National Nutrition Research Roadmap 2016–2021: Advancing Nutrition Research to Improve and Sustain Health

Interagency Committee on Human Nutrition Research

2016

About the Interagency Committee on Human Nutrition Research

The Interagency Committee on Human Nutrition Research (ICHNR) aims to increase the overall effectiveness and productivity of federally supported or conducted human nutrition research. The ICHNR includes representatives from the departments of Agriculture (USDA), Health and Human Services (HHS), Defense (DoD) and Commerce; the Federal Trade Commission (FTC), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the Agency for International Development (USAID), the Environmental Protection Agency (EPA), the Veterans Health Administration (VHA), and the White House Office of Science and Technology Policy (OSTP). The ICHNR is co-chaired by Dr. Catherine Woteki, the USDA Under Secretary for Research, Education and Economics and Chief Scientist and Dr. Karen B. DeSalvo, the HHS National Coordinator for Health Information Technology and acting Assistant Secretary for Health.

About this Roadmap

This *Roadmap* was developed by the ICHNR National Nutrition Research Roadmap (NNRR) Subcommittee co-chaired by Dr. Robert Holland, USDA National Institute of Food and Agriculture (NIFA) Associate Director of Operations and Dr. David M. Murray, HHS National Institutes of Health (NIH) Associate Director for Prevention and Director of the Office of Disease Prevention (ODP). The NNRR Subcommittee included representatives from each of the participating ICHNR departments and agencies, 28 members in total. Sixteen members of the NNRR Subcommittee served on the NNRR Writing Group. The *Roadmap* identifies research priorities for human nutrition and describes the role of the ICHNR departments and agencies in addressing those priorities over the next five to ten years. This document is published by the ICHNR.

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Suggested Citation

Interagency Committee on Human Nutrition Research. *National Nutrition Research Roadmap 2016–2021: Advancing Nutrition Research to Improve and Sustain Health*. Washington, DC: Interagency Committee on Human Nutrition Research; 2016.

The National Nutrition Research Roadmap was prepared by

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Acknowledgments

The ICHNR appreciates the logistical support provided by the HHS National Institutes of Health and the USDA National Institute of Food and Agriculture. This *Roadmap* would not be possible without the time, talent, and thoughts of the following dedicated NNRR contributors who assisted the ICHNR Committee and ICHNR NNRR Subcommittee by stepping up throughout this process and generously giving of their time and expertise.

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Executive Summary

Improved nutrition could be one of the most cost-effective approaches to address many of the societal, environmental, and economic challenges facing nations across the globe today. These challenges include the morbidity, mortality, and economic burden associated with chronic diseases and disorders. That is, nutrition plays an integral role in human growth and development, in the maintenance of good health and functionality, in genetic disorders such as inborn errors of metabolism, and in the prevention and treatment of infectious, acute, and chronic diseases. To effectively and efficiently advance the role of nutrition in improving and sustaining health, efforts must be made to coordinate nutrition research supported by the federal government, as well as federal workforce development and training efforts that support nutrition research.

Created in 1983, the Interagency Committee on Human Nutrition Research (ICHNR) was charged with improving the planning, coordination, and communication among federal agencies engaged in nutrition research and with facilitating the development and updating of plans for federal research programs to meet current and future domestic and international needs for nutrition. Early in 2013, the ICHNR recognized the need for a written strategic plan to identify critical human nutrition research gaps and opportunities that could be addressed over the next five to ten years. The Committee anticipates that an interagency plan for federal human nutrition research could foster a coordinated approach that would address knowledge gaps, accelerate innovations, and strengthen the capacity of the interdisciplinary workforce that is required to bring these innovations to fruition.

To develop a national plan, the ICHNR created a National Nutrition Research Roadmap (NNRR) Subcommittee with representatives from each of the participating ICHNR departments and agencies. Beginning in the summer of 2014, the NNRR Subcommittee and its subsidiary Writing Group, with the assistance of more than 90 federal experts, developed the *National Nutrition Research Roadmap*, which was reviewed and approved by the ICHNR. The *Roadmap* was developed to engage federal science agency leaders, along with relevant program and policy staff who rely on federally supported human nutrition research, in addition to the broader research community. Initial discussions addressed common knowledge gaps, opportunities, and research themes extracted from a variety of publications and websites, including human nutrition research reviews, as well as federal and non-United States strategic plans and reports. These discussions generated the following three framing questions that covered the broad spectrum of research likely to yield accelerated progress in nutrition research to improve and sustain health for all children, adults, families and communities.

Within these three questions, the following eleven topical areas were identified based on the following criteria: population impact, feasibility, and emerging scientific opportunities, given advances in research knowledge and capacity. In finalizing these topical areas, consideration was given to research gaps across the lifecycle, particularly for at-risk groups such as pregnant women, children, and older adults, in nutrition-related chronic diseases contributing most to the morbidity, mortality, and health disparities in the United States, and in understanding the role of nutrition for optimal

performance and military readiness. The *Roadmap* primarily focuses on population impact within the United States but also considered global reach. While the topical selections focused primarily on reducing nutrition-related chronic diseases in the United States, the research and resource initiatives could guide other national governments, non-government organizations, or collaborative global efforts to advance human nutrition research to improve and sustain health across the globe.

Key Research Priorities for 2016-2021

Question 1: How can we better understand and define eating patterns to improve and sustain health?
Question 1 Topic 1 (Q1T1): How do we enhance our understanding of the role of nutrition in health promotion and disease prevention and treatment?
Question 1 Topic 2 (Q1T2): How do we enhance our understanding of individual differences in nutritional status and variability in response to diet?
Question 1 Topic 3 (Q1T3): How do we enhance population-level food- and nutrition-related health monitoring systems and their integration with other data systems to increase our ability to evaluate change in nutritional and health status, as well as in the food supply, composition, and consumption?
Question 2: What can be done to help people choose healthy eating patterns?
Question 2 Topic 1 (Q2T2): How can we more effectively characterize the interactions among the demographic, behavioral, lifestyle, social, cultural, economic, occupational, and environmental factors that influence eating choices?
Question 2 Topic 2 (Q2T2): How do we develop, enhance and evaluate interventions at multiple levels to improve and sustain healthy eating patterns?
Question 2 Topic 3 (Q2T3): How can simulation modeling that applies systems science in nutrition research be used to advance exploration of the impact of multiple interventions?
Question 2 Topic 4 (Q2T4): How can interdisciplinary research identify effective approaches to enhance the environmental sustainability of healthy eating patterns?
Question 3: How can we develop and engage innovative methods and systems to accelerate discoveries in human nutrition?
Question 3 Topic 1 (Q3T1): How can we enhance innovations in measuring dietary exposure, including use of biomarkers?
Question 3 Topic 2 (Q3T2): How can basic biobehavioral science be applied to better understand eating behaviors?
Question 3 Topic 3 (Q3T3): How can we use behavioral economics theories and other social science innovations to improve eating patterns?
Question 3 Topic 4 (Q3T4): How can we advance nutritional sciences through the use of research innovations involving Big Data?

Each topical area first provides a rationale that explains the importance of the topical area to improving and sustaining health; then identifies research gaps and opportunities; and concludes with suggested short- (could be initiated in approximately

1–3 years) and long-term (could be initiated in approximately 3–5 years) research and resource initiatives. The NNRR Subcommittee also put forth recommendations for developing a diverse, interdisciplinary workforce able to advance nutritional sciences research. The role of current or future federal funding for human nutrition research was not within the charge of the NNRR Subcommittee.

Each of the participating ICHNR departments or agencies briefly describes their contributions to human nutrition research and, as the table below illustrates, gathered insights from senior leadership on relevant contributions to the identified topical areas.

Agency	Commerce	DoD	EPA	FTC	HHS	NASA	USAID	USDA	VHA
Question 1: How do we better understand and define eating patterns to improve and sustain health?									
Q1T1 Health Promotion and Disease Prevention and Treatment	X	X		X	X	X	X	X	X
Q1T2 Individual Differences Including “Omics”		X			X	X		X	X
Q1T3 Population-Level Monitoring	X	X	X		X		X	X	X
Question 2: What can be done to help people choose healthy eating patterns?									
Q2T1 Influences on Eating Patterns	X	X		X	X	X	X	X	X
Q2T2 Interventions		X		X	X	X	X	X	X
Q2T3 Systems Science					X				X
Q2T4 Environmental Sustainability	X	X					X	X	X
Question 3: How can we develop and engage innovative methods and systems to accelerate discoveries in human nutrition?									
Q3T1 Assessing Dietary Exposures	X	X	X	X	X	X	X	X	X
Q3T2 Biobehavioral Science		X			X	X	X	X	X
Q3T3 Behavioral Economics		X		X	X			X	X
Q3T4 Big Data	X	X		X	X		X	X	X

Critical ingredients to addressing the research needs put forth in this *Roadmap* will be interagency collaborations and public-private partnerships among government, academia, and private entities. These types of collaborations and partnerships could potentially:

- Expand the scope, interdisciplinary nature, and potential of a project;
- Enhance the likelihood of broader and more rapid implementation of the results;
- Allow for needed expertise to advance project goals;
- Reduce the cost of a project to an individual collaborator; and
- Increase the likelihood of adequate funding for meritorious projects.

Implementing the National Nutrition Research Roadmap

The ICHNR will distribute this *Roadmap* to encourage all relevant federal departments and agencies to coordinate human nutrition research programs to identify solutions to critical, nutrition-related, chronic disease prevention and health promotion issues. The aim is to have participating departments and agencies develop specific goals, objectives, strategies, and budget priorities based on the *Roadmap* and to identify their unique and collaborative roles, responsibilities, and the required resources and time frames to accomplish those research goals. Given the strong trans-agency interests in a number of these areas of research, we hope to foster coordinated research efforts to address research gaps and opportunities identified in this *Roadmap* and monitor their progress. The ICHNR recognizes the important laws, regulations, and policies for establishing research priorities governing participating federal departments and agencies. For several participating departments and agencies, this includes significant roles and responsibilities of the extramural scientific community to initiate promising investigator-initiated research proposals and to serve on rigorous peer-review systems that have been established to ensure the federal government only funds proposals that maintain standards of scientific excellence. Moreover, the ICHNR avoided further prioritization within each of the topical areas to acknowledge the funding criteria and capacity of government, non-government, and private sector funding agencies in the United States and across the globe varies. Our hope is the dissemination of these critical research gaps and opportunities across the eleven selected topical areas will inspire the broader scientific community—at all developmental stages across the globe—to accelerate advances in human nutrition research to help improve and sustain the health of all children, adults, families and communities.

Introduction

"Let food be thy medicine and thy medicine be thy food."
—Hippocrates, "the Father of Medicine" (c.460 BC to c.370 BC)

For more than a century, scientific discoveries have established the evidence for the integral role that nutrition plays in human growth and development, the maintenance of good health and functionality, in genetic disorders such as inborn errors of metabolism, and in the prevention and treatment of infectious, acute, and chronic diseases.[1] Improved nutrition could be one of the most cost-effective approaches to address many of the societal, environmental, and economic challenges facing nations across the globe today.[2] These challenges include reducing global and domestic food insecurity for a world population projected to reach nine billion in 2040.[3] Fundamental to ensuring global and domestic food security will be meeting the demand for a healthy, affordable, safe, and sustainable food supply. Proper nutrition is also tied to our nation's long-term national security by supporting our national defense personnel.[4,5] Another critical role of proper nutrition could be alleviating skyrocketing health care costs and enhancing economic productivity. In 2008 dollars, annual medical spending in the United States (U.S.) attributable to overweight and obesity was an estimated $147 billion.[6] Other studies have estimated significant indirect (non-medical) costs associated with absenteeism, disability, premature mortality, workers' compensation, and "presenteeism"—attending work while sick.[7]

National investments in human nutrition research have been instrumental in eliminating the occurrence of major dietary deficiency diseases such as pellagra and rickets.[8-10] Past investments have laid the groundwork for identifying health-promoting diets and lifestyles to reduce the incidence of nutrition-related chronic diseases and to provide the public with guidelines for better health based on rigorous assessments of the state of the science.[11] Federal nutrition research investments have also been invaluable in the development of innovative, cost-effective medical nutrition therapies and disease management.[12] More recent food and nutrition research has expanded the evidence of the critical role of the food supply and related food environment to nutrition and health among populations. As one example, a 2014 European Union foresight study on food and health argued for moving towards a more sustainable food system producing safe, sufficient, affordable, and healthy dietary components.

Building the evidence base on topics such as the food supply increasingly requires interdisciplinary scientific approaches and sensitivity to the complexity of food, nutrition, and health issues within the U.S. and across the globe. Human nutrition research now requires approaches that cross traditional health-related fields such as agricultural sciences, biochemistry, dietetics, dentistry, endocrinology, food technology, genetics, medicine, microbiology, molecular biology, physiology, and psychology. These approaches also encompass disciplines less traditionally involved in health-related research, including but not limited to behavioral economics, law, mathematics, physics, political science, regional and urban planning, and sociology.

Further investments in human nutrition research can accelerate progress in improving and sustaining health, as well as reducing the morbidity, mortality, and economic burden associated with nutrition-related diseases and disorders. Increasingly, these burdens are disproportionately faced by Americans of lower-economic status, racial/ethnic minority groups, or who reside in more isolated geographic settings.[13] Even though targeted investments have contributed to significant progress, millions of children across the globe continue to experience malnutrition with dire growth consequences of stunting, wasting or both.[14] Also problematic, adults across the globe continue to suffer from micronutrient deficiencies.[15]

Coordinating Nutrition Research across Federal Departments and Agencies

Addressing knowledge gaps and maximizing opportunities in human nutrition research demand coherent and coordinated efforts. In particular, mutually reinforcing federal nutrition research efforts will be fundamental to effectively and efficiently developing and applying the necessary innovations in research methodologies and technologies to advance human nutrition research. Coordinated federal workforce development and training efforts will also strengthen the capacity of new and current scientists to work collaboratively toward advancing human nutrition research priorities.

Congress first called for improved coordination of human nutrition research within and among federal departments and agencies in the Food and Agriculture Act of 1977 (P.L. 95-113, also known as the 1977 U.S. Farm Bill). Specifically, Congress designated the Secretary of the USDA responsible for establishing "jointly with the Secretary of Health and Human Services (HHS) procedures for coordination with respect to nutrition research in areas of mutual interest" (*See* Sec. 1405 [7 U.S.C. 3121]). Under the aegis of The White House Office of Science and Technology Policy's (OSTP) Federal Coordinating Committee for Science, Engineering, and Technology, the Joint Subcommittee on Human Nutrition Research (JSHNR) was chartered in September 1978 (*See* Appendix A). Consisting of representatives from the HHS, the USDA, and seven other federal departments and agencies, the JSHNR established the groundwork for developing an improved federal coordinated nutrition research planning system through its 1980 report, among other activities.[16] Under the auspices of the OSTP, the JSHNR felt it had accomplished most of its objectives, including the establishment of nutrition coordinators and/or nutrition policy or coordination groups to deal with crosscutting nutrition issues. The decision was made that issues related to human nutrition research could be adequately addressed through the establishment of a collaborative mechanism by the federal agencies that principally support human nutrition research. To realize this goal, in July 1983, the HHS and the USDA created the Interagency Committee on Human Nutrition Research (ICHNR) in association with the termination of the JSHNR in June 1983.

The ICHNR Charter established the scope of this Committee to include (1) all federally supported or conducted research on nutrition with emphasis on human nutrition; and (2) professional personnel needs in nutrition research. The ICHNR's purpose was also set forth, which was to increase the overall effectiveness and productivity of federal research efforts in nutrition by conducting the following functions:

- Improving the planning, coordination, and communication among federal agencies engaged in research on nutrition;
- Facilitating the development and updating of plans for federal research programs to meet current and future domestic and international needs for nutrition;
- Coordinating the collection, compilation, and dissemination of information on nutrition research, including that stipulated by the plan for a database of federally funded nutrition research known as the Human Nutrition Research Information Management System; and
- Preparing reports as necessary on special topics identified by the Committee.

The ICHNR co-chairs set forth by the Charter were the HHS Assistant Secretary for Health and the USDA Assistant Secretary for Science and Education or their designees. Currently, the ICHNR is co-chaired by Dr. Catherine Woteki, the USDA Under Secretary for Research, Education and Economics and Chief Scientist and Dr. Karen B. DeSalvo, the HHS National Coordinator for Health Information Technology and acting Assistant Secretary for Health. In addition, the ICHNR Charter requires representatives from the departments of Agriculture, Health and Human Services, Defense (DoD) and Commerce (specifically, the National Oceanic and Atmospheric Administration [NOAA] while the National Institute of Standards and Technology [NIST] now participates too); the Federal Trade Commission (FTC), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the U.S. Agency for International Development (USAID), the Veterans Health Administration (VHA), and the White House Office of Science and Technology Policy. The Committee is encouraged to invite other departments and agencies, as appropriate; as one example, the United States Environmental Protection Agency (EPA) currently participates, while not an original Charter member.

The ICHNR established the following definition of human nutrition research, accepted by all federal departments and agencies:

> Human nutrition research is the pursuit of new knowledge to improve the understanding of nutrition as it relates to human health and disease and, as here defined, encompasses studies in five major areas: biomedical and behavioral sciences, food sciences, nutrition monitoring and surveillance, nutrition education, and impact on nutrition and intervention programs and socioeconomic factors.

The ICHNR is also responsible for:

- Initiating the first coordinated discussion of nutrition and HIV/AIDS;
- Focusing attention on the interrelationships of food, nutrition, and health and their contribution to health care costs;
- Highlighting research needs related to osteoporosis and knowledge to be learned and applied to space-flight induced bone loss; and
- Holding one of the first trans-federal government meetings focused on overweight and obesity.

After a ten-year hiatus, and in light of the OSTP's encouragement to enhance coordination, the ICHNR was reassembled in 2013. At this time, the ICHNR renewed its commitment to improve coordination and increase the effectiveness and productivity of federal agencies engaged in nutrition research to help ensure that the nation benefits from focused, strategic human nutrition research and that the results provide clear information and guidance for Americans resolved to create a healthier future.

Recognizing the Need for a National Nutrition Research Roadmap

At the meeting held on January 14, 2013, the ICHNR recognized the need for a written strategic plan to identify critical knowledge gaps and opportunities that could be addressed over the next five to ten years to improve and sustain the health of all Americans and to facilitate coordination of federal human nutrition research. The Committee believed a national nutrition roadmap would enable the U.S. government to leverage the limited resources of the relevant federal departments and agencies to develop and coordinate the human nutrition research critical to establishing the evidence base for nutrition-related chronic disease prevention and health promotion intervening strategies. Moreover, the ICHNR recognized a roadmap could be instrumental in shaping the evidence that ultimately informs programs and policies across the federal government. Indeed, recent legislation and several federal policy and programmatic activities have been informed by federally supported human nutrition research and have short- and long-term implications for federally supported human nutrition research (*See* Appendix B). Another advantage of a roadmap could be as a planning tool for accelerating the coordination and communication around the most effective and efficient use of federal research investments and resources supporting human nutrition research across the Government. These could include insights on how potential interagency collaborations could be utilized to enhance engagement of the multiple research disciplines and sectors of society required to find solutions.

Developing a National Nutrition Research Roadmap

To develop a national plan, the ICHNR established a National Nutrition Research Roadmap (NNRR) Subcommittee on July 14, 2014, and appointed co-chairs to lead its development. The co-chairs then appointed representatives to the NNRR Subcommittee from each of the participating ICHNR departments and agencies, 28 members in total. Sixteen members of the NNRR Subcommittee served on the NNRR Writing Group. The Writing Group first met in early August 2014 and met almost weekly through late November 2014, holding twelve meetings in total. More than 90 federal experts contributed to this *Roadmap* (*See* ICHNR NNRR Subcommittee and Acknowledgments).

Initial discussions of the NNRR Writing Group addressed common knowledge gaps, opportunities, and research themes extracted from a variety of publications and websites, including human nutrition research reviews, as well as federal and non-U.S. strategic plans and reports. In addition, the NNRR Subcommittee, which included members also working on the United States Government (USG) Global Nutrition Coordination Plan, 2015–2020, kept abreast of this interagency plan throughout its developmental stages and, where possible, used this *Roadmap* to complement and

contribute to furthering the USG Global Nutrition Coordination Plan's relevant research aims and activities. The principal goal of the United States Global Nutrition Coordination Plan is to contribute to the fullest extent possible to the 2025 Global Nutrition Targets adopted at the Sixty-fifth World Health Assembly in 2012. The NNRR Subcommittee factored in the ICHNR's definition of human nutrition research. Based on the *Dietary Guidelines for Americans*, 2010, the operational definition for eating pattern was "the combination of foods and beverages that constitute an individual's complete dietary intake over time. This may be a description of a customary way of eating or a description of a combination of foods recommended for consumption. Specific examples include USDA Food Patterns, Dietary Approaches to Stop Hypertension (DASH) Eating Plan, and Mediterranean, vegetarian, and vegan patterns."[11]

Ultimately, the deliberations of the NNRR Writing Group generated the following three framing questions that covered the broad spectrum of research likely to yield accelerated progress in nutrition research to improve and sustain health for all Americans:

1) How do we better understand and define eating patterns to improve and sustain health?
2) What can be done to help people choose healthy eating patterns?
3) How can we develop and engage innovative methods and systems to accelerate discoveries in human nutrition?

Within these three questions, eleven topical areas were identified based on the following criteria: population impact, feasibility, and emerging scientific opportunities, given advances in research knowledge and capacity (*See* Key Research Priorities for 2016-2021). In finalizing these topical areas, consideration was given to research gaps across the lifecycle, particularly for at-risk groups such as pregnant women, children, and older adults, in nutrition-related chronic diseases contributing most to the morbidity, mortality, and health disparities in the U.S., and in understanding the role of nutrition for optimal performance and military readiness. Put another way, this *Roadmap* focused primarily on population impact within the U.S. but also considered global reach. While the topical selections focused primarily on reducing nutrition-related chronic diseases in the U.S., the research and resource initiatives could guide other national governments, non-government organizations, and collaborative global efforts to advance human nutrition research to improve and sustain health across the globe.

Each topical area first provides a rationale that explains the importance of the topical area to improving and sustaining health; then identifies research gaps and opportunities; and concludes with suggested short- (could be initiated in approximately 1–3 years) and long-term (could be initiated in approximately 3–5 years) research and resource initiatives. Throughout the *Roadmap*, topical areas are often referred to by their question number and topical number; for example, Question1, Topic 2 is referenced as Q1T2. Feasibility was factored into the selection of the eleven topical areas and the short- and long-term research and resource initiatives put forth within each of the topical areas; nevertheless, the role of current or future federal funding for human nutrition research was not within the charge of the NNRR Subcommittee. The

ICHNR recognizes the important laws, regulations, and policies for establishing research priorities governing participating federal departments and agencies. For several participating departments and agencies, this includes significant roles and responsibilities of the extramural scientific community to initiate promising investigator-initiated research proposals and to serve on rigorous peer-review systems that have been established to ensure the federal government only funds proposals that maintain standards of scientific excellence. Moreover, the ICHNR avoided further prioritization within each of the topical areas to acknowledge the funding criteria and capacity of government, non-government, and private sector funding agencies in the U.S. and across the globe varies.

The *Roadmap* also encompasses recommendations for developing a diverse, interdisciplinary workforce able to advance nutritional sciences research; shares insights from participating ICHNR senior leadership on agency contributions relevant to the identified topical areas; and provides suggestions for developing and enhancing collaborative research.

The *Roadmap* was developed to engage federal science agency leaders, along with relevant program and policy staff who rely on federally supported human nutrition research, in addition to the broader research community. The ICHNR will distribute this *Roadmap* to encourage all relevant federal departments and agencies to coordinate human nutrition research programs to identify solutions to critical, nutrition-related, chronic disease prevention and health promotion issues. The aim is to have participating departments and agencies develop specific goals, objectives, strategies, and budget priorities based on this *Roadmap* and to identify their unique and collaborative roles, responsibilities, and the required resources and time frames to accomplish those research goals. Given the strong trans-agency interests in a number of these areas discussed in the Topics of Interest section, we hope to foster coordinated research efforts to address research gaps and opportunities identified in this *Roadmap* and monitor their progress. Besides stimulating coordinated federal efforts, our hope is the dissemination of these critical research gaps and opportunities across eleven selected topical areas will inspire the broader scientific community—at all developmental stages across the globe—to accelerate advances in human nutrition research to help improve and sustain the health of all children, adults, families and communities.

National Nutrition Research Roadmap

Question 1. How can we better understand and define eating patterns to improve and sustain health?

Topic 1 (Q1T1). How do we enhance our understanding of the role of nutrition in health promotion and disease prevention and treatment?

Rationale

Nutritional status reflects a physiological state that is a culmination of ingestion, digestion, absorption, metabolism, and functional utilization of nutrients and bioactive components in food. Nutrient requirements may change as a result of aging, physiological demands, and/or disease status. Other factors influencing nutrient requirements include sex and gender, body composition, genetics, activity level, environmental exposures, smoking, and other health habits.[17-21] In this very broad topic addressing the role of nutrition in health promotion and disease prevention and treatment, we highlight areas not covered in later sections of this *Roadmap,* such as other emerging basic nutritional sciences areas of the microbiome and the use of "omic" technology (*See* Question1, Topic 2 [Q1T2]). Specifically, we address early development, healthy aging, disease management, mental/psychological health, cognitive development and maintenance, and the use of large prospective population-level data systems to examine the influence of dietary components and eating patterns.

Research indicates that nutritional needs differ across the continuum of health-to-disease, of inactive to active lifestyles, and throughout the lifecycle. However, more work is needed to better understand how these differences impact nutrient requirements. Beginning with maternal health and nutrition, evidence suggests this stage plays a pivotal role in fetal development. That is, studies of children from famine cohorts and other longitudinal population studies indicate that metabolic programming occurs in early development, leading to permanent changes in an individual's physiology and metabolism that affect disease risk later in life and may affect future generations.[22] Furthermore, given increases in pregnancy-related deaths in the U.S. as reported by the CDC's Pregnancy Mortality Surveillance System, in part associated with increases in high risk pregnancy from poor nutrition, research is needed on improving nutrition among pregnant and lactating women.

With the aging of the U.S. population, it has become more critical to understand the complex interactions of diet and health among older individuals who often have a complex set of comorbid conditions. While life expectancy is increasing in the U.S. and in most countries, an increasing proportion of this longer lifespan is spent with limitations and a poorer quality of life, largely attributable to chronic, non-communicable diseases. Evidence indicates several nutritional factors may predict longevity in midlife and may have different associations with health outcomes later in life. Research in older adults is also examining the influence of

nutrition and physical activity on conditions such as frailty, chronic kidney disease, sarcopenia, macular degeneration, and neuro-degenerative conditions, along with cognition and functional status. Current and lifelong physical activity also has a major impact on musculo-skeletal health and mental and physical functionality in older adults. Therefore, understanding the complex interactions of diet, activity, and health among older individuals is critical.

Research has led to major advances in combining nutrition with pharmaceutical and medical management of major chronic disease.[23-25] In addition, research has demonstrated that nutrient intake and nutritional status can affect a number of chronic metabolic and autoimmune conditions, including regional and systemic inflammation. As one example, certain nutrients (e.g., iron, zinc, vitamin A, protein) play key roles in host immunity, and can influence a person's susceptibility to infections. Infection and inflammation can, in turn, impact nutritional status through effects on appetite, metabolic demand, or other mechanisms. Research advances have identified specific nutrients important in the management of select inborn errors of metabolism, including phenylketonuria and galactosemia. Research is also continuing to explore the broader role of nutrition in mitochondrial dysfunction. Furthermore, research has expanded the role of enteral and parenteral nutrition in the management and maintenance of nutrition status for conditions such as intestinal failure and acute events such as surgery when oral nutrition is not possible. Another ongoing effort has been exploring how to improve oral health since poor oral health has been shown to limit one's ability to consume foods with nutrients beneficial to overall health. Furthermore, challenges remain in understanding how nutritional status, along with eating and activity patterns may improve the management of other neurological conditions such as Parkinson's disease, epilepsy, or autism. Limited research has focused on the role of nutrition in mental and psychological health and the development and maintenance of cognition. Likewise, the nutritional requirements of individuals with mobility limitations or other special needs require further delineation. Finally, more work is needed to understand how to foster healthy eating and activity patterns among adults with mental impairments who live independently.

Nutrition plays an essential role in survival and optimal health. In some cases, those relationships have been more clearly demonstrated, such as the role of folate in the prevention of neural tube defects, the negative influence of *trans* fat on blood lipids, or the role of sugar as one of the etiologic factors in the development of dental caries. Conversely, many relationships are less clear for combinations of nutrients or eating patterns. For example, both a Mediterranean-style and plant-based diet have been shown to be beneficial for health; nevertheless, more research is needed to explain how these eating patterns and the specific food components impact health promotion and disease risk.[26,27] Recent research exploring the role of eating patterns on mortality suggests that overall nutritional quality or certain food groups (e.g., fruits, vegetables) may be more predictive than individual nutrients. Research on eating patterns and health is refining the examination of individual components by further segmenting

components within large food groups by their nutrient constituents; for example, by segmenting fruits and vegetables into dark/green leafy and orange versus starchy or meat and legumes by types or sources of protein.

Research Gaps and Opportunities

An increased focus on the role of nutrition in early development is needed to understand how metabolic programming in early development influences disease risk later in life.[28] Given evidence suggesting that physical activity and nutrition may interact in their influence on metabolic programming, such research could also include examination of the role of physical activity and its interaction with nutrition. Likewise, the role of nutrition deserves further exploration in neurological development, including its impact on cognitive and behavioral development, as well as the maintenance of cognitive function throughout life. In addition, more mechanistic research in humans and relevant animal models is needed to establish the causal relationship between diet and disease progression. The role of specific nutritional approaches independent of and in combination with physical activity interventions for minimizing acute and chronic pain also needs further exploration.[29]

In the arena of disease treatment and management, research is needed to explore the complex interactions of nutrients and eating and activity patterns related to management of multiple co-morbid diseases—particularly among older populations. This includes addressing knowledge gaps specific to the role of malnutrition, particularly its effects on body function and clinical outcomes. If exposure data on nutrition and eating patterns are included, the Precision Medicine Initiative could contribute to addressing these research gaps. The Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative may help to identify new tools and insights to enable a more in-depth exploration of the role of nutrition on conditions such as Alzheimer's, along with other forms of dementia and depression (*See* Q3T2 for further discussion on the use of tools related to brain imaging in the examination of neurocognitive influences on nutrient and food intake). Another research need is a deeper understanding of the role of diet (total diet as well as individual nutrients) in the treatment and recovery from alcohol use disorders and other substance use disorders.[30-33]

Much more research is needed on the interaction between circadian timing of intake and health outcomes. Evidence suggests hunger/satiety and energy production, along with the expression of approximately one-third of the genome, vary in a rhythmic pattern of approximately 24 hours. More recently the human gut microbiome has been reported to show strong and reproducible circadian variations. The role of late day food consumption in weight gain, metabolic syndrome, and cancer risk remains controversial. The inclusion of data on timing of food consumption in both population studies and interventional research may clarify these issues, and improve our understanding of the health effects – and individualized health effects – of different dietary regimens (*See*, as one

example, The National Institutes of Health Big Data to Knowledge [NIH BD2K] initiative *and* Q3T4).

In the arena of disease prevention and health promotion, research could explore in more detail how different dietary regimens (e.g., Mediterranean-style diet, plant-based diets) and their components influence health outcomes.[26,34] Several population-level approaches have been used to explore these issues. As one example, the CDC, in partnership with the USDA, conducts the National Health and Nutrition Examination Survey (NHANES), a nationally representative cross-sectional study designed to evaluate, among other variables, the nutritional status of the free-living U.S. population. Estimates for a wide range of measures are reported for two-year intervals. Nonetheless, the NHANES cannot be utilized to examine the pathophysiology of disease without linkages to longitudinal data on health outcomes. Observational cohorts provide long-term follow-up and allow for exploration into the disease process; as one example, the National Heart, Lung, and Blood Institute uses various observational studies to collect data on factors associated with the development of overweight and obesity, as well as their relation of overweight and obesity to heart disease and its risk factors, pulmonary diseases, and sleep disorders. These types of cohorts also allow for the examination of relationships between diet and health. A number of long-term cohorts incorporate extensive and repeated measures of dietary and nutritional assessments and have been designed to examine how diet and other health behaviors influence a range of different disease outcomes over the lifecycle.

In an effort to merge data across multiple large prospective cohorts that gather dietary information, the National Cancer Institute Cohort Consortium supports meta-analysis across multiple national and international cohorts. Equally as important will be the use of cohorts nested within health care delivery systems. Integrating long-term clinical care data with data on nutrition and other lifestyle and sociodemographic factors that influence health will enhance our ability to understand the role of nutrition in the context of multiple factors that influence the pathophysiology of disease. In addition to observational study designs, research needs in the area of interventions and randomized controlled trials are addressed in Q2T2. More rigorous experimental intervention research designs are needed that examine causal relationships among the diverse aspects of diet, physical activity, and sedentary behavior. Data characterizing the range of responses across several intake levels are critical for establishing the Dietary Reference Intakes (DRIs), which represent the most current scientific knowledge on nutrition needs of healthy populations.

Research is also needed to better understand the impact of dose and timing of dietary supplement intake on the absorption/concentration of other nutrients, particularly from foods (e.g., the impact of zinc supplementation on iron status). Currently, the most common analytical approach used when examining the association of dietary supplement intake with health outcomes assumes additive effects and adds nutrient intakes from supplements and foods. Given the type and dose of the supplement, however, the effect of supplements may not simply

be additive to nutrients from food. Future work must recognize that supplements of individual nutrients—minerals in particular—may have both negative and positive impacts on nutrient status.

Research and Resource Initiatives

Short-term Initiatives

- Incorporate the examination of food, nutrition, eating, and activity patterns in research on the management of multiple complex comorbid diseases including the assessment of malnutrition.
- Support mechanistic research in humans to establish causal relationship between nutrition and disease pathophysiology.
- Support mechanistic research to understand how nutritional status affects individuals' response to different types of physical activity across the lifespan.
- Examine the role of nutrition, physical activity, and other health habits during pregnancy/gestation and early childhood in the support of good health and the avoidance of adverse health outcomes throughout the lifespan.
- Explore the potential to incorporate research on the role of nutrition in brain function within the context of the BRAIN Initiative.
- Expand the exploration of the association of eating patterns with cause-specific morbidity and mortality within large epidemiologic cohorts.
- Explore the potential to merge dietary and nutritional data across multiple existing prospective cohort studies, including efforts such as the NCI Cohort Consortium, to conduct meta-analyses on the association of nutrition, food, and eating patterns with multiple disease outcomes.

Long-term Initiatives

- Encourage collection of nutrition and activity-related data within the health care delivery systems for the integration of long-term clinical care information and health information systems with data for disease outcomes including the assessment of malnutrition.
- Examine the role of nutrition, physical activity, and other health habits in the support of good health and the avoidance of adverse health outcomes in older individuals, including those who are healthy with minimal chronic conditions, as well as those with complex comorbid conditions, and cognitive and physical disabilities.

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Topic 2 (Q1T2). How do we enhance our understanding of individual differences in nutritional status and variability in response to diet?

Rationale

Individuals exhibit significant variability in their nutritional status and may exhibit similar differential responses to alterations in diet. Extreme examples of this variability are relatively rare conditions such as inborn errors of metabolism. However, research suggests that even common conditions such as viral illnesses and increased physical exertion, such as vigorous physical activity in extreme weather conditions, may temporarily alter nutrient absorption and influence nutritional status, creating short-term deficiencies of water or electrolytes. Likewise, based on genetic or other characteristics, such as baseline nutrient and energy expenditure status, individuals may exhibit differential response to similar diets. The application of emerging, high-throughput analytical technologies in combination with established research approaches enhances our ability to define individual differences in health, responses to diet, and the development of disease. Established research approaches include studies incorporating the use of radio- or stable-isotopes to determine individual differences in nutrient metabolism. Emerging technologies include “omics”-based approaches such as nutrigenetics and nutrigenomics, transcriptomics, epigenomics, proteomics, and metabolomics.[35-38] In this topic, we describe factors that may contribute to several areas of particular, near-term promise related to enhancing the ability to identify and act on individual variability in response to diet. Examples include the microbiome; the effect of exposures on epigenetic expressions over the lifespan, with emphasis on early life exposures; the role of enhanced data capture of the many exposure characteristics, sometimes described as the “exposome,” to improve the identification of high risk phenotypes; and the contribution of advances in bioinformatics technologies.

“Omics”-based approaches vary widely depending on the technology and the nature of biomolecules to be identified and studied. Genetic and transcriptomic approaches employ high-throughput DNA, RNA, and protein analysis methods. On the other hand, proteomic and metabolomic approaches employ highly sensitive mass spectrometric (MS) and/or nuclear magnetic resonance (NMR) approaches to identifying and quantifying molecules of interest. These approaches can be targeted for use within individual tissues or for the systematic assessment of biological fluids. Metabolomic and proteomic approaches can assess a group of targeted compounds, or globally profile known and unknown compounds. The use of biological network approaches, or “systems biology,” will advance our understanding of the interaction of nutrition with DNA, RNA, and protein expression and function and subsequent metabolic and physiological responses.

Described as "the ecological community of commensal, symbiotic, and pathogenic microorganisms that literally share our body space,” the human microbiome consists of about 100 trillion microbial cells, outnumbering human

cells 10 to 1.[39] Diet can influence the microbiome, and variation in the microbiome between and within individuals over time can contribute to variation in response to foods consumed. Changes in the composition of the gut microbiota are associated with several clinical conditions, including obesity, type 2 diabetes mellitus, and certain types of allergies. Further, short- and long-term individual variation in the gut microbiome is vast, even in healthy individuals. Research has also shown how changes in oral microbiota are associated with dental caries and periodontal disease.[40,41] More work is needed to increase our understanding of individual variations in both gut and oral microbiomes, the impact of diet and physical activity on the microbiome, and the mechanisms by which the gut and oral microbiota and their metabolites impact host physiology and the development of disease. Furthermore, at present, the gut microbiome is recognized as contributing to absorbable nutrients, thus affecting overall nutritional status; however, the degree of contribution is difficult to measure and thereby not well understood. Similarly, the impact of the oral microbiome on overall nutritional status and on the gut microbiome has not been well established.

With the recognition that many chronic diseases are influenced by developmental or early life exposures and health habits including eating patterns, new research has focused on epigenetic mechanisms (i.e., dynamic alternations in the transcriptional potential of cell). These mechanisms are thought to be one factor mediating the influence of early nutritional status on the risk of disease later in life. Epigenetic mechanisms may be altered throughout life, and it is theorized that alterations at many vulnerable physiological periods may affect disease susceptibility as well. Further, this field is exploring how risk is transmitted across generations through genomic imprinting and other epigenetic mechanisms.

Utilization of emerging “omics”-based technologies in conjunction with established research techniques, such as nutrient balance studies and the use of radio- and stable-isotopes to understand nutrient metabolism, will provide unique methodologies for assessing individual variation. As with other areas of biomedical research in which new “omics”-based technologies are anticipated to provide insights related to individual variation, we need to enhance the potential to capture precise information about individual variability in exposure and in response to a wide range of social, economic, and environmental factors that may modulate physiology and health. Increased standardization on how these data are captured, along with efforts to develop phenotypic risk groups, will enhance the capacity to understand how variability in exposure influences response. Advances in more precise and comprehensive approaches for capturing these exposures such as the NIH’s Precision Medicine Initiative and Big Data to Knowledge (BD2K) initiative are addressed in other *Roadmap* topical areas (*See* Q2T1, Q3T1 and Q3T4). Similarly, research designs are required that can minimize potential confounding in the analysis of the often interrelated and collinear factors, particularly within observational research approaches. Baseline nutrient status and energy expenditure may be important sources of variation;

approaches are needed to effectively and efficiently screen research participants for their baseline nutritional status and energy expenditure at study entry.

In addition to the appropriate use of advanced analytical technologies, enhanced use of bioinformatics processing is needed to analyze high-dimensional data and integrate “omics” data along with data collected, using established research techniques from a variety of sources. These technologies allow for finer examination of multiple interactions between specific food components and biological pathways at the levels of genes, proteins, and metabolites. Increased focus has been dedicated to the integration of “omic” technologies, along with established nutrition research techniques, with the overall goal of mapping interactions between nutrient intake and molecular processes that underlie metabolic health and disease.

Research Gaps and Opportunities

Significant research gaps remain with regard to characterizing and understanding the factors that affect individual variation in nutritional status and the ways metabolic pathways are impacted by different physiologic states; for example, pregnancy, development, aging, and obesity. More work is also needed to understand individual responses to alterations in diet, physical activity, and environmental exposures. Cross-disciplinary research on the role of varying levels of physical activity or sedentary lifestyle on hydration, changes in gut motility, and digestion and absorption of nutrients is needed to better understand optimal levels of physical activity in combination with nutrient intake.

Using “omics” technologies coupled with established nutrition research techniques for the study of individual differences in nutritional status provides tremendous opportunities to improve and sustain nutritional health. Indeed, existing and emerging technologies will advance our ability to understand interactions between eating patterns and human metabolic processes involving genes, proteins, and metabolites that contribute to individual variation. As one example, data gleaned from studies assessing the role of the microbiome combined with “omics” technologies may enable the identification of biomarkers that are collectively affected by nutrient intake, eating patterns, and microbiome function. This type of research may enhance our ability to quantify the predictive utility of these biomarkers for overall health and disease.

