Pasteur's Quadrant and malnutrition

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Basic science has been the wellspring of advances in technology in everything from cellular phones to nutrient-fortified foods. Biochemistry and food technology afford new techniques that enrich nutritional science and aid in the fight against malnutrition. Bionutrition, the term used to describe the application of these techniques, can be the source of innovations that will help eradicate malnutrition globally. Which areas of bionutrition research are most likely to yield tomorrow's breakthroughs?

Malnutrition is a global challenge to physiologists and nutritional biochemists as well as to public health and government agencies. Protein–energy malnutrition (PEM) — a nutritional deficiency illness that results in anaemia, poor growth, weakness and oedema — is its worst-case scenario. It occurs when the supply of protein, energy and micronutrients in the diet is simply insufficient to meet the body's needs for proper growth and development, or even for survival. If we can eliminate PEM, we can do the same thing for malnutrition in general.

PEM is a high-priority public health problem. A billion human beings are undernourished or malnourished in the world today[1,2]. In North and South America alone, the 1995 estimate of infants with low birth weight was over a million; of girls and boys under the age of five, six million were seriously underweight as a result of the interaction between undernutrition and infection[1].

Insanitary environments breed repeated episodes of mild infectious illness or persistent chronic infections that impair the utilization of nutrients by the body and intensify the adverse impact of diets that lack both quality and variety. As well as the input from nutrition science, improvement in the general nutritional status of malnourished populations will require concerted public health efforts to improve water supplies, sanitation and immunization programmes.

Overcoming barriers

The prevention, diagnosis and treatment of PEM are highly dependent on the development of new technologies in food and nutrition science, new ways of delivering food to those who need it, and on changes in social, political and ecological systems (Fig. 1). Other factors that hamper progress include the complexities of malnutrition-related diseases, and the lack of scientific insight into the damaging physiological changes that they cause.

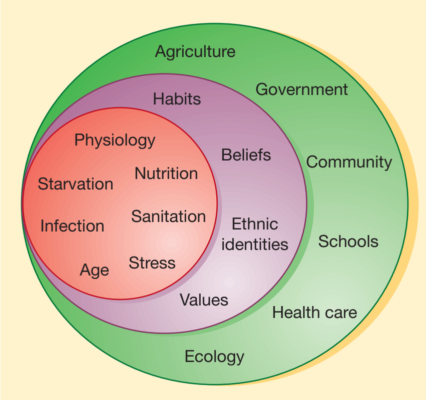

Figure 1 **Framework for determinants of malnutrition. Prevention, diagnosis and treatment of PEM are highly dependent on new technologies in food and nutrition science, food-delivery systems, and changes in social, political and ecological systems.**

These problems have impeded efforts to develop treatments for malnutrition-related diseases that are optimally tailored to particular populations and environments, for example, pregnant women who live in the poor, densely populated urban areas of Central America or children in remote, famine-stricken regions of Africa. Food and nutrition scientists, together with colleagues in related fields, can expedite success by revisiting assumptions about the relationship between basic and applied research, and by redesigning both treatments for malnutrition and the means of delivery to all those at risk. Malnutrition-related diseases are also diverse and often difficult to diagnose, with considerable potential for fatal errors in treatment. Given all these factors, scientists and clinicians will face many unforeseen challenges to successful intervention[2,3].

Pasteur's Quadrant

'Pasteur's Quadrant' is a modern framework for classifying the relationship between basic science and technological innovation. It is also a useful approach for exploring the necessary basic science of nutritional physiology that will lead to technologies for preventing and treating malnutrition. In his innovative book on science and technology policy[4], the late Donald E. Stokes, professor of politics and public affairs in the Woodrow Wilson School of Public and International Affairs at Princeton University, moved away from a one-dimensional model of technological innovation stemming from basic research. He proposed a two-dimensional model in which innovations can be presented as paths within the quadrant between two axes: one representing developments in basic research, and the other developments in technology. In recasting the relationship between understanding and use in scientific research, Stokes cited the work of Louis Pasteur as a model of how fundamental yet use-inspired studies established the foundations of microbiology over a century ago. Since then, technology has grown ever more science-based. At the same time, science has become increasingly technology-based, with the choice of problems and the conduct of research often guided by societal needs.

