the study of how genetic makeup influences individual response to nutrients and dietary patterns—offers a revolutionary lens through which to view this challenge (Mathers, 2017). Concurrent advances in point-of-care (POC) laboratory technology and health informatics create the practical means to operationalize this knowledge at speed and scale. We now possess the scientific and technical capacity to move nutrition from a supportive ancillary service to a central, personalized therapeutic strategy initiated at the earliest point of care. This paradigm shift necessitates a fundamental re-engineering of the crisis care continuum, integrating disparate professional domains that rarely interact: the paramedic in the field, the laboratory scientist processing rapid biomarkers, the clinical dietitian interpreting genetic data, the informatician building decision-support tools, and the administrators and coordinators who ensure the system functions logistically and securely (Kassem et al., 2023). Figure 1 illustrates the four-phase continuum of Precision Nutrigenomics in Crisis Care (PNCC), demonstrating how personalized nutrition can be initiated at the point of injury and sustained through emergency care, critical illness, and rehabilitation.

This narrative review synthesizes evidence from critical care nutrition, disaster medicine, nutrigenomics, and healthcare systems engineering to construct a novel framework for Precision Nutrigenomics in Crisis Care (PNCC). It argues that the future of optimal patient outcomes in emergency and disaster medicine hinges on our ability to identify individual metabolic vulnerabilities and intervene nutritionally in the "golden hour" and beyond, creating a seamless, data-driven nutritional pathway from point-of-injury to full recovery.

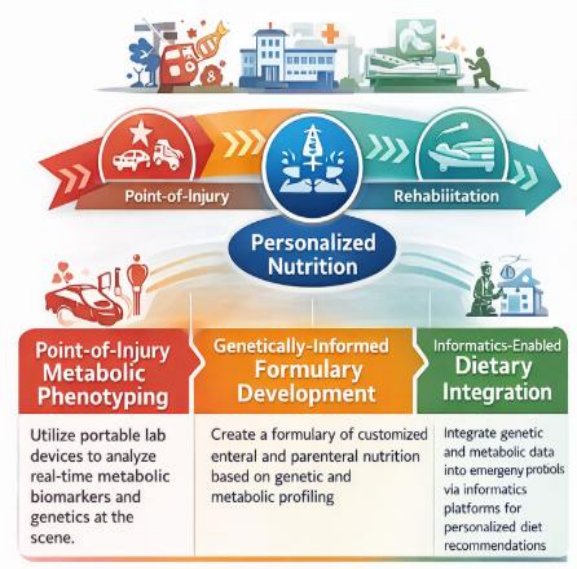

Figure 1. Precision Nutrigenomics in Crisis Care: A Continuum from Point-of-Injury to Rehabilitation

Why Personalization is Non-Negotiable in Metabolic Stress

The rationale for implementing personalized nutrition in crisis care is fundamentally rooted in the complex interplay between genetics, acute pathophysiology, and nutrient metabolism. The traditional paradigm of homogeneous nutritional support is critically undermined by robust evidence of profound heterogeneity in patient metabolic needs and responses. A one-size-fits-all strategy not only fails to leverage therapeutic opportunity but may actively contribute to adverse outcomes by mismatching intervention with individual biology. This scientific imperative is driven by distinct yet interconnected domains: immutable genetic determinants, a dynamic metabolic phenotype, and the documented consequences of generic feeding protocols.

Genetic Determinants of Nutrient Response

Individual genetic polymorphisms exert a powerful influence on nutrient requirements, utilization, and tolerance, particularly under the metabolic stress of critical illness or trauma. Key examples illustrate this deterministic variability. Firstly, common polymorphisms in the methylenetetrahydrofolate reductase (MTHFR) gene, such as C677T, impair the conversion of dietary folate to its bioactive form, 5-methyltetrahydrofolate (5-MTHF) (Molloy, 2011). As folate is essential for DNA synthesis, repair, and immune cell proliferation, patients harboring these variants may have a substantially higher requirement for pre-formed 5-MTHF during the reparative phase following major injury. Secondly, the apolipoprotein E (APOE) ε4 allele is associated with dysregulated lipid metabolism and a pronounced pro-inflammatory response (Dragasevic et al., 2022).

In critical illness, carriers of this allele demonstrate poorer clinical outcomes and may require a modified approach to lipid-based parenteral nutrition, potentially favoring formulations with anti-inflammatory lipid profiles (Anderson et al., 2023). Thirdly, pharmacogenomic interactions introduce a critical layer of complexity. Genetic variations in cytochrome P450 enzymes (e.g., CYP2D6, CYP2C19) and drug transporters significantly alter the metabolism and efficacy of essential medications, including sedatives, analgesics, and antibiotics (Pirmohamed, 2011). The plasma levels and effects of these drugs can be further modulated by specific nutrients, creating a high-risk interface where standard feeding may inadvertently lead to subtherapeutic dosing or toxic accumulation (Olivecrona et al., 2010).