Nutritional sciences research aims to utilize emerging technologies to ultimately identify optimal eating patterns that contribute to the maintenance of health, prevention, and control of disease at the population level in addition to the development of specific nutritional and lifestyle recommendations at the individual level that may vary based on specific disease conditions or risk for disease. Enhanced tools in the area of metabolomics and proteomics may enable the development and study of personalized eating patterns.[42] Such research may allow broad-based public health dietary guidance to become more specific in regard to eating patterns that may improve health and reduce risk of common disease for specific risk groups in the population. This innovative and

promising public health approach to dietary guidance has the potential to be complemented with more customized diet and activity "prescriptions" for disease treatment for individuals. Such customized prescriptions would be based on an individual's unique profile of characteristics, including existing diseases, disease risk, and a variety of other factors—all of which might alter "omics" signatures pertaining to characteristics such as genetic, behavioral, and microbiome profiles. These types of approaches could also be tailored based on more precise assessments of environmental and other exposures that may not be measurable by existing "omic" signatures.

One unmet challenge in this field is the development of model systems for basic research, such as tissue-on-a-chip models that include linked systems models that incorporate human-like food metabolism. Such models can be used to elucidate the effects of dietary components at a molecular and tissue level. These rapidly evolving model systems may better approximate effects in humans than vertebrate animal models, and are an excellent system for studying gene-diet interactions.

Research and Resource Initiatives

Short-term Initiatives

- Support collaborative, interdisciplinary research for understanding the effects of dietary and physical activity patterns and individual variability on biologic measures related to the epigenome, microbiome, metabolome, and proteome.
- Collate existing data in an effort to establish the relationship between eating patterns, individual variation, healthy development, and disease.
- Develop tissue-on-a-chip models including linked system models that incorporate human-like food metabolism to elucidate the effects of dietary components at a molecular and tissue level.
- Support research in humans to understand the effects of diet-induced changes in the microbiome, and other omics (e.g., epigenome, metabolome) on subsequent changes in biologic processes and health.
- Support research to understand the potential health effects of consuming nutrients (i.e., pre- or probiotics) that alter the gut or oral microbiome.
- Characterize the absorbable nutrient contributions of the gut microbiome under various conditions and with diverse populations.

Long-term Initiatives

- Characterize individual differences in "omics" using randomized controlled trials and other research designs as appropriate.
- Utilize adaptive and other controlled trial designs to test the potential for individualized nutrition and lifestyle interventions (i.e., physical activity) based on "omic" signatures to affect specific health outcomes.
- Support research to identify genetic characteristics related to differences in nutritional requirements and metabolism.

Q1T2 Glossary

Epigenetics	Study of physiological traits caused by modifications of gene expression (but not DNA sequence)
Epigenomics	Study of the complete set of epigenetic modifications on the genome
Exposome	Measures of environmental exposures of an individual
Metabolomics	Study of small molecules and their interaction
Microbome	Ecological community of microorganisms that reside within the body
Nutrigenetics	Study of the effect of genetic variation on responses to diet
Nutrigenomics	Study of the effect of diet and nutrition on gene expression
Proteomics	Study of the structure, function, and interaction of proteins
Transcriptomics	Study of the complete set of RNA transcripts produced by the genome

Topic 3 (Q1T3). How do we enhance population-level food- and nutrition-related health monitoring systems and their integration with other data systems to increase our ability to evaluate change in nutritional and health status, as well as in the food supply, composition, and consumption?

Rationale

Monitoring provides information on the population's health and nutritional status as well as on food system variables at one point in time and across time. For more than a half century, monitoring systems to assess population-level food consumption, nutrition status, and health status have informed public health practice and the nutritional sciences.[43] However, existing systems do not meet all the data needs for understanding an increasingly complex food system. This topic describes why food and nutrition monitoring systems are important, how monitoring data are used, and the opportunities that exist to enhance nutrition monitoring.

As explained in Q1T1, diet is a key component of health[11] and is influenced by the available food supply.[44,45] The U.S. food system is complex, global, and dynamic, as it is affected by social, economic, agricultural, and political factors. In addition to being impacted by changes in the food system, diet is shaped by other influential factors such as knowledge about diet, social support for making dietary changes, foods available in specific settings, consumer budget constraints, or health conditions and their treatment.[44,45] For this reason, comprehensively monitoring the multiple factors influencing diet as well as the nutritional and health status of populations is needed to address important questions such as:

- What foods and beverages are in the food supply?
- What is the source (domestic or imported) of the foods and beverages in the food supply?
- What are the costs of food and food production?
- What is the nutritional composition of the food supply?
- Where are foods and beverages bought, served, and consumed?
- Who consumes them, when and with what frequency?
- What nutritional supplements are used, and how does that use influence the nutritional status of the population?
- What is the nutritional status of the population?
- To what extent do people have eating patterns consistent with recommended patterns?
- How does the quality of the food supply and the nutritional status of the population relate to their health status?
- How well do individuals understand dietary recommendations?
- What policies, systems, and environmental and social supports are in place that make it easier or more difficult for individuals to make healthy dietary choices?

Monitoring data have widespread utility, as many stakeholders are interested in answers to these questions.[46] Policymakers, practitioners, clinicians, and other decision makers use the data to identify where to commit limited resources and to assess whether decisions and interventions have desired outcomes. Researchers use the data to identify who is engaged in specific parts of the food system, as well as to understand the relationships between different parts of the system. Researchers also use the information to develop and test hypotheses about what actions could improve nutritional status and health outcomes. This information, in turn, can inform policy decisions, guidance for practitioners, recommendations, as well as consumer nutrition education and health communication messages.

A number of federal data systems monitor select aspects of the U.S. food system (*See* Appendix C). For example, the nationally representative population-based survey, the National Health and Nutrition Examination Survey (NHANES) and its dietary assessment component, What We Eat in America (WWEIA), is used to monitor dietary and supplement intake of Americans. The NHANES also monitors many measures of nutritional status via physical examinations (e.g., weight, height, body composition) and laboratory tests of nutrition and health (e.g., various nutrients and their metabolites, along with clinical measures of inflammation, liver disease, or cardiovascular disease). In addition, the NHANES monitors physical activity and health outcomes through questionnaires and in-person evaluations. Nonetheless, the components measured vary by survey cycle and the demographics of participants. In addition to this national nutrition monitoring system, the CDC has two systems that gather selected self-reported measures of diet, physical activity, and height and weight at the state-level; specifically the Behavioral Risk Factor Surveillance System (BRFSS) and the Youth Risk Behavior Surveillance System (YRBSS).

The ongoing Food and Drug Administration (FDA) Total Diet Study collects data on levels of contaminants, pesticide residues, and nutrients in nearly 300 table-ready foods in the U.S. and estimates dietary intakes of these substances. The USDA Pesticide Data Program collects data on pesticide residue on fruits, vegetables, and other commodities which are used by the Environmental Protection Agency (EPA) for its dietary exposure assessments on pesticides. The USDA also collects many types of data on the food system including the Food Availability (Per Capita) Data, which represent the aggregate food supply in any given year, as well as several indicators of food prices and expenditures. The USDA tracks the nutrient composition of more than 8000 foods in the National Nutrient Database for Standard Reference. In addition, the USDA monitors food security using the Food Security Supplement on Current Population Survey and periodic School Nutrition Dietary Assessment (SNDA) studies, and School Food Purchase studies provide detailed, nationally representative data on foods available at schools and foods eaten at school and on school days. The Dietary Supplement Ingredient Database (DSID), created through a joint effort by the USDA and the NIH, provides analytically derived estimates of the ingredient levels of multivitamin/mineral supplements. The NIH and the National Library of

Medicine also sponsor the Dietary Supplement Label Database (DSLD), a searchable catalog containing the full label contents from a sample of dietary supplement products marketed in the U.S.

Environmental and policy supports for nutrition and diet are available for select settings, and monitoring systems exist to capture data on these factors. For example, the CDC's School Health Profiles and the School Health Policy and Practices Study provide this information on schools, and the Maternity Practices in Infant Nutrition and Care (mPINC) Survey documents supports for breastfeeding in maternity care settings. The USDA's Food Environment Atlas and Food Access Research Atlas provide sub-national data on indicators related to food availability and access at the regional, state and local levels. Examples include store/restaurant proximity, food prices, federal food and nutrition assistance program availability, and community demographic and economic characteristics. The CDC's Chronic Disease State Policy Tracking System collects information on state legislation and regulations related to chronic disease and chronic disease risk factors such as nutrition.

Research Gaps and Opportunities

Existing monitoring data and systems do not meet all research, practice and policy decision-making needs. Monitoring can be enhanced by establishing new data systems, incorporating relevant nutrition or nutrition-related health measures into existing systems such as electronic health records and health surveys, or by identifying and leveraging data already collected for other purposes. As the rapidly changing field of wearable devices to measure health parameters advances, research opportunities to explore the use of these devices in nutritional and related health status monitoring should be encouraged and supported to keep pace with emerging opportunities for accurate, timely, and cost-effective approaches for data capture. Developing standardized and efficient protocols for creating and sharing data through existing or emerging public-private partnerships could facilitate expansion of nutrition data resources for addressing important nutrition monitoring research questions.

Research gaps in monitoring include:

Key aspects of the U.S. and global food system and points of food distribution are not adequately monitored

Limited information exists on the nutritional environments and policies in key settings such as childcare, worksites, communities, and the variety of settings in which federal food and nutrition assistance programs operate. More information is also needed about the nutrient and food group composition of foods marketed and sold throughout the U.S., but manufactured elsewhere. Similarly, foods and beverages manufactured in the U.S. but exported and marketed elsewhere globally should be monitored for their impact on nutrition-related disorders such as the promotion of obesity. Consumers—some of whom are concerned regarding certain items (e.g., allergens, genetically modified ingredients)—want point-of-sale access to up-to-date, product-specific ingredients in all foods. Key

constructs need to be identified, and measures for these constructs selected or developed. To the extent possible, these measures should be valid and standardized to improve comparability across surveys.

Current assessment methods and measures are not feasible for all monitoring needs

For a number of aspects of monitoring, accepted and validated methodologies exist. For example, multiple 24-hour dietary recalls are recognized as the least-biased way to monitor food and nutrient intake in populations,[47] and 24-hour urine voids are used to optimally monitor sodium intake.[48] However, these types of assessments can be resource intensive, and as such, are not always feasible in population surveys where respondent burden or cost may be an issue. Recently, a web-based automated, self-administered 24-hour dietary recall known as ASA24 was shown to be a low-cost method for collecting accurate dietary intake information.[49] But more work remains on developing valid, easy-to-use assessment measures and biomarkers for multiple aspects of dietary behaviors and nutritional status. Innovations in mobile technologies applied to the field of dietary assessment may lead to further advances.

Sufficient information is not collected on all relevant subgroups in the population

Eating patterns, nutritional needs, nutritional status, and food security vary by characteristics such as age and physiological or health status (e.g., pregnancy, presence of chronic diseases).[10] Because of resource limitations, large-scale surveillance systems may not always capture this information for vulnerable subgroups. Such information would help improve dietary guidance, focus dietary interventions to those most in need, and help characterize the link between diet and health for these groups.

More information is needed on individual-level factors that influence diet

Limited periodic information exists on the population's knowledge and attitudes about diet, as well as their social supports for making food choices. Such information helps practitioners understand what knowledge gaps exist and what interventions might be most acceptable. Questions could be incorporated in existing surveys or systems, or periodically assessed in new surveys.

In addition to these research gaps, the following opportunities could accelerate more effective use of existing data systems:

More frequent updating of dietary composition data to reflect the dynamic nature of food and beverage product development and the global nature of the U.S. food supply

Dietary composition data are critical for translating foods and beverages as consumed into quantities of nutrients, guidance-based food groups, and other key dietary components relevant to public health. Because new food and beverage products are introduced into the food system at a rate of about 20,000 per year, current monitoring systems do not have the capacity to capture in real

time up-to-date dietary composition data on foods and beverages as they are introduced or reformulated.[50] Identifying new ways to more quickly incorporate information about these new or reformulated foods into dietary composition databases could reduce this information gap. This could include strengthening our existing food labeling database or working with the food and beverage industry through public-private partnerships.

Maximizing the use of data collected for other purposes for food and nutrition monitoring purposes
Because limited financial resources for monitoring exist, determining whether and how data collected for other purposes can be incorporated into food and nutrition monitoring systems could improve monitoring efficiency. Examples include information collected in electronic health records, customer purchase data collected by stores, industry food composition data, and legislative data regarding food policies.

Establishing linkages between monitoring data collected across the continuum of the food system to individual-level human nutrition
Existing monitoring systems primarily collect data on one or two components of the food system such as nutrient intake of individuals or which foods are in the food supply. However, linked data across multiple aspects of the food system can improve the understanding of the interrelationships within the system, as well as the ways changing one part of the system can impact other parts of the system. In addition, linking data on the food system to data on individual-level food consumption, nutritional status, and health outcomes would allow the examination of the ways changes in the food system influence human health at the population level. Models that incorporate such multilevel data also need to be developed.

Exploring how existing monitoring systems could be modified to prospectively capture links between lifetime diet and health outcomes
Links between diet, physical activity, and many health outcomes have been established; however, further examination is needed on whether critical time periods for nutrient intake exist or how lifetime dietary intake and physical activity patterns affects health outcomes. Monitoring systems could be enhanced to address this gap.

Research and Resource Initiatives

Short-term Initiatives

- Develop a federal nutritional monitoring plan—the National Nutrition Monitoring and Related Research Act of 1990 is one example of a legislative mandate that was instrumental in coordinating federal national nutrition monitoring activities to meet current and emerging data, reporting, program, and policy needs during the period of 1992 to 2002 (P.L. 101-445).
- Pilot test and evaluate nutrient databases for branded food products through innovative partnerships with the food and beverage industry, such as the

public-private partnership of Agricultural Technology Innovation Partnership (ATIP) Foundation, USDA, and the International Life Sciences Institute North America that is working to develop a publicly available "Branded Food Products Database for Public Health."

- Analyze foods bought, served, and consumed in schools using the USDA's School Nutrition Dietary Assessment Study, 2014–2015.
- Review existing consensus and expert body reports to identify specific indicators that could be included in monitoring systems.

Long-term Initiatives

- Ensure collection of dietary and nutrition status information on key population subgroups such as infants and toddlers, older adults, pregnant and lactating women, and racial/ethnic groups and in key population settings with limited data such as early care and education centers and worksites.
- Develop low-burden, low-cost, and valid assessments for dietary behaviors or nutritional status that can be used in population surveys.
- Ensure monitoring efforts include adequate coverage and sampling of federal food and nutrition assistance programs to support performance monitoring and evidence-based improvement strategies for these programs.
- Develop new, as well as enhance existing content of packaged food and beverage and restaurant databases to monitor the sales patterns and nutrient content of foods and beverages.
- Develop and validate measures for assessing key aspects of the U.S. and global food system and points of food distribution not currently monitored.
- Expand the capacity of food production and food composition data systems to reflect the food environment in real-time.
- Improve the ability to link data from multiple aspects of the food system and subsequent individual-level nutrition and health outcomes through geocodes or other standardized linking methods.
- Determine whether and how data collected for purposes not related to health or nutrition could be used to enhance food and nutrition monitoring systems.
- Explore how existing monitoring systems could be enhanced to capture links between lifetime diet and health outcomes.
- Develop a process for efficiently monitoring emerging research, and determine when and how important new topics should be incorporated into monitoring systems.
- Explore the development of monitoring systems capable of collecting data over the life course through longitudinal data started early in life or *in utero*.

Question 2: What can be done to help people choose healthy eating patterns?

Topic 1 (Q2T1). How can we more effectively characterize the interactions among the demographic, behavioral, lifestyle, social, cultural, economic, occupational, and environmental factors that influence eating choices?

Rationale

To accelerate improvements in addressing the morbidity and mortality associated with nutrition-related chronic diseases, research should develop approaches to more effectively characterize—individually and collectively—the multiple interacting, and potentially conflicting, factors that influence food choices. This is a challenging but necessary undertaking because each day, at multiple meal or snack occasions, individuals, families and social groups make food choices. Research has shown that a combination of factors either consciously or unconsciously influence eating choices, all of which converge to determine what, when, why and how much we eat.[51,52] This topic focuses on six key influencers of eating choices: biology, behaviors, socioeconomic status, occupational factors, environmental factors, and cultural beliefs.

Biological factors have marked influences on food choices. From *in utero* into childhood, research has shown how sensory experiences can and will shape future food preferences.[53] Improving our understanding of how chemical senses develop and function during early childhood may be key to promoting healthy choices as a child matures.[54] Genetics also serve an important role; for example, sour, sweet, bitter, and salty preferences have, in part, a genetic basis.[55] More research is needed to understand how these biological issues—individually and collectively—interact to promote or hinder healthy food choices.

Another important contributor to food choice is behavior, which is in large part a function of biology, education, environment, and experiences learned and acquired throughout life. All human behaviors are influenced by interactions with family, friends, peers, and other closely or remotely designated social structures; the same applies to food choices and behaviors. Many food choices are shaped by prior and ongoing experiences with those foods consumed during the first years and by the ways in which parents or caregivers interact with and present food to a child, including emotional context and feeding practices.[56] Beyond this, consumers are inundated with nutrition information available from multiple sources including peers, family, the Internet, television, marketing and social media, food and menu labeling, and the like, which makes it difficult to discern credible information and make healthy choices.[57] The confusion between food messages and marketing as to what constitutes “healthy eating” creates tension among families, peers and communities.[58] In addition, social modeling significantly influences food choice behaviors.[59] That is, children and adults tend to decide when, what, and how much to eat based on the people around them.

Other behaviors with biological implications that may be very important with regard to food choices are physical activity[60] and sleep[61,62]. For example,

research indicates that compared to adolescents who obtain adequate sleep, adolescents who sleep too little are more likely to consume less fruits and vegetables and more fast food and this may result in higher body weight and other adverse health outcomes.[61] Similarly, adult men who experienced acute sleep deprivation reported higher self-reported hunger and chose larger portions of snacks.[63] Thus, behaviors are critical with regard to food choice, especially given the complexity of what influences eating behaviors and the demonstrated difficulty in helping at-risk individuals, adults, families, and communities make sustained nutrition-related behavior changes.

In addition to and interacting with biology and behavior are socioeconomic status and other critical demographic factors. Recent data suggest that eating patterns vary among U.S. infants based on maternal race/ethnicity, income, and education, and these prenatal and early infancy differences may lead to near- and long-term disparities in food choices.[64] Moreover, an individual's perception of costs—including both monetary and time—has been associated with the propensity to choose healthy foods such as fresh fruits and vegetables.[65] Regardless of income, research indicates taste is the most important factor influencing food purchases.[65] However, low-income consumers have less discretionary income and tend to have a more difficult time accessing supermarkets and chain grocery stores, which tend to offer more healthful products such as fresh fruits and vegetables than convenience stores. This may explain their lower consumption of healthy foods and beverages, as compared to higher income consumers.[66] A healthy diet should be affordable for most U.S. households;[67,68] therefore, more research is needed to understand how socioeconomic status and other critical demographic factors affect food choice.

While employment status is often considered when evaluating socioeconomic status, more targeted research has demonstrated the independent role of occupational risk factors on nutrition-related behaviors and chronic disease outcomes.[69-71] This work is laying the foundation for more effectively targeting organizational level factors in worksite interventions such as scheduling to reduce the negative impacts of shift work on health outcomes, preventing worksite hostility, and designing worksite policies, programs and practices that promote health and prevent disease. Nevertheless, more work is needed to understand occupational risk factors and occupational health disparities; specifically, the pathways by which shiftwork, work-life conflict, and the physical and non-physical demands of an occupation contribute to nutrition-related chronic diseases.[72,73]

The role of environmental factors on food choice has been explored over the last decade.[74,75] A 2009 review of neighborhood food access reported that low-income, racial/ethnic minority, and rural communities faced limited access to supermarkets more frequently in comparison to wealthier, Caucasian communities.[44] Recent studies have found that low-income and racial/ethnic minority individuals typically live closer to supermarkets than higher-income and Caucasian individuals.[76,77] This is likely a function of population density and

access to public transportation, which has been interpreted to be a better predictor of distance to retail food outlets than area income.[77] As noted in the USDA's Food Access Report to Congress,[76] low-income and racial/ethnic minority communities tend to live in densely populated areas. But proximity to retail food outlets and restaurants is only one factor that influences food choice. More work is needed to understand how the interactions between availability, accessibility, affordability, and perceptions influence food choices, especially among low-income, racial/ethnic minority, and rural communities. Merging this research with related research on the influences of built environments and time use and its role in physical activity and other behaviors important to nutrition may provide new insights.

U.S. governmental programs and policies are critical components to examine when exploring the role of food access in promoting food security and healthy eating patterns, especially among at-risk individuals and families. Through collaborations with other federal agencies, the USDA works to ensure access to federal food and nutrition assistance programs, including the USDA Food Distribution Programs, Child Nutrition Programs, the Supplemental Nutrition Assistance Program, and WIC.[76,78-82] Research has shown how nutritional improvements in federal food and nutrition assistance programs such as WIC and the National School Lunch Program contribute to positive dietary changes.[83,84] Despite these positive changes, improving eating patterns among federal food and nutrition assistance program participants will require other strategies, including attention on how to change participant's behavior in retail food outlets and other places where food choices are made. This includes examining how to increase demand for healthier items.[85,86]

Finally, understanding the impact of cultural beliefs and practices on food choice is becoming more important as the diversity of our nation increases. Evidence suggests that specific cultures may prioritize food safety, taste, and quality differently.[87] Likewise, certain cultures may differentially prefer pleasure in eating rather than embracing the concept of healthy eating.[88] Studies also indicate an important interplay among culture, socioeconomic status, and family dynamics, which further add to the complexity of understanding the selection of healthy foods across diverse cultures.[89,90] The actual contribution of cultural beliefs and practices to food choices remains open, as they may be modifiable.

Taken together, the ability to more effectively characterize the interactions between the demographic, behavioral, lifestyle, social, cultural, economic, and environmental factors that influence eating choices will be instrumental to developing multi-pronged approaches aiming to improve healthy eating patterns. The complexity of these factors—individually and collectively—demands effort from a trans-disciplinary workforce, including health care providers and experts in the nutritional sciences, psychologists, behavioral scientists, sociologists, anthropologists, economists, and experts on the food supply. Understanding the interacting and competing factors that influence food choices can guide the development of effective change strategies.

Research Gaps and Opportunities

Food choice incorporates multiple domains, and research is needed on most, if not all, of the specific topic areas described above. Key general research gaps include:

1) What are the most important biological factors that impact food choices?
2) What particular behaviors most strongly predict and impact food choices?
3) How do socioeconomic status, occupational risk factors, and cultural practices influence food choices?
4) What are the environmental issues that mediate food choice?
5) How do all of these important influencers of food choice interact?

With regard to biological influences, more research is needed on how genetic variants, epigenetics, learning, and neural plasticity contribute to preference for various foods (e.g., sour, hot, sweet) and macronutrients (e.g., fat, protein, and carbohydrate). More work is also needed on how brain regions, cell types and circuits control homeostatic and hedonic eating in response to different types of food. With regard to brain regions, cell types and circuits, studies using model organisms together with functional neuroimaging under both physiological and pathological states, perhaps in combination with “omics,” would be useful for understanding obesity and eating disorders (e.g., anorexia nervosa, bulimia nervosa, binge-eating disorders). Another fruitful area is research investigating the molecular signaling mechanisms underlying food-choice behaviors, to include sensorimotor systems (e.g., sight, olfactory) as well as the relevance of visual food cues on human information processing. Over the last few decades, research has been examining the biological signals present and contributing to the control of eating behavior by focusing on individual units of energy intake, particularly a meal, which has a defined beginning and ending.[91,92]

Several research gaps and opportunities also exist in our understanding of food-related behaviors. Future studies could investigate the mechanisms whereby physical activity and sleep duration and quality affect or influence food choices. Other behavioral research is needed to examine interactions between biological status and propensity for modifying food choices. Furthermore, critical research gaps remain in our understanding of how early childhood eating experiences with food (e.g., social pressure, family functioning, environmental cues) influence future food-choice behaviors and willingness to adopt healthy behaviors. On the other hand, research is needed to understand how aging affects food-related behaviors. National research data on food consumption and its demographic, economic, knowledge, and attitudinal determinants could be invaluable to these research inquires. As one example, the NHANES Flexible Consumer Behavior Survey Module, conducted in partnership with the Economic Research Service of the USDA, includes information such as monthly income, amount of family food expenditures, and whether the household participates in federal food and nutrition assistance programs in addition to dietary and behavioral indicators such as self-reported diet quality. These data also incorporate information on the

use of nutrition labeling on packaged foods and retail food outlet menus, and could offer insights into how personal characteristics interact with policy-supported information to influence food choice behaviors.

Cross-disciplinary research teams and centers are increasingly emerging that have potential to increase our understanding of the interactions between food and physical activity environments and healthier food choices, especially among low-income, racial/ethnic minority, and rural communities. This work needs to account for how food costs, household income, and federal food and nutrition assistance program participation, as well as culture, religion, ethnicity, race, and occupation impact food choices. Given the number of local, state, tribal, and federal food financing initiatives or other environmental support systems for improving access of or promotion to healthier foods being considered or enacted, more research and evaluation efforts are needed to examine how these policies and programs affect demand for healthier food choices, along with their role in influencing short- and long-term community and economic development.[93]

With regard to individual and family choices, we need to understand the cognitive and non-cognitive processes that influence how individuals or households purchase, prepare, and eat across a variety of socially, culturally, and ethnically diverse groups. Such research could identify educational messages and interventions that are most likely to promote and sustain healthy choices. Thus, research on how consumers interpret and use information sources could guide development of materials such as food guides and labels, as well as the ways technology can be leveraged (e.g., text messaging, smartphone apps) to enhance the selection of healthier choices. These findings could be translated into effective interventions within educational institutions and worksites at local, state, and federal facilities that serve meals.

Environmental cues might be useful in influencing healthier food choices. In *Nudge: Improving Decisions about Health, Wealth, and Happiness*,[94] research in psychology and behavioral economics was used to defend a libertarian perspective that people should generally be free to do what they like and opt out of undesirable arrangements if they wish. *Nudge* authors proposed the use of “choice architecture” to influence people’s behavior in order to make their lives longer, healthier, and better. Put another way, *Nudge* recommends influencing individuals’ decisions without taking away their freedom of choice. For example, in a worksite cafeteria, active engineering of choice architecture would be to place healthier foods and beverages in easy-to-reach places while putting less-healthy options in harder-to-reach places. Customers would still be able to purchase less-healthy options, but this arrangement has the effect of decreasing consumption of less-healthy options and increasing consumption of healthier options. Developed from psychology, behavioral economics, and business research, choice architecture has been shown to foster healthier food and beverage choices. To illustrate, the Cornell Food and Brand Lab has partnered with the Smarter Lunchrooms Movement since 2010 to assist schools participating in the USDA National School Lunch Program with actively applying

and advancing understanding of using research-informed principles to create school environments that nudge students towards making healthier choices, while still offering the full spectrum of choice. In addition, the Duke-University of North Carolina at Chapel Hill (UNC)-USDA Center for Behavioral Economics and Healthy Food Choice Research (BECR Center) was funded by the USDA in 2014 to develop strategies for promoting healthy food choices, particularly among the 50 million Americans participating in federal food and nutrition assistance programs.

The concept of choice architecture[95] requires further exploration. As one example, research has shown that traffic light approaches for nutrition labeling helped sustain healthier choices in hospital cafeterias over a two-year period.[96] While food environment interventions may promote long-term changes in some populations, more work is needed to determine whether or not these types of interventions can encourage healthier food selections in all populations or only certain subgroups. Also, under what conditions would such traffic light labels or other labeling efforts influence food choice?[96] In an effort to improve the eating patterns of the 1.4 million military personnel it serves each day, the Department of Defense has initiated a Go For Green® identification system wherein foods available for purchase are categorized using traffic light—green, yellow, or red—labels, but its effectiveness has not yet been evaluated. Future interventions could focus on how environmental strategies promote healthy choices through many approaches such as altering the placement of food selections (e.g., rearranging cafeteria lines) or making use of pre-commitment devices (e.g., pre-ordering a healthy lunch rather than going through a cafeteria line). Such research could inform intervention research examining how community design and zoning policies could optimally foster healthy food choices.

For the first time, the USDA FoodAPS Survey provides comprehensive information on food acquired by a household from retail food outlets, restaurants, and other food prepared away from home, along with public programs such as the USDA Child Nutrition programs. The FoodAPS data also includes information on time and distance to purchase foods, amounts spent, prices paid, knowledge and attitudes related to food purchasing, diet, and health. These household data are complemented by geographic data on the food environment, such as the number and location of grocery stores and fast food restaurants. The FoodAPS data will provide increased ability to address such issues as the costs of healthful diets to different population subgroups defined by income, geographic location, or other factors, or identify key determinants of food purchase choices and effects of environmental characteristics such as the proximity to supermarkets and fast food venues.

Research and Resource Initiatives

For both short- and long-term objectives, efforts should include a cross-section of various ethnic/cultural/age groups to establish how selected variables influence/impact food choices.

Short-term Initiatives

- Continue conducting research using national and other data sources such as the USDA FoodAPS to investigate the effects of prices, income, federal food and nutrition assistance program participation, food access and the food supply, nutrition labeling and other information, and other socioeconomic and occupational factors on food choices.
- Identify how consumers use and interpret information sources such as multiple modes of advertising, nutrition labeling, and menu labeling to guide food choice(s) from a mechanistic to population level.
- Determine realistic, cost-effective ways to improve the accessibility, availability, and affordability of healthy foods and beverages.
- Develop a working understanding of the cognitive and non-cognitive processes and interactions among variables including forms of marketing and promotion that contribute to food choice.

Long-term Initiatives

- Identify key biological signatures (e.g., genetic variants, epigenetics, signaling pathways, brain processing) that have an impact on food choices.
- Quantify the extent to which biological factors influence food choices and determine if the relative importance of those factors to food choices varies across population subgroups.
- Characterize key behaviors that influence food choices and behaviors associated with change.
- Quantify the extent to which key socioeconomic and occupational issues influence change in food choices in specific populations and settings.
- Implement and evaluate key environmental, policy, and programmatic changes that promote healthy food choices.

Topic 2 (Q2T2). How do we develop, enhance and evaluate interventions at multiple levels to improve and sustain healthy eating patterns?

Rationale

A number of barriers may limit the potential for individuals to change their eating and activity patterns. This has led to research exploring the role of community, environmental, or policy strategies that intervene at the community or macro-levels to help make the healthy choice the easier and preferred choice.[97] Ideally, these multilevel efforts will link public health initiatives with education approaches, with clinical care providers, and with systems initiatives. What follows are some specific examples of promising interventions that address two major areas—micro- and macro-nutrients, and overall eating patterns. Then, we consider challenges to translating these efforts to broad population health effects. We address the potential for innovations in information technology, as well as data linkage capacity to facilitate evaluation research on the effects of interventions across multiple levels. Recent legislation in the areas of health care and federal food and nutrition assistance programs has the potential to advance progress as well (*See* Appendix B).

Randomized controlled trials focused on specific micro- and macro-nutrients have led to major advances in understanding specific nutrient and disease associations and, in some cases, have led to major changes in the U.S. food supply. As one example, findings from a randomized controlled trial conducted by the Medical Research Council pointed to the effectiveness of folic acid in reducing the risk of neural tube defects among women at high risk for an affected pregnancy. A subsequent Hungarian randomized controlled trial[99] confirmed these findings among a broader population of women of reproductive age. Based on findings from these types of studies, the U.S Public Health Service (PHS) recommended that women of childbearing age should consume at least 400 ug of folic acid daily. This recommendation contributed to the U.S. Food and Drug Administration (FDA) amending the standards of identify for several enriched grain products, such as enriched flour, enriched bread, rolls and buns and enriched macaroni products, to require the addition of folic acid, effective 1998. Fortification of cereal grain products labeled as enriched in the U.S. has been credited with major declines in the prevalence of neural tube defects. Other examples of interventions addressing specific nutrients include eliminating *trans* fat from processed foods, as well as fortification of milk with vitamin D and salt with iodine.

Beyond interventions to address specific deficiencies or risks, the evidence that many nutrition-related chronic diseases are influenced by multiple food components led to randomized controlled trials testing the effects of changes in eating patterns and physical activity on health outcomes such as hypertension, type 2 diabetes mellitus, and obesity. These trials demonstrated that intensive, individual-level behavioral interventions resulted in successful changes in eating and physical activity behaviors and improvements in many health outcomes including diabetes, hypertension, and dyslipidemia.[23-25] In addition, research to

advance the development of evidence-based guidelines has progressed from the discovery stage of basic and epidemiologic studies to trials of efficacy (Dietary Approaches to Stop Hypertension [DASH/DASH-Sodium] and the Diabetes Prevention Program (DPP)) and effectiveness (PREMIER).[25] Besides these trials in middle-aged adults, interventions have been tested among younger-aged adults. For example, the Early Adult Reduction of weight through LifestYle intervention (EARLY) Trials, funded by the NIH, are refining and testing innovative behavioral approaches for weight control in young adults 18-35 years of age at high risk for weight gain. Most of these interventions are technology-driven using novel methods such as mobile phones, social networks, webinars, podcasts, and web-based college curricula. Examining virtual reality (VR) technologies to support behavior change is a key component of the NIH-led Virtual Reality Technologies for Research and Education in Obesity and Diabetes, which evolved from a workshop sponsored by six NIH Institutes and Offices and the Department of Defense Telemedicine and Advanced Technology Research Center.

Research on the effect of interventions at the community level, as well as systems-level approaches within clinical practice, have been undertaken more recently, as has research to improve methods and designs for evaluation of the translation of national guidance into programs and policies. For example, the trans-NIH, cross cutting Healthy Communities Study: How Communities Shape Children's Health (HCS) is studying community programs and policies and their relationship with childhood obesity. Given the increasing prevalence of obesity in the U.S. and worldwide, a major focus of much current intervention research is weight control and obesity prevention – interventions that encompass changes in eating and physical activity behaviors as well as other behaviors known to influence energy metabolism, expenditure, and the ability to regulate energy intake.

Currently, neither American eating patterns nor the U.S. food supply match eating patterns recommended by the *Dietary Guidelines for Americans*.[101] There is a dynamic relationship between consumer demand and supply. Changes in the food supply that promote nutrition while satisfying consumer preferences could potentially support the population in moving towards healthier eating patterns. Indeed, an increasingly trans-disciplinary body of evidence is examining how the following factors influence human nutrition: changes in the type and quantity of food produced; modifications in where and how food is produced; and adjustments in agricultural production, trade, prices, nonfood uses, and crop acreage dedicated to food and feed. For example, in terms of agricultural production, research illustrated how baby carrot innovations that took place around 1986 led to marked reductions in waste and a doubling of national carrot consumption within one decade.[102] Another example is the trans-disciplinary research examining how gradual sodium reduction in packaged and restaurant foods may help reduce population sodium intake.[103] Both of these examples illustrate how research innovation in agriculture, food science and technology is intrinsically connected to advancing human nutrition. Innovations in nutrition

education and promotion are also key ingredients to stimulate consumer demand for good nutrition.

Besides changes in the food supply, evidence suggests changes in the community and retail food environment may foster healthy eating and promote improved food choices.[97] Indeed, a number of "natural experiments" to change the food supply and food environment are occurring at local, state, tribal, and federal levels. Examples of such "natural experiments" include efforts to increase access to fresh fruits and vegetables at retail food outlets, or efforts to reduce consumption of sugar-sweetened foods and beverages within worksites, schools, childcare centers, and community venues.[104-106] With rapid changes in the food supply and food environment often driven by market forces and preferences unrelated to health, research designs are needed that allow rigorous evaluation of the effects of "natural experiments" in the food supply and the food and physical activity environments, including policy or legislative initiatives that may impact healthy eating and activity patterns. To advance our understanding of the dynamic relationship between demand and supply, more attention is needed on how to best utilize trans-disciplinary research teams and public-private partnerships. Likewise, opportunities to investigate the impact of other community-level interventions such as housing vouchers, retail zoning, or mass transit improvements on health outcomes will enhance our understanding of the intersections between public health, policy, and regional and urban planning.[107]

As health and other information technologies transform systems and human interactions, they can also be incorporated into interventions to change eating patterns at the individual, family, community/environmental, and systems levels. Research is testing interventions to effectively communicate the rapidly evolving research evidence on food, nutrition, and health and is evolving the guidance that supports and motivates healthy eating patterns. The Patient Protection and Affordable Care Act (P.L. 111-148) and the Healthy, Hunger-Free Kids Act (P.L. 111-296), among other recent legislative initiatives, have led to an enhanced focus on the development and testing of interventions—including those focused on primary prevention—that are likely to be feasible, scalable, and sustainable within the context of primary care. The ability to evaluate the ways these efforts relate to improved outcomes can be enhanced by linking data on health behaviors and health outcomes with data on community, policy, and environmental efforts to advance healthy eating patterns through activities directed at individuals, clinical care providers, and systems and society at large.

The systematic review process has been used in nutritional sciences to address four major areas: research agendas, nutrient reference intakes, dietary guidance, and practice guidelines.[108] Several challenges exist in the development of evidence-based guidelines in the field of nutrition. The challenges include the need for a broad range of research designs to develop the evidence base for population-level interventions and dietary guidance, as well as the need for such guidance to address the dual issues of normal physiological function and disease prevention. The early nutrition-related guidance focused more on nutritional

adequacy or physiologic function, while more recent guidance has been focused on disease prevention. To be effective in informing decision-making, systematic reviews must objectively examine both the totality and quality of available evidence for the specific question being addressed. Current evidence-based reviews that evaluate the potential for clinical interventions rate randomized controlled trial designs as the "gold standard." However, given the relative dearth of nutrition-related randomized controlled trials, improved methodologies are needed for taking into account observational evidence in the circumstance when limited data are available from more controlled research designs. Furthermore, most current clinical practice evidence reviews evaluate the potential for clinical interventions to prevent disease, and are focused on the evidence base for clinical encounters addressing pharmaceutical, diagnostic testing, or surgical interventions that typically do not address a health behavior practiced throughout the day. In contrast, progress in improving the nutritional status of the U.S. population involves many sectors of society beyond the clinical sector. Addressing several critical research questions requires study designs not limited to randomized controlled trial designs. Several approaches have been used to evaluate individual-level interventions and include the U.S. Preventive Services Task Force (USPSTF), the Cochrane Collaboration, and other international approaches. The Community Guide is one approach to summarize the potential effect of population-level interventions. The USDA Nutrition Evidence Library examines the relationship between diet and health to inform dietary guidance. Therefore, new approaches that evaluate the combined evidence related to both physiologic function and disease prevention, address the complex context of nutrition interventions, and evaluate and integrate the strength of the evidence from individual and population-level research would facilitate improved understanding of food- and physical activity-related behaviors and dietary patterns, which are influenced by many sectors of society.

Research Gaps and Opportunities

Gaps in the field of multi-level intervention research can be broadly characterized under the four following areas. Other sections of this *Roadmap* highlight the continued need for basic behavioral research to better understand how to change dietary behaviors to improve efficacy of interventions across these multiple levels (*See* Q3T2). Likewise, another section of this *Roadmap* address the potential for systems science to identify and quantify which interventions may lead to the best outcomes for specific populations or settings (*See* Q3T3).

Increase data to enhance understanding of the influence of multilevel interventions on eating patterns

Advances in information science methods that enable the linkage of data on exposures such as the U.S. food supply or the local food environment to data on individual responses and health outcomes has led to the recognition that interventions at multiple levels will be required to improve and sustain healthy eating patterns. Recent advances in measurement science enable researchers to characterize the environments in which people live and work, including the food

and built environments. As one example, the use of geographic information system data on socioeconomic, environmental, and contextual factors influencing food and physical activity environments and choice have been explored in a number of observational research designs. However, linking such data to individual-level data within the context of randomized control dietary trials would enable evaluation of how these contextual forces modify response to the intervention. Another issue hindering our understanding of multilevel interventions influence on eating patterns is the lack of data on cost and cost-effectiveness for all types of interventions, including those conducted at the environmental, policy, and system levels. This gap impedes the identification of the cost-benefit of different interventions and the ability to select which, across a broad range of potential interventions, may be most appropriate for specific populations and settings. Furthermore, the lack of replication research on how interventions need to be adapted for specific populations and settings limits wider population implementation.

Expand research on effective approaches for engaging the clinical practice community in improving eating patterns in their patients and community

While research has demonstrated the efficacy of a number of intensive, nutrition-related interventions in terms of benefit for health outcomes, research has been limited on the efficacy of interventions that are feasible and sustainable within the context of primary care practice and that include linkage with the broader community. Such interventions will require adaptation to address needs across the lifecycle, for different population groups, and within different clinical practice settings. With the increase in use of electronic health records (EHR), research is needed to test the use of EHR clinical supports related to nutrition information, including flags for counseling, referral, and outreach resources. In order to reach the large number of patients in need of nutrition interventions, strategies must be tested to identify effective approaches for delivery of such interventions that involve the broad range of health care professionals such as physicians, medical assistants, nurses, nutritionists, registered dietitians, dentists, dental hygienists, and other health professionals (e.g., health counselors, exercise specialists, psychologists, community health workers). Furthermore, research should examine how efficacy and costs compare for interventions that occur within primary care clinical settings versus those that occur within commercial or community-based programs, including those provided at community centers and after-school programs that use successful, evidenced-based strategies. Research has demonstrated that mediating factors, such as mental health and disability, may influence the delivery and effectiveness of nutrition interventions, and these factors should be further examined.