Pasteur's Quadrant challenges the widely accepted validity of a dichotomy between basic and applied science. Taking inspiration from Pasteur, we need to look at the pathology and physiology of PEM to understand where the basic science of nutrition might help us most. For our purposes, Pasteur's Quadrant is best applied where the science of bionutrition — a term that refers to special opportunities afforded by biochemistry and food technology techniques that enrich nutrition science — intersects with the imperative to effectively address the many coexisting illnesses that result from malnutrition. New foods to prevent and treat these

Box 1 The physiology of starvation

Adequate clean water, energy, protein, vitamins (food-based organic substances that are not synthesized by the human body), minerals and certain other chemicals obtainable only from plants (for example, hormone-like substances such as carotenoids, flavonoids, lignans, sulphides and thiols) are necessary to sustain a balanced metabolism (metabolic homeostasis) and preservation of the body cell mass. Macronutrients are those nutrients required in relatively large amounts in the diet (amino acids, starches, sugars and fatty acids) and provide both the chemical building blocks from which cells are made and the metabolic energy that sustains life.

The healthy, well-fed person is protected from PEM by stores of glucose in the form of glycogen, labile protein reserves of amino acids, and a reserve of calories stored as fat. These can be mobilized during short periods without food and are built up again after a meal has been eaten. During such short periods of starvation, energy is obtained principally from free glucose and free fatty acids released from these stores[13]. Free glucose is the preferred fuel for such essential tissues as the blood-forming cells, the medulla of the kidney and the brain.

After three days without food, however, free glucose as an energy fuel becomes depleted. Glycogen stores in muscle and liver, which are used as primary energy sources, also become severely depleted. To continue to maintain blood glucose concentration, the liver starts to synthesize glucose from amino acids and other non-carbohydrates (gluconeogenesis).

During starvation, when glucose is unavailable, the primary fuels for brain, heart and muscle metabolism are ketone bodies, acetoacetate and β-hydroxybutyrate, all of which are derived from fatty acids. The breakdown of fat (lipolysis) in muscle and adipose tissue provides free fatty acids, the oxidation of which provides essential fuel and minimizes the use of visceral proteins for energy[13]. In kwashiorkor malnutrition, a deficiency of carnitine — an essential coenzyme in fatty acid metabolism that helps move fatty acid to the mitochondria from the cytoplasm — can impair the oxidation of fatty acids, leading to a state of advanced PEM.

Once a state of PEM is established, survival is threatened by reduced endogenous protein breakdown (proteolysis) coupled with depleted protein reserves and imbalances in the free amino acids available (Fig. 2). Many metabolic disorders that compromise cell function are the result of imbalances and deficiencies in amino acids. Cysteine, for example, is a component of many proteins and is also crucial for the synthesis of the tripeptide glutathione in red blood cells, which acts as a buffer for haemoglobin[14].

illnesses will come from technological innovations rooted in basic research into the physiology of PEM[5].

Protein–energy malnutrition

Although the first descriptions of PEM appeared in the 1800s, the condition was not recognized as a disease until the early twentieth century. The World Health Organization (WHO) and the Food and Agricultural Organization were founded in 1948. A year later they established clinical criteria for malnutrition and opportunities and priorities for future research.

In developing nations, PEM is most commonly found in overpopulated areas with scarce food supply or in environments blighted by famine, contaminated water and insanitary conditions. About 50% of children living in these conditions are malnourished or underweight, with symptoms of wasting and stunted growth. PEM coexists with hunger in areas of poverty and in groups with low socioeconomic status, where limited education means there is little understanding of diet and health. Severe malnutrition is also appearing in new adult populations, in particular in hospitalized patients with chronic diseases and in the institutionalized elderly in nursing homes, who cannot or will not eat. The mortality rate from severe malnutrition in these groups is 10 to 20 times higher than in healthy adults[1,2].

The physiology of PEM

PEM results when the body is stressed from starvation and is not receiving the protein and/or energy fuels and micronutrients needed to sustain the metabolic processes required for health and survival. The pathophysiology is failure of starvation and the related impetus of hunger to achieve the consumption of adequate amounts of essential foods. Prolonged starvation leading to severe PEM results in a cascade of physiological changes that cannot be resolved solely by the intake of available domestic foods. Therapeutic intervention requires nutrient-rich foods, oral rehydration fluids and often antibiotics. Functional foods could be important in promoting and sustaining recovery, particularly during the initial feeding period.