The Dynamic Metabolic Phenotype of Critical Illness

Beyond static genetics, the acute metabolic phenotype is in a state of constant, rapid flux, demanding real-time biochemical assessment. The failure to monitor and address this dynamism is a

cardinal shortcoming of generic protocols (Vankrunkelsven et al., 2021). For instance, plasma glutamine levels, a conditionally essential amino acid that serves as a primary fuel for immune cells and enterocytes, can plummet within hours of major trauma or sepsis. This depletion is strongly and independently associated with an increased risk of infections and mortality, highlighting the need for targeted repletion based on measured deficiency rather than presumptive dosing (Cruzat et al., 2018). Similarly, oxidative stress markers and the status of key micronutrients are highly variable. Vitamin C, a potent antioxidant, is rapidly consumed during systemic inflammatory response syndrome, while vitamin D deficiency can impair innate immunity and correlate with sepsis severity. Trace elements like selenium and zinc, cofactors for crucial antioxidant enzymes, are also commonly depleted and guide targeted micronutrient therapy (Jin et al., 2017). Relying on standardized, fixed-dose micronutrient additives in parenteral nutrition ignores these individual biochemical realities, potentially failing to correct specific deficiencies that directly impede recovery.

The Consequences of Generic Feeding

Standardized, one-size-fits-all feeding protocols carry significant and documented risks, representing a missed therapeutic opportunity. Overfeeding, particularly with high glucose loads, can exacerbate stress-induced hyperglycemia and insulin resistance, increasing the risk of infectious complications and organ dysfunction. Conversely, underfeeding perpetuates the catabolic breakdown of lean body mass, delaying weaning from mechanical ventilation and functional recovery (Taylor et al., 2016). Furthermore, inappropriate macronutrient ratios may not align with a patient's specific inflammatory or metabolic phase. This lack of precision likely contributes to the inconsistent and often modest clinical benefits observed in large, randomized nutrition trials, where inter-individual variability in response dilutes the effect of a uniform intervention (Heyland et al., 2015). The Precision Nutrigenomics in Crisis Care (PNCC) model posits that by integrating an understanding of the individual's genetic backdrop with real-time metabolic phenotyping, nutritional therapy can be precisely tailored to modulate inflammatory cascades, support specific organ function, and enhance recovery trajectories in a predictable manner (Moisey et al., 2022).

Point-of-Care and Laboratory Diagnostics – The Metabolic Compass

The PNCC framework is activated by timely and actionable diagnostic data, positioning the medical laboratory's role as the essential "metabolic compass." This requires an evolution from a centralized service to an integrated system encompassing both rapid point-of-care (POC) technologies in the field and advanced, rapid-turnaround assays in the core lab, all feeding a unified informatics platform. Figure 2 depicts the integrated, data-driven workflow underpinning Precision Nutrigenomics in Crisis Care.

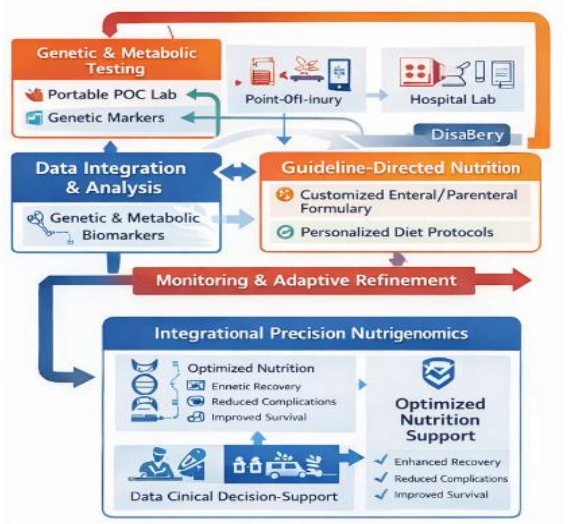

Figure 2. Integrated Precision Nutrigenomics Workflow for Emergency, Disaster, and Critical Care Response

The Role of Paramedics and Portable Labs

The first operational step involves equipping emergency response teams with tools for initial metabolic assessment at the point of injury or during transport. Modern POC devices already enable the measurement of capillary blood glucose, lactate, and ketones within seconds—biomarkers directly relevant to immediate energy substrate needs and anaerobic metabolism (Paula et al., 2023). The next frontier involves the validation and deployment of more sophisticated portable technologies, such as microfluidic chips or compact mass spectrometers, capable of quantifying a broader panel of critical biomarkers from a drop of blood or saliva. This panel could include pre-albumin (a short-half-life marker of protein synthesis and nutritional status), C-reactive protein (CRP) as a quantitative measure of systemic inflammation, and key electrolytes, providing a metabolic snapshot within the "golden hour" (Chen et al., 2016).