Engage public health, policy, and industry sectors in primary prevention research

Research is expanding to encompass research designs that recognize the various sectors beyond clinical care that influence eating patterns. These studies are occurring in controlled settings and through natural experiments in real-world

settings and are using a variety of designs. Randomized controlled trials test and observational studies observe the effects of nutrition-related policy or environmental changes on behavioral and health outcomes. One particular area of interest includes the identification of relevant behavioral economics and behavioral design approaches in retail food outlets and institutional food service settings—worksites and schools—on consumer food purchase and choice (*See* Q2T1, Q3T2 and Q3T3). These approaches include produce placement, point-of-purchase, choice architecture, pricing, promotion, and sensory information. With the growth in the proportion of the U.S. population participating in federal food and nutrition assistance programs, it has become increasingly important to evaluate how purposeful changes within these programs could potentially improve diet, health, and social outcomes. For example, a very large proportion of U.S. children consume a substantial proportion of their food within schools and childcare centers that participate in the federal food and nutrition assistance programs. Continued research is needed on the extent of participation in these programs, and more in-depth research is needed on how the programs contribute to improved eating patterns and associated health outcomes. Furthermore, innovative approaches within public-private research partnerships, such as the National Collaborative on Childhood Obesity Research (NCCOR) or the Healthy Weight Commitment Foundation, have the potential to enhance the study of how changes by the food and beverage industry and food marketing—especially to children and adolescents—influence eating patterns. Finally, as research demonstrates which approaches are most effective for specific populations and settings, expansion of implementation research is needed to identify best approaches for enhancing uptake of proven interventions.

Integrate research using multiple approaches to quantify the comparative effectiveness of different proposed interventions and to enhance their sustainability and potential to effect long-term change

In an effort to quantify the contribution of the many different combinations of approaches being considered for implementation, investigators are examining these approaches in models that allow for relative comparisons between different types of interventions (e.g., individual education versus population-level changes) on multiple outcomes (i.e., diet, disease, and health status) as well as their relative costs and cost effectiveness. The results of such models are useful in the decisions about which interventions to further develop and test at multiple levels (individual/environmental/systems) that are designed to increase adoption and enhance maintenance of healthy eating patterns over the long term. Rigorous research designs are needed to enhance the evaluation of multilevel interventions with planned variation and to identify the different sets of individual, environmental, and systems changes that will work best within specific populations and settings.

Research and Resource Initiatives

Short-term Initiatives

- Develop an implementation science framework for using rigorous research designs, including natural experiments, for the evaluation of interventions and federal food and nutrition assistance programs that are feasible to implement at the local, state, tribal, or federal levels; drawing upon lessons learned in other areas such as tobacco, alcohol, and HIV/AIDS.
- Develop additional criteria for conducting evidence-based reviews in the areas of clinical, public health, and community practice, which addresses the complexities of the interpretation of nutritional sciences from basic science to more applied research for the purposes of application to dietary guidance.
- Support the identification of improved methodologies for considering data from observational research designs when data are limited from more controlled research designs.
- Identify approaches to promote more trans-disciplinary research to both understand and stimulate consumer demand for good nutrition and to build public-private partnerships that may facilitate data sharing to advance dietary intervention research.
- Support the ongoing collection of cost and cost-effectiveness data for various types of nutrition interventions, including those conducted at the environmental, policy, and system level, with varying timeframes, to assure relevant prevention savings across the lifespan (e.g., 5, 10, 40 years).
- Examine the effects of the federal food and nutrition assistance programs for children and adults through periodic evaluations that address issues such as participation, improved eating patterns, and associated health outcomes.

Long-term Initiatives

- Support research, including the use of GIS, electronic health information systems data, and other methods, to enhance data linkage across multiple levels to enable examination of the effects of interventions.
- Advance implementation and effectiveness research to identify approaches for broadening the uptake and impact of population-level efficacious nutritional interventions.
- Identify strategies for delivery of nutrition interventions within the context of health care, including those that involve provision by primary care professionals, such as primary care clinicians and trained auxiliary staff, and by nutritionists, registered dietitians, and other health professionals (e.g., dentists, health counselors, exercise specialists, psychologists) that may maximize the effectiveness of primary-care-relevant interventions.
- Examine how efficacy and costs compare for interventions that occur within primary care clinical settings versus those that occur within commercial or community-based programs that use successful evidenced-based strategies.
- Develop ongoing processes to ensure cross-dialogue between investigators involved with intervention research at multiple levels with systems scientists

engaged in estimating potential effects of different combinations of interventions in specific populations and settings.

Topic 3 (Q2T3). How can simulation modeling that applies systems science in nutrition research be used to advance exploration of the impact of multiple interventions?

Rationale

Human nutrition takes place in a complex ecosystem influenced by many factors including, but not limited to: genetic make-up of the host (human) and the oral and intestinal microbiome; timing (including critical periods of development); presence or absence of risk or protective factors alone or in combination (e.g., physical activity levels, presence of disease, antibiotic treatment); proximal and distal dietary history and patterns; sex and gender; food availability and the food supply chain; poverty; competing demands for limited resources; family and cultural food practices; food and beverage industry practices; and the regulatory environment. When deciding which interventions to implement to achieve a desired outcome (e.g., reducing obesity prevalence, reducing health disparities in dietary intake or related to differential response to dietary interventions) the interactions of the components of the system must be considered. That requires methods capable of capturing the many salient features of the system while simultaneously tracking changes to discrete elements which can be expected to affect risk. If the complexity of a system is not well understood, it is easy to focus on a simple solution which may be incorrect, misleading, or result in unintended effects. For example, public health recommendations to reduce dietary fat intake led many processed food manufacturers to replace fat with sugars and other simple carbohydrates and consumers ate more calories which may well have contributed to increased levels of obesity.

"*Systems science"* is a broad construct referring to a suite of analytic approaches that aim to elucidate the behaviors comprising a complex system and inform efforts to address one or more system problems. Systems science methods have been developed to understand connections between a system's structure and its behavior over time. Applying these methodologies enables investigators to examine the dynamic interrelationships of system components while simultaneously studying the behavior of the system as a whole and over time.[109] Researchers have not yet reached consensus on a single formal definition of a "complex system" but most definitions refer to a collection of interconnected elements (a system) in which the behavior and characteristics of the system as a whole cannot be anticipated from the behavior and characteristics of any one element of that system or from the sum of the behavior and characteristics of those components when considered separately.[110] Other characteristics that distinguish a complex system include: the presence of many interrelated components of the system, bidirectional relationships between components (also known as feedback loops), nonlinear relationships among components, self-organization or adaptation of the system in response to interventions, a system structure that encompasses multiple levels of analysis (i.e., multi-scale), time-delayed effects within the system, and/or temporal dynamics (i.e., changes in the system behavior over time).[111] The field of complex systems cuts across all

traditional disciplines of science, as well as engineering, management, and medicine. Systems science focuses on specific questions about parts, wholes, and relationships.

Systems science uses simulation models to create *in silico* replicas of the system so that users can conduct virtual experiments and vary the inputs and parameters of the system to explore the impact of multiple, plausible interventions delivered individually and in combination, and in any sequence, including multilevel interventions, over a specified time frame. Simulation models also allow testing of systemic component modifications that have the potential for significant economic as well as health impact. In particular, models are useful for assessing which of the many possible alterations in a system are likely to have the largest (or smallest) effects on a desired outcome, allowing better prioritization of research. In complex systems, these predictions may seem obvious once the model has been developed and applied, but often escape detection without a detailed model. See, for example, work by Levy et al. in the area of tobacco control[112-115] and the CDC Prevention Impacts Simulation Model (PRISM)[116-121] that simulates the multiyear health and economic impacts of a wide array of interventions aimed at reducing risks for cardiovascular diseases.

Research Gaps and Opportunities

The number of such models that have been fully developed for obesity and/or nutrition is limited[122]; however, there have been calls for such models,[123,124] and early models in this area show promise.[125-127] For example, changes to the food environment can inform policy such as free trade agreements, which could reduce the cost of sugar; simulation models might show that a negative consequence to expect would be increased sugar consumption. In addition to better describing the person-based environment, simulation models can be used as decision support tools to gauge and compare the likely health and cost consequences of alternative interventions that impact policy and the food culture.

Systems science modeling can be used to address several gaps and opportunities:[128]

- Building systems science models requires that assumptions be explicit, rather than relying on implicit “mental models.” Making decisions based on implicit models is prone to errors based on individual knowledge, beliefs, and perceptions, which are not transparent to others. The alternative is to use explicit models to support decisions, particularly those expected to have an impact on the larger population.
- Building systems science models involves the compilation and synthesis of the evidence-based literature and subject matter expertise across different topic areas to identify the interconnected, yet often separate elements that contribute to the system. This transformation of a complex system into a mathematical simulation to conduct virtual experiments can provide a compelling case for change, specifically at a higher level of analysis for policy

decisions. Application of such models can highlight different performance trajectories over specified timeframes, allowing a more rigorous assessment of intervention or policy options. The National Institutes of Health has highlighted the utility of systems science methods in several Funding Opportunity Announcements, including PAR-11-314 and PAR-11-315 *Systems Science and Health in the Behavioral and Social Sciences* and PAR-13-054, PAR-13-055, and PAR-13-056, *Dissemination and Implementation Research in Health*.

- Using simulation models can accelerate group learning, bringing greater structure, more evidence, and shared creativity to the challenge of understanding a complex system. Without a common structure, people often talk past each other and have different frames of reference. Models bring more structure to the conversation; although models are imperfect representations of a system, they can bring greater organization or meaning to what is often poorly understood. Models attempt to bring the best evidence into one central framework.
- Working with stakeholders can improve our understanding of why some interventions or programs do not have the intended effect or are delayed, diluted, or defeated by "policy resistance."[129] Two examples of outputs from such modeling efforts include: (1) an indication of the research gaps in nutrition research (for the questions posed) and their relative importance for addressing the outcomes of interest; and (2) an indication of the relative benefits and costs associated with a number of different interventions, policies, or programs that may operate at different levels and interact with one another, including and maybe even especially, when they are all evidence-based.
- Creating a better understanding of a system via simulation models has the potential to lead to testable hypotheses of how, when and where an intervention in a system would be expected to have the greatest benefit or the greatest impact towards the desired outcome. Moreover, systems science can provide a better understanding of which factors are expected to have the greatest impact on outcomes, helping to target measurement efforts towards those factors with the greatest effect on outcomes.
- Depending heavily on the availability of accurate data based on validated measures and the input of content area experts to help develop the mathematical models will certainly be true in applications of systems science in nutrition research where measurement issues can be particularly challenging.

Research and Resource Initiatives

Short-term Initiatives

- Engage modelers from existing studies in other areas on the utility of models for evaluation of nutrition interventions and outcomes.
- Engage stakeholders in a face-to-face meeting to identify the most pressing research questions to address with simulation modeling; and generate a

conceptual map (causal framework) of these questions, which will result in an explicit and shared understanding of the specific issues to be addressed.

- Identify the nutrition outcomes of most interest to be considered for modeling and the specific research questions that modeling should address.
- Identify the data that will need to be developed to initiate the use of models and provide funding to collect those data.
- Provide initial funding (e.g., seed grants, contracts) to initiate the use of models.

Long-term Initiatives

- Provide a coordinated funding stream across funding agencies to support simulation models.
- Leverage investments in existing systems science projects and explore trans-agency funding support to build out the nutrition-related features of such systems.
- Support the development of comparative modeling efforts in which different teams model the same research question with different and same methods.
- Support development of more sophisticated modeling software.
- Using systems science and other methods, estimate how purposeful changes designed to improve population health within local, state, tribal, or federal food and nutrition policies and programs could improve diet, health, and social outcomes.

Topic 4 (Q2T4). How can interdisciplinary research identify effective approaches to enhance the environmental sustainability of healthy eating patterns?

Rationale

An emerging area in human nutrition research is advancing our understanding of how to ensure access to sufficient, safe, and nutritious food to maintain a healthy and active life while sustaining human and natural resources for future generations.[130] Sustainability implies an integrated system of practices that will, over the long term, satisfy population food and nutritional needs and maintain or enhance environmental quality and the natural resource base upon which the food system depends. To be socially sustainable, environmentally sustainable practices must be acceptable to the consumer and economically viable.[131,132]

The Federal Government administers and enforces several initiatives to promote a safe, sustainable, and nutritious food supply. For example, the USDA Strategic Plan for fiscal years 2014 to 2018 prioritizes goals to protect water resources, conserve grasslands and forests, and enhance crop resilience to climate change. In addition, multi-agency initiatives currently work on reducing food waste. Researchers at the USDA's Economic Research Service estimated that in 2010, 133 billion pounds or 31 percent of the 430 billion pounds of food available in the U.S. at the retail or consumer level went uneaten.[133] The estimate of wasted food would have been higher if it included losses at the farm and between the farm and retail level. The EPA points out that much of the food wasted is safe, wholesome food; therefore, food waste also represents a nutritional and food security loss.[134] Wholesome food may be discarded by consumers who misinterpret quality-based labeling such as "best by" as an indicator of food safety risk rather than an indicator of optimal taste or other sensory factors.[135] Other wasted food could be recycled to a nutrient-rich soil supplement rather than decomposing in landfills to generate methane, a potent greenhouse gas.[134]

Questions have been raised regarding the environmental impacts of some recommendations put forth in the *Dietary Guidelines for Americans*; specifically, researchers have explored the impacts of a greater consumption of fruits, vegetables, and fish, if these recommendations were followed by the U.S. population. As one example, between 1997 and 2002, fresh fruit was one of the food products with the highest increases in energy cost of transportation.[136] In addition, concerns have been raised that fish production does not have the potential to meet recommendations put forth in the *Dietary Guidelines for Americans*.[137] Interdisciplinary research is needed to explore the sustainability implications of transitioning the American population to a more healthy diet. Researchers focused on advancing human nutrition research to improve and sustain the health of Americans can also work collaboratively with agricultural and environmental researchers to broaden their efforts to further investigate effective approaches to enhance the environmental sustainability of healthy eating patterns. Such work will be wide-ranging, encompassing issues related to

water, land, and energy use, as well as consideration of how the food diversity that underpins access to a diverse, micronutrient-rich, and healthful diet can be promoted and maintained.[101,137,138]

Without question, consumer acceptance and economic viability of any proposed changes in environmental policies and practices would need to be assessed. The affordability, availability, and consumer acceptance of foods for healthful, sustainable diets demands investigation,[130] as do the costs and benefits of policies and programs designed to improve access and acceptance. For example, increased research on local production and marketing of foods could investigate impacts on access to a wide range of healthful foods such as fresh fruits and vegetables, increased consumer acceptance and interest through programs such as the USDA's Farm to School Program, and local economic development and on the energy costs associated with food transport.[139] Some improvements in environmental sustainability—such as reduction in food waste—may depend on food industry and consumer behavior. As one example, communication research to determine how to improve food package labeling such as "best by" to assist consumers in distinguishing food safety from sensory quality factors, and exploring the value of terms such as "freeze by" to encourage consumers to consider freezing foods as a means of preserving both safety and quality and avoiding waste, may be beneficial.[135] Retailer practices that decrease food waste could be examined and promoted. Additionally, identification of effective strategies to increase recycling of food wastes by local municipalities from homes, restaurants, schools, and other institutional food service settings could be valuable.

Research Gaps and Opportunities

The Institute of Medicine's (IOM's) Food Forum and Roundtable on Environmental Health Sciences, Research, and Medicine convened a public workshop in 2013 to engender trans-disciplinary dialogue and to explore current and emerging knowledge on the food and nutrition policy implications of the increasing environmental constraints of the food system. The workshop summary suggested a framework for assessing decisions about food and agriculture and the potential sustainability implications.[137] The necessity of considering the full range of potential effects of a decision was emphasized, including the health, environmental, social, and economic aspects. Moreover, the workshop summary explained how identifying and prioritizing research issues relevant to ensuring the sustainability of healthful diets has been a challenge because of limited communication between experts in the relevant disciplines, which can span nutrition, agriculture and natural resources, food science, public health, urban planning, and economics. More cross-disciplinary dialogue is needed to formulate an integrated research agenda. Similarly, conducting research will need, in many cases, interdisciplinary teamwork.

Although more work is needed to identify the full scope of research needs, some major issues have been identified as research priorities. One of the biggest challenges facing U.S. agriculture—and by extension, the availability of healthful diets for all Americans—is the decline in water availability across the western U.S., which has become essential for many crops that require ground water-sourced irrigation, and a major factor in depleting water supplies. Research that accelerates progress on enabling migration to more drought-tolerant crops and the development of more efficient water delivery is essential.

With increasing interest in the local production of agricultural crops and the development of local food hubs, a need exists to better understand the impacts of local food production and of how local food production and marketing might be best integrated within the agricultural and food marketing sector to enhance sustainability. More investigation of impacts of producing and buying locally on availability of high-quality, fresh fruits and vegetables and on energy costs and food waste is needed. More investigation is needed on whether producing and buying locally may lead to an increased availability of high-quality, fresh fruits and vegetables while decreasing energy costs associated with transport. More data on yield, water needs, growth and energy efficiency, and nutritional content of crops or animals raised in geographically diverse regions would inform development of local production and marketing efforts that best promote sustainability. To enable legitimate comparisons across production systems, more work focused on examining the economies of scale for production and processing of foods using product life-cycle assessment of total inputs is warranted, as is multifactorial research that examines effects on local economies and development of social capital.

In addition, research is needed to better document the causes of food waste and to develop improved food handling practices and technologies to reduce waste. Improvements in food packaging may reduce food waste. Consumer behavior research to identify and modify consumer behaviors associated with food waste will be instrumental to improving the environmental sustainability of healthier eating patterns. For instance, we need a better understanding of the strategies that may influence and help maintain consumer behaviors that promote the purchase and consumption of safe, nutritious, affordable, and sustainable foods and beverages. Investigation of the affordability of healthy, sustainable eating patterns would be helpful to the development of dietary guidance efforts.[130]

Another research need involves assessing the potential impacts on agricultural production and food distribution of a population-wide transition to a healthy diet. These assessments should examine interactions of resource, environmental, and food market policies with diet and food system sustainability goals. In particular, we need to examine the dynamics between the consumption of healthier diets and the resource and environmental implications of changes in production, involving biodiversity, land, water, and energy use.

Research and Resource Initiatives

Short-term Initiatives

- Promote cross-disciplinary dialogue to identify and prioritize research needs, as well as data and methodological needs through convening workshops of key stakeholders.
- Update and expand available information on local and regional foods systems to better understand consumer demand and willingness to pay for local food; costs of local food production; and evidence for food security impacts as well as nutritional, economic, social capital, and environmental impacts of local food systems.
- Monitor expansion of targeted local food efforts such as the USDA's Farm to School Program and the CDC's Farm to Preschool efforts and assess their effects on children's acceptance of healthy foods.
- Conduct research on post-harvest handling and processing (modified atmosphere packing, anti-microbial coatings, and other treatments) to extend the shelf-life of products subject to spoilage, and examine its contribution to reduced waste at retail and consumer levels.
- Continue to improve estimation of food waste at the retail and consumer levels.
    - Expand use of retail food outlet scanner data and other data to examine retail-level and consumer-level food loss and gain insights into reasons for food waste.
    - Assess the food waste implications of consumer food handling behavior, food packaging labeling, and food waste recycling policies and practices.
    - Investigate how innovative tools, such as the USDA's Food Safety and Inspection Service FoodKeeper application, affects retail and consumer food waste.

Long-term Initiatives

- Assess short- and long-run sustainability and economic implications of population-level transition to healthier diets as defined by the *Dietary Guidelines for Americans*, including such factors as water, energy, land use, and biodiversity.
- Examine how the scale of food systems and supply chains—global, domestic, regional, local—affects environmental sustainability and influences access to an affordable, healthful diet by Americans.
- Improve data and methodologies for conducting systems-level analyses to assess decisions about food and agriculture for impacts on the food supply chain.
- Examine potential approaches to improving data on food loss and strategies for reducing waste across the food chain from farm-to-fork.
- Assess the potential of strategies to encourage the consumption of sustainably produced or harvested fish and other seafood, as well as alternative sources, such as algae products with beneficial nutrients typically obtained from fish and other seafood.

Question 3: How can we develop and engage innovative methods and systems to accelerate discoveries in human nutrition?

Topic 1 (Q3T1). How can we enhance innovation in measuring dietary exposure, including use of biomarkers?

Rationale

Many questions in human nutrition research cannot be addressed without information on the intake of foods and dietary supplements and of their constituents (e.g., nutrients, other compounds). A persistent challenge is presented by how best to assess the quantities and types of foods and beverages consumed by individuals and how to estimate their contribution to intake of energy, macro- and micronutrients, other dietary constituents, and various food groups. For many research situations, there is no alternative to asking the participants about their consumption habits (foods, beverages, and dietary supplements) assessed over a given period of time. Commonly used methods include self-report dietary assessment tools, such as 24-hour dietary recalls, food records, food diary, and food frequency questionnaires, all of which rely on the information provided by the consumer or study participant, the manner in which the information is collected, and the availability of comprehensive nutrient and food group composition databases. Depending on the self-report method used, these data are subject to varying levels of reporting bias, missed reports, measurement error, and respondent burden.

For some purposes, typically in the context of risk calculations, such intake values are referred to as “exposures.” Dietary and nutritional supplement intake and exposure data have many uses, such as:

- Characterizing intakes of populations and individuals on a given day(s) to estimate intake distributions;
- Assessing the degree to which individuals or populations meet recommended levels of intake;
- Evaluating the nutritional adequacy of food environments;
- Estimating exposure to non-nutrient compounds (including bioactives or toxic or deleterious substances) and improving methods for their quantification in the food supply;
- Estimating risk of disease or other health outcomes (e.g., birth defects, other developmental disorders, acute illnesses, or chronic diseases) associated with intakes of nutrients, food groups, and eating patterns;
- Generating and testing hypotheses related to biological mechanisms whereby differences in diet relate to differences in metabolism or pathophysiology or other health outcomes;
- Assessing effects of behavioral or environmental interventions on dietary intakes;
- Assessing associations between socio-demographic, lifestyle, physiologic. and disease marker characteristics and diet; and

- Modeling potential impacts of changing dietary intake behavior (*See* Q2T3); in other words, if dietary intake is known, the information can be used to identify gaps and model what could be done to address these gaps with various interventions.

The source of information and the specific types of data collected must serve the purpose of the research, allowing the study questions to be answered with satisfactory precision and reliability. Observational research (e.g., cross-sectional or longitudinal epidemiology studies) typically will evaluate intakes from self-selected diets, chosen by free-living study participants. Experimental research (e.g., controlled feeding studies, mechanistic studies, efficacy trials) often will evaluate intakes from assigned diets or from foods directly provided in the research setting such as metabolic kitchens or other food delivery arrangements. Another form of experimental research is the effectiveness trial, which evaluates dietary and other interventions in real-world settings; protocols for such trials often will evaluate adherence to the intervention.

Intakes (or exposures) from dietary interviews or observations (collected by self-reported interviews or diaries, or by electronic capture of food images) represent a merger of data on reported foods and dietary supplements (food descriptions, quantities consumed, and frequency of consumption over a defined timespan) with data on the estimated or analyzed composition of the food items (content of nutrients or other components). Accuracy of the data is reliant on confirmed or imputed food composition values. Intakes can be calculated more precisely for foods and/or dietary supplements provided in controlled study settings; however, feeding study methodology is costly and labor intensive and thus is used less often, but is appropriate for efficacy studies and hypothesis-testing research on nutrient requirements.

In summary, precise, accurate, and replicable ways to assess dietary exposures are essential to improving the quality of nutrition research, translating research into workable practice, fostering behavior change, and developing sound policies. Nonetheless, the difficulties of assessing intake can be sufficient to undermine the credibility of nutrition research, affecting the statistical power and the capacity for studies to be replicated or generalized to a broader population. This has led to interest in the utility of biological markers of nutrient and food component exposure to obtain insights in terms of metabolically active compounds as affected by individual metabolism, absorption, and genetics. Such biomarkers, once identified and validated, could be of interest because of the possibility that they may provide greater precision and more specific mechanistic information in comparison to self-reported data.

Research Gaps and Opportunities

Intake Assessment

All dietary assessment methods are subject to measurement error and various sources of bias, including observed or self-reported intakes. The magnitude and

types of errors vary with the method employed, but often veer in the direction of underestimation of quantities and omission of consumed items. The choice of method depends on the question being asked and its context, such as the research setting and experiment design. When conducting a large survey, repeated 24-hour recalls or food diaries/records become difficult to obtain, due to respondent burden and higher attrition, and, thereby, lower generalizability. Other sources of error in characterizing diet, including nutrients and bioactive food constituents consumed, derive from errors in food composition databases. That is, dietary data must be linked to food composition databases that are complete and current (reflecting market trends). These sources of potential error must be minimized to enhance nutrition research.

In addition, several groups of commonly consumed items require different methodology for intake assessment than that used for typical foods and beverages. First, the methodology for collection of data on intake of dietary supplements needs further development. For many individuals, dietary supplements are major contributors to intake for a number of nutrients. Methods for collecting data on supplement use, however, draw more on methodology for intake of drugs than foods. Research is needed to develop data collection methods that will enhance the accuracy and reliability of information on supplement intakes, and statistical methods are needed that are suitable for merging supplement intake data with food intake data.[140] Furthermore, for some situations, water intake from various sources (bottled and tap) must be assessed to calculate total intakes of nutrients (minerals) and other compounds. Assessment of water intake requires information on quantities consumed from differing sources, as well as databases that have accurate information for these sources on the compounds of interest such as calcium concentration. This is a particularly challenging undertaking because of enormous local and regional variations in tap water from municipal or well sources, the paucity of data on bottled waters, and the varying use of water in food preparation. Finally, we need better methods to more accurately understand the role of alcohol per se (ethanol) or alcoholic beverages (e.g., wine, beer, spirits, mixed drinks) in human nutrition since these beverages contribute calories and other nutrients. Understanding the intake and health effects of various non-nutritive compounds, such as resveratrol in red wine, is also of interest. In addition, alcohol consumption may confound absorption of certain nutrients (e.g., thiamine) and other water-soluble vitamins. Often, the reporting of alcohol consumption is poor, generally in the direction of under-reporting, in part due to irregular intake patterns (concentrated on weekends or holidays for many people), including binge drinking and perceived stigma. Better methods for capturing alcoholic beverage consumption data are needed.[141]

Statistical advances have allowed for improved estimates of usual intakes from self-reported data (i.e., adjusting for measurement error and reporting bias) and have enabled combining instruments (e.g., intake propensity methods that combine information from food frequency questionnaires and 24-hour recalls). A particular concern is that many nutrition studies are underpowered for use in

evidence-based reviews, and these reviews form the basis of dietary guidance for healthy populations and individuals with chronic diseases or conditions. One way to address these concerns is by developing more consistent and accessible methodology, along with software that can handle the statistical issues unique to the dose categories of nutrition study designs, where intake and exposure patterns are distinct from those typical of drug trials (active and placebo agents). The development of user-friendly statistical software to assess dietary intake is needed. Ideally, this software is easily accessible and can be applied to answer multiple research questions and handle various data collection methods, while still accounting for the potential measurement errors previously mentioned. High-quality databases for foods, food components, and dietary supplements are also needed. A useful dimension of such databases would be the ability to distinguish among foods from different sources or preparation settings such as home, restaurant, grocery store, or institutional kitchen. For commercial food products, more information provided on the Nutrition Facts label would accelerate more in-depth analyses.

Furthermore, the data collection process often is expensive due to labor costs. New dietary assessment collection tools that employ technologies to improve accuracy—particularly for portion size estimation—can reduce costs, increase efficiency, and add contextual data by incorporating self- vs. interviewer-administration, image technology, time, geographic metadata, and automated coding. In addition, these new technologies allow the capture and feedback of real-time data that may have greater potential to influence food acquisition and consumption. At present, there are many mobile apps with the capacity to obtain food intake assessment information, and it may be useful to expand existing efforts by federal agencies with these companies to facilitate research. A challenge is that data collection and cleaning is a lengthy process, and the data may be outdated if analysis is not done efficiently. Therefore, approaches are needed to make this process more efficient and to be able to release the results more quickly. Lessons learned from use of clinical data for Big Data-style analyses may provide insights for addressing nutrition research questions (*See*, as one example, The National Institutes of Health Big Data to Knowledge [NIH BD2K] initiative and Q3T4).

Ultimately, any “novel” approaches to improve dietary assessment will still have shortcomings and biases. Nevertheless, improved methods suitable for both experimental and population research and survey designs will advance nutritional sciences research and implementation.

Biomarkers

A biomarker is a distinct biological or biologically derived molecule that can be detected in blood or other body fluids or tissues and indicates a sign of a process, event, condition, or disease.[142] Biomarkers are measurable characteristics of normal biological and pathogenic processes and pharmacologic responses. What might be a useful index of nutrient exposure may not

necessarily reflect nutrient status, which, in turn, may not necessarily reflect the effect or function of that nutrient. Ideally, a biomarker can also be considered a risk factor, in that their measurable levels both correlate with changes in disease risk or other health-related outcomes, and vary predictably in response to interventions (*See* Q1T1). These features allow a biomarker to serve as surrogate endpoint in clinical trials and other types of research as well as in clinical practice and could potentially reduce the cost and duration of trials since it might otherwise take years to observe an effect of dietary interventions on clinical endpoints. Despite their potential, only a few biomarkers have been demonstrated to be valid at assessing the risk or probability of developing certain chronic diseases or conditions. For example, LDL cholesterol can serve as a surrogate endpoint because it is intervention-responsive and a validated predictor of cardiovascular disease risk. Similarly, hemoglobin A1C and fasting blood glucose are surrogate endpoints often used to assess diabetes risk. HDL cholesterol, on the other hand, is associated with cardiovascular disease risk but has not yet been shown to respond to interventions that lead to fewer clinical events. More research is needed to support the qualification of nutrition-related biomarkers that can function as surrogate endpoints.

Nutrient-specific biomarkers could help to determine exposure, meaning their use might assist in providing a more accurate, more reliable, and less biased determination of the intake of specific nutrients or food components. Suitable biomarkers also could indicate nutrient status and help to clarify nutrient function. Time frame is important, as short-term intake markers are needed to answer some research questions, but long-term or chronic exposure markers are needed to assess the role of nutrition in disease prevention or disease risk. At present, there are very few nutrient-related biomarkers sufficiently developed for research use. Emerging approaches include but are not limited to: identification of food- and biochemical pathway-specific metabolic signatures; characterization of exogenous food derived biomolecules such as non-coding regulatory RNA; and profiling of the gut and oral microbiome.

Some of the challenges of developing biomarkers involve what to use as reference. For lack of alternatives, researchers often end up relating the biomarkers to dietary estimates and, as previously mentioned, dietary assessment has its own set of errors. It would be highly desirable to have independent “gold standards” to relate the biomarkers of dietary exposure to disease intermediates and disease/functional tests, and to have these biomarkers validated in a longitudinal manner, as appropriate. The variability in biomarkers remains important even if the markers are reasonably valid. A common assumption is that dietary intakes vary considerably within and among individuals, but that biomarkers are more stable and reliable. However, substantial measurement error may exist for a number of biomarkers of nutrient status and the degree of that error may vary by the method used. Better statistical methods are needed that can adjust for the effects of food and nutrient intake on variation in biomarker levels. Therefore, biomarker validation research

is essential. Ultimately, the choice of methods pertains to the question of interest, the population being examined, the research design, and the study setting.

Emerging "omics"-based technologies, particularly metabolomics approaches, now allow investigation on the complexity of interactions among nutrients within individuals, each one of whom has a unique genome and history of dietary, environmental, and behavioral exposures (*See* Q1T2). Increasingly, nutritional metabolomics is defined as the "use of small-molecule chemical profiling to integrate diet and nutrition in complex biosystems."[143] Nutritional metabolomics has largely focused on identifying and validating new biomarkers of nutritional exposure, nutritional status, and nutritional impacts on disease. Nevertheless, considerable research is needed to make use of these new methods as a way of enhancing nutrient exposure assessment. The low-molecular-weight metabolites within an organism cannot all be measured due to the practical limit of sensitivity; put another way, detection methods are inadequate to measure all individual small molecules. No single method has achieved a level of standardization to warrant consideration as a uniform platform for nutritional metabolomics. Consequently, a central challenge remaining for nutritional metabolomics is the development of comprehensive profiling capabilities.[144] Overall, the biomarker dimension of nutrition research should be better aligned with, and made comparable to, other biomarker-related research on normal and disordered metabolism. The Biomarkers Consortium is one example of a collaborative effort working to improve the identification of new biomarkers.

Research and Resource Initiatives

Short-term Initiatives

Intake Assessment

- Develop better assessment tools to evaluate the diets of individuals for clinical management.
- Develop research toolkits and Common Data Element approaches for assessment and analysis of food and supplement intakes that provide guidance related to which approaches are more appropriate for specific research designs.
- Develop and make available statistical methodology and related software tools to estimate and analyze dietary data from national surveys that can address concerns about the effects of measurement error on study results.
- Develop better methods to estimate and analyze dietary intake in nutrition surveillance and public health surveys, including public-access databases for weights such as balanced-repeated replicate weights (BRR) values needed for developing population-level estimates.
- Develop optical character recognition software for scanning Nutrition Facts panels to assist with crowd-sourcing of nutrient information in food and nutrient databases.

- Develop novel image capture technology for foods and beverages (before consumption) (*See*, as one example, The Genes, Environment, and Health Initiative of the National Institutes of Health).

Biomarkers

- Develop non-invasive tests using biological samples (e.g., saliva, exhaled breath, blood, urine) for estimation of intakes of high-priority foods and food groups as identified through risk-relationship analyses (e.g., fruits, vegetables, meats).
- Develop and validate biological fluid-based biomarkers of food and nutrient intake relevant to short- and long-term health outcomes (e.g., urine biomarkers of individual-level sodium and iodine intake) through human feeding studies, cohort studies, and other research designs.
- Evaluate existing and developing new predictive equations and methods for estimating 24-hour sodium execution using spot urinary sodium measures, particularly for different age and race/ethnic subgroups.
- Develop research toolkits and Common Data Element approaches for choice and use of biomarker profiles.

Long-term Initiatives

Intake Assessment

- Develop and validate data collection methodology suitable for persons of various ages (e.g., children, elderly) and literacy levels, as well as for different demographic and cultural groups.
- Develop and expand federal and international nutrition assessment websites for researchers, public health professionals, and other users that include standardized recommendations on dietary assessment tools and methods, analytic methods, and training and technical assistance (*See*, as examples, the Biomarkers of Nutrition for Development (BOND) program; the National Cancer Institute Measures of the Food Environment web-based resources; the National Collaborative on Childhood Obesity (NCCOR) Catalogue of Surveillance Systems and Measures Registry).
- Develop strong statistical techniques and user-friendly software to adjust for dietary intake measurement error.
- Develop and encourage use of innovative mobile technology to increase opportunities for real-time data collection of consumer behaviors including use of information and marketing modes, food purchasing, and food intake; consider if and how partnerships with technology providers may advance this research.
- Develop and validate practical, reliable image recognition and volume estimation techniques for real-time collection of food intake data.

Biomarkers

- Characterize the impact of dietary intake/exposure on health risks in relation to biomarkers of nutritional status through the lifespan. This may entail research approaches that include collecting dietary data at multiple points across the lifespan, using new technologies for self-reported diet and dietary biomarkers.

Topic 2 (Q3T2). How can basic biobehavioral science be applied to better understand eating behaviors?

Rationale

A better understanding of eating behavior—a remarkably complex phenomenon—is needed to improve and sustain health. Recent advances in behavioral and brain sciences related to appetitive behavior, including food intake behavior, have indicated that a critical role is played by traditional homeostatic functions (i.e., hunger, satiety) and the brain structures that support these functions. In addition, non-homeostatic neurocognitive functions (e.g., reward/motivation, learning/memory, and psychological mechanisms such as self-regulation and executive function) may interact with these homeostatic functions and also independently contribute to the regulation of food intake behavior.[145,146]

In humans, the motivation to eat is biologically regulated but is known to be heavily influenced by cognitive, economic, and environmental factors, among others (*See* Q2T1). Recent evidence indicates eating behavior is not always a purely volitional act, which has major implications for interventions addressing changes in appetitive behavior.[145] A promising new approach for advancing our understanding of the biological basis of eating behavior has been to focus on meals as individual units of energy intake. Because, meals have defined beginnings and ends, researchers can focus on the biological signals that contribute to the control of eating behavior. These signals fall into three categories: (1) those involved in initiating a meal, (2) those that maintain feeding once a meal has begun, and (3) those controlling meal termination. Factors involved in meal termination are of particular interest in the context of obesity, since one of the hallmarks of obesity involves overeating (i.e., long-term consumption in excess of energy needs).[91,92,147] In animal models, this overconsumption is characterized by greater meal size resulting from either increased meal duration or ingestion rate, and the increased exposure to food stimuli fails to terminate a meal appropriately. Thus, understanding the neurobiology of termination and the dysregulation often associated with obesity could help healthcare providers and their patients identify healthier eating patterns and may also accelerate the development of novel therapeutic treatments.

Promoting the behavioral sustainability of healthy eating patterns is another area that may benefit from a deeper understanding of underlying mechanisms.[148] Brain and metabolic processes underlying goal-directed versus habitual behavior need to be examined further to better elucidate how to transition individuals from maladaptive eating patterns to healthier, goal-directed eating patterns.[149,150] For example, “choice architecture,” is the design of environments in ways that influence decisions (*See* Q2T1 and Q3T3).[95,151] A better understanding of choice architecture may help to structure homes, schools, worksite cafeterias, and retail food outlets to encourage individuals to make healthful decisions. Also, basic research on communication has revealed that the way information is framed

(e.g., format, complexity, context) affects decisions and behavioral choices. Such findings have implications for how best to communicate nutrition information via media, packaging and labels, and health care providers. Further, research is needed to understand how the effectiveness of communication channels is mediated by the print literacy, health literacy, and numeracy of the intended audience(s).

Research Gaps and Opportunities

Basic behavioral research to elucidate factors underlying eating behavior entails laboratory experimentation in animals and humans, along with observational and qualitative studies. Much of the current research, however, has methodological or measurement limitations.[152] In many studies, for example, there is insufficient characterization of psychosocial or behavioral factors that might be driving individual responses.[153] These issues require careful examination in populations that are behaviorally and psychosocially well-characterized and for which researchers also have appropriate metabolic, physiologic, and/or neurocognitive data. In addition, better, more standardized, and repeated assessment of underlying mechanisms and process of change is needed. Nevertheless, to be able to generalize results more widely, researchers also need to assess behavior across contexts, in different sub-groups (e.g., sex and gender, racial/ethnic minority groups), and across the lifespan, assuming a developmental framework that acknowledges inherent change in behavior related to eating patterns.

Other knowledge gaps limiting our utilization of basic biobehavioral science to improve healthy eating patterns include:

- The ways brain nutrient requirements and metabolism vary over the lifespan and in health and disease;
- The way nutrition relates to learning and behavior, hippocampal structure/function, and neuroplasticity;
- The influence of eating patterns and nutrient intake on prevention or treatment of conditions such as Alzheimer's, depression, or other neuropsychiatric illness; and
- The ways unhealthful eating contributes to degradation in other neurocognitive processes.

The following topics of interest demonstrate the breadth and depth of research opportunities in advancing our understanding of basic biobehavioral science to improve healthy eating patterns[146]:

- Executive function, self-regulation, and impulse control;
- Reward, valuation, and motivational processes;
- Learning and memory;
- Introspective and prospective thinking;
- Attention, perception, and information processing;
- Model-free versus model-based decision-making;

- Marketing strategies, risk perception, and communication;
- Habit formation, maintenance, and change;
- Stress, resilience, and vulnerability; and
- Interpersonal processes, social engagement, and social networks.

In addition, a better understanding of the interactions between fundamental mechanisms underlying behavioral responses to food and food environments can elucidate new avenues for intervention. Examples include the interaction between stress, reward value of food (hedonics), and satiety; and the interaction between marketing strategies, behavioral economics, food culture, food preferences, food availability, and consumption. We also need to understand psychosocial and metabolic characteristics that predict behavioral and physiologic responses to efforts to restrict intake.

Considerable research is needed on the “Gut-Brain Axis” and its role in regulating food intake, particularly with regard to terminating eating episodes.[92] Interactions between the central and peripheral nervous systems and the gastrointestinal (GI) tract appear to occur in three realms: (1) between the central nervous system and the gut via the vagus nerve, a peripheral nerve which has anatomic structures linking the central nervous system and the GI tract; (2) between the vagus nerve and the brainstem-hypothalamic homeostatic brain system; and, as mentioned above, (3) between homeostatic (brainstem-hypothalamus) and non-homeostatic subcortical and cortical brain systems underlying higher-order functions (e.g., reward, learning/memory, cognitive control). Food intake is initiated by a variety of biological, social, visual and olfactory cues. These factors combined with taste and oral stimuli are thought to contribute to meal continuation. As eating proceeds, the presence of consumed foods in the stomach and small intestine results in accumulation of mechanical and chemical stimuli. Sensory nerves relay these gastrointestinal (GI) signals to the brain to provide within-meal negative feedback. As the negative feedback signals exceed the positive visual, olfactory, and oral signals, a meal is terminated. The importance of this gut-brain axis for obesity treatment is supported by the fact that most current surgical anti-obesity strategies (e.g., gastric banding, gastric bypass, gastric vagal stimulation, vagal blockade, implanted gastric balloons) target GI and vagal components of the axis, and each attempts to increase the potency of food-stimulated negative feedback from the gut to reduce food intake during a meal. Most remarkably, research has demonstrated the plasticity of vagal afferent neurons in response to food.[154] Nutrient sensing by the gut promotes release from enteroendocrine cells in the stomach and small intestine of GI satiety hormones such as cholecystokinin, which interact with receptors on the plasma membranes of vagal afferent neuron cells and activate meal-ending signals. More mechanistic and clinical research is needed since little is known about whether obesity in humans can be prevented or reversed by manipulating gut-to-brain signaling.