Functional foods are those that contain significant levels of biologically active components that impart health benefits or desirable physiological effects beyond basic nutrition. Functional attributes of many traditional foods are being discovered, while new food products are being developed to enhance or incorporate beneficial components. Ready-to-eat cereals are among the top ten food sources for 18 of 27 nutrients in the US diet, primarily because of fortification. Other examples include carotenoids and flavonoids to neutralize free radicals; ω-3 fatty acids to improve mental and visual functions; prebiotics/probiotics to improve the quality of intestinal microflora; and sulphides and thiols to maintain immune function.

A wide range of clinical manifestations characterizes malnutrition and undernutrition; the relative intensity of the starvation, its duration and the age of the victim determine these. In particular, PEM is associated with the presence of other nutritional deficiencies, such as deficiencies of certain vitamins. It is also associated with infections and metabolic stresses such as are found in densely populated areas at risk of famine[6].

There are two types of severe PEM — marasmus and hypoalbuminaemia or kwashiorkor. Marasmus is starvation that leads slowly to death, exemplified by the 'skin and bones' images of helpless infants displayed by relief organizations during aid appeals. In famine-stricken regions, it is the most common form of severe PEM, and is characterized by thinness, fatigue, irritability and weight loss of more than 20% of initial body weight. Victims have a low body-mass index or BMI — a measure used by the WHO as one method to categorize body size. BMI is calculated as the mass in kilograms (kg) divided by the square of the height in metres (m^2); a value below 19 kg m^{-2} is underweight. Sixty days of total starvation in a human of normal weight (7–12% body fat) results in marasmus malnutrition, which translates into a BMI <16 kg m^{-2} in adults and a weight-for-height ratio in children of <70% of the original value. Terminal marasmus malnutrition presents with BMI values <13.5 kg m^{-2} together with severe muscle wasting, gut atrophy and loss of subcutaneous fat.

Semi-starvation in children and adults, with consumption of less than 7 kcal per kg per day and less than 0.3 g protein per kg per day, can prolong the development of marasmus by months or even years. In such cases, survival depends on the quantity of fat stores, the degree of depletion of body cell mass, and the level of function in critical organ systems.

The main physiological changes that occur in starvation as the result of lack of macronutrients — starches, sugars, amino acids and fatty acids — are described in Box 1. In addition, the deficiencies in micronutrients, such as vitamins, trace elements and other compounds required in small amounts (phytonutrients), also have profound effects (Box 2).

As well as the symptoms of marasmus, malnutrition in children is characterized by a failure to grow. Amino acids are required for the biosynthesis of the protein hormones required for growth, such as insulin-like growth factor (IGF-1) and, in particular, IGF-1 binding protein 1. Such hormones are key control points at which nutritional status and metabolic homeostasis, the balanced functioning of essential metabolic processes, intersect.