Paramedic-Initiated Protocols

With appropriate training and decision-support algorithms, paramedics could utilize these POC data streams to guide immediate interventions (Khorram-Manesh et al., 2023). For example, trending lactate and glucose levels could inform the selection of specific intravenous fluid compositions or trigger protocol-driven, early micronutrient infusions in scenarios of prolonged field care or disaster triage where definitive hospital care is delayed (Kotwal et al., 2017). A metabolic signature of high lactate with low ketones might signal a specific derangement in energy metabolism, prompting early corrective action that begins the process of metabolic stabilization en route to the

hospital. This shifts the paradigm from merely sustaining life during transport to initiating targeted, physiology-guided therapy at the earliest possible moment (Ciaraglia et al., 2022).

Central Laboratory Genomics and Specialized Assays

While POC provides immediate data, the central medical laboratory delivers deeper precision. Rapid turnaround genomic panels for relevant nutrigenomic variants (MTHFR, APOE, vitamin D receptor polymorphisms) could be run alongside standard trauma panels (Horn et al., 2021). Furthermore, sophisticated nutritional profiling—measuring specific amino acid levels, oxidative stress markers (isoprostanes), and comprehensive micronutrient status—becomes a priority test, not an afterthought (Alipanah-Lechner et al., 2023). The laboratory must develop validated rapid assays and establish reference ranges for critically ill populations, which differ significantly from healthy individuals.

From Data to Decision Support

Raw data is useless without interpretation. Health informatics creates the essential bridge. POC devices and central lab systems must feed results into a unified data platform. Clinical decision support (CDS) algorithms, integrated into the electronic health record (EHR) and accessible via mobile devices to field teams, can synthesize this data: "Patient with high CRP, low glutamine, APOE ε4 genotype. Glutamine-enriched, anti-inflammatory lipid formula; consider additional antioxidant micronutrient cocktail" (Wong et al., 2022). This transforms complex multi-omic data into an actionable nutritional prescription (Table 1).

Table 1: Diagnostic Pillars of Precision Nutrigenomics in Crisis Care (PNCC)

Care Phase	Key Actors	Diagnostic Goal	Example Technologies/Biomarkers	Informatics/Logistics Need
Point-of-Injury / Field Triage	Paramedic, Emergency Medical Technician	Rapid metabolic phenotyping to guide immediate stabilization & inform receiving facility.	POC devices for: Lactate, Glucose, Ketones, Hemoglobin. Future: handheld spectrometers for CRP, pre-albumin.	Mobile EHR interface with CDS alerts; secure data transmission to hospital "nutritional trauma alert."
Emergency Department & ICU Admission	Medical Laboratory, Intensivist, Clinical Dietitian	Comprehensive nutrigenomic & metabolic profiling to personalize initial 24-48 hr nutrition plan.	Rapid genomic panels (MTHFR, APOE, CYP variants). Mass spectrometry for amino acid profile, oxidative stress markers, micronutrients (Vit C, D, Zn, Se).	Automated integration of lab data into nutrition-specific CDS; generation of a preliminary "Nutrigenomic Action Plan."
ICU Stabilization & Recovery	Clinical Dietitian, Medical Laboratory, Pharmacist	Dynamic monitoring of nutritional efficacy and adjustment based on metabolic evolution.	Serial measurements of pre-albumin, CRP, nitrogen balance, fatty acid profiles. Therapeutic drug monitoring to guide drug-nutrient interactions.	Predictive analytics on nutritional response; integration of data from wearable sensors (muscle mass, glucose trends).
Disaster Population Screening	Public Health Teams, Nutritionists, Lab Technicians	Population-level assessment of nutritional vulnerabilities to guide resource allocation & mass feeding strategies.	Field-deployable kits for anthropometry, hemoglobin, vitamin A deficiency. Geospatial mapping of nutritional risk factors.	Centralized dashboard for aggregating population nutritional data to inform supply chain and public health messaging.

The Personalized Therapeutic Formulary – From Data to Diet

The second pillar of the Precision Nutrigenomics in Crisis Care (PNCC) framework operationalizes diagnostic insights by translating complex genetic and metabolic data into tailored nutritional interventions. This critical translation necessitates a fundamental transformation in clinical nutrition practice, pharmaceutical compounding, and supply chain logistics, moving from a static inventory of standard formulas to a dynamic, modular system capable of personalization at scale.