More work is also needed to evaluate the sensory and chemical mechanisms related to pleasure and reward pathways, and the external and internal response cues for hunger and satiety.[155] Too often, investigations of eating behavior have failed to consider both the “on” and “off” switches that compel, control, or prevent food consumption.[156] Often these switches are presumed to be under the control of the individual, but this is an oversimplification of the control processes.[157] Sweet-tasting foods and a variety of tastes, for example, both result in increased food consumption overriding satiety mechanisms.[158] Therefore, the roles of taste, smell, nutrient content, and hedonic responses need to be carefully examined to increase adoption and maintenance of healthy eating patterns.[159] These findings have implications beyond obesity and could potentially advance our understanding and treatment of eating disorders such as anorexia nervosa, bulimia nervosa, and binge-eating disorder.

In addition to determining environmental and person-based predictors of food choices, more basic biobehavioral research is needed to elucidate how interventions affect the experience of hunger or satiety, macronutrient intake, taste, reward sensitivity, impulsivity, cognition, and mood. These findings might enable the development of risk and resilience profiles, leading to biobehavioral interventions that can be translated into clinical practice. Moreover, to develop more effective interventions for conditions such as obesity, type 2 diabetes, and hypertension, additional research is needed on how self-monitoring of physiological variables affects the individual’s subsequent behavior.[160] For example, future studies could address knowledge gaps around how self-monitoring of variables such as body weight, blood pressure, and blood glucose, and use of the resulting feedback, affects the individual’s subsequent behavior in realms such as diet, food choice, energy intake, and physical activity. Emerging research has indicated how self-monitoring of brain activity, so-called real-time neurofeedback[161], and neuromodulation technologies such as transcranial stimulation, may be used to directly target the brain to change behaviors relevant to obesity and type 2 diabetes.[162]

Translating research on the drivers influencing human eating behavior at the individual or population level requires bridging basic and applied areas of multiple research disciplines (e.g., psychologists, neuroscientists, bioengineers, nutrition scientists, economists, marketing research experts, food scientists). In addition, training investigators who are more able to collaborate or translate animal model findings to human application will help. As one example, human and animal researchers need to collaborate to use recently improved research tools to learn more about behavioral phenomena such as food intake, nutrient intake, and food choice, particularly when preferred technologies are not readily available for use in humans. Such tools include novel functional and structural neuroimaging (e.g., high-resolution magnetic resonance imaging (MRI), positron emission tomography (PET), calcium and photoacoustic imaging) and neuromodulatory technologies (e.g., transcranial stimulation, optogenetics, designer receptors exclusively activated by designer drugs (DREADD)). These tools may provide new approaches for understanding the role of nutrition in the central and

peripheral nervous systems, and endocrine systems including the enteric nervous system, and the interaction between these complex systems. Indeed, emerging methodologies for studying physiologic phenomena (e.g., neuroimaging and neuromodulatory technologies, passive sensing of eating behavior, unbiased molecular pathway methodologies, tissue and organ-specific signaling) and contextual influences (e.g., location, activity, social situation, environment) have the potential to improve our understanding of the drivers of eating behavior that can be targeted to improve strategies for individual-level and population-level behavior change. For example, researchers could explore integrated use of emerging device-based and imaging technologies (e.g., neuroimaging, neuromodulation, mobile technologies), with newer data-driven and statistical methodologies (e.g., citizen science and big data models, ecological momentary assessment).

Research and Resource Initiatives

Short-term Initiatives

- Link individual learning styles, health literacy, and cultural contexts to increased utilization and understanding of nutrition education materials and information on healthful diets.
- Identify effective communication methods to counteract the development of unhealthful eating behaviors, particularly among at-risk subgroups.
- Understand the role of sensory experience (e.g., taste, smell, texture), perception, neural pathways, and behavioral or psychosocial processes in modulating food choice and food intake, especially for foods or nutrients whose individual and population-level intake should be decreased (e.g., salt, fat, added sugars, calories) or increased (e.g., vegetables, fruits).
- Develop and validate improved objective measures of food intake behavior and other relevant psychological constructs and behaviors.
- Take advantage of new neuromodulatory technologies (e.g., vagal nerve stimulation, vagal nerve blocking) in combination with imaging and blood sampling to improve our understanding of mechanisms and pathways in humans of normal and disrupted meal patterns, eating behaviors, and phenomena such as cravings, snacking, and over-consumption during meals.

Long-term Initiatives

- Characterize which modalities of self-monitoring for body weight and other behaviorally-responsive physiologic risk factors (e.g., blood pressure, blood glucose) are the most effective for various demographic groups.
- Develop and test improved individualized and group-level interventions based on behavioral phenotyping.
- Link functional as well as neuro-anatomic imaging and cellular pathway methodologies with nutrient intake and food choice behavior.

Topic 3 (Q3T3). How can we use behavioral economics theories and other social science innovations to improve eating patterns?

Rationale

Behavioral economics draws on research from the fields of economics, cognitive psychology, social psychology, decision science, and marketing to better understand consumer behavior.[163] Findings have identified many ways that behavior predictably varies from what would be assumed under the standard economic assumption of rational decision-making. For example, cognitive biases lead to decisions that over-value short-term benefits such as the taste or convenience of foods versus long-term benefits such as health. Other factors identified by behavioral economics research may be relevant to food choice behavior; these include issues such as numeracy, mental accounting, loss aversion, satisficing, use of heuristics, effects of framing, precommitment, affective forecasting (and empathy gaps), counterfactual thinking, defaults, and norms.[164] Such insights may have implications for food choice behavior that may be used to design strategies to increase the effectiveness of food and nutrition programs and policies (*See* Q2T1, Q2T2 and Q3T2).[164] Additional work in related areas focuses on some of the emotional and motivational processes that influence food choices and other health-related behaviors. Both positive and negative emotions can promote consumption of calorie-dense "comfort" foods. Moreover, the motivation to be seen positively by others, see oneself positively, preserve cognitive and other resources, and make defensible judgments and decisions can influence food choice.

Many food choices are instigated by largely non-conscious, habitual influences. Indeed, research has demonstrated how subtle and seemingly inconsequential factors such as plate size influence food consumption.[165] Food choices can be influenced by environmental factors such as weather, perceptions of color, variations in color not associated with taste (e.g., differences in colors of candy-coated chocolates), and other seemingly irrelevant factors. Informational strategies such as nutrition labeling may influence consumers in unintended ways with implications for their effectiveness in encouraging healthy eating. For example, some consumers may assign a "health halo" to a food, assuming that because they perceive it to be healthier along one characteristic, it is also healthier in all characteristics, thereby leading to overconsumption.[166]

These and other findings from social science research can provide insights into factors influencing eating patterns, and can lead to the development of more effective policies and strategies for guiding consumers toward healthy eating patterns. As one example, behavioral research on how framing affects consumers' perceptions of information led researchers to examine alternative modes of presenting meat label information on the fat content of ground meat. Findings indicating that selective presentation of lean/fat content (e.g., "90 percent lean") tended to bias consumer decisions informed USDA regulations requiring that ground meat packages list both the percent lean and fat content.[95]

Research using behavioral economics principles has identified effective environmental modifications in school cafeterias that influence children to consume more of the healthy foods offered through the USDA's National School Lunch Program (NSLP).[167] These findings were applied to the development of the USDA HealthierUS School Challenge: Smarter Lunchrooms, which is being used in school cafeterias nationwide to promote healthy eating by the more than 31 million children who participate in the NSLP on a typical school day.[168] These examples illustrate the benefits of applying behavioral economics and other social science research to the design of policies, programs, and strategies to promote healthy eating patterns.

Research Gaps and Opportunities

Further investigation of how behavioral economics and other social science theories can explain how consumers make food choices could provide useful information for nutrition policies such as labeling. Such research could also be used to develop feasible, population-level interventions and to identify factors that may cause such applications to be more or less successful. For example, identifying what kinds of food choice behaviors are most susceptible to influence, as well as the food choice behaviors that could maximize the benefits of behavioral change would be useful for prioritizing interventions. Examination of how social factors (e.g., norms, social support), environmental factors (e.g., food access, food labeling, marketing), and economic factors (e.g., time and/or money constraints, educational attainment) interact with intrapersonal factors to determine food choice could suggest strategies for developing interventions tailored to particular consumer groups. Opportunities exist in the arena of time use research to examine interactions between diet and physical activity in the context of time use and time poverty. Health researchers are beginning to analyze time use data but their analyses are often simplistic. Time poverty or the feeling of time poverty is often cited as a barrier to healthy eating and to healthy levels of physical activity; understanding both of them in the context of other activities seems essential to achieving behavior change where needed and seems to require attention simultaneously to physical activity and food related behavior. More research is also needed on how factors such as behavioral design, behavioral economics, and social science research might yield new insights into more effective strategies for increasing consumer demand for healthy food and improving eating patterns. For example, the following federally supported research centers are both designed to incorporate diverse perspectives influencing the food supply: the Cornell Center for Behavioral Economics in Child Nutrition Programs and the Duke-University of North Carolina at Chapel Hill (UNC)-USDA Center for Behavioral Economics and Healthy Food Choice Research.

Research and Resource Initiatives

Short-term Initiatives

- Formulate an agenda for conducting behavioral economic and social science research to promote healthy eating that considers priority food choice behaviors in key settings such as retail venues as well as conceptual, methodological, and measurement issues.
- Conduct behavioral design, behavioral economics, and social science-based research that will yield insights into more effective strategies for increasing consumer demand for healthy foods and improving eating patterns.
- Conduct research studies using a variety of methods (e.g., experiments in controlled settings, field experiments, analysis of consumer survey data) that are focused on diverse population segments (by socioeconomic status, education level, and ethnic/cultural differences) to explore the effectiveness of factors suggested by behavioral economic and social science research in predicting or modifying food choice behaviors that impact eating patterns, nutritional status, and health.
- Conduct research studies investigating how the findings from behavioral economic and social science-based research on food choice can be used to inform nutrition policy and program actions. Examples include applications in federal food and nutrition assistance programs including the USDA Child Nutrition Programs, SNAP, WIC, and federally-regulated food and nutrition labeling, as well as other forms of information such as front-of-package information and in-store marketing such as shelf-tag nutrition symbols.

Long-term Initiatives

- Explore how findings from research studies can be implemented in policies, programs, and strategies to promote healthy food choices by Americans in a cost-effective manner.
- Support translational research, including the large-scale evaluation of current and future programs and activities designed using behavioral economics and social science principles; one current example is the "Smarter Lunchrooms" initiative being implemented by USDA to increase the effectiveness of the NSLP.

Topic 4 (Q3T4). How can we advance nutritional sciences through the use of research innovations involving Big Data?

Rationale

Leveraging innovative biomedical Big Data approaches and advanced analytics in clinical and population health research has tremendous potential to accelerate human nutrition research.[169,170] While the term 'Big Data' may be broadly applied to the analysis of large data sets, the concept of Big Data more fully encompasses methodological approaches for capturing, integrating, and analyzing very large and diverse (multimodal) data sets from a variety of sources. Big Data approaches carry unique characteristics and challenges, often described as "the Four V's": volume, velocity, variety, and veracity.[171] Big Data is information that is not just voluminously large, but information which is generated at high speed and relatively inexpensively, with great diversity and uncertain quality. For human nutrition research, special attention must be given to quality since dietary intake data of poor quality when combined with other large data sets could potentially amplify errors.

Big Data pertaining to human nutrition research can be conceptualized as emanating from four types of sources: 1) a small number of groups who produce very large amounts of data, usually as part of projects specifically funded to produce important resources for use by the entire research community; 2) individual investigators who produce large datasets, often empowered by the use of novel technologies; 3) a large number of sources who each produce small datasets (e.g., research data, clinical data in electronic health records), the value of which can be amplified by aggregating or integrating them with other data; and 4) transactional data relating to food, nutrition, and health products and services.

Federal agencies have several major pools of data within their systems as well as access to information pools whose collection was funded by federal grants. Additional information resources are also available through collaborations with private-sector industries and universities. Examples of such datasets and their content include: the NHANES physical examination, interview, and laboratory based tests (i.e., biomarkers); national and local information on food supply availability, composition, and use; USDA ERS data on food supply, food purchasing and acquisition, household food security, and related data, with special emphasis on recipients of food/income support; administrative data on the USDA food and nutrition assistance programs including data on participation and outcomes.

The following examples of federal resources could be leveraged in the collection, management, and utilization of nutrition research Big Data:

- Data.gov makes datasets collected by the federal agencies publically available for research and development purposes.
- USDA and HHS coordinate a number of federal nutrition databases and health monitoring programs.[43,172] Nutrition surveillance programs include the

National Health and Nutrition Examination Survey (NHANES), the National Health Interview Survey (NHIS), and Food Composition and Nutrient Intake reporting. Additionally, USDA projects such as the Food and Nutrient Availability Data System and the National Household Food Acquisition and Purchase Survey link nutrient information to large national databases on food purchases of Americans to assess factors influencing whether Americans purchase healthy diets.

- The National Collaborative on Childhood Obesity Research brings together the CDC, the NIH, the Robert Wood Johnson Foundation (RWJF), and the USDA to improve the efficiency, effectiveness, and application of research to accelerate progress in reducing childhood obesity. The NCCOR Catalogue of Surveillance Systems and the Measures Registry was developed to allow investigators rapid access to information from nutrition and health surveillance systems, as well as to support validation studies on the development of standardized metrics for diverse research designs. The information compiled by these programs could potentially be comprehensively integrated, through application program interfaces (APIs), to support evaluative research on how changes in the food and physical activity environment influence individual-level eating patterns and physical activity behaviors.
- The USDA Economic Research Service Food Access Research Atlas and Food Environment Atlas integrate statistics on food choices, health, well-being, economic status, supermarket availability, and other data relevant to the food environment. An online interface for each offers a spatial overview that can be accessed for community planning and research purposes.
- The NIH-supported PhenX Toolkit (Consensus Measures for Phenotypes and Exposures) provides standardized measures to assess complex diseases, phenotypic traits, and environmental exposures, including those related to individual dietary intake and the food environment. For research on exposures that may be important in identifying disease-risk phenotypes, the use of PhenX measurements facilitates combining data from a variety of studies, and can help investigators expand a study design beyond the primary research focus.
- The NIH Big Data to Knowledge (BD2K) initiative was established to capitalize on the exponential growth of medical datasets by promoting innovative advances in Big Data resources, analytics, and training. BD2K engages with partners in academia, nonprofits, and other government organizations to coordinate the access to, linkages between, and analysis of diverse and multimodal biomedical datasets.
- The NIH Health Care Systems (HCS) Research Collaboratory Program works to strengthen national capacity to implement cost-effective, large scale research studies that engage health care delivery organizations as research partners. This effort aims to rethink clinical trial design and provide a framework of implementation methods and best practices that will enable the participation of many health care systems in clinical research.

- Several NIH program efforts could be harnessed in the development of large open-access systems for sharing genomic data, along with encouraging innovative hypotheses and investigations related to nutrition and health. Such efforts hold promise for developing a more precise and individualized understanding of nutritional needs.
- The CDC is spearheading a Healthy Weight Measures Initiative that is creating consistent Healthy Weight IT standards for all stakeholders to help improve quality data capture, care coordination, and population health analytics. As part of this initiative, new LOINC® standard questions will be globally available through electronic health systems.

These diverse efforts in federal research programs not only demonstrate a wealth of opportunities for Big Data in nutrition research, but also indicate critical challenges which must be addressed. In general terms, the full realization of Big Data's potential requires transformative methods of data collection, storage, access, and analysis. Data standardization is critical for all Big Data efforts, and this is particularly true in nutritional data. To fully valorize the large and diverse data accumulating on food, nutrition, and health, coordinated efforts are needed to promote the development and utilization of standard metrics in nutrition research. In particular, standardized metrics of nutrient access, intake, and status are needed to support the creation of integrated data systems utilizing multiple government and non-governmental sources. A comprehensive integration of such multimodal data could then be effectively analyzed to aid in nutrition research strategic planning and to inform policy decisions.

Research Gaps and Opportunities

Big Data encapsulates the opportunities and challenges facing all researchers in the nutritional sciences and related fields in accessing, managing, analyzing, and integrating multimodal data. This data includes imaging, phenotypic, molecular (including various "omics"), exposure, clinical, behavioral, socioeconomic, environmental, and many other types of biological and biomedical data that are increasingly larger, more diverse, and complex. Effective management and analysis of these data will require concerted efforts to enhance both computational infrastructure and nutrition research workforce training. At the same time, federal agencies are mindful of the privacy and ethical concerns associated with Big Data, including the potential that Big Data could be used in ways that might exclude certain populations within our economy. To this end, federal research agencies must provide patients and consumers with appropriate choices about the collection and use of their data, report our findings on an aggregate and de-identified basis, and continually examine research designs and results for potential biases.

In the arena of Big Data research, advances have been made to enhance the abilities of researchers and program evaluators to access large-scale national nutrition monitoring resources. However, opportunities exist for nutrition research relevant to chronic disease prevention to be further improved. This improvement

could be initiated by the development of comprehensive and integrated databases on food composition, biomarkers of food intake, and molecular patterns following exposure. Efforts to integrate such databases within the context of clinical care systems might further clarify the role of nutrition and nutrients in pathophysiology and disease prevention. As one example, expanded use of pragmatic trials, which are designed to evaluate intervention effectiveness in real-life practice conditions and mostly measure patient-reported outcomes, could potentially guide best practices for effective and efficient integration of dietary assessment methods into routine medical practice and, ultimately, electronic health records. This optimization of clinical care could be both informed by Big Data analytics as well as generate new Big Data resources.

The research community could greatly benefit from access to robust data on food supply and distribution trends, including transactional data, common perceptions about food, personal consumption patterns, marketing, and socioeconomic factors that can influence food choices. Comprehensive integration of information from both government and non-government sources is needed to facilitate such research efforts. Broadly, there is a critical need to leverage existing data while also developing new databases and integrated “data commons” to support nutrition research. Effective integration of Big Data requires data interoperability and inter-comparability. In turn, these critical data characteristics are created through well-designed metadata standards and indexing classifications. The NIH Office of the Associate Director for Data Science is currently developing The Commons as a framework for catalyzing information sharing and discovery in biomedical Big Data. Existing Big Data efforts that successfully integrate administrative, demographic, and health information, such as the Soldier Outcome Trajectory Assessment (SOTA) project of the U.S. Army Medical Command, can provide insights on the development of such databases and may serve as key partners for collaboration.

Innovative systems modeling approaches have potential to address questions about nutrition and health at several different organizational levels but integrating data from multiple sources is required for that potential to be realized. For example, models may explore factors influencing individual intake, population consequences of changes in the environment, or consequences of environmental change for the food supply. Models of individual consumption behavior, as well as models of population-level energy balance parameters require data about individual behavior related to energy balance as well as factors influencing such behaviors. More work is needed to improve our understanding of how to translate data from health surveys, GIS systems, ecological momentary assessment, and other data streams into meaningful parameters needed for modeling. Exemplary data sets needed to be developed to compare modeling approaches and to further determine which variables are relevant, the level of spatial and temporal detail required for different models, and the utility of new data streams such as information from mobile devices.

In addition, advances in computation methods and mathematical simulation models that enable the integration of information from multiple sources are needed. The rise in availability of real-time data collection from mobile sensor technologies and social media sources, including their use for capturing eating behaviors, has stimulated the development of statistical and programming tools for extracting research relevant measurements out of these complex and repeated assessments. Advances in computational methods must provide the basis to assess the relevant statistical properties of the diverse datasets, and support policy-relevant analysis across the merged data. With the increased use of observational Big Data drawn from clinical care interactions, the need for statistical approaches that can adjust for unmeasured confounding and non-random bias will be amplified. Furthermore, by sharing and reusing data originally collected for other purposes, the knowledge gained through Big Data computation analysis and simulation modeling has the potential to increase our understanding of how to reduce the need for expansive randomized intervention trials.

Big Data utilization in the arena of the human genome and nutrition also holds promise for advances in understanding disease risk by enabling the identification of clinically meaningful relationships between genomic data and human health indicators. Management and utilization of such personalized nutrition data, for individuals and populations, is both a tremendous challenge and an enormous opportunity. Nutrition community-derived data standards should be utilized for the promulgation of data sets compiled from nutrigenetics and nutrigenomics investigations. These scientific fields study the effects of genetic variation on dietary response and the influence of food compounds on gene expression, respectively. Integration of this genomic information along with high-throughput “omic” technologies may enhance understanding of nutrient-gene interactions and, ultimately, the development of individualized nutrition strategies for optimal health and disease prevention. The practical application of nutritional genomics for complex chronic diseases such as cardiovascular disease, diabetes, and cancer is an emerging science area. Notwithstanding, patient record privacy, confidentiality, and security remain critical factors when designing and implementing Big Data approaches for individual and population genetic studies.

To better leverage federally funded nutrition-related research resources, Big Data approaches need to be explored to help manage, analysis, and integrate datasets from across the Federal Government as well as other funding sources. At the same time, scalable solutions are important for Big Data approaches in nutrition research in order to facilitate highly focused research projects and to support discovery across the full range of individual and public health. By bringing together information from all nutrition-related research, Big Data has the potential to provide insight on funding trends, identify gaps in funded nutrition research and possible areas of overlap, and uncover opportunities for coordinating efforts to more effectively and efficiently leverage available resources.

Research and Resource Initiatives

Short-term Initiatives

- Enhance the integration of and access to current national databases on nutritional status such as the National Health and Nutrition Examination Survey (NHANES) and its dietary assessment component, What We Eat in America (WWEIA), the USDA National Nutrient Database for Standard Reference, and the NIH Office of Dietary Supplements and National Library of Medicine Dietary Supplement Label Database.
- Enhance the integration of and access to current national databases of references and abstracts on food, agriculture, nutritional science and other health related topics such as the Library of Congress, the U.S. National Library of Medicine PubMed, and the USDA National Agriculture Library.
- Expand upon existing research and health databases such as the Federal RePORTER and HealthData.gov (or initiate a long-term initiative to develop a new database) to support baseline assessment of the Federal Government's total nutrition research portfolio, as well as a more in-depth analysis focusing on specific priorities identified through this *Roadmap* process.
- Develop comprehensive and integrated databases on food composition, biomarkers of food intake, and molecular response patterns following nutrient intake.
- Develop and implement nutrition community-based standardized approaches for nutritional data collection, structure, and documentation, such as Common Data Elements (CDEs) in clinical research and patient registries.
- Develop and promulgate defined metadata standards and indexing criteria for nutritional data entry, as they are critical elements for effective information curation in Big Data systems.
- Ensure that nutrition-related expertise is included in trans-federal, biomedical-related Big Data strategic planning and advisory efforts, such as the Networking and Information Technology Research and Development (NITRD) Program, the Big Data Senior Steering Group, and relevant NIH BD2K Program Management Working Groups to support the design, implementation, and sustainability of comprehensive databases on nutrition-related information.
- Through the development and support of application program interfaces (APIs), systematically enhance researcher access to nutrition data to improve their ability to utilize diverse data on food supply, consumption patterns, and eating behaviors. These efforts should also work towards the implementation of simulation research programs that are informed by real-time data collection.
- Leverage current simulation models, such as the Prevention Impacts Simulation Model (PRISM) for Chronic Disease Policymaking, to explore the health and cost outcome trajectories of various interventions in complex questions that pertain to food systems, nutritional status, and health.

Long-term Initiatives

- Support research that develops dietary assessment tools which can be incorporated into patient portals within health care delivery systems, in order to enable comprehensive integration of nutritional, genetic, and health outcome data.
- Support, develop, and implement workshops, collaborative activities, and other training resources to impart the skills and knowledge needed by nutrition researchers to extract the full value of nutritional and biomedical Big Data.
- Support the development of statistical methodologies that can be applied in nutritional epidemiology studies and clinical trials to adjust for unmeasured confounding and non-random bias.
- Enhance the linkages between federal data resources and industry data on food store locations and characteristics, food product composition, and food marketing and advertising.
- Utilize existing federal nutrition-related datasets to examine complex questions requiring the use of long-term, Big Data approaches.
- Utilize existing longitudinal cohort studies with data on health risks and characteristics, genetics, dietary intake, and nutritional status, as well as cohorts nested within health care systems to further clarify the role of nutrition and nutrients in pathophysiology and disease prevention.
- Capitalize on advances in nutrigenomics and nutrigenetics with high-throughput “omic” technologies to examine nutrient-gene interactions and the potential for individualized nutrition strategies for optimal health and disease prevention.

Workforce Readiness for Advancing Nutritional Sciences Research

A key component to implementing this *Roadmap* includes developing and leveraging a diverse, interdisciplinary workforce capable of and empowered to advance nutritional sciences research, policy, and practice.[173] This workforce readiness section discusses the need to recruit, cultivate, and develop nutrition scientists across all stages of professional development and build their capacity to work across diverse disciplines and entities. This section identifies key disciplines and research sectors that will be essential partners, and discusses ways to enhance their human nutrition research training and capacity. In addition, attention is given to relevant scientific and health professional staff and other partners in the laboratory, clinic, and community. Recommendations focus on opportunities within graduate, medical, dental and other health professional education, postdoctoral, residency, and fellowship training, as well as continuing education (*See* Appendix D for Examples of Federally Supported Career Development and Training Programs Relevant to Human Nutrition Research).

Naturally, education begins with supporting science, technology, engineering, and math (STEM) programs starting as early as pre-kindergarten and consistently interwoven into educational and experiential curriculum throughout high school. Although this *Roadmap* does not focus on undergraduate education or vocational and technical experiences, attention to high-quality training during these earlier phases will be critical. Likewise, strengthening the science and health capacity at minority-serving institutions such as 1890 Land Grant Universities, the 1994 Tribal Colleges and Universities, Alaska Native-serving, Native Hawaiian-serving and Insular Areas Institutions and Hispanic-serving Institutions is necessary to ensure the recruitment and retention of a diverse, skilled workforce.

Fostering the Next Generation of Human Nutrition Researchers

Building the skills and capacity necessary to conduct interdisciplinary research is a dynamic process and should span all developmental stages of education and career development. First, we must build a pipeline of talent capable of developing the critical knowledge, skills, values, analytical approaches, communication strategies, and practical application of nutritional sciences necessary to advancing the field. Motivated undergraduate students from a variety of majors should be recruited to pursue interdisciplinary graduate studies in the nutritional sciences. During graduate education and training, efforts should be made to enhance students' understanding of the many relevant disciplines to food, nutrition, and health research, including agriculture, anthropology, biochemistry, biology, biophysics, biostatistics, climate science, dentistry, economics, environmental science, law, sociology, psychological, and medical nutrition therapy.

Specific to postdoctoral training,[174] strategic efforts must be made to ensure that postdoctoral trainees and fellows successfully transition into junior faculty positions marked by independent human nutrition research or into other nutrition-relevant research, policy, or practice opportunities. Similarly, new and early career investigators need specialized training and capacity building that will enhance their ability to conduct

innovative interdisciplinary human nutrition research. Continuing education opportunities will be instrumental in ensuring more senior scientists continue to expand and refine their skill set, particularly in more innovative and interdisciplinary methods, technologies, and collaborative research team arrangements.

Special attention should be given to recruiting, cultivating, and developing medical students,[175] residents and fellows,[176] and other health professionals (e.g., registered nurses, dentists, dental hygienists, and pharmacists)[177,178] during their early training stages to ensure they develop human nutrition research skills and segue to research careers in human nutrition research. These students and fellows bring critical clinical skills to prevent, control, and treat nutrition-related diseases. Efforts to instill the critical differences and issues in human nutrition research would help to ensure their success in advancing human nutrition research. A challenge for recruiting future researchers involved in clinical care is their need to balance research career development with clinical skills acquisition and training time. Another issue is that many health professionals with doctoral degrees face significant educational debt which often forces them to turn down or delay research training or career paths. Support for loan repayment and protected time to conduct research is crucial to their success. For instance, the NIH Loan Repayment Programs provide at least two years of loan repayment funding support and protected time to conduct research. The DoD and other HHS agencies such as the Health Resources and Services Administration (HRSA) also offer health professional loan repayment programs.

Increasingly, nutrition scientists see how models and theories from outside the field could strengthen future investigations and expand the potential of human nutrition research. Targeted efforts across the various professional and developmental stages could be made to build the skills and capacity among individuals with expertise in the ever-expanding list of relevant disciplines.

An important component to fostering the next generation of human nutrition researchers will be to develop models specific to human nutrition research that can inform decisions about training the optimal number of people for the appropriate types of positions.[179,180] As one example, the NIH created an office to assess the biomedical research workforce and convened a working group to study the optimal research training of individuals in clinical disciplines.[181,182] Yet, more work is needed to assess and strategically plan for the current and future workforce needs unique to human nutrition research that are distinct from general issues and opportunities in the biomedical and scientific workforce.

Invigorating an Interdisciplinary Scientific Workforce

While effort must be made to recruit and train researchers, equally important are the time, talent, and thoughts of the relevant scientific and health professional staff and other partners in the laboratory, clinic, and community.[177,178] Particular attention is needed for those within the health care sector who have great potential to contribute directly and indirectly to the “synchronizing and reinforcing” of healthy eating.[178]

Improving the quality and quantity of basic and applied nutritional sciences research, policy, and practice covered in existing academic and continuing education opportunities will help. So will creating new and more innovative nutrition-related didactic and practicum learning opportunities throughout the student and professional development continuum. Several relevant curricula have been developed for medical training, while more tailored work is needed for other allied health sectors such as registered nurses. As one medical education example, the Nutrition Academic Award (1998–2005), supported by the National Heart, Lung and Blood Institute (NHLBI) and the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), provided support to U.S. schools of medicine and osteopathy that encouraged the development or enhancement of medical school curricula to increase opportunities for students, house staff, faculty, and practicing physicians to learn nutrition principles and clinical practice skills.[175-178,182-184] The program emphasis included preventing cardiovascular diseases, obesity, type 2 diabetes mellitus, and other nutrition-related chronic diseases. Recently, the National Heart, Lung and Blood Institute convened a Working Group Meeting to develop recommendations for implementing nutrition across the continuum of clinical health professional education and specialty training.[182] Another curriculum example created by the National Cancer Institute for both health professionals and patients was the Nutrition in Cancer Care (PDQ®).

More targeted and comprehensive efforts will be needed to build and foster meaningful collaborative relationships around interdisciplinary research agendas between these health care sectors and human nutrition researchers. The Patient Protection and Affordable Care Act of 2010 (P.L. 111-148) and The Health Information Technology for Economic and Clinical Health Act of 2009 (enacted under Title XIII of The American Recovery and Reinvestment Act [P.L. 111-5]) provide federal examples supporting the interactions between health care sectors and prevention research. Yet, additional programmatic and policy changes are needed at the academic, health care system, and federal policymaking levels to more robustly support the potential of the health care sector.[176,177,183,184] Understanding the clinical effectiveness of strengthening the human nutrition research skills of key health care workers will accelerate progress in this area.

Besides clinical collaborators, efforts must be made to invigorate the contributions of public health professionals. The Patient Protection and Affordable Care Act of 2010 (P.L. 111-148) set forth significant provisions to raise connections between prevention and health care; specifically acknowledging how public health professionals and approaches could improve the availability, accessibility, and affordability of healthy foods and beverages that influence food choice, nutritional status, and health outcomes. Whether through private or public organized approaches, more nutrition-relevant work is needed to mobilize and maximize public health professionals working through education, policymaking, and research to protect the safety and improve the health of communities.

As research continues to illustrate the potential of environmental, policy, and systems change to foster active living and healthy eating at the individual and population levels, more work is needed to improve interactions between nutrition scientists and those trained in fields such as architecture, engineering, law and economics, residential and

commercial development, and public administration and policy, as well as urban and regional planning.[185,186]

Workforce Readiness Recommendations

- Support research and infrastructure to recruit, cultivate, and develop the optimal and appropriate number of graduate students, postdoctoral fellows, medical and dental students, residents, fellows, other key allied health graduate students, and early-stage investigators working on innovative and interdisciplinary human nutrition research especially among under-represented groups, including policies and programs that address securing support for independent investigations.
- Develop partnerships between and among government, academic institutions, professional societies, nongovernment organizations, and the private sector to:
    - Promote and disseminate relevant training and continuing education opportunities, including how to build research collaborations across diverse disciplines and secure support for cutting-edge and interdisciplinary human nutrition research projects; and
    - Keep abreast of pre- and postdoctoral and early-stage clinical nutrition researchers' interests and concerns in pursuing a career in human nutrition research, especially among researchers from underrepresented groups.

Topics of Interest to ICHNR Participating Departments and Agencies

This section provides background on the human nutrition research and *Roadmap* interests of each of the participating ICHNR agencies or departments.

The following table illustrates the topics of interest by each of the participating ICHNR departments and agencies, in alphabetical order by abbreviations.

Agency	Commerce	DoD	EPA	FTC	HHS	NASA	USAID	USDA	VHA
Question 1: How do we better understand and define eating patterns to improve and sustain health?									
Q1T1 Health Promotion and Disease Prevention and Treatment	X	X		X	X	X	X	X	X
Q1T2 Individual Differences Including “Omics”		X			X	X		X	X
Q1T3 Population-Level Monitoring	X	X	X		X		X	X	X
Question 2: What can be done to help people choose healthy eating patterns?									
Q2T1 Influences on Eating Patterns	X	X		X	X	X	X	X	X
Q2T2 Interventions		X		X	X	X	X	X	X
Q2T3 Systems Science					X				X
Q2T4 Environmental Sustainability	X	X					X	X	X
Question 3: How can we develop and engage innovative methods and systems to accelerate discoveries in human nutrition?									
Q3T1 Assessing Dietary Exposures	X	X	X	X	X	X	X	X	X
Q3T2 Biobehavioral Science		X			X	X	X	X	X
Q3T3 Behavioral Economics		X		X	X			X	X
Q3T4 Big Data	X	X		X	X		X	X	X

United States Department of Commerce

National Institute of Standards and Technology (NIST)

About NIST: The National Institute of Standards and Technology (NIST), a non-regulatory agency within the Department of Commerce, is one of the nation's oldest physical science laboratories. The current mission of NIST is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

About NIST's Human Nutrition Research: For more than 40 years, NIST has provided food-matrix Standard Reference Materials (SRMs) for the determination of trace element content, including both nutrient elements (minerals) and toxic metal contaminants. Examples of these early food-matrix SRMs include total diet, spinach, rice and wheat flour, milk powder, and oyster tissue. More recently, NIST has developed food SRMs for measurements of vitamins, carotenoids, fatty acids, and cholesterol in foods including infant formula, baby food composite, peanut butter, baking chocolate, meat homogenate, breakfast cereal, milk powder, and egg powder. Many of these SRMs were developed at the request of and/or in collaboration with USDA, FDA, and/or the food manufacturers industry. NIST uses its expertise in chemical measurement science to assign a value for the amount of nutrients or contaminants in these food matrices. The NIST assigned value, generally based on multiple results from numerous analyses using several different analytical measurement techniques, is considered to be of the highest quality and accuracy. These food-matrix SRMs are used worldwide by laboratories involved in testing of food products for nutrient composition and/or potential contaminants, to validate measurement methods and to assist in assuring the quality and accuracy of measurements of nutrients in similar food materials. One of the most regulated food products in the U.S. is infant formula. In 1996, NIST produced the first infant formula SRM, in collaboration with FDA and USDA. The current version of the infant formula material, SRM 1849a Infant/Adult Nutritional Formula, which has values assigned for more than 90 nutrients including minerals, vitamins, fatty acids, and cholesterol, is the most widely distributed food-matrix SRM, with sales exceeding 525 units per year.

NIST also has a long history associated with the development of measurement methods and SRMs for clinical health and nutritional assessment. The first SRMs for clinical analyses were developed to improve measurements of cholesterol in human serum to assess health status. Prior to the early 1970s, it was difficult to assess whether an individual had high cholesterol levels, because cholesterol tests were inaccurate by more than 20 percent, which resulted in either unnecessary treatment or an increased (and unacknowledged) risk of death. Since the development of SRM 909 Human Serum (with a value for cholesterol) and SRM 1952 Cholesterol in Human Serum in the 1980s, the quality of cholesterol measurements has improved significantly. Additional SRMs to assess health status were developed in the 1990s for measurement of other clinical health status markers (e.g., glucose, creatinine, uric acid) and for biomarkers of nutritional status (e.g., fat-soluble vitamins, carotenoids). Most of these serum-based SRMs were developed at the request of the relevant Institutes within the NIH (e.g., NCI).

About NIST's NNRR Interests: The *Roadmap* topical areas of most interest to NIST are those that rely on nutrient measurements such as Q1T3 (Population-Level Monitoring) and Q3T1 (Assessing Dietary Exposure). However, there may be other questions and tasks that require some level of standardization or validation of nutrient measurement accuracy that would be supported by NIST SRMs.

A recent interagency activity relevant to Q1T3 (Population-Level Monitoring) was NIST's collaboration with the NIH Office of Dietary Supplements to develop several SRMs for nutritional assessment biomarkers in human serum to specifically support the measurement needs of the NHANES and the CDC. That is, human serum-based SRMs have been developed for the determination of vitamin D metabolites, vitamin B_6 metabolites, vitamin B_{12} biomarkers, fatty acids, and folate. SRM 972 Vitamin D Metabolites in Human Serum, issued in 2009, and the replacement material SRM 972a, issued in 2012, have had a wide distribution worldwide (with sales exceeding 800 units per year for SRM 972) and a significant impact on the quality of vitamin D metabolite measurements. SRM 972 and SRM 972a were developed to address concerns about the reliability and comparability of measurements for total 25-hydroxyvitamin D, defined as the sum of 25-hydroxyvitamin D_2 and 25-hydroxyvitamin D_3, which are the predominant metabolites of vitamin D_3 and vitamin D_2. NIST SRMs for vitamin D measurements are a key component within the NIH Office of Dietary Supplements Vitamin D Standardization Program (VDSP), established in 2010 as an international collaborative effort to standardize the laboratory measurement of vitamin D status.

To assist in assessing nutrient intake, the ODS, USDA, and other federal agencies collaborated to establish the Dietary Supplement Ingredient Database (DSID), which contains estimates of the ingredients in dietary supplement products sold in the U.S. DSID initially focused on multivitamin/mineral (MVM) dietary supplements, the major dietary supplement used in the U.S. To assess and improve the quality of the data entered in the DSID, NIST, in collaboration with the ODS, developed a multivitamin/minerals tablet SRM with values assigned for all of the vitamins and minerals typically on MVM product labels. Two DSID studies for adult MVM and children's MVM have been conducted using SRM 3280 for quality control of the analytical measurements for the data in the DSID. As part of the on-going collaboration with the ODS, NIST has developed additional dietary supplement SRMs, including fish and plant oils containing omega-3 and omega-6 fatty acids, botanicals (e.g., ginkgo, saw palmetto, kelp) and calcium tablets; these dietary supplement SRMs can be used to assist in assuring the quality of data in studies to assess dietary intake of nutrients from supplements.

Related to Q3T1 (Assessing Dietary Exposures), NIST continues to produce food-matrix SRMs for the determination of nutrients. The number and variety of food-matrices used to develop SRMs will expand to better match the matrices typically analyzed to assess nutrient content. As new biomarkers for nutritional assessment are identified, NIST will pursue the development of measurement methods and SRMs to support the study of these biomarkers in nutrition research. NIST will continue to partner with other federal agencies such as USDA, FDA, NIH, and CDC to provide the measurement methods and standards to support their studies and regulations related to nutrition research.

National Oceanic and Atmospheric Administration (NOAA)

About NOAA: Within the Department of Commerce, NOAA is an agency that enriches life through science. NOAA's dedicated scientists use cutting-edge research and high-tech instrumentation to provide citizens, planners, emergency managers, and other decision makers with reliable information they need when they need it.

About NOAA's Human Nutrition Research: NOAA contributes to advancing human nutrition research through its work on seafood, which the *Dietary Guidelines for Americans* recommend a part of a healthy eating pattern. NOAA's seafood work resides in NOAA Fisheries (formally known as the National Marine Fisheries Service), which is made up of five regional offices, six science centers, and more than 20 laboratories around the U.S. and its territories, and has partnerships across the nation. The mission of NOAA Fisheries implies that the agency has a role in: 1) maintaining a healthy and sustainable seafood supply; 2) providing information about the seafood supply that is widely available and understandable; and 3) contributing to seafood safety research, inspection, education and trade.

Using the Magnuson-Stevens Fishery Conservation and Management Act (P.L. 94-265) as the guide, NOAA Fisheries works in partnership with the U.S. Regional Fishery Management Councils to assess and predict the status of fish stocks, set catch limits, ensure compliance with fisheries regulations, and reduce bycatch. Moreover, the resilience of our nation's marine ecosystems and coastal communities depend on healthy marine species, including protected species such as whales, sea turtles, corals, and salmon. Under the Marine Mammal Protection Act (P.L. 92-522) and the Endangered Species Act (P.L. 93-205), NOAA Fisheries works to recover protected marine species while allowing economic and recreational opportunities.