Kwashiorkor develops in conditions of infection, diarrhoea, trauma and critical

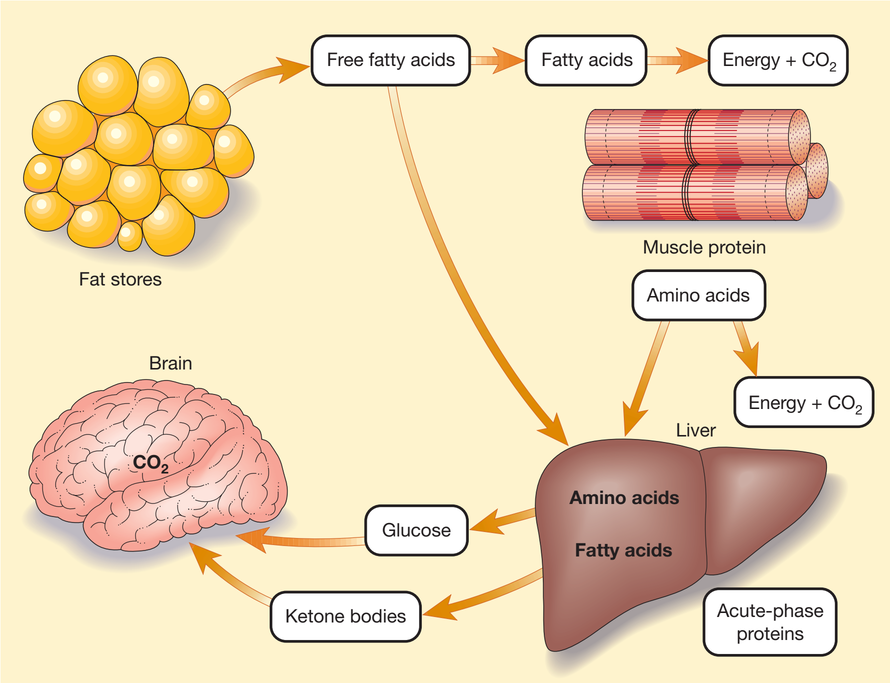

Figure 2 **The metabolic response to malnutrition. Malnutrition triggers a functional redistribution of muscle protein (body cell mass) to provide the nitrogen necessary for synthesis of tissue protein, formation of red blood cells, wound healing and immune function (for example, the synthesis of acute-phase proteins). The interrelationship of fat, muscle and liver entails catabolism of muscle protein and release of gluconeogenic precursors for use by the liver. During starvation, ketone bodies are synthesized in the liver from fatty acids and used as fuel by the brain and other organs instead of glucose. The efficiency of physiological changes triggered by malnutrition is influenced by the extent of starvation and infection. It is important be aware of these changes when designing nutritional therapies.**

illness, and occurs in some 2% of severely malnourished individuals. It is particularly prevalent in Africa, Central and South America and Southeast Asia, regions where the diet consists mainly of starchy vegetables contaminated with aflatoxin — a fungal toxin that commonly attacks crops in humid, temperate areas of the tropics.

In the developing world, children with oedematous kwashiorkor malnutrition often have their condition complicated by amino-acid imbalances and various micronutrient deficiencies, including vitamins A and C and riboflavin[7]. They also suffer from tissue swelling that occurs when fluid leaks from the blood into the tissues, changes in the skin and hair, and low levels of secretory proteins such as serum albumin. Depending on the extent, onset and duration of the nutritional deficiency, they develop severe fluid retention and abdominal bloating, the swollen stomachs also familiar from images of famine. Shock and coma precede death.

Kwashiorkor malnutrition is physiologically more complex than marasmus[8] because of the wide-ranging effects of selective deficiencies in amino acids, and its association with opportunistic diseases such as pertussis and tuberculosis. The energy- and protein-requiring immune response that the body mounts against infection compounds an imbalance in the amino acids essential for protein synthesis and growth (Fig. 2).

Hormones and malnutrition

A shift from feasting to fasting alters the hormonal milieu in ways that signal a change in metabolic priorities from biosynthesis (anabolism) and growth to a post-absorptive state that maintains metabolic homeostasis between meals. During prolonged starvation, this hormonal response effects a redistribution of amino acids (from body muscle) and fatty acids (from adipose tissue) to meet the protein and energy needs of vital visceral-tissue functions of the brain, liver, intestine, bone marrow, heart and kidneys (Box 1). Hormonal modifications include reductions in insulin, IGF-1 and leptin, which act individually and together as anabolic hormones to muscle and adipose tissue. In contrast, there are increases in glucagon, glucocorticoids, growth hormone and catecholamines, which catabolize muscle (proteolysis) and adipose tissue (lipolysis) to meet the protein and energy requirements of visceral tissue.

Additional hormonal changes include increased production of reverse T3, the active tissue form of thyroid hormone, which results in decreased basal energy expenditure. The drop in basal metabolic rate is regulated primarily through a decline in the activities of the thyroid and sympathetic nervous system.

The hormone leptin, produced by adipose tissue in response to starvation, is an important mediator between nutritional status and the neuroendocrine system. By its effects on the latter, leptin may prompt the maintenance of levels of cortisol and growth hormone necessary for effective lipolysis. During starvation, lipolysis is the only way to ensure an adequate supply of energy fuel for the brain (in the form of ketone bodies) and other organs (in the form of fatty acids).

Prolonged PEM leads to decreased synthesis of IGF-1 and low levels of insulin and leptin, or to their diminished effect owing to impaired receptor function in the presence of high levels of circulating growth hormone and cortisol. Their absence diverts the energy fuel substrate (that is, ketone bodies, acetoacetate and β-hydroxybutyrate, glutamine and other gluconeogenic amino acids) away from anabolism (biosynthesis and growth) and towards energy conservation and metabolic fuel adaptations that protect vital organs.