Genetically-Informed Enteral and Parenteral Nutrition

The contemporary model of a monolithic formulary for enteral and parenteral nutrition is fundamentally incompatible with the principles of PNCC. Future preparedness requires the development of a modular, genetically-informed formulary that functions as a "nutritional pharmacy." This system would comprise interchangeable macronutrient and

micronutrient modules, allowing for the compounding of patient-specific regimens. For macronutrients, lipid emulsions could be selected based on an individual's APOE genotype and inflammatory biomarker profile (Zhou et al., 2023). For instance, patients carrying the APOE ε4 allele, associated with a pro-inflammatory phenotype, may benefit from lipid formulations enriched with omega-3 fatty acids, which have demonstrated anti-inflammatory properties, rather than standard soybean oil-based emulsions (Zhang et al., 2023). Similarly, protein modules could be titrated and enriched with specific conditionally essential amino acids, such as glutamine or arginine, based on quantified plasma deficits identified through rapid laboratory assessment.

Concurrently, micronutrient delivery must evolve beyond standardized multivitamin preparations (Mehta et al., 2023). The PNCC model advocates for personalized "micronutrient cocktails" compounded in response to specific, assayed deficiencies. Evidence supports targeted high-dose intravenous vitamin C in septic patients with documented deficiency, given its role as a potent antioxidant and immune modulator (Carr & Rowe, 2020). Likewise, repletion of selenium and zinc should be guided by measured serum levels, as these trace elements are critical cofactors for antioxidant enzymes like glutathione peroxidase, which are rapidly depleted during systemic inflammation (Eveleens et al., 2021). The implementation of such a system falls significantly under the purview of hospital administration and pharmacy leadership. Pharmacy & Therapeutics committees must conduct rigorous cost-benefit analyses, evaluating not only the acquisition cost of a modular formulary but also the substantial evidence linking personalized nutrition to improved hard outcomes—such as reduced incidence of ventilator-associated pneumonia, shorter duration of mechanical ventilation, and decreased ICU length of stay—which collectively drive significant downstream cost savings for the healthcare system (Singer et al., 2019).

Paramedic-Initiated Nutritional Support

To extend the therapeutic window of PNCC into the pre-hospital phase, paramedics must be empowered to initiate basic personalized nutritional support. For patients experiencing prolonged transport times or in disaster scenarios with delayed access to definitive care, this could involve protocol-driven administration of specific intravenous micronutrient solutions. Examples include the immediate administration of parenteral thiamine for patients with suspected deficiency in the context of alcohol-related trauma to prevent Wernicke's encephalopathy, or magnesium for refractory ventricular arrhythmias (Roberts et al., 2021). Furthermore, for hemodynamically stable patients, paramedics trained in advanced protocols could initiate low-volume, trophic enteral feeding via a nasogastric tube, guided by point-of-care data suggesting metabolic stability. This early enteral stimulation can help maintain gut barrier integrity, a key defense against bacterial translocation and subsequent sepsis (Prudovsky et al., 2022).

Safety, Security, and Coordination in Delivery

The logistical execution of delivering personalized nutrition in a complex hospital or austere disaster environment presents formidable challenges, underscoring the indispensable role of support services. The medical secretary or clinical coordinator becomes the essential nexus of communication and logistics. Their role involves managing the intricate workflow: ensuring rapid laboratory results are communicated to the clinical dietitian, that the dietitian's complex prescription is accurately transmitted to the pharmacy or food production unit, and that the final, patient-specific formula is delivered to the correct bedside without error—a task of heightened importance for patients in isolation requiring special handling or those under security restrictions where protocol adherence is paramount. Concurrently, the domain of safety and security expands to encompass the safeguarding of high-value, specialized nutritional products from diversion or tampering. In disaster scenarios, this function is critical for securing the nutritional supply chain itself, protecting these precision medical therapeutics with the same rigor as pharmaceuticals, thereby distinguishing the delivery of targeted nutrition from the simple distribution of generic calories (Kunz et al., 2016).

Informatics Integration and Continuity of Care

The efficacy of personalized nutrition is intrinsically tied to the seamless flow and accessibility of data. The third pillar of PNCC ensures that nutrigenomic insights and therapeutic prescriptions form a continuous, actionable thread throughout the patient's journey, preventing fragmentation of care across multiple settings and providers.

The Nutrigenomic EHR and Interoperability

A foundational requirement is the development of a dedicated module within the Electronic Health Record (EHR) to serve as a dynamic repository for the "nutritional genome." This module must securely aggregate and display nutrigenomic data (MTHFR, APOE genotypes), serial nutritional biomarkers (glutamine, pre-albumin, micronutrient levels), and the evolving personalized diet prescription (Bates et al., 2014). This record must be portable, traveling with the patient from the ambulance EHR through the emergency department, ICU, step-down unit, and into rehabilitation or primary care (Sharma et al., 2022). Achieving this continuity demands robust interoperability based on modern standards like HL7 Fast Healthcare Interoperability Resources (FHIR), which enable secure data exchange between disparate healthcare

information systems (Mandel et al., 2016). This is particularly vital for disaster medicine, where patients may be evacuated and receive care in facilities outside their home network, necessitating immediate access to their unique metabolic and nutritional profile to avoid therapeutic missteps (Rindal et al., 2023).