A sustainable seafood supply is the focus of the NOAA Fisheries Office of Sustainable Fisheries and Office of Aquaculture. The Office of Sustainable Fisheries works to manage fish stocks important to commercial, recreational, and subsistence fisheries through guidance and support of our Regional Offices and the U.S. Regional Fishery Management Councils. Sustainable Fisheries also strives to facilitate effective communication between and among constituents and supports a variety of seafood safety measures in the National Seafood Inspection Laboratory. The Office of Aquaculture works to foster marine aquaculture and business opportunities in coastal communities to support a domestic seafood supply that is safe and sustainable.

Additional NOAA research and resources include:

- Fishwatch provides web-based information on seafood sustainability and supply, including species-specific information about the science on the biology, population status, harvest, management, economics, farming, buying, and eating seafood.
- National Seafood Inspection Laboratory provides analytical laboratory, data management, Regulatory Compliance Risk Analysis, and Technology Transfer expertise to meet the Office of Sustainable Fisheries fishery management and

seafood safety responsibilities and supplies seafood and aquatic animal health information and data to federal and state agencies, academia, industry, and consumers.

- Northwest Fisheries Science Center conducts state-of-the-art science and technology on seafood safety through studies of seafood pathogens, toxins from harmful algal blooms, chemical contaminants, and other stressors of marine ecosystems that pose significant risks to the health of seafood resources and humans. The Center focuses on research to improve understanding of those risks, how to forecast them, and identify ways to mitigate their impacts.
- Seafood Inspection Program provides inspection services for fish, shellfish, and fishery products.

In addition, NOAA has a long history of responsiveness to regional, national, and international disasters that release toxic chemicals into the ocean. A primary response is environmental surveillance for seafood safety, usually in the immediate aftermath of a major event.

About NOAA's NNRR Interest: NOAA is very interested in the research and resource initiatives put forth in the *Roadmap*, particularly as they relate to understanding the role of seafood in a healthy diet and maintaining a sustainable seafood supply; specifically, Q1T1 (Nutrition in Health Promotion and Disease Prevention and Treatment), Q1T3 (Population-Level Monitoring), Q2T1 (Influences on Eating Patterns), Q2T4 (Environmental Sustainability), Q3T1 (Assessing Dietary Exposures), and Q3T4 (Big Data).

United States Department of Defense (DoD)

About the DoD: The Department of Defense is America's oldest and largest Government agency. The mission of the DoD is to provide the military forces needed to deter war and to protect the security of our country.

About the DoD's Human Nutrition Research: The military community has a long history of interest in nutrition. Indeed, many military leaders made extraordinary strides in the nutritional sciences. First, in 1753, Dr. James Lind, considered the father of military nutrition, wrote "*A Treatise of the Scurvy*." In 1778, Dr. Benjamin Rush wrote "*Directions for Preserving the Health of Soldiers*," which advocated that the diet of soldiers should consist chiefly of vegetables. Military nutrition research in the U.S. formally began in 1917 when the Surgeon General's Office established a Food Division for the purpose of "safeguarding the nutritional interests of the Army." Many more historical examples could be offered, but military nutrition has always been associated with safety, health, readiness, and performance.

Since 1949, when the National Military Establishment was renamed the Department of Defense, the energy and nutritional demands of service members engaged in training and missions has been of interest. The activities of service members, or warriors, are often unique and vary greatly from the general population, particularly with regard to environmental exposures (e.g., heat, cold, altitude) and physical activity. Service members must be well nourished to remain healthy and fit for service. Today,

developing, implementing, and evaluating effective nutritional strategies to optimize performance before, during, and after training and operations remains a high priority for the Department.

About DoD's NNRR Interests: A number of efforts are currently underway that focus on questions embedded within the research thrust noted in the NNRR as described by topical areas below. In addition to promoting eating patterns for improving health and preventing disease, the DoD is interested in the concept of human performance optimization (HPO) and how eating patterns and various nutrients contribute to performance and resilience. A focus on performance rather than health is critical, given most service members are young, which the DoD has found means health is a low priority since they tend to view themselves as invincible. At the same time, the DoD has found young service members want to perform at their peak. The DoD has also determined a focus on performance is more effective at gaining the interest and cooperation of service members.

For Question 1, the DoD is interested in the following questions:

- What are the nutritional needs and most effective feeding approaches for those engaged in strenuous physical activity under a wide range of environmental exposures—from very hot to very cold and from hypo- to hyperbaric conditions?
- Would the provision of specific antioxidants or other bioactive ingredients counter the effects of prolonged 100-percent oxygen exposure of divers?
- Are there any bioactive ingredients that might protect against heat or cold stress?
- Are there particular eating patterns or ingredients that could extend performance by increasing the oxidation of fatty acids as a fuel source?

In regard to performance, the DoD researchers are currently investigating the relationship between nutritional status and military health and readiness across a broad spectrum of the population—from the very healthy to those with post-traumatic stress disorder (PTSD) and mild to moderate traumatic brain injury (TBI)—but robust nutritional assessments are not typical in a clinical setting. Other questions DoD is interested in answering include:

- Do nutrition and eating patterns serve important roles in recovery from military-related health disorders (e.g., amputation, PTSD, TBI)?
- Do service members who have undergone a limb amputation have different nutritional needs than an able-bodied person?

In addition, the DoD is always considering how individual differences in nutritional status might impact both physical and cognitive performance. Efforts are also underway to understand whether garrison (on base feeding facilities) and deployment feeding requirements differ from those at home in order to optimize ration components and ensure adequate dietary intakes during deployments.

Other innovative research topics of interest relate to research on how the distribution and percentage of various macronutrients affects performance and behaviors (e.g., anxiety, depression). For example, which diet—a high-fat or very low-fat diet—is most effective in promoting healthy physical and cognitive function? Also, does the percentage of omega-3 fatty acids in the diet contribute to readiness and performance or protect against TBI? Do various antioxidants or other bioactive ingredients have a beneficial impact on cognition and performance? These questions remain to be answered and are of interest to the DoD.

The microbiome is of interest to the DoD from various perspectives, ranging from infant and maternal nutrition, to changing the microbiome as a countermeasure for indigenous diseases in foreign countries, to altering the microbiome for fatigue mitigation and enhanced recovery. All of these questions are relevant, but the capabilities in microbiota analyses are limited. So opportunities for collaboration are wide open.

Finally, Military Dietary Reference Intakes (MDRIs) are always revised to reflect the current state of science. Researchers within the DoD are always interested in forming partnerships to collaborate with sister agencies to address research gaps and opportunities in these areas.

Addressing Question 2 is very important to the DoD, given the diverse ethnic, cultural, social, and environmental backgrounds and exposures of service members and their families. DoD-supported research on in-garrison feeding facilities is attempting to apply and evaluate choice architecture and other interventions to optimize healthy food choices. That is, the DoD is working with the CDC on the Go For Green® and other choice architecture initiatives to determine the best ways to make the healthy choice the preferred and easiest option. Likewise, with regard to choosing healthy and sustainable foods, food scientists and technologists at the U.S. Army Natick Soldier Research, Development, and Engineering Center (NSRDEC) conduct research to identify foods for combat rations that are nutritious, palatable, and nonperishable. Often, combat rations supplied to warriors engaged in field operations must be carried over long distances and stored for long periods of time. These daily rations must also provide adequate nutrition and energy to support health and survival under demanding physical and environmental conditions. NSRDEC is continually trying to identify options that are nutritious, palatable, nonperishable, and environmentally sustainable—in terms of preparation, usability, preservation and packaging—and yet still have the rations meet operational requirements. Other efforts in healthy eating patterns and sustainability include examining the possible role of hydroponics and other such techniques within the DoD to provide healthy foods locally. Another topic of interest is the question as to whether teaching healthy cooking skills leads to healthier eating patterns. Finally, dietary supplement safety, education, surveillance, and adverse-event reporting continues to be one of our top research priorities. In particular, the DoD is interested in knowing how to convince service members that healthy eating patterns contribute more to health and performance than dietary supplements marketed for body building, performance enhancing, and weight loss.

For Question 3, the military community is known for many innovations and discoveries in human nutrition. Current DoD research is primarily focused on strategies to optimize health, readiness, and performance. Future research will focus on nutritional biomarkers for performance and selected deployment injuries. The DoD is investigating what markers of nutritional status are most predictive of selected psychological, social, behavioral, and physical characteristics. Biomarkers are a fruitful and important area for multiple federal collaborations with regard to nutrition and performance research and nutrition and trauma research. In regard to Big Data, the DoD has the capability of contributing in the area, given the multiple datasets and electronic health records that could be merged and analyzed. If nutritional biomarkers could be made available in an existing dataset to merge with others, it is likely nutritional sciences could advance in a meaningful way; this would be an opportunity to collaborate with other federal agencies.

Although research dollars for nutrition research have been limited within the DoD, various lines of effort are currently examining the physical and cognitive domains of human performance optimization. Future DoD efforts may place a higher priority on nutrition research and focus on individual differences in nutritional needs, adaptations to austere environments, psychological resilience, and disease prevention. Also, understanding the relationship between the microbiome and all associated aspects of human performance optimization (HPO) is of interest. The DoD is very interested in these questions and would welcome partnerships with other federal agencies.

United States Environmental Protection Agency (EPA)

Office of Pesticide Programs (OPP)

About the EPA: The mission of the EPA is to protect human health and the environment. The EPA's Office of Pesticide Programs (OPP) works with and across many programs within the EPA including the Office of Research and Development, the Office of Pollution Prevention and Toxics, and the Office of Science Coordination and Policy. Within OPP, the Health Effects Division is responsible for assessing pesticide exposure and risks to humans and domestic animals and maintains a database of food commodity consumption data derived from the NHANES/WWEIA food consumption survey.

About the EPA's Human Nutrition Research: While the EPA is not involved in human nutrition research *per se*, the EPA has interests in dietary exposure of chemicals through food. To accomplish assessment responsibilities, the EPA works with other federal agencies and nongovernmental partners. As one example, the EPA Office of Pesticide Programs (OPP) collaborated with the USDA to develop a food component (ingredient) consumption database derived from the NHANES/WWEIA food consumption survey. Through a joint collaboration between the OPP and the EPA Office of Research and Development, this data was incorporated into the EPA *Exposure Factors Handbook 2011 Edition (Final)*, which provides the most up-to-date data on the various human factors used in assessing exposure. Subsequently, the OPP worked with the Joint Institute for Food Safety and Applied Nutrition (JIFSAN) to post the EPA's What We Eat in America-Food Commodity Intake Database to the web in an open,

user-friendly format. Food consumption data comprises an integral part of dietary risk assessments across the EPA.

About the EPA's NNRR Interest: The EPA is very interested in the research and resource initiatives put forth in the *Roadmap*, particularly as they relate to maintaining and growing our nation's ability to conduct rigorous population-level monitoring (Q1T3) and assessing dietary exposures (Q3T1).

Federal Trade Commission (FTC)

About the FTC: The mission of the FTC is to prevent business practices that are anticompetitive or deceptive or unfair to consumers; enhance informed consumer choices and public understanding of the competitive process; and accomplish this without unduly burdening legitimate business activity.

About FTC's Human Nutrition Research: Relevant FTC work and interest primarily focuses on food marketing to children. For example, the FTC, in collaboration with the CDC, FDA, and USDA, worked on the Interagency Working Group on Food Marketed to Children—a group established by the 2009 Omnibus Appropriations Act (P.L. 111-8). In 2011, the Working Group issued for public comment a set of proposed voluntary principles for marketing to children, informed by federally supported research. In response to concerns raised by Congress, the Working Group suspended its activities and did not issue final recommendations. In addition to the Interagency Working Group effort, the FTC has issued two reports in 2008 and in 2012 on food marketing to children and adolescents. The reports summarize the youth-directed marketing activities and expenditures of U.S. food and beverage marketers. These reports also provide a picture of the nutritional quality of foods marketed to youth and the impact of industry self-regulatory efforts to encourage promotion of healthier foods.

About FTC's NNRR Interests: FTC is interested in all of the research and resource initiatives put forth in the *Roadmap*. The types of research and resources the FTC generally works on would contribute towards Q1T1 (Health Promotion and Disease Prevention and Treatment), Q2T1 (Influences on Eating Patterns), Q2T2 (Interventions), Q3T1 (Assessing Dietary Exposures), Q3T3 (Behavioral Economics), and Q3T4 (Big Data).

United States Department of Health and Human Services (HHS)

The following table illustrates the topics of interest by each of the HHS sub-agencies, in alphabetical order by abbreviations.

HHS Agency	CDC	FDA	HRSA	NIH
Question 1: How do we better understand and define eating patterns to improve and sustain health?				
Q1T1 Health Promotion and Disease Prevention and Treatment	X	X	X	X
Q1T2 Individual Differences Including "Omics"		X	X	X
Q1T3 Population-Level Monitoring	X	X	X	X
Question 2: What can be done to help people choose healthy eating patterns?				
Q2T1 Influences on Eating Patterns	X	X	X	X
Q2T2 Interventions	X	X	X	X
Q2T3 Systems Science	X	X	X	X
Q2T4 Environmental Sustainability				
Question 3: How can we develop and engage innovative methods and systems to accelerate discoveries in human nutrition?				
Q3T1 Assessing Dietary Exposures	X	X		X
Q3T2 Biobehavioral Science		X		X
Q3T3 Behavioral Economics	X	X	X	X
Q3T4 Big Data	X	X		X

Centers for Disease Control and Prevention (CDC)

About the CDC: The CDC works 24/7 to protect America from health, safety, and security threats, both foreign and in the U.S. To accomplish this mission, the CDC conducts critical science and provides health information that protects our nation against expensive and dangerous health threats, and responds when these arise.

About the CDC's Human Nutrition Research: As a public health agency, the CDC addresses nutritional issues related to population health through surveillance, intramural and extramural research, the translation of research into practice, and program

implementation. Work is done at multiple Centers in the Agency, including the National Center on Birth Defects and Developmental Disabilities, the National Center for Chronic Disease Prevention and Health Promotion, the National Center for Environmental Health, the National Center for Health Statistics (NCHS), and the National Institute for Occupational Safety and Health.

About the CDC's NNRR Interest: The following is a summary of how current CDC activities support the questions and actions put forth in this *Roadmap*.

For Q1T1 (Nutrition in Health Promotion and Disease Prevention and Treatment), the CDC provides funding support and employs scientists that work on research examining how diet and nutrition impact significant health outcomes. For example, the CDC funds the National Birth Defects Prevention Study (NBDPS) and the Birth Defects Study to Evaluate Pregnancy Exposures (BD-STEPS). Data from these studies are used to examine the relation of birth defects with multiple exposures, including eating patterns, supplement intake, and alcohol consumption. Another example is the CDC's planned support of an update to an Agency for Healthcare Research and Quality (AHRQ) review on breastfeeding and its relationship to subsequent health outcomes in children and mothers. In addition, CDC researchers conduct secondary analysis of existing data sets to examine the relation between select eating patterns and health outcomes including obesity, hypertension, and birth defects.

For Q1T3 (Population-Level Monitoring), CDC surveillance systems play a critical role in population monitoring of health, nutrition, and environmental and policy supports for diet. Data from these systems are used to provide reference information and identify public health problems, targets for intervention, and trends in dietary intake and nutritional status. Furthermore, a number of nutrition-related *Healthy People* objectives are monitored with these systems. In addition to being used for monitoring, data from these systems could be used by researchers to answer questions in this *Roadmap* including those related to environmental supports for diet and nutrition, the epidemiology of dietary behaviors, and the associations between nutrition factors and outcomes. Furthermore, data from a number of the systems can be linked to data from other sources to expand the utility of the systems.

For example, the NHANES data can be linked to the National Death Index or the Centers for Medicare and Medicaid Services (CMS) files on healthcare utilization. The NHANES examines a nationally representative sample of U.S. residents. Nutritional status is assessed via dietary intakes (from food, beverages, and supplements), laboratory tests of nutritional status, anthropometric assessments (including body composition data), and selected clinical findings. Health status (oral health, infectious disease, and chronic disease) is examined via questionnaires and clinical examination. Nutrition data from the NHANES allow researchers to estimate usual intake distributions and to assess adequacy of nutrient intakes in relation to Dietary Reference Intakes (DRIs), dietary guidance (e.g., Healthy Eating Index), and other policy recommendations and guidelines. The USDA's Food and Nutrition Service (FNS) uses the NHANES data to evaluate dietary quality in the National School Lunch Program (NSLP), WIC food packages, and other federal food and nutrition assistance programs.

The 2015 Dietary Guidelines Scientific Advisory Committee relied heavily on data from the NHANES to describe intake distributions, the food environment, and the prevalence of chronic disease. The NHANES oversamples certain sociodemographic groups in various cycles (e.g., pregnant women, adolescents, elderly, low-income, race/ethnic groups) and has the capacity to carry out specialized studies on specific demographic groups to address nutrition monitoring needs, such as infants and toddlers.

State-level data on select nutrition behaviors are collected and tracked in the Behavioral Risk Factor Surveillance System for adults and the Youth Risk Behavior Surveillance System for adolescents in grades 9–12. The BRFSS uses a telephone survey to gather information on obesity as well as on the consumption of fruit and vegetables and alcohol. A module on sugar-sweetened beverage intake is also available. The YRBSS uses a survey administered in schools to collect information on weight and the consumption of select drinks, fruits and vegetables, breakfast, and alcohol. The National Immunization Survey provides data on breastfeeding rates.

The CDC periodically collects data on environmental and policy supports for nutrition and diet in schools through the School Health Profiles and the School Health Policy and Practices Study; for breastfeeding in maternity care settings through the Maternity Practices in Infant Nutrition and Care Survey; and for diet at the state level through the Chronic Disease State Policy Tracking System. Information on the policies and standards adopted by local governments that support healthful eating and active living for residents was recently collected on a national sample of municipalities. Currently, the CDC is conducting a national survey of worksites, which will include questions on nutrition supports. The CDC also plans to collect information regarding the nutrition-related policies and practices of early care and education centers across the nation.

In addition to administering surveillance systems, the CDC collaborates with other federal partners to improve surveillance. For example, to monitor the amount of sodium in restaurant and processed food, the CDC is working in partnership with the USDA, FDA, and others to track primary contributors to sodium intake and to determine changes in sodium content. Approaches being used include developing a sentinel food monitoring system and packaged food databases, partnering with New York City to report data on the sodium content of top chain restaurant foods, and exploring opportunities to partner with other federal agencies and with industry on reporting accurate nutrition information.

The CDC also has a significant role in the dissemination of information from these systems. In addition to publications in scientific journals, the CDC regularly reports this information through the CDC Vital Signs reports, the NCHS Data Briefs, the CDC Breastfeeding Report Cards, the CDC Fruit and Vegetable Indicator Reports, and interactive data portals. The CDC also publishes the National Report on Biochemical Indicators of Diet and Nutrition in the U.S. Population (Nutrition Report). This serial publication provides ongoing assessment of the populations' nutritional status. The Nutrition Report presents data on blood and urine biomarker concentrations for select water- and fat-soluble vitamins and nutrients, trace elements, and dietary bioactive compounds from a representative sample of the population participating in the

continuous NHANES. The Second Nutrition Report (released in 2012) contained reference information for 58 biomarkers.

For Q2T1 (Influences on Eating Patterns), CDC scientists contribute to research on the influences on eating patterns through secondary analysis of existing data. Researchers are currently conducting analyses that describe breastfeeding and complementary feeding patterns, as well as the consumption of synthetic folic acid and natural food folate, alcohol, fruits and vegetables, foods and beverages with added sugars, and sodium. Scientists are also characterizing consumer knowledge and attitudes related to sodium, added sugars, and restaurant menu labeling; environmental and policy supports for breastfeeding; and links between school nutrition policies and dietary behaviors.

In collaboration with the NIH, the CDC National Center for Health Statistics (NCHS) implemented health examination questions and procedures for the NHANES to assess taste sensitivity of standard salt and bitter taste solutions among U.S. adults aged 40 years and older. This project will help track the taste preferences for salt in the population and estimate relationships between salt taste preferences, diet, and blood pressure.

The CDC National Institute for Occupational Safety and Health Total Worker Health™ integrates occupational safety and health protection with policies, programs, and practices that promote health and prevent disease to advance worker safety, health, and well-being.[187] NIOSH also supports research to address implications of the changing workplace including an aging workforce and to provide information and practical solutions to the health, safety, and well-being challenges faced by workers and their employers.

For Q2T2 (Interventions), CDC research and program evaluation provide evidence on how nutrition interventions work in real world settings. The CDC funds the Nutrition and Obesity Policy Research and Evaluation Network (NOPREN) to assess policy interventions related to nutrition and obesity, including nutrition standards in childcare, schools, municipal buildings, and food banks; healthy retail food interventions related to grocery in-store marketing and stable food ordinances; drinking water access; and federal food and nutrition assistance programs. The CDC's Childhood Obesity Research Demonstration project (CORD) uses a comprehensive, multilevel, multi-setting approach that links primary care interventions with clinical counseling and management to improve dietary quality and to prevent and reduce childhood obesity in underserved children ages 2–12 in three communities in the U.S. In addition, the CDC conducts program evaluation of its funded state and community programs for chronic disease prevention. A number of these programs include nutrition strategies (e.g., implementing food services guidelines; improving healthy retail food; improving the school nutrition environments). Results from these program evaluations will contribute to the practice-based literature by identifying barriers and facilitators of implementation and the feasibility of implementing strategies in locations with different levels of resources, population characteristics, or other contextual factors.

For Q2T3 (Systems Science), the CDC developed the Prevention Impacts Simulation Model to evaluate the potential health and economic outcomes of several of its program initiatives. The model integrates the best available evidence on select policy, environment, and system interventions and their effects on chronic disease risk factors and outcomes. Included in the model are interventions related to changing dietary behaviors. PRISM is currently being updated with the most current literature to support the causal framework.

For Q3T1 (Assessing Dietary Exposures), the CDC works collaboratively with the USDA, the NIH, and academic partners on various projects to improve the assessment of dietary exposures including biomarkers. These include collaborations to:

- Improve dietary data collection and coding in the Automated Multiple Pass Method;
- Update the databases for foods, nutrients, and bioactives such as the Food and Nutrient Database for Dietary Studies, as well as databases for dietary supplements;
- Evaluate and standardize existing laboratory methods for nutritional status assessment;
- Evaluate the use of a spot or single urine specimen to assess population sodium intake in the NHANES survey;
- Assess sodium and electrolyte excretion through 24-hour urine collection;
- Measure and describe the sources of sodium intake among a diverse convenience sample of U.S. adults; and
- Develop a field-friendly assay for assessing folate status.

For Q3T3 (Behavioral Economics), the CDC is working collaboratively with other members of the National Collaborative on Childhood Obesity Research to convene experts in the area of behavioral design to identify best practice approaches for major food service venues, including cafeterias in worksites and schools, restaurants, and grocery stores.

For Q3T4 (Big Data), because the CDC data, such as the NHANES, are publicly available, these data can be linked to other external databases to support Big Data initiatives. The NHANES is also in the process of seeking approval to reopen the DNA bank for public use. This will offer a valuable resource to scientists and policymakers to address research in the nutrition-epigenetics area.

In addition to providing information to answer questions put forth in this *Roadmap*, the CDC uses and translates nutrition research for its program activities. Research informs the strategies used in funded public health programs in states, communities, and tribes, including those related to reducing sodium consumption, preventing chronic disease, and preventing alcohol exposure during pregnancy. Findings from nutrition research are also incorporated into CDC guidance documents for public health practitioners.

Food and Drug Administration (FDA)

About FDA: The FDA is responsible for protecting the public health by assuring the safety, efficacy, and security of human and veterinary drugs, biological products, medical devices, our nation's food supply, cosmetics, and products that emit radiation. The FDA is also responsible for advancing the public health by helping the public get the accurate, science-based information they need to use medicines and foods to maintain and improve their health.

About FDA's Human Nutrition Research: Supporting a healthy and safe food supply is a key FDA mission. A strong evidence base, supported by interdisciplinary collaborations and data sharing, is necessary to further this mission and expand our knowledge to improve and promote a healthy diet and to prevent chronic diseases and other conditions. The FDA depends on nutrition research to inform its many regulatory and other activities on food labeling, oversight of food additives and constituents of foods, nutrition education activities, and other nutrition-related work.

The FDA conducts its own research activities including consumer studies to support nutrition labeling and claims; assessments of constituents of the food supply; development of methods for analyzing food constituents; surveys on health; analyses of dietary intake; monitoring of adverse events from dietary foods and supplements; and cost/benefit analyses of various nutrition regulatory activities. The FDA's research not only adds to the existing science base but the FDA depends on the research conducted and funded by other federal agencies.

About FDA's NNRR Interests

For Question 1, the FDA depends on basic nutritional research investigating the role of food or nutrients in health promotion and disease prevention and treatment to inform regulatory and other activities on the safety of food constituents or food labeling. Research to support such activities at the FDA include: identification of new and improved nutrient intake/status biomarkers; qualification of biomarkers for use as surrogate endpoints of chronic disease risk and; assessment of exposures (e.g., added sugars, dietary supplement products) over time and their associations with chronic health outcomes, especially those with large public health impact (e.g., cardiovascular disease, obesity, type 2 diabetes, inflammation, depression, cancer, reproductive outcomes, autoimmune conditions, age-related declines); microbiome and other research to support further understanding of prebiotics (e.g., dietary fiber) and probiotics and their impact on health.

Understanding constituents in the food supply, eating patterns, and nutrient intakes is critical to the FDA's role in ensuring a safe and healthy food supply and for its regulatory, educational and enforcement activities. The FDA conducts a number of studies to: assess the levels of nutrients in foods; develop new methods for analysis of nutrients in foods; and monitor constituents of foods, dietary intake, and adverse events. Many of the analyses conducted by the FDA employ data collected by other agencies. Examples of FDA research and the databases employed include:

- sampling of foods for analysis of chemical contaminants and nutrients in the food supply over time (e.g., iodine, sodium) through the FDA's Total Diet Study and market surveys;
- analyses to monitor the intake of various foods, food groups, and food constituents (e.g., sodium, *trans* fat) using existing data bases (e.g., the National Health and Nutrition Examination Survey (NHANES));
- analyses to support exposure assessments related to intake of safe or inadequate levels of food constituents;
- analyses of databases (e.g., USDA, proprietary databases) of food products to determine levels of various nutrients in foods;
- analyses of data on adverse events (e.g., dietary supplements); and,
- analyses of the costs and benefits of regulatory efforts related to improving dietary intake (e.g., Nutrition Facts label, menu labeling).

Expansion of some of the information in existing databases would be important for FDA's efforts. Examples of such expansion include longitudinal data sources, with standardized data collection and analyses. These data sources could build on resources already in place, such as transforming existing cross-sectional surveys into longitudinal studies (e.g., the FDA Health and Diet Survey, the National Health and Nutrition Examination Survey (NHANES)); and the continued expansion of the USDA National Nutrient Database to include branded food items (e.g., Agricultural Technology Innovation Partnership, a public-private partnership underway).

For Question 2, the FDA is very interested in survey data, along with consumer and experimental studies that help to identify factors that influence food choices, especially as it relates to food labeling. The FDA will continue to depend on information from: surveys to assess consumer knowledge, attitudes, and behaviors (e.g., the FDA's Health and Diet Survey, the Behavioral Risk Factor Surveys, the NHANES data); studies to determine consumer understanding of the healthiness of foods and consumer responses to various claims on food packages (e.g., understanding of whole grains and food labeling studies); analyses to monitor composition of foods bearing FDA health claims to ascertain accuracy of the usage of such claims; and analyses of data to determine characteristics of groups consuming certain foods/nutrients (e.g., characteristics of those who eat outside the home). Also helpful are consumer studies that evaluate the impacts of FDA's regulatory and other activities intended to help people choose healthy diets.

For Question 3, the FDA has engaged in numerous research projects over the years to: develop new models to understand behavior; determine dietary intakes; determine the cost of regulatory initiatives; and develop analytical methods for assessing food constituents. Continued development of new models and systems are needed by the FDA to assist in better assessments and analytic efforts. Additional tools needed include: new models to assess risk (e.g., investigation of U-shaped dose-response models, particularly relevant in the setting of nutrient fortification/supplementation); improved methods for conducting human studies on the functionality of new sources of dietary fiber; innovative experimental designs for conducting social science research

related to consumer cognitive and behavioral responses to information on food labels to understand the effects of FDA's regulatory actions on food labels; new models for assessing nutrient intakes for safety assessments (e.g., sodium, *trans* fat, folic acid); innovative models for calculating costs and benefits of nutrition initiatives; and newer methodologies to monitor compositional changes as foods are reformulated in response to labeling initiatives (e.g., *trans* fat, polyunsaturated fatty acids [PUFA], fiber, vitamin E).

Health Resources and Services Administration (HRSA)

About HRSA: HRSA is the primary federal agency for improving access to health care by strengthening the health care workforce, building healthy communities, and achieving health equity.

About HRSA's Human Nutrition Research: HRSA's programs provide health care to people who are geographically isolated, economically or medically vulnerable, including people living with HIV/AIDS, pregnant women, mothers, and their families, and those in need of high-quality primary health care. HRSA also supports the training of health professionals, the distribution of providers to areas where they are needed most, and improvements in health care delivery.

About HRSA's NNRR Interests: Related to the eleven topical areas presented in this *Roadmap*, HRSA's top three areas of interest include Q1T3, Q2T1, and Q3T3. The following highlights specific HRSA programs related to these priority areas:

The Autism Intervention Research Network on Physical Health (AIR-P) has conducted a number of nutrition-related studies in children with Autism Spectrum Disorders (ASD). The AIR-P Studies for Nutrition/Obesity from 2008–2015 include the following: Diet and Nutrition in Children with ASD; Markers of Iron Status and Metabolism in Children with ASD; Overweight and Obesity in ASD: Prevalence, Correlates, and Predictors of Weight Changes Over Time; and Treatment of Overweight Induced by Antipsychotic Medication in Young People with ASD. These studies will inform the development of guidelines for nutritional management of children with ASD and will provide the data necessary to plan prospective trials related to nutritional interventions.

In addition, HRSA's Healthy Weight Research Network for Children with ASD and other Developmental Disabilities (DD) aims to advance the understanding of obesity risk factors in this vulnerable subpopulation, promote the development of evidence-based solutions to achieve healthy weight in this population, and disseminate research findings to broad and diverse audiences. This Network conducts research using existing datasets to improve knowledge about the prevalence of overweight/obesity, key risk factors, eating patterns/behaviors, family practices around mealtimes, environmental influences on children's food intake and physical activity, and obesity-related chronic and secondary health conditions among children and youth with ASD/DD. In addition, the Network engages in formative work with the aim of understanding biopsychosocial barriers and facilitators to achieving healthy weight status and conducts pilot and feasibility studies of interventions designed to prevent or reduce excess weight among children and youth with ASD/DD.

Within HRSA's Bureau of Primary Health Care, the funded Health Centers, located in or serving a high-need community, provide comprehensive primary health care services as well as supportive services that promote access to health care. All of the HRSA Health Centers track nutrition services provided at the centers. Among the 1289 Health Centers in 2014, 977 or 76 percent provide nutrition services directly or with formal agreement with another entity. This is an example of the monitoring of nutrition services in a vulnerable subpopulation.

Workforce development is also of great interest. HRSA has a commitment to translating research to practice, which impacts policy affecting our target populations. The Maternal and Child Health (MCH) Nutrition Training Program enhances faculty and student leadership skills to develop and promote innovative practice models in MCH nutrition. Currently six centers of excellence are funded to provide leadership education and training for graduate-level trainees and fellows and to deliver continuing education for the MCH nutrition workforce. These centers focus on clinical and public health nutrition. Students receive training in leadership skills, core public health principles, epidemiology, environmental approaches to population intervention, and the development and evaluation of nutrition-related, cost-effective interventions for specific populations. Training is also provided in identifying and designing outcome evaluations and in evaluating the potential physiological and biochemical mechanisms linking diet and nutritional status with risk or disease status and provides both clinical and public health approaches to working with the pediatric and maternal populations. Examples of areas of emphasis include specialized neonatal intensive care training, children with special health care needs, breastfeeding promotion and maternal nutrition, adolescent nutrition, and pediatric obesity.

The Maternal and Child Health Bureau (MCHB) also established a Pediatric Nutrition Obesity Collaborative Improvement and Innovation Network (CoIIN) to assure that core nutrition services are provided for the prevention and treatment of childhood obesity. A CoIIN has been described as a cyber-team of self-motivated people with a collective vision, and is designed to facilitate collaborative learning and adoption of proven quality improvement principles and practices among participating states toward a common goal. In a CoIIN, participants learn from one another and national experts, share best practices and lessons learned, and track progress toward shared benchmarks. The goal of the CoIIN is to create state models for strategic implementation of *The Expert Committee Recommendations Regarding the Prevention, Assessment, and Treatment of Child and Adolescent Overweight and Obesity.*[188] The focus is on increasing the proportion of children ages two to five years old within a healthy weight range. During the initial phase of the CoIIN, all state teams will focus on policies and practices in early care and education (ECE). That is, states will act to implement policy changes and practices in the early care and education systems in their state that support healthy eating and physical activity.

The National Institutes of Health (NIH)

About the NIH: The NIH is the nation's primary biomedical research funding agency—making important discoveries that improve health and save lives. The NIH's mission is to seek fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to enhance health, lengthen life, and reduce illness and disability.

About the NIH's Human Nutrition Research: The NIH supports biomedical research, research training, and research infrastructure in nutrition as a part of the NIH mission to improve health through research. Research related to nutrition encompasses many different scientific disciplines and is carried out by investigators in research organizations and settings throughout the country, primarily in universities and biomedical research centers, but also in other settings. Many of the 27 Institutes and Centers at the NIH support research relevant to nutrition as it relates to their own specific missions. The NIH supports investigators using many types of grant mechanisms, most often using investigator-initiated research proposals. The NIH common fund programs support large, organized grant programs such as the Human Microbiome Project and the Metabolomics initiative, as well as clinical studies and clinical trials to support nutrition-related research. In addition, infrastructure is supported through research centers and sample and data repositories. To support a continuing pipeline of new investigators, the NIH invests in individual fellowship, training, and career development programs. Additional support is available throughout the NIH to fulfill its mandate to support small business research. The NIH and its Institutes and Centers also support public communication and education programs to provide to the public important health information that is the result of NIH research. Finally, the intramural research programs of the NIH support nutrition-related research on the main NIH campus and at other NIH intramural sites around the country, conducted by scientists who work directly for the NIH. This work is far-ranging, from very basic research through translational and clinical research. The Clinical Center on the NIH campus is the largest dedicated research hospital in the U.S., and is known for cutting-edge clinical research and unique resources such as advanced imaging and the metabolic chamber.

To best use funds available, the NIH carries out many activities to plan for future research needs through meetings, workshops, and strategic planning activities. The NIH is planning to establish a trans-NIH group to engage in a strategic planning process for nutrition research. With input from the nutrition research community both inside and outside of the NIH, this planning activity will stimulate support for a cutting-edge nutrition research portfolio and complement the existing Strategic Plan for NIH Obesity Research.

The NIH recognizes that improving eating patterns and nutritional status and its associated health consequences will require broad-based efforts by the Federal Government, along with other national and global governing bodies, the private and nonprofit sectors, businesses, community organizations, health care professionals, schools, families, and individuals. This recognition of the multiple societal levels that

influence eating and activity behaviors and nutrient intake and subsequent health has led NIH-supported research to engage investigators from many research disciplines to address a number of the topics summarized in this *Roadmap*. NIH-supported researchers are examining many questions, such as:

- How can we enhance our understanding of the role of nutrition in health and disease prevention and control, and in treatment of disease?
- What are the challenges and opportunities for improving eating and activity patterns for enhancing optimal development and disease prevention and management throughout the lifespan, from very young children to older adults and across diverse population groups?
- What are the biologic, social, and other factors that explain individual differences in nutritional status and variability in response to diet, and how can advances in research methods and technology help us explore those differences?
- How can we augment and use our knowledge of human biology, behavior, and the influence of social and environmental forces to develop better and more targeted nutrition-related prevention and treatment approaches for disease prevention and control?
- What can we learn from local, state, and national food and nutrition and health monitoring data systems about which populations are most adversely effected by unhealthy eating and activity patterns, as well as food and physical activity environments that make it difficult to access healthy and affordable foods and lead an active lifestyle?
- What factors in our community environments and daily lives contribute to unhealthy eating and activity related behaviors, and what can we modify so that people could more feasibly attain and maintain healthy eating and activity patterns?
- How can we enhance innovation in the measurement of dietary exposures at the individual and environmental level?
- How can we rigorously evaluate interventions—whether based on individual lifestyle changes, nutritional supplements, community-based programs, environmental changes, local or national policy changes, or a combination of strategies—to determine which really work, and who could most benefit?
- How can advances in the creation and analysis of Big Data resources be applied to questions at the population level?
- How do we scale up the approaches that show promise, and implement or expand those proven effective, to reach more people?
- Given that no single intervention will solve this complex problem, how can we continue identifying new opportunities to spark innovative approaches?

<u>About the NIH's NNRR Interests</u>: Most of the NIH-supported research that examines questions outlined in this *Roadmap* is undertaken by investigator-initiated research. In addition, the NIH has supported targeted initiatives that directly address a number of the identified key topical areas. Both NIH's intramural and extramural research initiatives engage the full range of research disciplines identified throughout this *Roadmap*. The

following paragraphs provide examples to capture the breadth and depth of work NIH supports to sustain and improve health.

For Question 1, this area has traditionally been a major focus of the NIH. In this field, the NIH has supported research on understanding the role of nutrition in early development and childhood and in the subsequent development and management of diseases during adult life. The NIH has supported extensive research to enhance understanding of the mechanisms by which nutrition, dietary constituents, supplements, and eating patterns influence disease prevention, control, and treatment. Much of this research has examined the influence of these exposures on specific disease outcomes such as heart disease, cancer, gastrointestinal disorders, diabetes, or dental caries. As the U.S. population ages and an increasing proportion of older adults are living with multiple comorbid conditions, research is needed to examine how eating patterns, nutrition, and dietary supplements influence a combination of comorbid diseases. The NIH has supported extensive research to characterize the association of disease outcomes with specific nutrients and constituents from diets, supplements, and/or eating patterns, and how those associations may vary across population groups defined by age, sex and gender, race, ethnicity, socioeconomic status, health status, or other comorbid diseases. However, advances in a wide range of technologies, including “omics”-based technologies, are anticipated to enhance the ability to define individual variability in response to diverse eating and activity patterns and individual nutrients and food constituents. The NIH has supported national nutrition and health monitoring systems, including refinements in the assessment of dietary exposures and in the measurement of dietary quality at the individual and food environment level. Through collaboration with the CDC, the USDA, and the RWJF, the NIH has supported efforts to more rapidly release data on food group composition within U.S. diets for investigators evaluating progress in achieving dietary recommendations.

The NIH also supports research that informs best practices for medical nutrition therapy of an array of acute and chronic diseases and conditions, to mitigate symptoms, delay progression, and prevent complications. These include studies of the biological mechanisms and effectiveness of dietary approaches for management of conditions such as cardiovascular disease, type 1 and type 2 diabetes mellitus, obesity, chronic kidney disease, inborn errors of metabolism, inflammatory bowel disease, food allergy, and consequences of cancer treatment modalities (e.g., surgery, radiation, chemotherapy).

For Question 2, this area has been a major focus of NIH-supported behavioral, socioeconomic, epidemiologic, and systems science research. The NIH research has explored the influence of the many interacting forces that influence eating and activity patterns and food choices, including biology, behavior, socioeconomic status, environmental factors, and cultural beliefs. Given the interaction among these factors, more recent NIH efforts have supported research to examine the multiple interactions among these factors, often using trans-disciplinary research designs that include research expertise in the nutritional sciences, psychologists, sociologists, anthropologists, agricultural economists, and other experts examining forces influencing the U.S. food supply. The NIH has applied evidence from this and other fields to

develop intensive, individual-level behavioral interventions that resulted in successful changes in eating patterns and improvements in a number of related health outcomes. However, longer-term follow-up of participants in these trials demonstrated that these changes were difficult to maintain in current U.S. food environments. The NIH is exploring new areas of research on enhancing maintenance of changes in eating behaviors—multilevel research that will require a focus not only on the individual but also on policy and environmental change. In addition, the NIH has supported the expansion of systems science methods to evaluate promising approaches for multilevel changes being considered for obesity prevention, and these approaches could be further expanded to other complex nutritional problems.

For Question 3, the NIH has been a major contributor to advancing the identified topical areas. A key requirement for most human nutrition research is the capacity to accurately characterize what people have been eating, including foods, beverages, and dietary supplements, and to classify that intake in terms of eating patterns, nutrients, and other constituents of foods that may have biologic effects. The NIH has supported extensive research on enhancing self-report and biologic markers of food intake. Advances in visual and computer technologies have led to innovations in other approaches to recording food intake. In keeping with increased appreciation of the important role of the food environment, the NIH has also supported research on assessing the nutritional adequacy of retail food settings and other aspects of the food environment and food supply. Basic biobehavioral research has the potential to enhance understanding of the fundamental mechanisms underlying behavioral responses to food and food environments that may elucidate new approaches for intervention. Advances in tools such as neuro-anatomic imaging, may provide new approaches for understanding the role of nutrition in the central nervous system and endocrine system. Social science research and fields such as behavioral economics have provided insights into how consumer perceptions and environmental modifications may influence people’s food choices. Finally, as with many areas of biomedical research, the next discoveries will be facilitated by advances that allow the exploration of these complex questions in large data systems that provide opportunities to explore questions among diverse populations that are more fully characterized by the many factors that influence human health.