New ‘functional foods’

A better understanding of the metabolic response to starvation and stress will be a key element in the evolution of strategies to develop new foods for the treatment of PEM.

The initial phase of feeding — for example, enteral delivery of nutrients and rehydration fluids — is particularly precarious in those with kwashiorkor or severe weight loss (>25% of usual or normal body weight). Feeding solutions need to meet the nutritional needs, stimulate appetite and cause minimal side effects. In cases of severe and prolonged starvation, feeding has to be slow (hourly), consistent and gradual to avoid clinical complications that include anorexia and re-feeding syndrome, a generalized fluid and electrolyte imbalance that may cause significant morbidity and mortality[6,8]. If the patient regains his or her appetite within the first four days of the intervention, the feeding treatment can be considered a success.

Fatalities result when dietary therapy is limited only to macronutrient replacement. Indeed, inattention to micronutrients, salts and phytonutrients (for example: nutrients derived from phytochemicals; hormone-like substances found in plants, such as carotenoids, flavonoids, sulphides and thiols; ω-3 fatty acids; and probiotics) may explain the lack of correlation between severity of malnutrition and treatment outcome[9].

Better treatment and prevention of PEM will require the development of specialized ‘functional foods’ — foods or food ingredients that provide a health benefit beyond that conferred by the nutrients the food contains[10–12]. These functional foods will have to incorporate the micronutrients essential for increased protein synthesis, decreased protein catabolism and improved immune function (see Box 2). Efforts to produce nutrient-fortified commodities and genetically modified (GM) foods containing vital micronutrients such as vitamin A and iron must also be based firmly in an understanding of the complexities of malnutrition. To achieve a complete re-alimentation diet, any therapeutic or functional food would have to supplement the intake of locally available foods.

As well as gross changes in physiology, many other potentially harmful changes occur in response to starvation. One of the key areas where intervention could be crucial is in the relatively little understood interactions between nutrition and the immune system, the body's defence against infection (see Box 2). Immune responses are essential for survival, but they are also vulnerable to protein, energy and micronutrient deficiencies. In malnourished individuals, immune responses generally tend to be suppressed, a state which enables opportunistic infections to flourish.

Food scientists should pay close attention to re-feeding diets rich in ω-6 fatty acids that increase production of prostaglandin E2 (PGE2). This compound is a potent inflammatory agent, and helps stimulate the development of immune responses. Properly designed ω-6/ω-3 fatty acids can achieve the desired immune response and serve as potent antioxidants that can minimize the damage caused by free radicals. The presence of α-linolenic acid and other highly unsaturated fatty acids leads to inhibition of cytokine production, which in turn leads to suppression of the immune response.

The metabolic and endocrine adaptations to starvation are critical to survival during periods of extended nutritional deprivation. They cannot, however, minimize or slow the damage caused by multiple nutrient deficiencies linked to PEM; damage that underscores the need to prevent and treat this disease with carefully constructed diets or medical foods. A special focus is required on antioxidants, agents that minimize the negative impact of free radicals and lipid peroxidation and help maintain cell-mediated immunity. Their potential role in preventing organ failure, infectious disease and the morbidity, disability and mortality of PEM makes that abundantly clear.

Functional, nutrient-fortified and GM foods represent opportunities for the development of viable solutions to the problem of malnutrition. This applies not only to re-feeding for severe PEM, but also for cases of early-onset undernutrition — a condition with lifelong effects that could be reversed by changes in sociopolitical conditions (Fig. 1).

Box 2 Micronutrients and malnutrition

PEM is also linked to shortfalls in micronutrients that are crucial in metabolism and in the proper functioning of the immune system. Imbalances and deficiencies in a variety of micronutrients, as well as amino acids and fatty acids, favour opportunistic infections, including tuberculosis, measles, malaria, hepatitis B (which leads to liver cancer), and secondary infections in HIV-compromised individuals.

Marginal micronutrient status also interferes with the efficiency of macronutrient utilization, further compromising the immune system. A diet restricted to very few foods can be lacking in some essential and conditionally essential amino acids. In general, a mixture of plant and animal proteins is required to optimize the use of macronutrients; the same applies to acute-phase proteins involved in host defence against infectious agents.

A diet deficient in antioxidants is associated with a rise in free radicals that cause tissue damage. The oedema of kwashiorkor, for instance, is linked to insufficient copper, zinc, selenium and vitamins A, E and C. These shortfalls, in turn, lead to increased production of superoxide dismutase, which results in lipid peroxidation and a rise in free iron, effects thought to be major causes of malnutrition-related oedema.