Patient-Facing Tools and Long-Term Health

The value of data acquired during acute crisis care extends far beyond the hospital stay. Informatics enables the transformation of this acute-phase data into a long-term health asset. Following stabilization, personalized dietary recommendations for convalescence and chronic disease prevention can be generated based on the individual's genetic predispositions and acquired metabolic insights. Patient-facing mobile applications or secure web portals can deliver these tailored guidelines, facilitate tracking of nutritional intake, and provide educational resources (Ahmed et al., 2020). This approach fosters sustained patient engagement, empowers self-management, and capitalizes on the diagnostic investment made during the crisis, effectively turning a traumatic event into a pivot point for sustained, precision health management.

Table 2: Multi-Professional Roles & Challenges in Implementing PNCC

Professional Domain	Core Role in PNCC Framework	Key Operational Challenges	Required Enablers for Success
Medical Laboratory	Provide rapid turnaround of genomic & metabolic biomarkers; develop POC assays for field use.	Validating assays for critically ill populations; high cost of rapid genomic testing; maintaining quality in field-deployed testing.	Investment in rapid sequencing & mass spec technology; research to define crisis-specific reference ranges.
Paramedicine	Initiate POC metabolic screening; administer protocol-driven early micronutrient/feeding support in prolonged field care.	Scope of practice limitations; training in nutrition-focused diagnostics; carrying additional medical equipment/supplies.	Revised clinical practice guidelines; specialized training modules; compact, rugged POC diagnostic devices.
Clinical Nutrition	Interpret complex nutrigenomic/metabolic data; design & prescribe personalized feeding regimens; monitor efficacy.	Lack of training in genomics; need for rapid clinical decision-making in ICU; navigating a new, modular formulary.	Advanced practice degrees integrating genomics; access to real-time CDS tools; leadership on nutrition support teams.
Health Informatics	Design integrated data platforms & CDS algorithms; ensure interoperability of nutritional data across care continuum.	Integrating disparate data sources (genomic, biomarker, dietary); data privacy/security for genetic information; user-friendly design.	Development of data standards for nutritional phenotyping; strong cybersecurity protocols; user-centered design with clinicians.
Hospital Administration	Conduct cost-benefit analysis; manage formulary innovation; allocate resources for technology & training.	High upfront costs of technology & specialized formulas; demonstrating ROI; changing established procurement & care pathways.	Health economic models linking PNCC to hard outcomes (LOS, infections); pilot project funding; value-based procurement.
Medical Secretary / Coordinator	Orchestrate logistics of personalized diet delivery; manage communication between lab, dietitian, pharmacy, and bedside.	Managing complexity and preventing errors in custom orders; handling sensitive genetic/dietary information confidentially.	Training in new protocols and information systems; clear communication workflows; integration into care coordination teams.
Safety & Security	Secure storage/transport of high-value nutritional products; ensure integrity of nutritional supply chains in disasters.	Physical security of specialized formulas; cybersecurity of dietary data; managing access in isolation/containment scenarios.	Risk assessment protocols for nutritional assets; collaboration with IT security; inclusion in disaster logistics planning.

Ethical, Economic, and Equity Considerations

Implementing PNCC raises significant challenges that must be addressed proactively. A

primary concern is the potential to exacerbate health disparities. Advanced nutrigenomic testing and personalized formulas are expensive. Without deliberate policy, PNCC could become a luxury available only in wealthy hospitals or to insured patients, creating a two-tiered system of crisis care (Bayer & Galea, 2015). Strategies must include advocating for insurance coverage, developing lower-cost genotyping panels, and creating simplified, evidence-based protocols that can bring elements of personalization to resource-limited settings.

Obtaining meaningful informed consent for genetic testing in an emergency (e.g., an unconscious trauma patient) is fraught. Policies must be established for presumed consent for time-sensitive, actionable genetic tests, with clear pathways for later disclosure and counseling (Braverman et al., 2018). The privacy and security of highly sensitive nutrigenomic data within EHRs is paramount, requiring robust cybersecurity measures and strict access controls.

The economic argument is central to adoption. Hospital administrators require evidence that PNCC improves outcomes enough to offset its costs (Tatucu-Babet & Ridley, 2022). Research must focus on hard endpoints: reduced incidence of ventilator-associated pneumonia, decreased acute kidney injury, shorter duration of mechanical ventilation and ICU stay, and improved functional recovery (Lambell et al., 2020). Demonstrating a positive return on investment (ROI) is essential for securing funding for the necessary technology, personnel, and formulary expansion.