National Aeronautics and Space Administration (NASA)

About NASA: Since its inception in 1958, NASA has accomplished many great scientific and technological feats in air and space. NASA is a leading force in scientific research and in stimulating public interest in aerospace exploration, as well as science and technology in general.

About NASA's Human Nutrition Research: NASA conducts life sciences research in space flight on the International Space Station (ISS) and in ground-based analogs of space flight (e.g., extended bed rest, Antarctic winters, undersea habitats). Two books available through open access summarize the evidence base for space nutrition.[189,190] The importance of nutrition in exploration has been documented repeatedly throughout history. A key difference between exploration on Earth and future space exploration is that astronauts will not find food along the way. While cultivation may add to nourishment, because of crop issues and food safety, food will likely always have to be provided. Thus, understanding the nutritional requirements of space travelers and the role of nutrition in human adaptation to microgravity are critical to crew safety and mission success.

Many gaps in our knowledge of relationships between nutrition and health in space need to be filled before we can safely embark on exploration-class missions, that is, missions beyond low Earth orbit.[189,190] At the surface of these unknowns is the need to understand and define basic nutrient requirements during extended stays in microgravity. Beyond this lies the need to know the role of nutrition in the adaptation of physiological systems to microgravity, and the impact of these changes on nutrition. Additionally, the space flight environment can alter nutritional status and nutritional requirements of space flight. Partial gravity (on, for example, the moon or Mars) may complicate the situation further. Other knowledge gaps relate to modifying dietary intake, where appropriate, to counteract or mitigate negative effects of space flight on the human body.

Most of the key areas of nutrition concerns are related to overall intake of macro- and micronutrients, including loss of body mass and depletion of body nutrient stores because of inadequate food supply, inadequate food intake, increased metabolism, changes in physiology during flight, and/or irreversible loss or degradation of nutrients during long-duration exploration missions. Space travel-induced physiological changes that involve nutrition include bone and muscle loss, cardiovascular degradation, altered immune function, changes in red blood cell mass, along with neurological changes. Vision changes have recently been identified in crewmembers on the ISS, and are a major health concern for long-term space missions. Aspects of the space environment, including radiation and the cabin environment (e.g., O_2/CO_2, temperature, humidity), can have profound effects on nutrition and health, and may provide areas where nutrients can serve as countermeasures. When crewmembers are outside the spacecraft, the spacesuit becomes a spacecraft as well, with associated concerns, including high oxygen exposure, limited water availability, inability to eat for up to 8 to 10 hours at a time while in the suit, and high metabolic activity.

About NASA's NNRR Interests: Several NNRR topics have implications for NASA. The answers to Question 1 can contribute to NASA's effort to provide an optimal food system to mitigate health risks. In particular, research designed to address Q1T1 (Nutrition in Health Promotion and Disease Prevention and Treatment) and Q1T2 (Individual Differences Including Omics) have relevance to NASA human nutrition research interests.

Most of NASA's nutrition research addresses Question 1 using unique study models — space flight and ground analogs—with generally healthy individuals that are studied in challenging environments. One key benefit of research with these models is that it allows the study of aging, sedentary lifestyle, and disease processes (e.g., bone loss, muscle and cardiovascular deconditioning) in healthy individuals, typically without the comorbidities often found in Earth-based clinical trials. A unique and scientifically beneficial aspect of space flight is that crewmembers eat from a limited and essentially closed, but well-characterized, pantry. Research in space brings challenges because of limited resources such as power, volume, and crew time; hazardous material restriction; and fluid dynamics issues. Research techniques, equipment, and procedures often need to be adapted for use in space flight, and these adaptations often provide tools and techniques that can be further adapted for use in laboratory situations or in field studies. With respect to bone loss at least, the changes during space flight occur much faster than in Earth-based populations. Therefore, astronauts on six-month ISS missions have roughly the same degree of bone loss one would find after five years in a postmenopausal woman.

While the number of astronauts flying in space is relatively small, each crewmember is studied in extensive detail and any interventions such as exercise or use of pharmaceuticals are recorded, providing an integrated view of human health during missions. Indeed, a medical requirement to evaluate nutritional status of astronauts was developed and implemented near the end of the NASA missions to the Space Station Mir in the mid-to-late 1990s, and all U.S. crewmembers on the ISS since 2000 have been evaluated.[189-191] This effort included pre- and post-flight biochemical analyses to assess nutritional status, as well as bone metabolism and general chemistry, and an in-flight evaluation of dietary intake and body mass. In 2006, with the deployment of a centrifuge for blood samples and a -80° freezer, the "Nutritional Status Assessment" project began in-flight nutritional testing to enhance the nominal medical testing. This project has expanded our knowledge of human adaptation to space flight, effects of space flight on crew health, and effectiveness of countermeasures. From 2006 to 2014, a total of 32 crewmembers participated in this project, which has yielded 11 peer-reviewed publications to date.

NASA is also interested in Question 2 because astronauts self-select foods to consume in space. The space food system is based on a nutritionally adequate diet, but the diet is rather limited, and the role of psychological overlay may be more important in crews far from home. Any way to intervene to sustain healthy eating patterns would be valuable on space exploration missions so NASA is interested in work designed to address Q2T2 (Interventions). And, facets of Question 3 interest NASA as well. For NASA, Q3T1 (Assessing Dietary Exposures) would carry the additional burden of being

able to measure any potential biomarkers in a spacecraft en route to a planetary surface. Moreover, Q3T2 (Biobehavioral Science) touches on NASA's need to understand the interrelationship of behavioral health and performance, and to apply that knowledge to nutrition and food.

In summary, NASA's nutritional support of space travelers relies heavily on research conducted by other federal departments and agencies. Still, ground and flight research addressing NASA knowledge gaps is needed to complete this picture. Findings from space nutrition research have implications beyond NASA and could be invaluable to general medical and scientific communities.

United States Agency for International Development (USAID)

About USAID: USAID is the lead U.S. Government agency that works to end extreme poverty and enable resilient, democratic societies to realize their potential.

About USAID's Human Nutrition Research: USAID adopts, adapts, modifies, and increases the information, evidence, practices, and technologies of U.S. institutions in human nutrition to be applicable to USAID target populations in developing countries to: improve food security and nutrient adequacies; increase access to safe water; and reduce infectious diseases, environmental toxins, poor sanitation, and parasitism. All of these conditions create special challenges in both under-nutrition and over-nutrition.

The following examples illustrate some of USAID's human nutrition work aiming to improve and sustain health.

- **Formulating and assessing processed foods to prevent and treat moderate wasting (also called moderate acute malnutrition, MAM) and reduce stunting**

In the past, USAID supported a number of research projects that produced evidence that showed that lipid-based nutrient supplements (LNS) based on peanut paste combined with milk powder, vegetable oil, different sources of vegetable protein, and micronutrients were successful in attaining both adequate recovery from severe acute malnutrition (SAM) and the ability to increase coverage and decrease defaults as compared to the traditional F100-milk formula. Now, USAID has turned its attention to prevention of stunting, and prevention and treatment of MAM. USAID is currently sponsoring several studies led by its global nutritional projects Food and Nutrition Technical Assistance (FANTA). These studies are conducted by U.S. universities including Washington University at Saint Louis, Tufts University, and the University of California at Davis in collaboration with United Nations agencies, international NGOs, foreign universities and research centers (mainly from developing countries) to test different formulations as well as smaller quantities of LNS than those used with the ready-to-use therapeutic foods for SAM recuperation. These newer LNS products are being provided to treat and prevent MAM, as well as to prevent stunting in children under the age of five years old. In addition, these newer LNS products are being compared to more traditional products. Those other products include fortified corn-soy blend (CSB) traditionally supplied in emergency situations, and many development

nutrition programs, and derivatives such as a CSB with an improved micronutrient formulation called Super Cereal (SC), or added milk powder and vegetable oil called Super Cereal+ (SC+) in Bangladesh, Burkina Faso, Burundi, Guatemala, Malawi, and Uganda. Complementary work is assessing the impact of micronutrient powders (MNP) to reduce anemia and other micronutrient deficiencies. Studies with SC, SC+, LNS, and MNP will include cost-effectiveness analysis—considering production, procurement, and distribution—to determine the most efficient vehicles or combinations (e.g., type, size or dose, duration, timing) to be scaled up in communities affected by MAM. Similar research is targeted to pregnant and lactating women in order to improve fetal development and quality of breastfeeding. Concomitant research is the determination of the impact of lean body mass accretion after recovery from MAM for preventing relapse.

- **Searching for solutions to stunting**

Linear growth failure in childhood is a useful and simple syndrome to measure the impact of several factors on the restriction of physical, mental, and socio-economic development of individuals and societies, and which predicts morbidity and mortality as well as future school performance, wages, and risk of non-communicable diseases. USAID supports research on potential interventions to address several causes of stunting, such as lack of dietary diversity; environmental enteric dysfunction; mycotoxins—mainly aflatoxins—exposure; poor water, sanitation, and hygiene (WASH) conditions; and poor access to health services. These studies are being carried out through several strategies including Feed the Future Innovation Labs, which focus on discovering how policy and program interventions can most effectively achieve improvements in maternal and child nutrition by leveraging agriculture, nutrition, and health inputs at-scale. The Feed the Future Food Security Innovation Center leads USAID's implementation of the Feed the Future Research Strategy through seven interlinked research, policy and capacity programs aimed at sustainable transforming agricultural production systems. The Program for Research on Nutritious and Safe Foods focuses on improving the production and safe processing of nutritious agricultural products and on increasing our understanding of the role of fruits, vegetables, meat, fish, dairy and legumes in improving household dietary quality. The Program puts special attention on improving nutrition in the first 1000 days of life, which are critical to a child's cognitive and physical growth and development. Under the Program for Research on Nutritious and Safe Foods, focus areas include: Horticulture, Aquaculture, Livestock and Diary, Mycotoxins, Biofortification and Nutrition. The Nutrition Innovation Lab for Africa and Asia is coordinated by Tufts University in collaboration with Johns Hopkins University, Harvard, Tuskegee, Purdue, Colorado State, Columbia, Virginia Tech, University of Georgia, NASA, and other national, international, and developing country institutions. The Nutrition Innovation Labs emphasize operationally relevant research that can support African and Asian national governments in their efforts to improve nutrition, health, and agricultural productivity. The current countries of actions are Egypt, Malawi, Uganda, and Nepal.

Validating novel ways to determine dietary intake and nutritional status in populations: The USAID Food and Nutrition Technical Assistance Project have worked on the creation and validation of indicators, tools, and procedures applicable to food intake

appraisal and nutrition assessment for many years. Products of this work are the Household Hunger Scale, the Minimum Acceptable Diet for children, the Dietary Diversity Score for children, the Women's Dietary Diversity Score, and field validation of the Mid-Upper Arm Circumference, all of which complement the traditional anthropometric indicators (i.e., wasting, stunting, underweight) to identify and qualify under-nutrition. Continuing with this tradition, USAID is collaborating with other institutions in improvement and use of secondary analysis of Household Consumption and Expenditure Surveys (HCES) to make inferences in food and nutrient intakes based on food acquisition data. Similarly, USAID is supporting the use of linear programming, which uses statistical calculations to optimize the results depending on several factors, to identify the appropriate combination of local and accepted foods to improve dietary quality ("Opti-food" methodology). Moreover, along with the CDC, the World Health Organization (WHO), the United Nations International Children's Fund (UNICEF), and other institutions, USAID is promoting good practices to improve the reliability, accuracy, and precision of the determination of anthropometric indicators and hemoglobin concentration to screen for under-nutrition and anemia in large population surveys.

- **Designing and validating indicators that measure consumer preferences in the selection of foods**

Ensuring availability and access to foods is insufficient to promote diverse and balanced diets; it is also essential that the food products be desirable and convenient for consumers. Based on information for the latter topics, the food industry can contribute to the improvement of human nutrition through the design and production of foods and beverages that are not only more nutritious but better positioned to the local habits of the target population. USAID is supporting research in this field through its projects, FANTA, and in collaboration with the Global Alliance for Improved Nutrition (GAIN) and other international institutions dedicated to improving nutrition in developing countries.

- **Increasing effectiveness by applying social and behavioral change to improve infant and young child feeding and health**

USAID aims to improve infant and child feeding through promoting good feeding and care practices, which includes timely and appropriate use of complementary foods and micronutrient supplements, as well as promoting hygienic and sanitation behaviors to increase access and use of safe water and foods, clean environments, reduction of open defecation and appropriate disposal of waste. In collaboration with other institutions such as the White House Social and Behavioral Sciences Team, the USAID Office of Health, Infectious Diseases and Nutrition plans to initiate a rapid randomized controlled trial measuring the effectiveness of behavioral interventions on health outcomes for infants and young children in India. USAID is also carrying out operation research on nutrition counseling and social behavioral change communication in Burkina Faso, Niger, Nigeria, and Haiti.

- **Using common food staples and products as micronutrient fortification vehicles and preventing non-communicable diseases**

USAID has been a pioneer and the main force in the introduction of food fortification (addition of vitamins and minerals to edible products to correct nutrient inadequacies in common diets) in developing countries as a public health strategy. High intake of some of the foods used in fortification (salt, sugar, vegetable oil, refined cereals) is undesirable, as they are associated with non-communicable chronic diseases. USAID is working with UNICEF, the WHO, the World Food Program, and other international organizations to improve global food fortification, from design to evaluation, including enactment and enforcement of standards and regulations and appropriate promotion. Research is being planned to refine indicators to determine iodine and sodium intakes in order to combine policies for reduction of salt intake but keeping salt as the most important delivery system for iodine. Similar work may be undertaken in the future for continued use of staple fortification and simultaneously reducing negative consequences due to excessive intakes of the fortification vehicles. USAID works with the International Food Policy and Research Institute (IFPRI) for ensuring sustainable food production, promoting healthy food systems, improving markets and trade, and transforming agriculture, with the vision that the diet should provide not only nutrients but also protective substances that reduce risk of occurrence of non-communicable diseases.

About USAID's NNRR Interests: USAID is most interested in the following topics put forth in the *Roadmap*: Q1T1 (Nutrition in Health Promotion and Disease Prevention and Treatment), Q1T3 (Population-Level Monitoring), Q2T1 (Influences on Eating Patterns), Q2T2 (Interventions), Q2T4 (Environmental Sustainability), Q3T1 (Assessing Dietary Exposures), Q3T2 (Biobehavioral Science), and Q3T4 (Big Data). USAID is also looking to further explore synergies between the ICHNR and the United States Government Global Nutrition Coordination Plan, 2015–2020 which is in development to contribute to the 2025 Global Nutrition Targets adopted at the Sixty-fifth World Health Assembly in 2012.

United States Department of Agriculture (USDA)

The following table illustrates the topics of interest by each of the USDA sub-agencies, in alphabetical order by abbreviations.

USDA Agency	ARS	CNPP	ERS	FNS	NIFA
Question 1: How do we better understand and define eating patterns to improve and sustain health?					
Q1T1 Health Promotion and Disease Prevention and Treatment	X	X		X	X
Q1T2 Individual Differences Including "Omics"	X				
Q1T3 Population-Level Monitoring	X		X	X	
Question 2: What can be done to help people choose healthy eating patterns?					
Q2T1 Influences on Eating Patterns	X	X	X	X	X
Q2T2 Interventions	X			X	X
Q2T3 Systems Science					
Q2T4 Environmental Sustainability	X		X	X	X
Question 3: How can we develop and engage innovative methods and systems to accelerate discoveries in human nutrition?					
Q3T1 Assessing Dietary Exposures	X				
Q3T2 Biobehavioral Science	X				
Q3T3 Behavioral Economics			X	X	X
Q3T4 Big Data	X		X	X	

Agricultural Research Service (ARS)

About ARS: As the USDA's chief scientific in-house research agency, the job of ARS is finding solutions to agricultural problems that affect Americans every day—from field to table. The mission of ARS is to conduct research to develop and transfer solutions to agricultural problems of high national priority and provide information access and dissemination to:

- Ensure high-quality, safe food and other agricultural products;
- Assess the nutritional needs of Americans;
- Sustain a competitive agricultural economy;

- Enhance the natural resource base and the environment; and
- Provide economic opportunities for rural citizens, communities, and society as a whole.

About ARS' Human Nutrition Research: The ARS works to advance human nutrition research in a variety of ways, drawing from a number of its national programs. As one example, the ARS Human Nutrition National Program works to define the role of food and its components in optimizing health throughout the lifecycle for all Americans by conducting high national priority research. The Human Nutrition National Program components include: (1) linking agricultural practices and beneficial health outcomes; (2) monitoring food composition and nutrient intake of the nation; (3) determining the scientific basis for dietary guidance; (4) preventing obesity and obesity-related diseases; and (5) understanding life-stage nutrition and metabolism.

About ARS' NNRR Interests: ARS currently works in or plans to contribute further to nine of the following eleven NNRR topical areas.

For Q1T1 (Nutrition in Health Promotion and Disease Prevention and Treatment), ARS researchers will elucidate how foods and health-promoting bioactive food components, along with physical activity, affect metabolic and physiologic factors related to quality of life and longevity. This work will determine factors such as bioavailability and metabolism that influence the efficacy of nutrients and other food components. How these factors change as a result of physiologic state (e.g., pregnancy, aging, obesity) and are influenced by genotype and other environmental factors will be determined. ARS scientists will develop and utilize innovative tools for assessing impacts on molecular, cellular, and physiologic mechanisms.

For Q1T2 (Individual Differences Including "Omics"), ARS is working on novel tools, methodologies, and applications for monitoring and modeling biological and behavioral responses, including the development of genomic, epigenomic, and metabolomic biomarkers that are expected to be useful as biomarkers of health and specific diseases. This work is intended to develop personalized solutions to prevention of conditions such as heart disease, type 2 diabetes mellitus, and obesity, among others.

For Q1T3 (Population-Level Monitoring), ARS provides the food composition data and nutritional data from the NHANES, which form the foundation for most diet and health epidemiology in the U.S. and provide the only nationally representative American dietary survey. The food supply is fluid, and the task of providing timely and accurate food composition data is made complex by constant change in food regulations and policy; food choices and consumer preferences; food production and processing methods that induce compositional variability; and demographic changes in the American population. Data must also reflect increased research and consumer interest in components of foods that either positively or negatively affect health. Continued development of state-of-the-art analytical techniques is essential to providing accurate and reliable data.

For Q2T1 (Influences on Eating Patterns), ARS scientists are studying how parental characteristics and behaviors influence how much food they serve their children and how much is actually consumed at meals. Other scientists are examining the role of stress in eating choices. Additional work is in progress on how attitudes of children and adults toward the *Dietary Guidelines for Americans* influence their choices for and against following those recommendations.

For Q2T2 (Interventions), ARS research will identify and evaluate methods of promoting dietary change in diverse populations. There is a need for research on single and multi-component interventions to identify effective methods of change for healthier lifestyles. Scientists will develop a greater knowledge base of how obesity prevention solutions are influenced by sociodemographic, environmental, economic, psychological, and biological factors.

For Q2T4 (Environmental Sustainability), ARS has no current work in this topical area specifically tied to human nutrition but is interested and expects projects across its programs in the coming years.

For Q3T1 (Assessing Dietary Exposures), ARS scientists recognize there is a strong need for biomarkers of intake, nutrient status, and health, and are working in multiple areas related to this. For example, ARS scientists are studying the association of vitamin K with reduced cardiovascular disease and the amounts and types of dietary fatty acids that influence immunity and inflammation. There is also a need for development of more objective measures of food intake and physical activity. To that end, scientists are testing electronic capture devices that require no input from the user and can download to databases.

For Q3T2 (Biobehavioral Science), ARS scientists are studying how stress and differences in executive function affect dietary choices and how diet may influence these factors. ARS scientists are also using animal models to determine areas and specific cell types of the brain that control eating activity, including preferences for specific foods.

For Q3T4 (Big Data), ARS Big Data initiatives include expansion of the nutrient composition database and linkage of it to the NHANES dietary survey data along with the Dietary Supplement Ingredient Database jointly developed by ARS and the NIH Office of Dietary Supplements. In addition, ARS is expanding its metabolomics capabilities, which will be linked to dietary data. A small cohort is being fully phenotyped, including the intestinal microbiome, to enable identification of dietary factors that modulate potential changes in biomarkers.

Center for Nutrition Policy and Promotion (CNPP)

About CNPP: The mission of CNPP is to improve the health of Americans by developing and promoting dietary guidance that links scientific research to the nutrition needs of consumers.

About CNPP's Human Nutrition Research: CNPP primarily conducts secondary research such as systematic reviews and policy-related research, including development of the USDA Food Patterns, the Healthy Eating Index, the USDA Food Plans, and communications research. CNPP provides science-based advice on how nutrition and physical activity can help promote health across the lifespan and reduce the risk for major nutrition-related chronic diseases in the U.S. population.

About CNPP's NNRR Interest: A key part of the Scientific Report developed by the *Dietary Guidelines Advisory Committee (DGAC)* every five years is the identification of future research needs related to diet, nutrition, and health. These research gaps and opportunities, as well as CNPP's research, primarily fall under Q1T1 (Role of Nutrition in Health and Disease Prevention) and Q2T1 (Influences on Eating Patterns) but also touch on other topical areas relating to Q3T1 (Assessing Dietary Exposures) and Q2T2 (Interventions), to name a few. The following briefly describes the core CNPP research activities as they relate to Q1T1 (Nutrition in Health Promotion and Disease Prevention and Treatment) and Q2T1 (Influences on Eating Patterns).

For Q1T1 (Nutrition in Health Promotion and Disease Prevention and Treatment), CNPP is actively working on the following activities:

- **USDA's Nutrition Evidence Library (NEL)**

To help develop and promote dietary guidance in collaboration with the HHS Office of Disease Prevention and Health Promotion (ODPHP) as required by law (P.L.101-445, Title III, 7 U.S.C. 5301 et seq.) every five years, CNPP's primary research contributions include reviewing the current scientific and medical knowledge using the USDA's Nutrition Evidence Library (NEL), as well as conducting data analysis and food pattern modeling analysis. Housed within CNPP, the NEL provides ongoing support to the *Dietary Guidelines Advisory Committee's* scientific review process to inform the development of the *Dietary Guidelines for Americans* and other federal efforts by conducting rigorous and transparent systematic reviews of the literature to inform food and nutrition policy and programs. The process that is followed is outlined here: recruiting expert collaborators (if not supporting the Dietary Guidelines Advisory Committee); formulating systematic review questions; conducting protocol-driven literature searches and selection; extracting evidence and critically appraising each study; describing and synthesizing the evidence; and developing and grading a conclusion statement. To date, the NEL supported systematic reviews conducted by the 2010 and 2015 Dietary Guidelines Advisory Committees; a series of reviews on the relationship between eating patterns and health outcomes; and another series of reviews on nutrition education and dietary intake. Approximately 150 reviews are publicly available on the NEL website. The NEL is currently supporting the Dietary Guidance Development Project for Infants and Toddlers from Birth to 24 Months and

Women Who are Pregnant (B-24/P) with systematic reviews focusing on: (1) human milk and infant formula feeding, (2) taste preference development, (3) feeding practices and methods, and (4) complementary feeding: foods and beverages.

- **Dietary Guidance Development Project for Infants and Toddlers from Birth to 24 Months and Women Who Are Pregnant (B-24/P)**

CNPP is very interested in *Roadmap* topical areas that address knowledge gaps focused on populations that include the birth to 24-months life-stage and women who are pregnant. The USDA and HHS initiated the B-24/P to spur a review of science to support development of comprehensive, evidence-based guidance for the birth-to-24-month age group and pregnant women as mandated in the 2014 Farm Bill (*See* The Agricultural Act of 2014 [P.L. 113-79]). A rigorous and transparent process is used and informed by a broad range of experts in the field of infant and toddler nutrition and health. Evidence will be used by a Federal Expert Group to develop a technical report, and draws from the USDA's Nutrition Evidence Library systematic reviews; data analysis/surveillance data; food pattern modeling; and existing high-quality reports. This technical report, to be completed in January 2018, will be provided to the 2020 Dietary Guidelines Advisory Committee for their use in incorporating the B-24/P population groups into its advisory report. The 2020 advisory report will, in turn, be used as the scientific basis for the 2020 *Dietary Guidelines for Americans*.

- **Healthy Eating Index (HEI)**

HEI is a measure of diet quality that assesses conformance to federal dietary guidance, particularly the *Dietary Guidelines for Americans*. The USDA's primary use of the HEI is to monitor the diet quality of the U.S. population and the low-income subpopulation. CNPP is planning to update the current HEI-2010 tool, based on the 2015 *Dietary Guidelines for Americans* and continues to expand the application of the HEI from the population to the individual and the food supply levels.

For Q2T1 (Influences on Eating Patterns), the USDA CNPP has conducted and continues to conduct communication research to inform a comprehensive communication initiative which includes the MyPlate icon, related nutrition messaging, and ChooseMyPlate web applications. The goal of this communication is to help consumers make healthier food choices as outlined in the *Dietary Guidelines for Americans*. Past research has included environmental and market scans, interviews with nutrition professionals, focus groups with parents, surveys with middle- and low-income consumers, and usability testing for web-based tools. In preparation for the 2015 *Dietary Guidelines for Americans*, CNPP is conducting consumer communication research to provide insights into (1) food/beverage decision-making modeling; and (2) consumer messages and concepts specifically tied to the *Dietary Guidelines for Americans*.

Economic Research Service (ERS)

About ERS: The mission of ERS is to inform and enhance public and private decision-making on economic and policy issues related to agriculture, food, the environment, and rural development. With more than 300 employees, ERS is the primary source of economic information and research in the USDA.

About ERS's Human Nutrition Research: The ERS food and nutrition research program, conducted within its Food Economics Division, studies the actions of and interactions among consumers, food industry, and Government as they relate to food supply and access; food choice and its impact on diet quality; and federal food and nutrition assistance, regulation, and other aspects of food policy. ERS food and nutrition research aims to inform and improve public and private decision-making on issues concerning the adequacy and healthfulness of the American diet, related nutrition outcomes, and their health and health expenditure effects. ERS also studies the efficiency and effectiveness of food markets and the USDA's food and nutrition assistance programs in meeting public policy and nutrition goals.

About ERS's NNRR Interest: The ERS nutrition research program includes a strong data and monitoring component that is responsive to Q3T3 (Population-Level Monitoring). That is, ERS measures, estimates, and publishes data on a variety of food and nutrition indicators. ERS also maintains the Food Availability (Per Capita) Data System (FADS), which provides long-term information on the U.S. food supply and food supply trends over time. ERS, with support from the USDA's Food and Nutrition Service, measures and monitors the food security status of the American population. The food security data are collected annually in the Current Population Survey, which is sponsored jointly by the U.S. Census Bureau and the U.S. Bureau of Labor Statistics (BLS) to provide national estimates. ERS, again with support from FNS, has conducted the National Household Food Acquisition and Purchase Survey. As the first comprehensive national household food expenditure survey in more than 30 years, FoodAPS provides current data on food spending, quantities, and prices on foods purchased or acquired from all sources. Data on consumer food behavior are gathered through the Flexible Consumer Behavior Survey, a supplement to the NHANES fielded since 2007, while the Eating & Health module fielded with the American Time Use Survey in 2006–2008 and again in 2014 provides data on time-use patterns for food choice-related activities. In addition, ERS publishes a number of data series related to food prices and expenditures. ERS also develops data products for policy and research use such as the ERS Food Expenditure Series of how food expenditures are spread across the supply chain and the Quarterly Food-at-Home Price Database and Quarterly Food-Away-From-Home Price data sets.

As ERS research evolves to address complex social and policy issues, it is integrating data from a wide range of sources to improve public understanding and permit more sophisticated analyses. This is responsive to Q3T4 (Big Data). Such projects may integrate a range of data options including primary data collection, geographic data integration and mapping systems, development and linking of program administrative data with national surveys, and systematic tracking of food from farm to consumer. ERS

conducted pioneering research on defining and mapping levels of food access and food environment across the entire U.S. at the state, county, and sub-county level. To illustrate, ERS produced data products such as the Food Environment Atlas and the Food Access Research Atlas, which enabled both researchers and other stakeholders to more effectively and efficiently analyze and understand food access issues. A forward-looking collaboration with the U.S. Census Bureau and the FNS will link USDA food and nutrition assistance program administrative data with national data obtained from Census surveys to create a next-generation administrative data platform. The following examples will be included in this innovative platform: the American Community Survey, the Survey of Income and Program Participation, and the Current Population Survey, as well as the ERS FoodAPS survey. This effort will enhance USDA food and nutrition assistance program performance and impact evaluation research.

In addition to its data development and monitoring activities, ERS conducts descriptive and econometric peer-reviewed research on policy-relevant topics, alone or in collaboration with university and other external researchers. Food choices and their determinants are major foci, responsive to Q2T1 (Influences on Eating Patterns). That is, ERS research includes examination of trends affecting food choices and diet quality in the overall population such as shifts to consumption of food prepared away from home, and response to information such as food labeling. ERS work also includes: analyses of demographics' effect on food demand; environmental effects, such as product reformulation; and new product introductions in response to changing consumer preferences and nutrition labeling regulations. Economic factors investigated include food price forecasting and analysis of the cost of healthy foods, especially fruits and vegetables; economic modeling of the effects of farm policies on food choice, nutrition and obesity; and econometric estimation of the effects of food prices on food demand, food intake, and obesity. Research investigates macroeconomic factors associated with food insecurity levels and federal food and nutrition assistance program participation, as well as food and nutrition assistance program participation effects on the economy. Targeted analyses investigate determinants of food security status, including socioeconomic characteristics and health status factors; determinants of federal food and nutrition assistance program participation; and estimation of program participation effects on food security, diet quality, nutrition, and health outcomes.

ERS is a leader in examining the potential for use of behavioral economics-based approaches to improving food choices, responsive to Q3T3 (Behavioral Economics). That is, ERS conducts and sponsors behavioral economics research on strategies to improve the diet quality of federal food and nutrition assistance program participants, low-income households, and children. For example, ERS established two university-based research centers, the Cornell Center for Behavioral Economics in Child Nutrition Programs and the Duke-University of North Carolina at Chapel Hill (UNC)-USDA Center for Behavioral Economics and Healthy Food Choice Research.

ERS, with research emphases in both nutrition and resource economics, is conducting research responsive to Q2T4 (Environmental Sustainability). ERS draws on its food availability data series to generate estimates of food waste, informing efforts to reduce waste. ERS is also investigating the sustainability implications of transitions to healthy

diets; examining the current food consumption pattern; looking at transitions of the current pattern to diets closer to federal recommendations; and investigating how such transitions may affect cropping patterns and the use of natural resources including water, land, and energy.

Food and Nutrition Service (FNS)

About FNS: FNS works to end hunger and obesity through the administration of 15 federal food and nutrition assistance programs including SNAP, the National School Lunch Program (NSLP), the School Breakfast Program (SBP), the Child and Adult Care Food Program (CACFP), the Supplemental Nutrition Program for Women, Infants, and Children (WIC), and The Emergency Food Assistance Program (TEFAP).

About FNS' Human Nutrition Research: In administering most of the major domestic food and nutrition programs targeted to reduce hunger and improve nutrition for children and low-income families, FNS is one of the major users of the *Dietary Guidelines for Americans,* and thus the research that supports the periodic updates to these Guidelines. In addition, FNS conducts research and makes use of the nutrition research sponsored by other federal agencies to help assess and improve the 15 FNS programs.

About FNS' NNRR Interests: In broad terms, the *Roadmap* reflects FNS-sponsored research, cooperative efforts with other federal agencies, and the research by other agencies frequently used by FNS in the following five categories: (1) program impact evaluations, (2) process evaluations, (3) cost/benefit analysis, (4) performance measurement and operational assessment, and (5) demonstration evaluations.

(1) Program Impact Evaluations

Through repeated periodic assessments such as the FNS-sponsored School Nutrition Dietary Assessment and School Food Purchase series, FNS determines the impact of changes in program regulations, guidance, technical assistance, and management evaluations on the foods and beverages available in school, and the foods and nutrients consumed by students at school and on school days. Recently started, the Study of Nutrition and Local Wellness Quality in Child Care Settings intends to start a similar series for CACFP. FNS's long-standing joint efforts with the USDA Economic Research Service monitor and help assess the impact of FNS programs on food security, and foster development of innovative approaches to determining the causes and consequences of domestic food insecurity. A recent FNS study, known as "*Measuring the Effect of SNAP Participation on Food Security*," assessed the impact of SNAP participation on changes in food security from the point of enrollment. FNS and CDC have a memorandum of understanding to facilitate joint efforts to assess WIC-related changes in early childhood obesity.

(2) Process Evaluations

The role of FNS programs in the national food and nutrition safety net requires the ability to take effective nutrition and food security interventions to a national scale. Process evaluation studies during the demonstration or pilot phase are conducted by

FNS to assist in the development of regulations, technical assistance, and legislative proposals that facilitate national coverage and effective operations. For example, process evaluation was included in the Evaluation of the Healthy Incentives Pilot study, the Evaluation of the Fresh Fruit and Vegetable Program, and the Summer Electronic Benefit Transfer for Children studies.

(3) Cost/Benefit Analysis

FNS is sponsoring a study to determine the feasibility of updating and expanding findings on the impact of prenatal participation in WIC on birth outcome and Medicaid costs, and of child WIC participation on Medicaid costs and health care utilization.

(4) Performance Measurement and Operational Assessment

FNS nutrition-related research in this area includes nationally-representative studies assessing compliance with regulatory meal pattern requirements (for NSLP, SBP, and CACFP) and provision of approved foods in benefit redemption (e.g., by the more than 200,000 SNAP-approved retailers and the more than 45,000 WIC-approved retailers). In addition, this category includes needs assessments. The report, entitled "*Nutrient and MyPyramid Analysis of USDA Foods in Five of Its Food and Nutrition Programs*," assessed the balance of foods directly provided by USDA using an adaptation of the Healthy Eating Index. Analyses generated from FNS-sponsored data collections and collections by other federal agencies are used by FNS to identify gaps in the federal food and nutrition assistance programs and opportunities for improvement. For example, FNS sponsored the National Research Council report known as "*Supplemental Nutrition Assistance Program: Examining the Evidence to Define Benefit Adequacy*." Research also helps identify gaps within program components. As one example, the WIC Breastfeeding Policy Inventory recently revealed that almost a quarter of WIC local agencies do not have at least one staff member with a certification in lactation counseling, consulting, education, or management.

(5) Demonstration Evaluations

As part of FNS's effort to improve effectiveness and efficiency, FNS is frequently asked by Congress to field and evaluate demonstrations of new programs or new program components. These demonstration evaluations typically make use of nutrition research products of other federal agencies and interdepartmental groups such as the *Dietary Guidelines for Americans*, the Dietary Reference Intakes, the USDA food composition datasets, the 24-hour recall methodology used for the NHANES What We Eat in America, the NCI method for statistical adjustment for usual intake, the CDC growth charts and standards for defining overweight and obesity, the Healthy Eating Index, and the USDA food security assessment tools. Examples of recent major demonstration evaluations include the Summer Electronic Benefit for Children Demonstration Evaluations and the Evaluation of the Fresh Fruit and Vegetable Program.

National Institute of Food and Agriculture (NIFA)

About NIFA: Congress created NIFA through the Food, Conservation, and Energy Act of 2008 (P.L. 110-234). NIFA replaced the former Cooperative State Research,

Education, and Extension Service, which had been in existence since 1994. NIFA is one of four USDA agencies that make up its Research, Education, and Economics (REE) mission area. The mission of NIFA is to invest in and advance agricultural research, education, and extension to solve societal challenges. The vision of NIFA is to catalyze transformative discoveries, education, and engagement to address agricultural challenges. NIFA works through an extensive network of state, regional, and county extension offices in every U.S. state and territory. These offices have educators and other staff who respond to public inquiries and conduct informal, noncredit workshops and other educational events. With support from more than 600,000 volunteers, 4-H—USDA's 105-year-old youth development program administered through NIFA—engages more than 6.5 million young people every year and teaches them life skills through hands-on learning and leadership activities.

About NIFA's Human Nutrition Research: NIFA's Food, Nutrition, and Health programs strengthen the nation's capacity to address issues related to diet, health, food safety, food security, and food science and technology.

About NIFA's NNRR Interest: NIFA has an interest in the three broad areas addressed in the *Roadmap*, as illustrated in the following examples.

For Question 1, NIFA is funding research to prevent and reduce the prevalence of childhood obesity. This program is designed to achieve the long-term outcome of reducing the prevalence of overweight and obesity among children and adolescents aged 2–19 years. Strategies include changing food preparation and eating behaviors, as well as increasing activity in children. For example, NIFA is funding research to reduce the prevalence of childhood obesity for minority children from low-income families. The feasibility and effectiveness of a summer fitness and wellness program designed to address the social and environmental barriers that are unique to low-income families is being assessed. This project proposes to identify and address the individual, family, community, and environmental factors that are more likely to prevent childhood obesity in low-income minority communities. NIFA also funds the iCook project whose goal is to increase culinary competence, family meal times, and physical activity of youth to help prevent childhood obesity. Using a community-based participatory research approach through the integration of research and extension, but utilizing 4-H programming, the iCook project aims to better understand eating patterns in families. NIFA uses its nutrition education efforts as key opportunities to promote healthier eating across the Nation. Cooperative Extension System staff work with school systems to develop educational materials in the area of health and nutrition.

For Question 2, NIFA is funding research to identify environmental and behavioral factors that act as barriers to consumption of a high quality diet, while identifying factors that promote healthy eating behaviors, e.g., increasing home access and availability of fruits and vegetables, and whether this leads to increased fruit and vegetable consumption. NIFA also funds research on access to low-cost and affordable fruits and vegetables by utilizing research on the food environment. Overall, NIFA funds research, education, and extension that demonstrate effective strategies that promote the

adoption of research-based healthy eating practices in vulnerable populations (low-income, rural, and minority populations).

For Question 3, NIFA is funding research to identify and test behavioral economic strategies that parents can use in the home to nudge their children to improve vegetable intake, variety, and liking. In addition, NIFA is funding behavioral economics research to examine how low- or no-cost changes in the school cafeteria environment lead children to choose healthier meals; and how Nutrition Report Cards alter lunch selections and home-related nutrition discussions and eating behavior. Nutrition Report Cards include information about children's food purchases during school along with messaging on how to discuss nutrition with children. The behavioral strategies used in altering lunchrooms include changes in food presentation and location, descriptive naming of healthier food options, changes in payment mechanisms, and changes in the relative convenience of food items. Another behavioral strategy funded by NIFA is research on optimal defaults in the college dining environment. This study hypothesizes that making the default option more optimal or less obesogenic will lead to more frequent choice of healthier foods, thus yielding less caloric intake and more fruit and vegetable consumption in college-aged freshmen.

United States Department of Veterans Affairs (VA)

Veterans Health Administration (VHA)

About the VHA: The VHA is home to the largest integrated health care system in the U.S., consisting of 150 medical centers, nearly 1,400 community-based outpatient clinics, community living centers, Vet Centers, and domiciliaries. Together, these health care facilities and the more than 53,000 independent licensed health care practitioners who work within them provide comprehensive care to more than 8.3 million veterans each year.

About the VHA's Human Nutrition Research: The VHA Office of Research and Development supports proposals in the following areas of research and development: biomedical laboratory, clinical science, cooperative studies programs, health services, and rehabilitation. These areas of current support include Deployment Health Research (includes Veterans from Operation Enduring Freedom [OEF], Operation Iraqi Freedom [OIF], and Operation New Dawn), traumatic brain injury, amyotrophic lateral sclerosis, Parkinson's disease, Alzheimer's disease, and Gulf War veterans' illnesses. Genomics is an emerging area in VHA Research and Development. The Million Veteran Program is a project to explore how genes affect health and illness by establishing one of the largest databases of genetic, military exposure, lifestyle, and health information. This is an ongoing research project for the next five to seven years.

VHA Health Services Research and Development has the following ongoing research projects in nutritional areas of interest:

- Veterans Integrated Service Network 6 (VISN 6) investigators at the Center for Health Services Research in Primary Care at the Durham VA Medical Center (VAMC) recently completed a study examining whether giving patients a choice

between two diets (low-carbohydrate or low-fat) led to better weight loss than being randomly assigned to one of the diets.

- VISN 6 investigators at the Center for Health Services Research in Primary Care at the Durham VA Medical Center recently completed a prospective cohort study using VA administrative data to examine health, economic, and weight outcomes after bariatric surgery in Veterans. The study found that mortality appears lower over the long-term in patients undergoing bariatric surgery compared with matched peers.
- VISN 6 Center for Health Services Research in Primary Care investigators are studying whether a behaviorally-based intervention delivered in-person and by phone can lead to better weight loss maintenance after an intensive behavioral weight loss program.
- VISN 6 Center for Health Services Research in Primary Care investigators are studying whether an intensive low-carbohydrate dietary program can lead to better glycemic control, fewer hypoglycemic events and less need for diabetes medication compared with shared medical appointments for diabetes.