Unforeseeable technology

Bionutrition and functional foods

Those suffering from PEM need essential nutrients as well as specialized ones (conditional essential) that will reverse the effects of starvation, restore immune-defence mechanisms and recover body cell mass and energy stores. These nutrients, which change the hormonal milieu to an anabolism that facilitates re-feeding[6–9,13,14], could be supplied by functional foods[10–12].

Functional food ingredients can deliver nutrient density without overstimulating the hormonal response to the initial therapeutic feeding. They can be particularly effective in supporting organ function, protein synthesis and antioxidant activity required for early recovery. Foods fortified with vitamins C, E and A can modulate metabolic stresses and enhance immune status. Diets enriched with branched-chain amino acids, which are often provided in intravenous amino-acid solutions and enteral formula diets, can stimulate liver function, modulate insulin secretion and enhance cellular immune function. Diets fortified with fish oil, arginine and ribonucleotides can create nutritional immunomodulation that can minimize the metabolic stresses associated with malnutrition and infection. But the benefits that such immunostimulatory foods could confer would depend on a balanced total diet, adequate sanitation, and the availability of oral rehydration solutions, antibiotics and appropriate health care.

The health benefits of functional foods have never been as well developed as they are today. Bi-directional research, as embodied in the notion of Pasteur's Quadrant, will focus on the further development and refinement of functional foods and the investigation of their mechanisms of action. These efforts, in turn, will fuel growth in the field of bionutrition.

As nutrition scientists move into this new discipline, they will need to build on the wealth of information that already exists in plant biology. Many valuable natural phytonutrients are so-called 'secondary chemicals' produced by plants for purposes other than their general metabolism. The evolutionary and physiological bases of secondary chemical production in plants will have to be considered to plan meaningful experiments that test the functionality of chemical compounds as foods for special dietary purposes.

Functional foods that possess gastrointestinal functions related to nutrient absorption, redox and antioxidant systems will be promising subjects for investigation, as will macronutrients that function in the re-feeding period of malnutrition treatment. But only a rigorous scientific approach that produces highly significant results will guarantee the success of bionutrition itself, and the development of foods for the prevention and treatment of PEM.

Nutrient cocktails

The metabolic response to stress is characterized in part by an increase in muscle catabolism, a reduction in total body protein synthesis, and increased oxidation of branched-chain amino acids (for example, novel essential amino acids, released from muscle, that stimulate liver protein synthesis). The result is an obligatory negative nitrogen balance (Fig. 2). Clinical investigation has led to the hypothesis that particular nutrients or mixes of nutrients may have a favourable impact on organ function independent of their general nutritional effects. Such 'nutrient cocktails' can reduce nitrogen loss and support protein synthesis better than standard amino-acid solutions[11].

In such cases, several normally dispensable amino acids become 'semi-essential' amino acids[12]. Clinical studies show that supplemental dietary arginine, glutamate and tyrosine improve nitrogen retention and enhance immune response and brain neurotransmitter function. Designers of functional foods are thus currently investigating combinations of immunostimulatory nutrients such as branched-chain amino acids, arginine, glutamate, ribonucleotides and fish oil.

Structured lipids

The importance of polyunsaturated fatty acids (PUFA) in ameliorating inflammatory disorders has long been recognized. ω-3 and ω-6 PUFA are precursors of eicosanoids and leukotrienes, both of which are involved in modulating inflammation. ω-3 fatty acids are present in certain plant oils and most fish oils. γ-Linolenic acid, a novel ω-6 fatty acid that also suppresses inflammation, is present in borage and evening primrose seeds. Although nature may not have provided the desired combination of fatty acids in a single triglyceride molecule for particular use as a functional food, this can be remedied by rearranging the properties of natural fatty acids to create new, structured lipids.

Structured lipids are created by enzymatically or chemically combining short-, medium- and long-chain fatty acids to form a new triglyceride molecule. These structurally mixed acids take advantage of two physiological pathways of absorption — long chains are absorbed through the lymph system, short and medium chains through the circulatory system. Specially synthesized fatty acids not found in nature, such as highly unsaturated ω-3 fatty acids, might be inserted into 2-glycerol, creating a molecule of unique digestibility and bioavailability.