Conclusion

The integration of precision nutrigenomics into emergency and disaster medicine represents a paradigm shift of the highest order. It redefines nutrition from a supportive macronutrient delivery service to a central, information-intensive therapeutic discipline. The vision outlined in this review—of paramedics wielding metabolic sensors, laboratories generating rapid genetic and biochemical portraits, dietitians prescribing from a modular, genetically-informed formulary, and all of this enabled by seamless informatics and coordinated logistics—is no longer science fiction. The component technologies and scientific understandings are converging.

The greatest barrier is no longer a lack of tools, but a lack of integration. Realizing the PNCC framework demands unprecedented collaboration across professional silos. It requires medical educators to integrate nutrigenomics into paramedic, nursing, and dietetic curricula. It demands that laboratory scientists engage with field protocols, that informaticians speak the language of metabolism, and that administrators calculate the value of preventing complications rather than just the cost of formulas.

By embarking on this integrative path, we can aspire to a future where the metabolic and genetic individuality of every patient in crisis is recognized and addressed from the very first moments of care. In doing so, we can transform nutritional support from a blunt instrument into a precise metabolic therapy, ultimately forging a more resilient, effective, and equitable system of crisis response for the 21st century.

References

1. Ahmed, Z., Mohamed, K., Zeeshan, S., & Dong, X. (2020). Artificial intelligence with multi-functional machine learning platform development for better healthcare and precision medicine. *Database*, *2020*, baaa010. https://doi.org/10.1093/database/baaa010
2. Alipanah-Lechner, N., Neyton, L., Mick, E., Willmore, A., Leligdowicz, A., Contrepois, K., ... & Calfee, C. S. (2023). Plasma metabolic profiling implicates dysregulated lipid metabolism and glycolytic shift in hyperinflammatory ARDS. *American Journal of Physiology-Lung Cellular and Molecular Physiology*, *324*(3), L297-L306. https://doi.org/10.1152/ajplung.00278.2022
3. Anderson, C., Carmichael, J., Hicks, A. J., Burke, R., & Ponsford, J. (2023). Interaction between APOE ε4 and age is associated with emotional distress one year after moderate-severe traumatic brain injury. *Journal of Neurotrauma*, *40*(3-4), 326-336. https://doi.org/10.1089/neu.2022.0226
4. Bates, D. W., Saria, S., Ohno-Machado, L., Shah, A., & Escobar, G. (2014). Big data in health care: using analytics to identify and manage high-risk and high-cost patients. *Health affairs*, *33*(7), 1123-1131. https://doi.org/10.1377/hlthaff.2014.0041
5. Bayer, R., & Galea, S. (2015). Public health in the precision-medicine era. *N Engl J Med*, *373*(6), 499-501. DOI: 10.1056/NEJMp1504077
6. Braverman, G., Shapiro, Z. E., & Bernstein, J. A. (2018). Ethical issues in contemporary clinical genetics. *Mayo Clinic Proceedings: Innovations, Quality & Outcomes*, *2*(2), 81-90. https://doi.org/10.1016/j.mayocpiqo.2018.03.005
7. Carr, A. C., & Rowe, S. (2020). The emerging role of vitamin C in the prevention and treatment of COVID-19. *Nutrients*, *12*(11), 3286. https://doi.org/10.3390/nu12113286
8. Casaer, M. P., & Van den Berghe, G. (2014). Nutrition in the acute phase of critical illness. *New England Journal of Medicine*, *370*(13), 1227-1236. DOI: 10.1056/NEJMra1304623
9. Chen, J., Gorman, M., O'Reilly, B., & Chen, Y. (2016). Analytical evaluation of the epoc® point-of-care blood analysis system

in cardiopulmonary bypass patients. *Clinical Biochemistry*, *49*(9), 708-712. https://doi.org/10.1016/j.clinbiochem.2015.12.015