The Mental Illness Research, Education, and Clinical Centers (MIRECC) were established by Congress with the goal of researching the causes and treatments of mental disorders and using education to put new knowledge into routine clinical practice in the VA. Specialized mental health centers of excellence (MH CoE) are an essential component of the VA's response to meeting the mental health needs of veterans. VHA Mental Health Services supports a variety of ongoing nutritional relevant research projects and works with the VA National Center for Health Promotion and Disease Prevention (NCP) on weight-management research projects. The NCP commissioned the SMITRECC evaluation center to conduct the National Evaluation of MOVE!® Outcomes for veterans with and without mental health disorders. An interdisciplinary team of Quality Enhancement Research Initiative (QUERI) clinical-researcher consultants from the VISN 6, 16, and 22 MIRECCs have participated, as well as researchers from Puget Sound, New Haven, and the Bronx VA Medical Centers. The quality improvement evaluation has been possible through funding from the former Diabetes and Mental Health QUERIs through an award. Many supported projects have resulted from this partnership exploring mental illness, associated medications, and impact on body weight and cardiometabolic effects. The relationship between nutrition, metabolism, and mental illness is of great importance to veterans and the VHA. The relationships between mental illness, medications, and nutrition/weight/metabolism are an important area of mental health research.

About the VHA's NNRR Interest: VHA is most interested in Questions 1 and 3. In addition, future VA research may focus on addressing the following research questions:

- What is the best treatment approach for eating disorders in veterans? There is little research being done on primary eating disorders. This topic is of increasing interest to the VHA because of the increasing numbers of veterans who are women.

- Independent of weight status, what is the impact of nutrition on cardiovascular disease and other comorbidities?
- What role and impact do prevention and nutrition care delivery have in multiple comorbidities, age-related issues, primary care focus, and team-based care in providing nutrition guidance and behavior change, and longitudinal care models?
- How do we assess the specific effects of psychotropic medications (including but not limited to second generation antipsychotics) on weight gain?
- What are the nutritional and body weight implications in the treatment plans of the seriously mentally ill and patients with traumatic brain injury?
- How do we address both over-nutrition and under-nutrition in homelessness, and food insecurity in low socioeconomic status?
- What is the impact on nutrition behavior change of mobile applications, e-health, and demonstration and hands-on learning modalities?
- How can we influence food companies to produce healthier foods that are appealing in taste, texture, appearance and cost?
- What is the environmental and population health impact of purchasing power in large scale nutrition supply chains?
- How to better characterize the weight and health impact of the nutrient content of manufactured and restaurant foods and of altering the content of these foods?
- How to better characterize the effects of food additives on human health?
- How to conduct large-scale nutrition studies more efficiently to answer important questions that require large sample sizes?
- What is the current state of nutrition-related advice and counseling in primary care settings including barriers and facilitators for providing nutrition counseling at the patient, clinical team, and health system levels?
- How does nutrition-related advice and counseling in health care settings impact patient knowledge, perceptions, motivation, and behavior change?
- How can we enhance the reach and effectiveness of behavioral counseling interventions to improve healthy eating patterns in health care settings, particularly primary care settings?
- What can we do to better integrate effective behavioral counseling interventions that address healthy eating into other preventive interventions in health care settings?
- What can we do to increase patient engagement and use of interventions that focus on nutrition behavior change in health care settings?

Interagency Collaborations and Public-Private Partnerships to Advance Nutritional Sciences Research

Overview

Collaboration among governmental, nongovernmental, academia, and private entities will help address the research needs put forth by this *Roadmap*. That is, interagency collaborations and public-private partnerships could help:

- Expand the scope, interdisciplinary nature, and potential of a project;
- Enhance the likelihood of broader and more rapid implementation of the results;
- Allow for needed expertise to advance project goals;
- Reduce the cost of a project to an individual collaborator; and
- Increase the likelihood of adequate funding for meritorious projects.

In a time of system approaches for interdisciplinary science, joint funding and oversight will become more common.

Examples of Established Federal Human Nutrition Research Collaborations

The following selected collaborations have produced trans-agency clinical trials, databases, surveys, scientific meetings, interdisciplinary methods development, and research resources that have helped to advance federal human nutrition research.

Biomarkers of Nutrition for Development (BOND)

Co-Sponsors: The NIH Eunice Kennedy Shriver National Institute of Child Health and Human Development in collaborations with partners representing the breadth of the global food and nutrition communities and supported by several sponsoring partners, including the Bill and Melinda Gates Foundation, EURopean micronutrient RECcommendations Aligned (EURRECA), Micronutrient Genomics Project, the NIH Division of Nutrition Research Coordination, the NIH Office of Dietary Supplements, and PepsiCo.

About BOND: Aims to develop a unified approach to examine the scientific basis for choosing appropriate biomarkers for assessing the function and effect of diet and nutrition on health and disease in individuals and populations; and, supporting the development and evaluation of evidence-based programs and policies to improve diet and nutrition as a way to improve health.

Branded Food Products Database for Public Health

Co-Sponsors: Agricultural Technology Innovation Partnership Foundation, USDA's Agricultural Research Service and the International Life Sciences Institute North America

About the Branded Food Products Database for Public Health: A 2011 Presidential Memorandum directed federal agencies to develop public-private partnerships in areas

of importance to the mission of each agency. In response, Dr. Cathie Woteki, Under Secretary and Chief Scientist of the USDA, developed multiple initiatives, including one to augment the USDA National Nutrient Database with compositional data on branded food products. This will be accomplished by obtaining comprehensive food composition data from the food manufacturers and making it available to Government, industry, the scientific community, and the general public through an enhanced National Nutrient Database, developed and maintained by the USDA ARS Nutrient Data Laboratory in Beltsville, MD.

Dietary Guidance Development Project for Infants and Toddlers from Birth to 24 Months and Women Who Are Pregnant (B-24/P)

Co-Sponsors: USDA Center for Nutrition Policy and Promotion and HHS Office of Disease Prevention and Health Promotion

Contributors: Involves experts from across Government, including USDA (CNPP, FNS, ARS), HHS (Office of the Secretary/Office of the Assistant Secretary for Health-H/ODPHP, NIH, CDC, FDA, HRSA/MCHB) and USAID and more than 50 external experts.

About B-24/P: A highly collaborative project conducting foundational work to support inclusion of the birth-to-24-month age group and women who are pregnant into the *2020 Dietary Guidelines for Americans*. The *Dietary Guidelines for Americans*, the cornerstone of the U.S. Government's nutrition policy to promote health and help prevent disease, has traditionally focused on adults and children 2 years of age and older. This project was initiated in 2012 to describe the relevant topics, feasibility, and research gaps for creating dietary guidance for children from birth to 2 years old. The products from the first phase of this project are available at www.NEL.gov. In 2014, a broadly representative Federal Expert Group was established to provide oversight for the next phase of the project. Products from this project will be provided to the 2020 Dietary Guidelines Advisory Committee for their use in incorporating these population groups into its advisory report. The advisory report will, in turn, be used as the scientific basis for the 2020 *Dietary Guidelines for Americans*.

Dietary Supplement Ingredient Database (DSID)

Co-Sponsors: Nutrient Data Laboratory, USDA ARS, the NIH Office of Dietary Supplements, along with CDC NCHS, Commerce NIST and DoD

About DSID: Provides estimated levels of ingredients in dietary supplement products sold in the U.S. and is intended primarily for research applications. The analytically verified DSID estimates can be used to replace labeled levels for specific dietary supplement categories to improve the accuracy of ingredient intake assessment in public health studies. The current release of the DSID has application tables linking analytical estimates to dietary supplement products reported in the National Health and Nutrition Examination Survey (NHANES). In the future, the DSID data will also be linked to products in the Dietary Supplement Label Database (DSLD), which will eventually include label information for all dietary supplements sold in the U.S. The third release of

the DSID provides access, for the first time, to analytically-validated estimates of ingredient content for non-prescription prenatal multivitamin/minerals (MVMs) and omega-3 fatty acid supplements. These estimates were derived from the chemical analysis of representative non-prescription prenatal MVMs and omega-3 fatty acid supplements. The DSID 3.0 release also includes adult and children's MVM data, which replace the DSID 2.0 data. The previously released data were updated with diversified regression models and modified label ranges for equations, application tables and on-line calculators of estimated ingredient content. All of these data are appropriate for use in population studies of nutrient intake rather than for assessing individual products.

Dietary Supplement Label Database (DSLD)

Co-Sponsors: The NIH Office of Dietary Supplements and the National Library of Medicine along with other NIH collaborating agencies, Nutrient Data Laboratory, USDA ARS, CDC NCHS, Commerce NIST and DoD

About DSLD: Contains the full label contents from a sample of dietary supplement products marketed in the U.S., and makes possible searches for products either in the market (DSLD On Market), off the market (DSLD Off Market) or consumed by National Health and Nutrition Examination Survey (NHANES) participants in the latest survey in the DSLD database.

Federal Food Service Guidelines Workgroup

Team Members: CDC (coordinating body), National Prevention Council, Department of Commerce/NOAA, DoD, Department of the Interior (DoI), Department of Education, EPA, GSA, other HHS agencies (FDA, NIH, and ODPHP), USDA, and VA

About the Federal Food Service Guidelines Workgroup: In 2011, HHS and GSA jointly released the *Health and Sustainability Guidelines for Federal Concessions and Vending Operations*, also known as the food service guidelines. These guidelines assist facility leadership, management, and food service operators in providing healthy dietary options in cafeterias, snack bars, and vending machines to which federal employees and visitors have access. In addition, these guidelines provide fair market choices, support healthy eating habits, and recommend environmentally responsible facility practices. The Federal Food Service Guidelines Workgroup plans to update the food service guidelines to align the nutrition guidance with the *Dietary Guidelines for Americans, 2015*, which has an anticipated release date of December 2015. The update will also include strategies to encourage the purchasing of healthier foods and beverages as well as guidance on efficiency of facility operations and food safety. The Workgroup continues to work together to explore ways to evaluate the implementation and impact of these guidelines at the local, state, and federal levels.

Joint Institute for Food Safety and Applied Nutrition (JIFSAN)

Sponsors: FDA and the University of Maryland

Other Collaborators: EPA Office of Pesticide Programs

About JIFSAN: The Institute is the foundation of public and private partnerships that provide the scientific basis for ensuring a safe, wholesome food supply, as well as providing the infrastructure for contributions to national food safety programs and international food standards. One example of a nutrition research-related activity was the collaborative development of a food component database in the NHANES that is an integral part of EPA's dietary risk assessments.

Let's Move!

About *Let's Move!*: Launched by First Lady Michelle Obama in February 2010, *Let's Move!* is a comprehensive initiative dedicated to helping kids and families lead healthier lives. *Let's Move!* has mobilized a variety of federal and non-federal activities and collaborations to promote healthy eating and physical activity, which has sparked and sustained a national conversation on this issue. On the same day that *Let's Move!* launched, President Barack Obama signed a Presidential Memorandum creating a Task Force on Childhood Obesity charged with developing a national plan to maximize federal resources and setting concrete benchmarks toward the First Lady's goals. The Task Force recommended *Let's Move!* focus on five pillars: (1) creating a healthy start for children; (2) empowering parents and caregivers; (3) providing healthy foods in schools; (4) improving access to healthy, affordable foods; and (5) increasing physical activity. Over the last five years, *Let's Move!* has been working with various sectors towards putting these recommendations into actionable steps. The initiative has instituted ten programs that work to create healthier environments in schools and communities across the country (e.g., *Let's Move!* Cities, Towns and Counties, *Let's Move!* Active Schools).[189]

National Collaborative on Childhood Obesity Research (NCCOR)

Co-Sponsors: Robert Wood Johnson Foundation, NIH, CDC, and USDA

About NCCOR: Brings together leading research funders of childhood obesity in a public-private collaboration to accelerate progress on reversing the epidemic of overweight and obesity among U.S. youth. NCCOR's focus is on evaluating and identifying effective interventions, particularly policy and environmental interventions at the individual, community, and population levels in the areas of nutrition, physical activity, and weight control, with a special emphasis on the lower-income and racial/ethnic populations at highest risk. NCCOR aims to improve the efficiency and application of childhood obesity research by building capacity for research and creating infrastructure needed for translation and dissemination of research findings.

National Food and Nutrient Analysis Program (NFNAP)

Primary Sponsor: Nutrient Data Laboratory, USDA ARS

Co-Sponsors: NIH, CDC, and FDA

About NFNAP: Enables the USDA to broaden its analysis of the nutrient content of the U.S. food supply with additional support from several HHS agencies. The main purposes include monitoring key foods and their nutrient content—key foods being defined as those providing more than 75 percent of any nutrient for the U.S. population; developing nutrient databases for foods consumed by ethnic minorities that are of research interest to HHS including Latinos, Asians, and American Indian/Alaska Natives; developing and expanding databases for non-essential bioactive food components such as anthocyanins, flavonoids, and oxalic acid; and, developing label and content databases for ingredients in dietary supplements. NFNAP allows more accurate estimation of the ever-changing nutrient profile from foods and supplements in the marketplace.

National Health and Nutrition Examination Survey (NHANES)

Co-Sponsors: CDC, NIH, USDA, and FDA

About NHANES: Conducted by the CDC National Center for Health Statistics (NCHS), the NHANES is designed to assess the health and nutritional status of adults and children in the U.S. Each year, the survey examines a nationally representative sample of about 5,000 persons. The NHANES is unique in that it combines interviews (demographic, socioeconomic, dietary, and health-related questions) and physical examinations (laboratory tests and medical, dental, and physiological measurements). Findings from the NHANES are used to: determine the prevalence of major diseases and risk factors for diseases; assess nutritional status and its association with health promotion and disease prevention; provide the basis for national standards for such measurements as height, weight, and blood pressure; and conduct epidemiological studies and health sciences research. The NHANES dietary survey, referred to as What We Eat in America, is carried out through collaboration with the USDA.

Scientific Report of the Dietary Guidelines Advisory Committee (DGAC)

Co-Sponsors: HHS Office of Disease Prevention and Health Promotion and the USDA Center for Nutrition Policy and Promotion, along with the USDA Agricultural Research Service

About the DGAC: Every five years, HHS and USDA publish the *Dietary Guidelines for Americans* (P.L.101-445, Title III, 7 U.S.C. 5301 et seq.). To accomplish this task, since the 1985 edition, the Departments jointly appointed a Dietary Guidelines Advisory Committee to review the scientific and medical knowledge current at the time. The culmination of the Committee's work is the delivery of a scientific Advisory Report to the Secretaries of HHS and USDA. This Advisory Report is used along with public and federal agency comments to develop the next edition of the *Dietary Guidelines for*

Americans. In addition to its scientific findings, the Advisory Report identifies knowledge gaps critical to developing dietary guidance for all Americans.

The Federal Working Group on Dietary Supplements (FWGoDS)

Co-Sponsors: The NIH ODS, along with other NIH Institutes and Centers, AHRQ, Administration for Community Living, CDC, FDA, FTC, HHS ODPHP, HRSA, NASA, NIST, USAID, U.S. Army Research Institutes of Environmental Medicine, U.S. Consumer Product Safety Commission (CPSC), USDA, U.S. Department of Justice (DOJ), U.S. Department of Veterans Affairs (VA) and the Uniformed Services University of the Health Sciences (USUHS)

About FWGoDS: A collection of individuals from federal agencies who share information and discuss issues, initiatives, and research related to dietary supplements. Serves as means of communication between the ODS and its federal partners in several ways, including co-funding research investigations within the NIH; expanding opportunities for research-investigator training; and strengthening collaborative efforts involving dietary supplement research, education, and communication across the Government. The Dietary Supplement Health and Education Act of 1994 (DSHEA) (P.L. 103-417) authorized the establishment of ODS at the NIH and specified that ODS serve as an advisor to federal health agencies on issues related to dietary supplements. The FWGoDS also exists in response to a goal in the ODS Strategic Plan to expand and conduct outreach efforts that inform and educate the public about supplements.

The NIH Nutrition Coordinating Committee (NCC)

Primary Sponsor: NIDDK Office of Nutrition Research

Other Participants: NIH Institutes and Centers, AHRQ, CDC, DoD, FDA, HRSA MCHB, Indian Health Service, HHS ODPHP, and USDA

About the NCC: Improves inter-organization communication and research coordination of nutritional sciences activities within the NIH by working to review, stimulate, and encourage the necessary support of nutrition research and training and to define the role of nutrition in health promotion and disease prevention and management.

The Pre-B Project

Primary Sponsor: NICHD, NIH, HHS

Other Sponsor: Academy of Nutrition and Dietetics (AND)

About The Pre-B Project: The project is exploring the level and quality of the evidence to support nutrition specifications to fulfill essential and/or conditionally essential macro- and micro-nutrient requirements for preterm infants that are distinct from currently established recommendations for term infants. In phase I, the project aims to develop a structure and provide an initial report to the Academy of Nutrition and Dietetics (AND).

In phase II, AND systematic reviews will be conducted using the AND evidence analysis library. In phase III, the project will discuss implementation.

The Weight of the Nation (WOTN)

Co-Sponsors: CDC, NIH, the Michael and Susan Dell Foundation, Kaiser Permanente, the IOM and HBO

About WOTN: A four-part Emmy-nominated HBO documentary, WOTN collaborators worked together on a public service campaign that included a nationwide community-based outreach of 40,000 film kits in English and Spanish. Scientific and communications staff from the CDC and the NIH worked to insure that the documentary presented fact-based information demonstrating the consequences of obesity; illustrating what the science has shown about how to lose weight, maintain weight loss, and prevent weight gain; documenting the damage obesity is doing to our nation's children; and highlighting the challenges to examining the major driving forces causing the obesity epidemic including agriculture, economics, evolutionary biology, food marketing, racial and socioeconomic disparities, physical inactivity, social and cultural influences, and the strong influence of the food and beverage industry. To address childhood obesity, the WOTN collaborative developed additional films targeting youth. The CDC and the NIH scientific and communications staff also provided important input into companion books that support youth film messages, which were distributed by Scholastic to schools across the U.S. In April 2013, "*The Weight of the Nation*" collaboration received the HHS Innovates award from U.S. Secretary of Health and Human Services Kathleen Sebelius.

Vitamin D Standardization Program (VDSP)

Co-Sponsors: This collaboration involves the coordinated efforts of ODS; NIST; CDC; the Vitamin D External Quality Assessment Scheme; the College of American Pathologists; the American Association for Clinical Chemistry; the International Federation of Clinical Chemistry and Laboratory Medicine; the Laboratory for Analytical Chemistry; the Faculty of Pharmaceutical Sciences; Ghent University, Ghent, Belgium; plus national surveys and collaborators around the world. Since the inception of this program, ODS has enlisted the participation of national health surveys from Australia, Canada, Germany, Ireland, Mexico, South Korea, the United Kingdom, and the United States.

About VDSP: Aims to standardize the laboratory measurement of vitamin D status and improve the detection, evaluation, and treatment of vitamin D deficiency and insufficiency by promoting the standardized laboratory measurement of serum total 25-hydroxyvitamin D [25(OH)D] by making it accurate and comparable over time, location, and laboratory procedure.

Suggestions for Developing and Enhancing Collaborative Research

Each participating ICHNR department and agency will need to develop its own procedures for developing or maximizing existing collaborative research endeavors. These procedures should be guided by ethical principles that include transparency, good stewardship of public resources, and benefits to all partners.[192] An important first step in successful collaborations requires that partners develop a deeper understanding of the mission and culture of all the organizations involved. Building trust among partners will be a fundamental step to building strong collaborative activities, which will demand open communication. Equally as important is a clear delineation of goals, expectations, and responsibilities for each partner. This step should occur early in the process of developing, renewing, or expanding the scope of a partnership. Given that interagency collaboration and public-private partnerships require lead times and approvals beyond the usual, this should be factored into any planned interactions. This may be particularly true for public-private partnerships, but such partnerships enhance the potential for innovation and flexibility in research mechanisms. Successful long-term collaborations use processes that allow identification of the evolving important issues facing the U.S. population and incorporate new expertise to solve these evolving research questions. We recommend participating ICHNR departments and agencies work together to identify best practices for developing such collaborative relationships and share lessons learned about cost-sharing, using various funding mechanisms such as grants, contracts, and agency agreements.

Appendix A: Charter of the Interagency Committee on Human Nutrition Research

Background: The Joint Subcommittee on Human Nutrition Research (JSHNR) was chartered under the aegis of the Office of Science and Technology Policy's (OSTP) Federal Coordinating Committee for Science, Engineering, and Technology in September 1978. Under the auspices of the OSTP, the JSHNR accomplished most of its objectives, and the decision was made that issues related to human nutrition research could be adequately addressed through the establishment of a collaborative mechanism by the federal agencies that principally support human nutrition research. To realize this goal, the Department of Health and Human Services (HHS) and the United States Department of Agriculture (USDA) created the Interagency Committee on Human Nutrition Research (ICHNR) in July 1983 subsequent to the termination of the JSHNR in June 1983.

CHARTER

Because of the vital importance of the benefits from human nutrition research to the welfare of the American people and the world population, it is essential that the nutrition research efforts of the federal agencies be mutually reinforcing.

In recognition of this need, the U.S. Department of Health and Human Services (HHS) and the U.S. Department of Agriculture (USDA) hereby establish an Interagency Committee on Human Nutrition Research (ICHNR).

Scope: This Committee is concerned with: (1) all federally supported or conducted research on nutrition with emphasis on human nutrition; and (2) professional personnel needs in nutrition research. This includes research directed to identifying:

- Basic physiological and biochemical mechanisms for the digestion, absorption, metabolism, and transport of nutrients; and the role of food ingredients in human health and performance and in the prevention and treatment of disease.
- Nutrient composition of foods; the effects of storage, processing, and packaging; and the biological availability of nutrients in the foods at the time of consumption.
- Determinants of dietary practices and methods for educating the public about dietary practices.
- Methods of assessing food consumption patterns and the nutritional status of the general population and of special high-risk subgroups within the population; the nutritional impacts of various intervention strategies and public policies.
- The professional personnel necessary to carry out research on human nutrition; appropriate training programs in nutrition research in medical schools, dental schools, schools for allied health professionals, schools of nutrition, teachers' colleges, and schools of food and agriculture.

Purpose and Function: The purpose of ICHNR is to increase the overall effectiveness and productivity of research efforts in nutrition. In fulfilling this purpose, the Committee will:

a. Improve planning, coordination, and communication among federal agencies engaged in research on nutrition.
b. Facilitate the development and updating of plans for federal research programs to meet current and future domestic and international needs for nutrition.
c. Coordinate the collection, compilation, and dissemination of information on nutrition research, including that stipulated by the plan for the Human Nutrition Research Information Management System.
d. Prepare reports as necessary on special topics identified by the Committee.

Organization of the Committee: The Co-Chairpersons of ICHNR will be the Assistant Secretary for Health of the U.S. Department of Health and Human Services and the Assistant Secretary for Science and Education of the U.S. Department of Agriculture, or their designees. Chairpersons of the task forces or working groups of the Committee will arrange for staff assistance from their own agencies.

In addition to the Co-Chairpersons, the Committee will include two representatives each from HHS and USDA, and one representative each from the following agencies:

- Agency for International Development
- Department of Commerce (NOAA)
- Department of Defense
- Federal Trade Commission
- National Aeronautics and Space Administration
- National Science Foundation
- Veterans Administration (Department of Veterans Affairs)
- Office of Science and Technology Policy

Other federal agencies may participate, as appropriate, upon invitation by the ICHNR Co-Chairpersons.

The Committee will follow a schedule of periodic meetings and hold special meetings at the call of the Co-Chairpersons. Agendas for meetings will be made available for members prior to each meeting. Minutes of meetings will be prepared and distributed to all members of the Committee.

The Committee may establish task forces or working groups as necessary for the conduct of required Committee work.

Compensation: All members will be full-time federal employees who are allowed reimbursement for travel expenses by their agencies plus per diem for subsistence while serving away from their duty stations in accordance with Standard Government Travel Regulations.

Annual Cost Estimates: Estimated annual cost of operating the Committee, excluding staff support, is $1,000.

Reports: The Committee shall prepare reports as needed and requested by the Co-Chairpersons.

Determination: I hereby determine that the formation of the Interagency Committee on Human Nutrition Research is in the public interest in connection with the performance of duties imposed on the Executive Branch by law, and that such duties can be performed through the advice and counsel of such a group.

APPROVED:

Edward N. Brandt, Jr., M.D.
Assistant Secretary for Health
U.S. Department of Health and Human Services

Orville G. Bentley, Ph.D.
Assistant Secretary for Science and Education
U.S. Department of Agriculture

ORIGINALLY SIGNED ON JULY 7, 1983

Appendix B: Selected Federal Policy and Programmatic Activities Relevant to Human Nutrition Research

Dietary Guidelines for Americans

Every five years, HHS and USDA are required (P.L. 101-445, Title III, 7 U.S.C 5301 et seq.) to review the scientific and medical knowledge current at the time and publish the *Dietary Guidelines for Americans*. In addition, both agencies are working together on the mandated guidance for pregnant women and children from birth to 24 months (P.L. 113-79, Sec. 4204). An initial, foundational component to this project has been identifying knowledge gaps.[193]

Child Nutrition and WIC Reauthorization Examples

The Healthy, Hunger-Free Kids Act of 2010 (P.L. 111-296) authorized funding and establishes significant nutritional reforms for the USDA Child Nutrition Programs, which were based on decades of research examining how best to reduce hunger and nutrition-related chronic diseases among America's most-at-risk infants, children, and adolescents, in addition to low-income pregnant and breastfeeding and non-breastfeeding postpartum women. A significant WIC development has been the evidence-informed final rule revising its food packages. Research has shown these changes have helped to increase the initiation and duration of breastfeeding among participants and has contributed to decreases in total and saturated fat intakes, increases in fruit and vegetable intake, and improvements in participants' overall diet quality.[194,195]

Farm Bill Examples

Congress required a study of food deserts—areas of limited access to affordable and nutritious foods—in the Food, Conservation, and Energy Act of 2008 (P.L. 110-234). Another example authorized by this Act was the Healthy Incentives Pilot that evaluated if incentives provided to SNAP recipients at the point of sale would contribute to increasing the purchase of fruits, vegetables, or other healthful foods. Informed by a growing body of literature about the interactions between food, nutrition, and health, The Agricultural Act of 2014 (P.L. 113-79) made significant investments in improving access to healthy food in local and regional food systems. For example, the Food Insecurity Nutrition Incentive (FINI) Grant Program funds programs that encourage increased fruit and vegetable consumption by SNAP recipients at the point of purchase through increased purchasing power. Another example was the authorization of $125 million for the national healthy food financing initiative to make nutritious food more accessible.

The Patient Protection and Affordable Care Act (P.L. 111-148)

Authorized significant research investments to promote health and reduce chronic diseases, maximizing evidence-informed approaches to fostering healthy eating.

Proposed Update of the Nutrition and Supplement Facts Label

The proposed changes reflect dietary recommendations, consensus reports, and national survey data, along with input obtained through four advance notices of proposed rulemaking and numerous citizens' petitions.

Appendix C: Federally Supported Human Nutrition Monitoring and Surveillance Resources

- The National Collaborative on Childhood Obesity Research Catalogue of Surveillance Systems
  - Provides one-stop access to more than 100 publicly available datasets relevant to childhood obesity research, including several of the examples listed below. In addition, the National Collaborative on Childhood Obesity Research Measures Registry provides a searchable database of diet and physical activity measures relevant to childhood obesity research to help standardize use of common measures and research methods across childhood obesity research at the individual, community, and population levels.
- American Time Use Survey
  - Collects data on the amount of time spent on various activities, including leisure, by individuals in the U.S.
- Annual Agricultural Statistics
  - Collects data about the production, economics, and demographics of agriculture, and its environment in the U.S.
- Behavioral Risk Factor Surveillance System (BRFSS)
  - Collects state-specific data about preventive health practices and risk behaviors linked to chronic diseases, injuries, and preventable infectious diseases for adults in the U.S.
- Census of Agriculture (Ag Census)
  - Collects data about production, sales, agricultural practices, and sales practices for farms, ranches, and the people who operate them in the U.S. and its territories.
- Chronic Disease State Policy Tracking System
  - Provides a single data source for identifying and tracking policies and programs at the state level designed to address chronic diseases.
- Classification of Laws Associated with School Students (C.L.A.S.S.)
  - Collects data about state nutrition environments, physical education, and physical activity laws in the U.S. and scores them in comparison to national standards.
- Consumer Expenditure Survey (CE)
  - Collects data about buying habits, including food expenditures, income, and other U.S. household characteristics.
- Dietary Supplement Ingredient Database (DSID)
  - Provides levels of ingredients in dietary supplement products.
- Dietary Supplement Label Database (DSLD)
  - Provides information on dietary supplement labels.
- Early Childhood Longitudinal Study, Birth Cohort (ECLS-B)
  - Collects data about the care and education, health and development of children from birth through kindergarten entry.

- Early Childhood Longitudinal Study, Kindergarten Class of 1998–99 (ECLS-K)
  - Collects data on children's early school experiences from kindergarten through middle school in the U.S.
- Fast Response Survey System (FRSS)
  - Collects data about key education issues for children in elementary and secondary schools in the U.S.
- Food Attitudes and Behaviors (FAB) Survey
  - Collects data about attitudes and behaviors related to fruit and vegetable intake of adults in the U.S.
- Food Availability (Per Capita) Data System
  - Collects estimated data regarding foods, nutrients, and calories available for consumption for each individual in the U.S.
- Food Access Research Atlas
  - Presents a spatial overview of food access indicators for low-income and other census tracts using different measures of supermarket accessibility; provides food access data for populations within census tracts; and offers census-tract-level data on food access that can be downloaded for community planning or research purposes.
- Food Commodity Intake Database
  - Complements the NHANES/WWEIA food consumption survey databases by providing estimates of food consumption expressed as food commodities as opposed to foods *per se* (i.e., "as eaten") which is used by the EPA Office of Pesticide Programs for dietary exposure assessments on pesticides.
- Food Environment Atlas
  - Assembles statistics on food environment indicators to stimulate research on the determinants of food choice and diet quality and provide a spatial overview of a community's ability to access healthy food and its success in doing so.
- Food Intakes Converted to Retail Commodities Database (FICRD)
  - Converts foods consumed in national dietary intake surveys to commodities at the retail level in the U.S.
- Food Patterns Equivalents Database (FPED)
  - Converts foods and beverages in the USDA Food and Nutrient Database for Dietary Studies to 37 USDA Food Patterns components.
- Food and Nutrient Database for Dietary Studies (FNDDS)
  - Translates typical portions of foods into gram weights and provides associated nutrient values.
- Health Information National Trends Survey (HINTS)
  - Collects data about how adults in the U.S. access and use information related to cancer and general health.
- Health Resources and Service Administration (HRSA) Geospatial Data Warehouse
  - Provides demographic data and information about access to and use of health services for geographic areas in the U.S.

- Health and Diet Surveys
  - Collects data about awareness, attitudes, and practices related to health and diet issues among consumers in the U.S.
- Infant Feeding Practices Study II (IFPS)
  - Collects data about feeding practices and patterns for infants in their first year of life in the U.S.
- Local Area Unemployment Statistics
  - Collects and publishes monthly employment, unemployment, and labor force data by place of residence for census regions and divisions, states, counties, federal statistical areas, and many cities in the U.S.
- Maternity Practices in Infant Nutrition and Care Survey (mPINC)
  - Collects data about maternity care practices and policies from facilities providing intrapartum care in the U.S. and its territories.
- Medical Expenditure Panel Survey-Household Component (MEPS-HC)
  - Collects data about the use, cost, and payment of health services from families and individuals in the U.S.
- National Ambulatory Medical Care Survey (NAMCS)
  - Collects data about the provision of medical services at ambulatory care facilities in the U.S.
- National Automotive Sampling System General Estimates System (NASS/GES)
  - Collects data about characteristics and trends for motor vehicle crashes in the U.S.
- National Center for Education Statistics Common Core of Data (NCES/CCD)
  - Provides an official listing of public elementary and secondary schools and school districts in the U.S., along with descriptive and demographic data on these schools and districts.
- National Health Interview Survey (NHIS)
  - Collects data on health status and the use of health services by individuals in the U.S.
- National Health and Nutrition Examination Survey (NHANES)
  - Collects data about the health, nutritional status, and health behaviors of individuals in the U.S.
- National Hospital Ambulatory Medical Care Survey (NHAMCS)
  - Collects data about the provision and use of ambulatory care services in hospital emergency, outpatient, and surgery departments in the U.S.
- National Hospital Discharge Survey (NHDS)
  - Collects data about demographics and medical diagnoses and treatments for patients discharged from hospitals in the U.S.
- National Household Travel Survey
  - Collects data about travel behavior by members of households in the U.S.
- National Immunization Survey (NIS)
  - Collects data on vaccinations and breastfeeding for children in the U.S.
- National Longitudinal Survey of Youth 1979 (NLSY79)
  - Collects data about demographics, health, and life/work trajectories of individuals who were between the ages of 14 and 22 years and residing in the U.S. in 1979.

- National Longitudinal Survey of Youth 1997 (NLSY97)
  - Collects data about demographics, health, the transition from school to work, and life/work trajectories for individuals who were ages 12 to 17 years and residing in the U.S. in 1997.
- National Longitudinal Survey of Youth-Children and Young Adults (NLSY79ch)
  - Collects data about the demographics, health, and development of children and their mothers in the U.S.
- National Nutrient Database for Standard Reference, Release 25 (SR-25)
  - Provides authoritative food composition data for foods available in the U.S.
- National Survey of Ambulatory Surgery (NSAS)
  - Collects data about visits to hospital-based and freestanding ambulatory surgery centers (ASCs) by patients in the U.S.
- National Survey of Family Growth (NSFG)
  - Collects data about family life, marriage and divorce, pregnancy, infertility, use of contraception, and reproductive health for adolescents and adults in the U.S.
- National Survey on Recreation and the Environment
  - Collects data about participation in outdoor recreational activities and related behaviors and attitudes for individuals in the U.S.
- National Visitor Use Monitoring Program
  - Collects data about characteristics of recreational activities engaged in, and facilities used by, visitors to National Forests and Grassland in the U.S.
- National Vital Statistics System (NVSS)
  - Collects data about births and deaths for individuals in the U.S. and its territories.
- Pesticide Data Program
  - Collects data about pesticide residues in food commodities and drinking water in the U.S.
- Private School Universe Survey/Private School Survey Series (PSS)
  - Produces aggregate counts of private schools, students, and teachers and serves as a sampling frame for the National Center for Education Statistics sample survey of private schools. Gathers descriptive and demographic data on these schools, teachers, and students.
- Quarterly Food-at-Home Price Database (QFAHPD)
  - Provides estimates of average market-level prices for more than 50 food groups in the U.S.
- Schools and Staffing Survey
  - Collects data about characteristics of schools and their staff in the U.S.
- School Food Purchase Study
  - Periodically collects individual item price and quantity information on all foods purchased from a nationally representative sample of school food authorities.

- School Health Profiles
  - Offers a system of surveys assessing school health policies and practices in states, large urban school districts, territories, and tribal governments that are conducted every two years by education and health agencies among middle- and high-school principals and lead health education teachers.
- School Health Policies and Practices Study (SHPPS)
  - Collects national data periodically to assess school health policies and practices at the state, district, school, and classroom levels.
- School Nutrition Dietary Assessment Study (SNDA)
  - Collects nationally representative data about every five years on foods offered and served in schools, and school food service characteristics; and about every 10 years also obtains dietary intake at school and over 24 hours on school days, along with factors affecting participation in school meals.
- Supplemental Nutrition Assistance Program (SNAP) Data System
  - Provides data about SNAP participation and benefit levels in the U.S.
- Supplemental Nutrition Assistance Program (SNAP) Policy Database
  - Collects data about state Supplemental Nutrition Assistance Program (SNAP) rules and policies in the U.S.
- Supplemental Nutrition Assistance Program (SNAP) Retailer Locator
  - Provides data about SNAP-approved retail markets in the U.S.
- Supplemental Nutrition Assistance Program Quality Control Data File (SNAP-QC)
  - Collects data on demographic and economic status related to eligibility for households participating in SNAP.
- Total Diet Study
  - Collects data on levels of contaminants, pesticide residues, and nutrients in table-ready foods in the U.S. and estimates dietary intakes of these substances.
- U.S. Decennial Census
  - Provides a variety of population and economic data, including aspects on geographic features in the U.S. and its territories, such as the American Community Survey, Census TIGER®, Current Population Survey, Economic Census, Survey of Income and Program Participation, and Survey of Program Dynamics.
- USDA Center for Nutrition Policy and Promotion Food Prices Databases
  - Collects data about estimated cost of specific food items consumed in the U.S.
- USDA National Resources Conservation Service – Geospatial Data Gateway
  - Collects data about environmental and natural resources for geographic areas in the U.S.
- What We Eat in America
  - Provides the dietary intake interview component of the National Health and Nutrition Examination Survey (NHANES).

- WIC Infant-Toddler Feeding Practices Study
  - Periodically provides information on dietary intake of infants participating in the USDA Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), as well as the feeding practices of their caretakers.
- Youth Risk Behavior Surveillance System/Youth Risk Behavior Survey (YRBSS/YRBS)
  - Collects data about priority health risk behaviors among students in grades 9–12 in the U.S.