New technology, such as innovations in computing power that enable instant processing and analysis of computationally intensive scientific and nutritional data, will enable the creation of new mixtures of structured lipids that can modulate the potentially damaging immune response that results from high levels of PGE2.

Ligand-binding proteins

Other nutritional innovations include the use of ligand-binding proteins to stabilize volatile or potentially harmful agents (such as drugs, vitamins, flavourings or pheromones), shielding them from the environment or preventing their oxidation and degradation. Binding these agents to carriers with high affinity and selectivity for targeted sites can be useful in the fight against PEM, especially when subsequent controlled release can be engineered into these carriers. A protein envelope that acts as a diffusion barrier for the ligand can provide excellent slow-release features, which would be important in foods designed for therapeutic feeding.

Although natural proteins often possess one or more of the phytochemicals, biotechnology and bioinformatics provide the tools that bioengineers need to adapt these proteins to practical use. In fact, researchers have already engineered glucose-triggered release of glycosylated insulin from specially designed lectin carriers, and are using tools provided by biospecific antibodies to target nutrient, antioxidative and degradative compounds for special dietary purposes.

Probiotics and prebiotics

A probiotic is a live microbial dietary supplement that has a beneficial impact on the host through its effects in the intestinal tract. Probiotics are available as freeze-dried cultures and are widely used to prepare fermented dairy products such as yoghurt. In the future they may also be found in fermented vegetables and meats. Several health-related effects associated with the intake of probiotics, including alleviation of lactose intolerance and immune enhancement, have been reported in human studies. Probiotics may be particularly valuable in reducing the risk of rotavirus-induced diarrhoea, which is a major source of malnutrition in infants in developing countries.

Prebiotics are non-digestible food ingredients that benefit the host by selectively stimulating the growth or activity of selected bacterial species that live in the intestinal tract. Inulin-type fructans, for example, are proving sufficiently promising to warrant their use as functional food ingredients.

The use of symbiotic or combined probiotics and prebiotics represents a promising direction for future research. Such combinations may be effective in improving the transit of viable, enriched microbial agents through the upper part of the gastrointestinal tract, thereby enhancing their delivery into the large bowel. This effect hastens the restoration of the normal gut flora at this site, and alleviates diarrhoea and dysentery.

Nutrient fortification

A classic approach to discovering the mechanisms by which diet prevents or treats malnutrition starts with the identification of individual nutrient components responsible for diet-related disease. This type of component research into single-nutrient, single-condition intervention will provide the rationale for developing nutrient-fortified and single-gene-modified foods.

Food technology

Processing methods can convert basic ingredients into practical foods and also change their physical and nutritional properties in useful ways. Extrusion cooking, for example, can process mixtures of plant foods into soup bases, flour mixes and other dry foods. The resulting products have functional properties that change their bulk density, water absorption and solubility indices. The use of extrusion cooking to add soybeans to sweet potatoes can increase the protein, fat, ash and trypsin inhibitor levels of the raw material mixtures.

New food technologies can also be used to speed and amplify the effect of drugs. Phytocompounds can be designed into bioavailability enhancers that modify drug metabolism in ways that increase the odds that the first dose will produce a strong therapeutic effect in any given individual. Phytocompounds also have the potential to alter the metabolism of pharmaceuticals and prevent their elimination before they enter the blood stream. Reduction in the activity of drug-metabolizing enzymes is by far the most important of these effects.

Nutrition's pivotal role

Nutrition can be expected to play a pivotal role in optimizing health and productivity, and in reducing the factors that cause PEM in at-risk populations. The next generation of scientists will use complex systems and models to guide the development and evaluation of intervention programmes. The eradication of PEM and other forms of malnutrition will depend as much on their efforts as it will on the commitment of politicians, governments and transnational public health organizations to end the suffering caused by preventable and tragic nutrition-related disease.

Research outcomes can support recommended ways of preventing and treating PEM. The actual production, distribution and delivery of functional foods to those who need them, however, will require more than scientific effort alone.

Organizations such as the US National Institutes of Health's new Office of Dietary Supplements, the Agrotechnological Research Institute in The Netherlands, the Department of Food Science and Technology in Nigeria, and various academic institutions and industrial companies across the globe are currently providing leadership in the field of bionutrition[10,15]. It will take these efforts and more to develop, test and realize the promise of tomorrow's breakthroughs.

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