10. Ciaraglia, A., Brigmon, E., Braverman, M., Kidd, E., Winckler, C. J., Epley, E., ... & Jenkins, D. (2022). Use of whole blood deployment programs for mass casualty incidents: South Texas experience in regional response and preparedness. *Journal of Trauma and Acute Care Surgery*, *93*(6), e182-e184. *DOI:* 10.1097/TA.0000000000003762
11. Cruzat, V., Macedo Rogero, M., Noel Keane, K., Curi, R., & Newsholme, P. (2018). Glutamine: metabolism and immune function, supplementation and clinical translation. *Nutrients*, *10*(11), 1564. https://doi.org/10.3390/nu10111564
12. Dragasevic, S., Stankovic, B., Kotur, N., Milutinovic, A. S., Milovanovic, T., Stojkovic Lalosevic, M., ... & Popovic, D. (2022). Genetic Aspects of Micronutrients Important for Inflammatory Bowel Disease. *Life*, *12*(10), 1623. https://doi.org/10.3390/life12101623
13. Eveleens, R. D., Witjes, B. C., Casaer, M. P., Vanhorebeek, I., Guerra, G. G., Veldscholte, K., ... & Joosten, K. F. (2021). Supplementation of vitamins, trace elements and electrolytes in the PEPaNIC Randomised Controlled Trial: composition and preparation of the prescription. *Clinical nutrition ESPEN*, *42*, 244-251. https://doi.org/10.1016/j.clnesp.2021.01.028
14. Ferguson, L. R., De Caterina, R., Görman, U., Allayee, H., Kohlmeier, M., Prasad, C., ... & Martinez, J. A. (2016). Guide and position of the international society of nutrigenetics/nutrigenomics on personalised nutrition: part 1-fields of precision nutrition. *Lifestyle Genomics*, *9*(1), 12-27. https://doi.org/10.1159/000445350
15. Heyland, D. K., Dhaliwal, R., Wang, M., & Day, A. G. (2015). The prevalence of iatrogenic underfeeding in the nutritionally 'at-risk'critically ill patient: Results of an international, multicenter, prospective study. *Clinical Nutrition*, *34*(4), 659-666. https://doi.org/10.1016/j.clnu.2014.07.008
16. Horn, D. L., Bettcher, L. F., Navarro, S. L., Pascua, V., Neto, F. C., Cuschieri, J., ... & O'Keefe, G. E. (2021). Persistent metabolomic alterations characterize chronic critical illness after severe trauma. *Journal of Trauma and Acute Care Surgery*, *90*(1), 35-45. *DOI:* 10.1097/TA.0000000000002952
17. Jin, J., Mulesa, L., & Carrilero Rouillet, M. (2017). Trace elements in parenteral nutrition: considerations for the prescribing clinician. *Nutrients*, *9*(5), 440. https://doi.org/10.3390/nu9050440
18. Kassem, N. M., Abdelmegid, Y. A., El-Sayed, M. K., Sayed, R. S., Abdel-Aalla, M. H., & Kassem, H. A. (2023). Nutrigenomics and microbiome shaping the future of personalized medicine: a review article. *Journal of Genetic Engineering and Biotechnology*, *21*(1), 134. https://doi.org/10.1186/s43141-023-00599-2
19. Khorram-Manesh, A., Carlström, E., Burkle, F. M., Goniewicz, K., Gray, L., Ratnayake, A., ... & Magnusson, C. (2023). The implication of a translational triage tool in mass casualty incidents: part three: a multinational study, using validated patient cards. *Scandinavian journal of trauma, resuscitation and emergency medicine*, *31*(1), 88. https://doi.org/10.1186/s13049-023-01128-3
20. Kotwal, R. S., Montgomery, H. R., Miles, E. A., Conklin, C. C., Hall, M. T., & McChrystal, S. A. (2017). Leadership and a casualty response system for eliminating preventable death. *Journal of trauma and acute care surgery*, *82*(6S), S9-S15. *DOI:* 10.1097/TA.0000000000001428
21. Lambell, K. J., Tatucu-Babet, O. A., Chapple, L. A., Gantner, D., & Ridley, E. J. (2020). Nutrition therapy in critical illness: a review of the literature for clinicians. *Critical Care*, *24*(1), 35. https://doi.org/10.1186/s13054-020-2739-4
22. Mandel, J. C., Kreda, D. A., Mandl, K. D., Kohane, I. S., & Ramoni, R. B. (2016). SMART on FHIR: a standards-based, interoperable apps platform for electronic health records. *Journal of the American Medical Informatics Association*, *23*(5), 899-908. https://doi.org/10.1093/jamia/ocv189
23. Mathers, J. C. (2017). Nutrigenomics in the modern era. *Proceedings of the Nutrition Society*, *76*(3), 265-275. doi:10.1017/S002966511600080X
24. Mehta, N., Pokharna, P., & Shetty, S. R. (2023). Unwinding the potentials of vitamin C in COVID-19 and other diseases: An updated review. *Nutrition and Health*, *29*(3), 415-433. https://doi.org/10.1177/02601060221139628
25. Moisey, L. L., Merriweather, J. L., & Drover, J. W. (2022). The role of nutrition rehabilitation in the recovery of survivors of critical illness: underrecognized and underappreciated. *Critical Care*, *26*(1), 270. https://doi.org/10.1186/s13054-022-04143-5
26. Molloy, A. M. (2011). Genetic aspects of folate metabolism. *Water Soluble Vitamins:*

Clinical Research and Future Application, 105-130. https://doi.org/10.1007/978-94-007-2199-9_7

27. Olivecrona, M., Wildemyr, Z., & Koskinen, L. O. D. (2010). The apolipoprotein E ε4 allele and outcome in severe traumatic brain injury treated by an intracranial pressure–targeted therapy. *Journal of neurosurgery*, *112*(5), 1113-1119. https://doi.org/10.3171/2009.8.JNS09636
28. Paula, R. F., Távora, P. F., Gomes, M. M., Neto, J. D., Leonel, T. C., Santos, L. I., & Midrigal, A. D. (2023). A-387 Evaluation of the Analytical and Clinical Performance of epoc Point of Care Equipment Compared to Standard Blood Gas in Patients with Nephropathy. *Clinical Chemistry*, *69*(Supplement_1), hvad097-343. https://doi.org/10.1093/clinchem/hvad097.343
29. Pirmohamed, M. (2011). Pharmacogenetics: past, present and future. *Drug discovery today*, *16*(19-20), 852-861. https://doi.org/10.1016/j.drudis.2011.08.006
30. Prudovsky, I., Kacer, D., Zucco, V. V., Palmeri, M., Falank, C., Kramer, R., ... & Rappold, J. (2022). Tranexamic acid: beyond antifibrinolysis. *Transfusion*, *62*, S301-S312. https://doi.org/10.1111/trf.16976
31. Rindal, D. B., Pasumarthi, D. P., Thirumalai, V., Truitt, A. R., Asche, S. E., Worley, D. C., ... & Mitchell, S. G. (2023). Clinical decision support to reduce opioid prescriptions for dental extractions using SMART on FHIR: implementation report. *JMIR Medical Informatics*, *11*(1), e45636. https://doi.org/10.2196/45636
32. Roberts, I., Shakur-Still, H., Aeron-Thomas, A., Beaumont, D., Belli, A., Brenner, A., ... & Williams, J. (2021). Tranexamic acid to reduce head injury death in people with traumatic brain injury: the CRASH-3 international RCT. *Health Technology Assessment (Winchester, England)*, *25*(26), 1. https://doi.org/10.3310/hta25260
33. Sharma, A., Malviya, R., & Gupta, R. (2022). Big data analytics in healthcare. *Cognitive Intelligence and Big Data in Healthcare*, 257-301. https://doi.org/10.1002/9781119771982.ch10
34. Singer, P., Blaser, A. R., Berger, M. M., Alhazzani, W., Calder, P. C., Casaer, M. P., ... & Bischoff, S. C. (2019). ESPEN guideline on clinical nutrition in the intensive care unit. *Clinical nutrition*, *38*(1), 48-79. https://doi.org/10.1016/j.clnu.2018.08.037
35. Tatucu-Babet, O. A., & Ridley, E. J. (2022). How much underfeeding can the critically ill adult patient tolerate?. *Journal of Intensive Medicine*, *2*(02), 69-77. https://doi.org/10.1016/j.jointm.2022.01.002
36. Taylor, B. E., McClave, S. A., Martindale, R. G., Warren, M. M., Johnson, D. R., Braunschweig, C., ... & Society of Critical Care Medicine. (2016). Guidelines for the provision and assessment of nutrition support therapy in the adult critically ill patient: Society of Critical Care Medicine (SCCM) and American Society for Parenteral and Enteral Nutrition (ASPEN). *Critical care medicine*, *44*(2), 390-438. *DOI:* 10.1097/CCM.0000000000001525
37. Vankrunkelsven, W., Gunst, J., Amrein, K., Bear, D. E., Berger, M. M., Christopher, K. B., ... & Casaer, M. P. (2021). Monitoring and parenteral administration of micronutrients, phosphate and magnesium in critically ill patients: the VITA-TRACE survey. *Clinical nutrition*, *40*(2), 590-599. https://doi.org/10.1016/j.clnu.2020.06.005
38. Wischmeyer, P. E., Bear, D. E., Berger, M. M., De Waele, E., Gunst, J., McClave, S. A., ... & van Zanten, A. R. (2023). Personalized nutrition therapy in critical care: 10 expert recommendations. *Critical Care*, *27*(1), 261. https://doi.org/10.1186/s13054-023-04539-x
39. Wong, A., Otles, E., Donnelly, J. P., Krumm, A., McCullough, J., DeTroyer-Cooley, O., ... & Singh, K. (2021). External validation of a widely implemented proprietary sepsis prediction model in hospitalized patients. *JAMA internal medicine*, *181*(8), 1065-1070. doi:10.1001/jamainternmed.2021.2626
40. Zhang, C., Li, G., Lu, T., Liu, L., Sui, Y., Bai, R., ... & Sun, B. (2023). The interaction of microbiome and pancreas in acute pancreatitis. *Biomolecules*, *14*(1), 59. https://doi.org/10.3390/biom14010059
41. Zhou, X., Jin, S., Pan, J., Lin, Q., Yang, S., Lu, Y., ... & Hong, W. (2023). Relationship between cholesterol-related lipids and severe acute pancreatitis: from bench to bedside. *Journal of Clinical Medicine*, *12*(5), 1729. https://doi.org/10.3390/jcm12051729

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