Appendix D: Examples of Federally Supported Career Development and Training Programs Relevant to Human Nutrition Research

Career Development Opportunity	Description	Career Stage	Type of Opportunity
Multi-Departments and Agencies			
AAAS Science and Technology Policy Fellowships	Provides opportunities for scientists and engineers to learn firsthand about policymaking and implementation while contributing their knowledge and analytical skills in the federal policy realm.	Fellows have ranged in age from late 20s to early 70s and represent a spectrum of career stages, from recent PhD graduates to faculty on sabbatical to retired scientists and engineers	Fellowship
John A. Milner Fellowship Program	Offers postdoctoral fellows an opportunity to conduct research in the area of bioactive components in foods and dietary supplements and learn about the translation of nutrition science into policy through the support of the USDA Beltsville Human Nutrition Research Center and the NIH Office of Dietary Supplements.	Postdoctoral fellows	Fellowship
HRSA Maternal and Child Health Bureau			
Centers of Excellence in Maternal and Child Health in Education, Science and Practice	Trains the current and future workforce in applied research and state-of-the-art public health management, planning, and leadership principles to promote healthier children, families, and communities.	Training of graduate and post-graduate public health professionals in an interdisciplinary Maternal Child and Health setting	Grant

Leadership Education in Developmental Behavioral Pediatrics (DBP)	Provides training for the next generation of leaders in developmental behavioral pediatrics and provides practitioners, residents, and medical students with essential biopsychosocial knowledge and clinical expertise.	Supports fellows in developmental-behavioral pediatrics	Grant
Leadership Education in Neurodevelopmental and Related Disabilities (LEND)	Provides interdisciplinary training to enhance the clinical expertise, research, and leadership skills of professionals dedicated to caring for children with neurodevelopmental and other related disabilities and special health care needs.	Trains future leaders in a variety of disciplines	Grant
Maternal and Child Health Nutrition Training Program	Provides leadership education and training for graduate-level trainees and fellows and delivers continuing education for the Maternal and Child Health nutrition workforce.	Graduate training to nutritionists and registered dietitians	Grant
NIH			
NCI Cancer Prevention Fellowship Program	Provides postdoctoral training opportunity in the fields of cancer prevention and control including support to obtain an M.P.H. degree at an accredited university during the first year, followed by mentored research with investigators at the National Cancer Institute (NCI).	Postdoctoral fellows	Fellowship
NHLBI Programs to Increase Diversity Among Individuals Engaged in Health-Related Research (PRIDE)	Provides consecutive two-year summer institute research education experiences for junior faculty from under-represented backgrounds and aims to train about 20 to 30 scholars over the four-year course of the grant.	Primarily targets junior faculty with connections to Historically Black Colleges and Universities	Grant

NIDDK Short-term Research Experience for Underrepresented Persons (STEP-UP)	Offers hands-on summer research experience at institutions around the country for high school and undergraduate students.	Undergraduates	Summer Research Experience
NIDDK Diversity Summer Research Training Program (DSRTP) for Undergraduate Students	Offers students from backgrounds underrepresented in biomedical research including individuals from disadvantaged backgrounds and individuals from underrepresented racial and ethnic groups opportunities to train in basic and clinical laboratories and NIDDK branches.	Undergraduates	Summer Research Experience
NIH Established Investigator/Mentor	Provides funding for independent investigators who have an established track record of research and supports mentoring activities of mid-career patient-oriented investigators who are both nationally recognized experts in an NIH-relevant field and strong mentors. NIDDK compilation highlights both NIH wide and NIDDK specific funding mechanisms.	Independent investigators and mid-career patient-oriented investigators	Grant
NIH Newly Independent Investigator	Provides additional research funding for investigators who recently achieved independence by receiving their first R01. NIDDK compilation highlights both NIH wide and NIDDK specific funding mechanisms.	Investigators who recently achieved independence by receiving their first R01	Grant
NIDDK Junior Faculty/Transition	Supports junior faculty and investigators just beginning their research careers in NIDDK related mission areas, which includes nutritional sciences.	Junior faculty and investigators just beginning their careers	Grant

NIH Post-Graduate Funding Mechanisms	Supports postdoctoral fellows and physical scientists in research fellowship training in NIH related mission areas, which includes nutritional sciences. As one example, the NIDDK Institutional National Research Service Awards (NRSA) support postdoctoral fellows via slots on an Institutional Training Grant and/or through individual fellowships. NIDDK compilation highlights both NIH wide and NIDDK specific funding mechanisms.	Postdoctoral fellows and physical scientists in research fellowship training	Fellowship
NIH Funding Mechanisms for Graduate/Medical Students	Supports graduate/medical students conducting research in NIDDK related mission areas, which includes nutritional sciences. NIDDK compilation highlights both NIH wide and NIDDK specific funding mechanisms.	Graduate/medical students	Grant and Fellowship
NIH Office of Dietary Supplements Research Scholars Program	Provides a one-year competitive scholarship opportunity to study the role of dietary supplements in health promotion and disease prevention.	NIH intramural early career investigators	Scholarship
Medical Research Scholars Program	Offers a year-long research enrichment program designed to attract the most creative, research-oriented medical, dental and veterinary students to the NIH intramural campus.	Medical, dental, and veterinary students	Enrichment Program

NIH Common Fund's Metabolomics Program	Aims to increase national capacity in metabolomics by: supporting the development of next-generation technologies to enhance the sensitivity and speed with which specific elements of the cellular metabolome can be identified and quantified; providing training and mentoring opportunities; increasing the inventory of chemically identifiable metabolites through the synthesis and availability of high quality reference standards; and promoting data sharing and collaboration.	Various	Training and Mentoring Opportunities
NIH Office of Intramural Training and Education	Provides overview of the various training and internship programs the NIH offers across the student and professional development continuum including participation in the Pathways Program and NIH Summer Programs.	Various	Various
National Institute of Minority Health and Health Disparities Translational Health Disparities Course	Offers a two-week intensive course focusing on the principles and practice of health disparities research.	Faculty, students, and practitioners	Course
The John Milner Nutrition and Cancer Prevention Research Practicum	Offers a one-week educational opportunity focused on the role of diet and bioactive food components as modifiers of cancer incidence and tumor behavior.	Faculty, students, and practitioners	Practicum
The Mary Frances Picciano Dietary Supplement Research Practicum	Offers a four-day intensive educational opportunity focused on dietary supplements.	Faculty, students, and practitioners	Practicum

USDA			
Agricultural Research Service (ARS) Research Participation Program	Provides participants with opportunities to continue their education/training, enhance their professional development in specific areas, become familiar and assist with research areas of the ARS, and become interested in long-term research goals in areas related to the ARS mission.	Various	Research Experience
Agricultural Research Service (ARS) Postdoctoral Research Associate Program	Offers a unique opportunity for recent recipients of the doctoral degree to conduct critically needed basic research in association with some of the most prominent scientists in their field and also enables them to receive advanced and highly specialized training and experience that may not be available anywhere else.	Postdoctoral fellows	Fellowship
Internship Program	Provides paid and unpaid work experience to students who are in high school or pursuing an undergraduate or graduate degree in an accredited college or university.	High school, undergraduate, or graduate students	Internship
USDA 1890 National Scholars Program	Provides full tuition, employment, employee benefits, fees, books, and room and board each year for up to four years to 1890 Historically Black Land-Grant Universities to increase the number of minorities studying agriculture, food, natural resource sciences and the related disciplines.	Undergraduates	Scholarship for Service - graduates commit to at least one year of service to the USDA for each year of financial assistance provided

USDA Center for Nutrition Policy and Promotion National Volunteer Student Internship Program	Provides first-hand experience in one or more of the following areas: (1) development of nutrition policy and communication, (2) promotion of public health policy, (3) economics and food consumption, (4) nutrition research, (5) development of nutrition education materials and electronic tools, and (6) communications, customer marketing, and public affairs.	Undergraduate and graduate students enrolled in US colleges and universities	Internship
USDA National Institute of Food and Agriculture (NIFA) Agriculture and Food Research Initiative – Food, Agriculture, Natural Resources and Human Sciences Education and Literacy Initiative	Provides fellowships to students in agricultural sciences.	Undergraduate, pre-doctoral, and postdoctoral students	Fellowships
USDA National Institute of Food and Agriculture (NIFA) Higher Education Multicultural Scholars Program (MSP)	Provides funding through the Special Experiential Learning (SEL) opportunities to further the development of student scientific and professional competencies through programs that provide MSP Scholars with hands-on opportunities to solve complex problems including policy development and management, in the context of real-world situations.	Baccalaureate degrees within the food and agricultural sciences discipline or the Doctor of Veterinary Medicine (D.V.M.)	Competitive Scholarship Grant Program - awarded to eligible colleges and universities, not individual students

Acronyms

AAAS – American Association for the Advancement of Science
ACIP – Advisory Committee on Immunization Practices
ACS – American Community Survey
AIR-P – Autism Intervention Network on Physical Health
AND – Academy of Nutrition and Dietetics
ARS – USDA Agricultural Research Service
ATIP – Agricultural Technology Innovation Partnership Foundation
B-24/P – Dietary Guidance Project for Infants and Toddlers from Birth to 24 Months and Women Who Are Pregnant
BD2K – NIH Big Data to Knowledge initiative
BD-STEPS – Birth Defects Study to Evaluate Pregnancy Exposures
BGH – USAID Bureau of Global Health
BFS – USAID Bureau for Food Security
BMI – body mass index
BOND – Biomarkers of Nutrition for Development Program (NIH Collaborative)
BRAIN – Brain Research through Advancing Innovative Technologies
BRFSS – Behavioral Risk Factor Surveillance System
BRR – balanced-repeated replicate weights
CACFP – USDA Child and Adult Care Food Program
CDC – HHS Centers for Disease Control and Prevention
CDE – Common Data Elements
CLASS – Classification of Laws Associated with School Students
CMS – HHS Centers for Medicare and Medicaid Services
CNPP – USDA Center for Nutrition Policy and Promotion
CoIIN – Pediatric Nutrition and Obesity Collaborative Improvement and Innovation Network
Commerce – United States Department of Commerce
CORD – CDC Child Obesity Research Demonstration Project
CSB – corn-soy blend
DASH/DASH-Sodium – Dietary Approaches to Stop Hypertension (supported by NIH)
DBP – Leadership Education in Developmental Behavioral Pediatrics
DCHA – USAID Bureau for Democracy, Conflict and Humanitarian Assistance
DD – developmental disabilities
DGA – Dietary Guidelines for Americans
DGAC – Dietary Guidelines Advisory Committee
DNA – Deoxyribonucleic Acid
DoD – United States Department of Defense
DoI – United States Department of Interior
DREADDs – designer receptors exclusively activated by designer drugs
DRI – Dietary Reference Intake
DSID – Dietary Supplement Ingredient Database
DSLD – Dietary Supplement Label Database
ECE – Early Care and Education

ECLS-B – Early Childhood Longitudinal Study, Birth Cohort
ECLS-K – Early Childhood Longitudinal Study, Kindergarten Class of 1998–99
EHR – electronic health records
EIS – CDC Epidemic Intelligence Service
EPA – United States Environmental Protection Agency
ERS – USDA Economic Research Service
FAB – Food Attitudes and Behaviors Survey
FADS – Food Availability (Per Capita) Data System
FANTA – Food and Nutrition Technical Assistance
FDA – HHS Food and Drug Administration
FICRD – Food Intakes Converted to Retail Commodities Database
FINI – Food Insecurity Nutrition Incentive
FNCS – USDA Food, Nutrition, and Consumer Services
FNDDS – Food and Nutrient Database for Dietary Studies
FNS – USDA Food and Nutrition Service
FOP – front-of-package information
FoodAPS – USDA National Household Food Acquisition and Purchase Survey
FPED – Food Patterns Equivalents Database
FRSS – Fast Response Survey System
FTC – Federal Trade Commission
FWGoDS – Federal Working Group on Dietary Supplements
GAIN – Global Alliance for Improved Nutrition
GEI – Genes, Environment and Health Initiative (planned and led by NIH)
GIS – Geographical Information Systems
GSA – Government Services Administration
HBO – Home Box Office
HCES – Household Consumption and Expenditure Surveys
HEI – Healthy Eating Index
HHS – United States Department of Health and Human Services
HINTS – Health Information National Trends Survey
HIV/AIDS – Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome
HMO – health maintenance organization
HNRIM – HHS/NIH Human Nutrition Research Information Management
HPO – Human Performance Optimization
HRSA – HHS Health Resources and Services Administration
HSR&D – Health Services Research and Development
ICHNR – Interagency Committee on Human Nutrition Research
IFPRI – International Food Policy Research Institute
IFPS – Infant Feeding Practices Study
IOM – Institute of Medicine
ISS – International Space Station
JIFSAN – Joint Institute for Food Safety and Applied Nutrition
JSHNR – Joint Subcommittee on Human Nutrition Research
LNS – lipid-based nutrient supplements
LEND – Leadership Education in Neurodevelopmental and Related Disabilities
MAM – moderate acute malnutrition

MCH – maternal and child health
MCHB – HRSA Maternal and Child Health Bureau
MDRI – Military Dietary Reference Intakes
MEPS-HC – Medical Expenditure Panel Survey-Household Component
MHCoE – Mental Health Centers of Excellence
MIRECC – Mental Illness Research, Education, and Clinical Centers
mPINC – CDC Maternity Practices in Infant Nutrition and Care Survey
MRI – magnetic resonance imaging
MS – mass spectrometric
NAMCS – National Ambulatory Medical Care Survey
NASA – National Aeronautics and Space Administration
NASS/GES – National Automotive Sampling System General Estimates System
NBDPS – National Birth Defects Prevention Study
NBS – National Bureau of Standards (historical)
NCC – NIH Nutrition Coordinating Committee
NCCOR – National Collaborative on Childhood Obesity Research
NCDs – non-communicable diseases
NCES/CCD – National Center for Education Statistics Common Core of Data
NCHS – CDC National Center for Health Statistics
NCI – NIH National Cancer Institute
NEL – USDA Nutrition Evidence Library
NHAMCS – National Hospital Ambulatory Medical Care Survey
NHANES – National Health and Nutrition Examination Survey
NHDS – National Hospital Discharge Survey
NHIS – National Health Interview Survey
NHLBI – NIH National Heart, Lung, and Blood Institute
NIDDK – NIH National Institute of Diabetes and Digestive and Kidney Diseases
NIFA – USDA National Institute of Food and Agriculture
NIH – National Institutes of Health
NIS – National Immunization Survey
NIST – National Institute of Standards and Technology
NLM – NIH National Library of Medicine
NLSY79 – National Longitudinal Survey of Youth 1979
NLSY79ch – National Longitudinal Survey of Youth-Children and Young Adults
NLSY97 – National Longitudinal Survey of Youth 1997
NMR – Nuclear Magnetic Resonance
NNRR – National Nutrition Research Roadmap
NOAA – National Oceanic and Atmospheric Administration
NOPREN – Nutrition and Obesity Policy Research and Evaluation Network
NSAS – National Survey of Ambulatory Surgery
NSF – National Science Foundation
NSFG – National Survey of Family Growth
NSLP – USDA National School Lunch Program
NSRDEC – U.S. Army Natick Soldier Research, Development, and Engineering Center
NVSS – National Vital Statistics System
OASH – HHS Office of the Assistant Secretary for Health

ODP – NIH Office of Disease Prevention
ODPHP – HHS Office of Disease Prevention and Health Promotion
ODS – NIH Office of Dietary Supplements
OEF – Operation Enduring Freedom
OIF – Operation Iraqi Freedom
OPP – EPA Office of Pesticide Programs
OSEC – USDA Office of the Secretary
OSTP – The White House Office of Science and Technology Policy
PET – positron emission tomography
PREMIER – NIH-funded study testing whether counseling to make simultaneous lifestyle changes could prevent or control high blood pressure
PRISM – Prevention Impacts Simulation Model
PSS – Private School Universe Survey/Private School Survey Series
PTSD – post-traumatic stress disorder
QFAHPD – Quarterly Food-at-Home Price Database
QUERI – Quality Enhancement Research Initiative
REE – USDA Research, Education, and Economics
RNA – ribonucleic acid
RWJF – The Robert Wood Johnson Foundation
SAM – severe acute malnutrition
SBCC – social behavioral change communications
SBP – USDA School Breakfast Program
SC/SC+ – super cereal/super cereal +
SFSP – USDA Summer Food Service Program
SHPPS – School Health Policies and Practices Study
SMI – severe mental illness
SMITRECC – Severe Mental Illness Research, Education, and Clinical Centers
SNAP – USDA Supplemental Nutrition Assistance Program
SNAP-QC – Supplemental Nutrition Assistance Program Quality Control Data File
SNDA – USDA School Nutrition Dietary Assessment Study
SOTA – Soldier Outcome Trajectory Assessment Project of the U.S. Army Medical Command
SPRING – Strengthening Partnerships, Results, and Innovations in Nutrition Globally
SR-25 – National Nutrient Database for Standard Reference, Release 25
SRMs – Standard Reference Materials
STEM – science, technology, engineering, and math education
TBI – traumatic brain injury
UNC – University of North Carolina
UNICEF – United Nations International Children's Emergency Fund
USAID – United States Agency for International Development
USDA – United States Department of Agriculture
USPSTF – United States Preventive Services Task Force
VA – United States Department of Veterans Affairs
VDSP – NIH Vitamin D Standardization Program (ODS)
VHA – Veterans Health Administration
VISN – Veterans Integrated Service Network

WASH – water, sanitation, and hygiene
WHO – World Health Organization
WIC – USDA Special Supplemental Nutrition Program for Women, Infants, and Children
WOTN – The Weight of the Nation
WWEIA – What We Eat in America
YRBSS – Youth Risk Behavior Surveillance System

References

1. Ross CA, Caballero B, Cousins RJ, Tucker K, Ziegler MD. *Modern Nutrition in Health and Disease*, 11th ed. Baltimore, MD: Lippincott Williams & Wilkins; 2014.

2. Ohlhorst S, Russell R, Bier D, et al. Nutrition research to affect food and a healthy life span. *J Nutr.* 2013;143(8):1349-1354.

3. United States Census Bureau. International Programs. http://www.census.gov/population/international/. Accessed December 4, 2014.

4. Committee on Military Nutrition Research, Institute of Medicine. *Military Strategies for Sustainment of Nutrition and Immune Function in the Field*. Washington, DC: The National Academies Press; 1999.

5. Cawley J, Rizzo J, Haas K. Occupation-specific absenteeism costs associated with obesity and morbid obesity. *J Occup Environ Med.* 2007;49(12):1317-1324.

6. Finkelstein E, Trogdon J, Cohen J, Dietz W. Annual medical spending attributable to obesity: payer- and service-specific estimates. *Health Aff (Millwood).* 2009;28(5):w822-w831.

7. Trogdon J, Finkelstein E, Hylands T, Dellea P, Kamel-Bahl S. Indirect costs of obesity: a review of the current literature. *Obes Rev.* 2008;9(5):489-500.

8. Dwyer J, Wiemer K, Dary O, et al. Fortification and health: challenges and opportunities. *Adv Nutr.* 2015;6(1):124-131.

9. United States Department of Health and Human Services Centers for Disease Control and Prevention, Division of Laboratory Sciences, National Center for Environmental Health. *Second National Report on Biochemical Indicators of Diet and Nutrition in the U.S. Population*. Atlanta, GA: Centers for Disease Control and Prevention; 2012. http://www.cdc.gov/nutritionreport/. Accessed December 11, 2014.

10. Otten JJ, Hellwig JP, Meyers LD, eds. *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements*. Washington, DC: The National Academies Press; 2006. http://www.nal.usda.gov/fnic/DRI/Essential_Guide/DRIEssentialGuideNutReq.pdf . Accessed December 11, 2014.

11. United States Department of Agriculture and United States Department of Health and Human Services. *Dietary Guidelines for Americans, 2010*. 7th ed. Washington, DC: US Government Printing Office; 2010. http://health.gov/dietaryguidelines/dga2010/DietaryGuidelines2010.pdf. Accessed December 9, 2014.

12. Executive Office of the President, Office of Science and Technology Policy. *Meeting the Challenge: A Research Agenda for America's Health, Safety, and Food*. Washington, DC: US Government Printing Office; 1996.

13. United States Department of Health and Human Services Centers for Disease Control and Prevention. CDC Health Disparities and Inequalities Report – United States, 2013. *Mort Mortal Wkly Rep*. 2013;62(Suppl 3).

14. The United Nations International Children's Emergency Fund (UNICEF), the World Health Organization (WHO), and the World Bank. *Levels and Trends in Child Nutrition: Overview UNICEF-WHO-The World Bank Joint Child Malnutrition Estimates 2014*. http://www.who.int/nutgrowthdb/jme_unicef_who_wb.pdf. Accessed July 1, 2015.

15. Flour Fortification Initiative, Global Alliance for Improved Nutrition (GAIN), Micronutrient Intitiative, the United States Agency for International Development, the World Bank, and the United Nations International Children's Emergency Fund (UNICEF). *Investing in the Future: A United Call to Action on Vitamin and Mineral Deficiencies*. http://www.unitedcalltoaction.org/documents/Investing_in_the_future.pdf. Accessed July 1, 2015.

16. General Accounting Office. *Report by the Comptroller General of the United States. Progress Made in Federal Human Nutrition Research Planning and Coordination; Some Improvements Needed*. Washington, DC: US General Accounting Office; 1982.

17. Wonoputri N, Djais J, Rosalina I. Validity of nutritional screening tools for hospitalized children. *J Nutr Metab*. 2014;2014:143649.

18. Midttun O, Townsend M, Nygard O, et al. Most blood biomarkers related to vitamin status, one-carbon metabolism, and the kynurenine pathway show adequate preanalytical stability and within-person reproducibility to allow assessment of exposure or nutritional status in healthy women and cardiovascular patients. *J Nutr.* 2014;144(5):784-790.

19. Jimenez-Redondo S, Beltran De Miguel B, Gavidia Banegas J, Guzman Mercedes L, Gomez-Pavon J, Cuadrado Vives C. Influence of nutritional status on health-related quality of life of non-institutionalized older people. *J Nutr Health Aging.* 2014;18(4):359-364.

20. Surwillo A, Wawrzyniak A. Nutritional assessment of selected patients with cancer. *Rocz Panstw Zakl Hig.* 2013;64(3):225-233.

21. Jimenez-Redondo S, Beltran De Miguel B, Gomez-Pavon J, Cuadrado Vives C. Non-institutionalized nonagenarians health-related quality of life and nutritional status: is there a link between them? *Nutr Hosp.* 2014;30(3):602-608.

22. Cho I, Yamanishi S, Cox L, et al. Antibiotics in early life alter the murine colonic microbiome and adiposity. *Nature.* 2012;488(7413):621-626.

23. Sacks F, Svetkey L, Volmer W, et al.; DASH-Sodium Collaborative Research Group. Effects on blood pressure of reduced dietary sodium and the Dietary Approaches to Stop Hypertension (DASH) diet. *N Engl J Med*. 2001;344(1):3-10.

24. Diabetes Prevention Program Research Group. Reduction in the incidence of type 2 diabetes with lifestyle intervention or Metformin. *N Engl J Med*. 2002;346:393-403.

25. Appel LJ, Champagne CM, Harsha DW, et al.; Writing Group of the PREMIER Collaborative Research Group. Effects of comprehensive lifestyle modification on blood pressure control: main results of the PREMIER clinical trial. *JAMA*. 2003;289(16):2083-2093.

26. Struijk E, Beulens J, May A, et al. Dietary patterns in relation to disease burden expressed in Disability-Adjusted Life Years. *Am J Clin Nutr.* 2014;100:1158-1165.

27. Shariat Moharari R, Motalebi M, Najafi A, et al. Magnesium can decrease postoperative physicological ileus and postoperative pain in major non laparoscopic gastrointestinal surgeries: a randomized controlled trial. *Anesth Pain Med.* 2013;4(1):e12750.

28. Painter R, de Rooij S, Bossuyt P, et al. Early onset of coronary artery disease after prenatal exposure to Dutch famine. *Am J Clin Nutr.* 2006;84(2):322-327.

29. Russell W, Gratz S, Duncan S, et al. High-protein, reduced carbohydrate weight-loss diets promote metabolite profiles likely to be detrimental to colonic health. *Am J Clin Nutr.* 2011;93:1062-1072.

30. Ross L, Wilson M, Banks M, Rezannah F, Daglish M. Prevalence of malnutrition and nutritional risk factors in patients undergoing alcohol and drug treatment. *Nutrition.* 2012;28(7-8):738-743.

31. Hatcher A. Weight matters during recover: unhealthy eating behaviors can impede client progress. *Addiction Professional* 2004;2:23-24.

32. Cowan J, Devine C. Food, eating, and weight concerns of men in recovery from substance addiction *Appetite.* 2008;50:33-42.

33. Mohs M, Watson R, Leonard-Green T. Nutritional effects of marijuana, heroin, cocaine, and nicotine. *J Am Diet Assoc.* 1990;90(9):1261-1267.

34. Korpela K, Flint H, Johnstone A, et al. Gut microbiota signatures predict host and microbiota responses to dietary interventions in obese individuals. *PLoS One.* 2014;9(3):e90702.

35. Gibney M, Walsh M, Brennan L, Roche H, German B, van Ommen B. Metabolomics in human nutrition: opportunities and challenges. *Am J Clin Nutr.* 2005;82:497-503.

36. Kussmann M, Panchaud A, Affolter M. Proteomics in nutrition: status quo and outlook for biomarkers and bioactives. *J Protome Res.*9:4876-4887.

37. Claus S, Swann J. Nutrimetabolomics: applications for nutritional sciences, with specific reference to gut microbial interactions. *Annu Rev Food Sci Technol.* 2013;4:381-399.

38. Albennerg L, Wu G. Diet and the intestinal microbome: associations, functions and implications for health and disease. *Gastroenterology.* 2014;146:1564-1572.

39. Lederberg J, McCray A. 'Ome sweet' omics—a genealogical treasury of words. *Scientist.* 2001;15:8.

40. McLean J. Advancements toward a system level understanding of the human oral microbiome. *Front Cell Infect Microbiol.* 2014;4:98.

41. Hajishengallis G, Lamont R. Beyond the red complex and into more complexity: the polymicrobial synergy and dysbiosis (PSD) model of periodontal disease etiology. *Mol Oral Microbiol.* 2012;27(6):409-419.

42. Claus S. Development of personalized functional foods needs metabolic profiling. *Curr Opin Clin Nutr Metab Care.* 2014;17:567-573.

43. Interagency Board for Nutrition Monitoring and Related Research. Bialostoksy K, ed. *Nutrition Monitoring in the United States: The Directory of Federal and State Nutrition Monitoring and Related Research Activities*. Hyattsville, MD: National Center for Health Statistics; 2000. http://www.cdc.gov/nchs/data/misc/direc-99.pdf. Accessed December 9, 2014.

44. Larson N, Story M. A review of environmental influences on food choices. *Annu Behav Med.* 2009;38:S56-S73.

45. Sobel J, Kettel Khan L, Bisogni. A conceptual model of the food and nutrition system. *Soc Sci Med* 1998;7:853-863.

46. Briefel RR. Nutrition monitoring in the United States. In: Bowman BA, Russell RM, eds. *Present Knowledge Nutrition*, 8th ed. Washington, DC: ILSI Press; 2001:617-635.

47. Gibson, RS. Food composition of individuals. In: Gibson, RS, ed. *Principles of Nutritional Assessment*. New York, NY: Oxford University Press; 1990:37-54.

48. Mclean R. Measuring population sodium intake: a review of methods. *Nutrients.* 2014;6:4654-4662.

49. Thompson F, Dixit-Joshi S, Potischman N, et al. Comparsion of interviewer-administered and automated self-administered 24-hour dietary recalls in 3 diverse integrated health systems. *Am J Epidemiol.* 2015;181(12):970-978.

50. United States Department of Agriculture Economic Research Service. New Products. http://www.ers.usda.gov/topics/food-markets-prices/processing-marketing/new-products.aspx#.VEVXBmeM2ad. Accessed October 20, 2014.

51. Behary P, Miras A. Brain responses to food and weight loss. *Exp Physiol.* 2014;99(9):1121-1127.

52. Levy D, Riis J, Sonnenberg L, Barraclough S, Thorndike A. Food choices of minority and low-income employees: a cafeteria intervention. *Am J Prev Med.* 2012;43(3):240-248.

53. Mennella J. Ontogeny of taste preferences: basic biology and implications for health. *Am J Clin Nutr.* 2014;99(3):S704-S711.

54. Mennella J, Ventura A. Early feeding: setting the stage for healthy eating habits. *Nestle Nutr Workshop Ser Pediatr Program.* 2011;68:153-163.

55. Tornwall O, Silventoinen K, Hiekkalinna T, Perola M, Tuorila H, Kaprio J. Identifying flavor preference subgroups. Genetic basis and related eating behavior traits. *Appetite.* 2014;75:1-10.

56. Vereijken C, Weenen H, Hetherington M. Feeding infants and young children. From guidelines to practice-conclusions and future directions. *Appetite.* 2011;57(3):839-843.

57. Basch C, Ethan D, Rajan S. Price, promotion and availability of nutrition information: a descriptive study of a popular fast food chain in New York City. *Glob J Health Sci.* 2013;5(6):73-80.

58. Pridgeon A, Whitehead K. A qualitative study to investigate the drivers and barriers to healthy eating in two public sector workplaces. *J Hum Nutr Diet.* 2013;26(1):85-95.

59. Cruwys T, Bevelander K, Hermans R. Social modeling of eating: a review of when and why social influence affects food intake and choice. *Appetite.* 2015;86:3-18.

60. Bellisle F. Food choice, appetite and physical activity. *Public Health Nutr.* 1999;2(3a):357-361.

61. Kruger A, Reither E, Peppard P, Krueger P, Hale L. Do sleep-deprived adolescents make less-healthy food choices? *Br J Nutr.* 2014;111(10):1898-1904.

62. Capers P, Fobian A, Kaiser K, Borah R, Allison D. A systematic review and meta-analysis of randomized controlled trials of the impact of sleep duration on adiposity and components of energy balance. *Obes Rev.* 2015;16(9):771-782.

63. Hogenkamp P, Nisson E, Nisson V, et al. Acute sleep deprivation increases portion size and affects food choice in young men. *Psychoneuroendrinology.* 2013;38(9):1668-1674.

64. Wen X, Kong K, Eiden R, Sharma N, Xie C. Sociodemographic differences and infant dietary patterns. *Pediatrics.* 2014;134(5):e1387-e1398.

65. Mancino L, Guthrie J. SNAP households must balance multiple priorities to acheive a healthful diet. *Amber Waves.* Posted November 3, 2014. http://www.ers.usda.gov/amber-waves/2014-november/snap-households-must-balance-multiple-priorities-to-achieve-a-healthful-diet.aspx. Accessed January 14, 2015.

66. Baker E, Schootman M, Barnidge E, Kelly C. The role of race and poverty in access to foods that enable individuals to adhere to Dietary Guidelines. *Prev Chron Dis.* 2006;3(3):A76.

67. Golan E, Stewart H, Kuchler F, Dong D. Can low-income Americans afford a healthy diet? *Amber Waves*. Posted November 1, 2008. http://www.ers.usda.gov/amber-waves/2008-november/can-low-income-americans-afford-a-healthy-diet.aspx#.VPnEd3zF-So. Accessed March 6, 2015.

68. Stewart H, Hyman J, Frazao E, Buzby J, Carlson A. Can low-income Americans afford to satisfy MyPyramid fruit and vegetable guidelines? *J Nutr Educ Behav.* 2011;43(3):173-179.

69. Schulte P, Pandalai S, Wulsin V, Chun H. Interaction of occupational and personal risk factors in workforce health and safety. *Am J Public Health.* 2012;102(3):434-448.

70. Luckhaupt S, Cohen M, Li J, Calvert G. Prevalence of obesity among U.S. workers and associations with occupational factors. *Am J Prev Med.* 2014;46(3):237-248.

71. Luckhaupt, SE, Calvert, GM, Centers for Disease Control and Prevention. Prevalence of coronary heart disease or stroke among workers aged <55 years--United States, 2008-2012. *Mort Mortal Wkly Rep*. 2014;63(30):645-649.

72. Baron S, Beard S, Davis L, et al. Promoting integrated approaches to reducing health inequites among low-income workers: applying a social ecological framework. *Am J Ind Med.* 2014;57:539-556.

73. Lowden A, Moreno C, Holmback U, Lennernas M, Tucker P. Eating and shift work—effects on habits, metabolism, and performance. *Scand J Work Environ Health.* 2010;36(2):150-162.

74. Ni Mhurchu C, Vandevijvere S, Waterlander W, et al. Monitoring the availability of healthy and unhealthy foods and non-alcoholic beverages in community and consumer retail food environments globally. *Obes Rev.* 2013;14(1):108-119.

75. Williams L, Abbott G, Thornton L, Worsley A, Ball K, Crawford D. Improving perceptions of healthy food affordability: results from a pilot intervention. *Int J Behav Nutr Phys Act.* 2014;11(1):33.

76. United States Department of Agriculture Economic Research Service. *Access to Affordable and Nutritious Food: Measuring and Understanding Food Deserts and Their Consequences. A Report to Congress*. Washington, DC: US Department of Agriculture; 2009.

77. Wilde P, Llobrera J, Ver Ploeg M. Population density, poverty and food retail access in the United States: an empirical approach. *International Food and Agribusiness Management Review.* 2014;17(A).

78. Murphy SP, Yaktine AL, Suitor CW, Moasts S, eds; Institute of Medicine, Committee to Review Child and Adult Care Food Program Meal Requirements. *Child and Adult Care Food Program: Aligning Dietary Guidance for All*. Washington, DC: The National Academies Press; 2011.

79. Schirm A, Kirkendall N, eds; National Research Council Panel on Estimating Children Eligible for School Nutrition Programs Using the American Community Survey. *Developing and Evaluating Methods for Using American Community Survey Data to Support the School Meals Programs: Interim Report*. Washington, DC: The National Academies Press; 2010.

80. Caswell JA, Yaktine AL, eds; Committee on Examination of the Adequacy of Food Resources and SNAP Allotments; Food and Nutrition Boards; Committee on National Statistics; Institute of Medicine; National Research Council. *Supplemental Nutrition Assistance Program: Examining the Evidence to Define Benefit Adequacy*. Washington, DC: The National Academies Press; 2013.

81. Mabli J, Worthington J. Supplemental Nutrition Assistance Program participation and child food security. *Pediatrics.* 2014;133(4):610-619.

82. Sharkey J, Dean W, Nalty C. Child hunger and the protective effects of Supplemental Nutrition Assistance Program (SNAP) and alternative food sources among Mexican-origin families in Texas border colonias. *BMC Pediatr.* 2013;13:143.

83. Cumming P, Welch S, Mason M, Burbage L, Kwon S, Kuo T. Nutrient content of school meals before and after implementation of nutrition recommendations in five school districts across two U.S. counties. *Prev Med.* 2014;67(1):S21-S27.

84. Kong A, Odoms-Young A, Schiffer L, et al. The 18-month impact of special supplemental nutrition program for women, infants and children food package revisions on diets of recipient families. *Am J Prev Med.* 2014;46(6):543-551.

85. Blumenthal S, Hoffnagle E, Leugn C, Lofink H, Jensen H, Forerster S. Strategies to improve the dietary quality of Supplemental Nutrition Assistance Program (SNAP) beneficiaries: an assessment of stakeholder opinions. *Public Health Nutr.* 2014;17(12):2824-2833.

86. Mayer V, Hillier A, Bachhuber M, Long J. Food insecurity, neighborhood food access and food assistance in Philadelphia. *J Urban Health.* 2014;91(6):1087-1097.

87. Lee P, Lusk K, Mirosa M, Oey I. The role of personal values in Chinese consumers food consumption decisions. A case study of healthy drinks. *Appetite.* 2014;73:95-104.

88. Delaney M, McCarthy M. Saints, sinners and non-believers: the moral space of food. A qualitative exploration of beliefs and perspectives on healthy eating of Irish adults aged 50-70. *Appetite.* 2014;73:105-113.

89. Gerchow L, Tagliaferro B, Squires A, Nicholson J, Savarimuthu S, Gutnick D. Latina food patterns in the United States: a qualitative metasynthesis. *Nurs Res.* 2014;63(3):182-193.

90. Tiedje K, Wieland M, Meiers S, Mohamed A, Formea C, Ridgeway J. A focus group study of healthy eating knowledge, practices and barriers among adult and adolescent immigrants and refugees in the United States. *Int J Behav Nutr Phys Act.* 2014;11:63.

91. Smith G. The direct and indirect controls of meal size. *Neurosci Biobehav Rev.* 1996;20(1):41-46.

92. Smith G. The controls of eating: a shift from nutritional homeostatis to behavioral neuroscience. *Nutrition.* 2000;16(10):814-820.

93. Fleischhacker S, Flournoy R, Moore L. Meaningful, measurable, and manageable approaches to evaluating healthy food financing initiatives: an overview of resources and approaches. *J Public Health Manag Pract.* 2013;19(6):541-549.

94. Thaler RH, Sunstein CR. *Nudge: Improving Decisions about Health, Wealth, and Happiness*. New Haven, CT: Yale University Press; 2008.

95. Sunstein C. Nudges.gov: behavioral economics and regulation. In: Zamier E, Teichman, D, eds. *Oxford Handbook of Behavioral Economics and the Law*. Oxford: Oxford University Press; 2014.

96. Thorndike A, Riis J, Sonnenberg L, Levy D. Traffic-light labels and choice architecture: promoting healthy food choices. *Am J Prev Med.* 2014;46(2):143-149.

97. Story M, Kaphingst K, Robinson-O'Brien R, Glanz K. Creating healthy food and eating environments: policy and environmental approaches. *Annu Rev Public Health.* 2008;29:253-272.

98. Medical Research Council Vitamin Study Research Group. Prevention of neural tube defects: results of the Medical Research Council Vitamin Study. *Lancet*. 1991;338(8760):131–137.

99. Czeizel A, Dudas I. Prevention of the first occurrence of neural-tube defects by periconceptional vitamin supplementation. *N Engl J Med.* 1992;327(26):1832-1835.

100. United States Department of Health and Human Services Centers for Disease Control and Prevention (CDC). CDC Grand Rounds: additional opportunities to prevent neural tube defects with folic acid fortification. *Morb Mortal Wkly Rep*. 2010;59:980–984.

101. Buzby JC, Wells HF, Vocke G. *Possible Implications for US Agriculture From Adoption of Select Dietary Guidelines*. Economic Research Report No. 31. Washington, DC: US Department of Agriculture, Economic Research Service; 2006.

102. Putnam JJ and Allshouse JE. *Food Consumption, Prices, and Expenditures, 1970-1997*. Statistical Bulletin No. (SB-965). Washington, DC: US Department of Agriculture, Economics Research Service; 1999.

103. Levings J, Cogswell M, Peralez Gunn J. Are reductions in population sodium intake achievable? *Nutrients.* 2014;6(10):4354-4361.

104. McKinnon R, Orleans C, Kumanyika S, et al. Considerations for an obesity policy research agenda. *Am J Prev Med.* 2009;36(4):351-357.

105. Blanck H, Kim S. Creating supportive nutrition environments for population health impact and health equity: an overview of the Nutrition and Obesity Policy Research and Evaluation Network's efforts. *Am J Prev Med.* 2012;43(3 Suppl 2):S85-S90.

106. United States Department of Health and Human Services National Institutes of Health. *Strategic Plan for NIH Obesity Research: A Report of the NIH Obesity Research Task Force*. NIH Publication No. 11-5493. March 2011. http://www.obesityresearch.nih.gov/about/strategic-plan.aspx. Accessed December 9, 2014.

107. Ludwig J, Sanbonmatsu L, Gennetian L, et al. Neighorhoods, obesity, and diabetes—a randomized social experiment. *N Engl J Med.* 2011;365(16):1509-1519.

108. Brannon P, Taylor C, Coates P. Use and applications of systematic reviews in public health nutrition. *Annu Rev Nutr.* 2014;34:401-419.

109. Midgeley G. *Systems Thinking.* Thousand Oaks, CA: Sage Publications; 2003.

110. Gallagher R, Appenzeller T. Beyond reductionism. *Science.* 1999;284(5411):79.

111. Hassmiller Lich K, Ginexi E, Osgood N, Mabry P. A call to address complexity in prevention science research. *Prev Sci*. 2012. doi:10.1007/s11121-012-0285-2.

112. Levy D, Mabry P, Graham A, Orleans T, Abrams D. Exploring scenarios to dramatically reduce smoking prevalence: a simulation model of the three-part cessation process. *Am J Public Health.* 2010;100:1253-1259.

113. Levy D, Graham A, Mabry P, Abrams D, Orleans T. Modeling the impact of smoking-cessation treatment policies on quit rates. *Am J Prev Med.* 2010;38(3):S364-S372.

114. Levy D, Mabry P, Graham A, Orleans T, Abrams D. Reaching Healthy People 2010 by 2013: a SimSmoke simulation. *Am J Prev Med.* 2010;38(3):S373-S381.

115. Abrams D, Graham A, Levy D, Mabry P, Orleans T. Boosting population quits through evidence-based cessation treatment and policy. *Am J Prev Med.* 2010;38(3):S351-S363.

116. Homer J, Milstein B, Wile K, Pratibhu P, Farris R, Orenstein D. Modeling the local dynamics of cardiovascular health: risk factors, context, and capacity. *Prev Chronic Dis.* 2008;5(A63).

117. Homer J, Milstein B, Wile K, et al. Simulating and evaluating local interventions to improve cardiovascular health. *Prev Chronic Dis.* 2010;7(1):A18.

118. Loyo H, Batcher C, Wile K, Huang P, Orenstein D, Milstein B. From model to action: using a system dynamics model of chronic disease risks to align community action. *Health Promot Pract.* 2013;14(1):53-61.

119. Hirsch G, Homer J, Trogdon J, Wile K, Orenstein D. Using simulation to compare 4 categories of intervention for reducing cardiovascular disease risks: results for the United States and a less-advantaged county. *Am J Public Health.* 2014;104(7):1189-1195.

120. Honeycutt A, Wile K, Dove C, Hawkins J, Orenstein D. Strategic planning for chronic disease prevention in rural America: looking through a PRISM lens. *J Public Health Manag Pract.* 2015;21(4):392-399.

121. Homer J, Wile K, Yarnoff B, et al. Using simulation to compare established and emerging interventions to reduce cardiovascular disease risks in the United States. *Prev Chronic Dis.* 2014;11:E195.

122. Levy D, Mabry P, Wang C, et al. Simulation models of obesity: a review of the literature and implications for research and policy. *Obes Rev.* 2011;12:378-394.

123. Maglio P, Sepulveda M, Mabry P. Mainstreaming modeling and simulation to accelerate public health innovation. *Am J Public Health.* 2014;104(7):1181-1186.

124. Gortmaker S, Swinburn B, Levy D, et al. Changing the future of obesity: science, policy, and action. *Lancet.* 2011;378(9793):838-847.

125. Hammond R, Ornstein J, Fellows L, Dube L, Levitan R, Dagher A. A model of food reward learning with dynamic reward exposure. *Front Comput Neurosci.* 2012;11(6):82.

126. Hammond R, Ornstein J. A model of social influence on body mass index. *Ann N Y Acad Sci.* 2014;1331:34-42.

127. Struben J, Chan D, Dube L. Policy insights from the nutritional food market transformation model: the case of obesity prevention. *Ann N Y Acad Sci.* 2014;1331:57-75.

128. Epstein J. Why model? *J Artif Soc S (JASSS).* 2008;11(4):12.

129. Sterman J. Learning from evidence in a complex world. *Am J Public Health.* 2006;96:505-514.

130. 2015 Dietary Guidelines Advisory Committee. *Scientific Report of the 2015 Dietary Guidelines Advisory Committee, Advisory Report to the Secretary of Health and Human Services and the Secretary of Agriculture*. http://www.health.gov/dietaryguidelines/2015-scientific-report/. Accessed March 5, 2015.

131. European Commission, Joint Research Centre. *Tomorrow's Healthy Society: Research Priorities for Foods and Diets, Final Report*. Luxembourg: Luxumbourg Publication Office of the European Union; 2014. https://ec.europa.eu/jrc/sites/default/files/jrc-study-tomorrow-healthly-society.pdf. Accessed January 28, 2015.

132. United States Department of Agriculture. Sustainable Agriculture: Defintitions and Terms. http://www.nal.usda.gov/afsic/pubs/terms/srb9902.shtml. Accessed October 23, 2014.

133. Buzby J, Wells H, Bentley J. ERS's food loss data help inform the food waste discussion. *Amber Waves*. Posted June 3, 2013. http://www.ers.usda.gov/amber-waves/2013-june/ers-food-loss-data-help-inform-the-food-waste-discussion.aspx#.VElF3GfYuad. Accessed October 23, 2014.

134. United States Environmental Protection Agency. Food Recovery Challenge. http://www.epa.gov/foodrecoverychallenge/. Accessed December 10, 2014.

135. The National Resources Defense Council Report. *The Dating Game: How Confusing Food Date Labels Lead to Food Waste in America*. September 2013. R:13-09-A. http://www.nrdc.org/food/files/dating-game-report.pdf. Accessed January 29, 2015.

136. Canning P, Charles A, Huang S, Polenske K, Waters A. *Energy Use in the U.S. Food System*. Economic Research Rep. No. 94. Washington, DC: US Department of Agriculture, Economic Research Service; March 2010.

137. Pray, L, Rapporteur; Food Forum; Food and Nutrition Board; Roundtable on Environmental Health Science, Research, and Medicine; Board on Population Health and Public Health Practice; Institue of Medicine. *Sustainable Diets: Food for Healthy People and a Healthy Planet: Workshop Summary*. Washington, DC: The National Academics Press; 2014.

138. Muller M, Tagtow A, Roberts S, MacDougall E. Aligning food systems policies to advance public health. *J Hunger Environ Nutr.* 2009;4(3-4):225-240.

139. Martinez S, Hand M, Da Pra M, et al. *Local Food Systems: Concepts, Impacts, and Issues*. Economic Research Report No. 97. Washington, DC: US Department of Agriculture, Economic Research Service; May 2010.

140. United States Department of Health and Human Services National Institutes of Health National Cancer Institute Division of Cancer Control and Population Sciences Epidemiology and Genomics Research Program. Measurement Error Webinar Series. http://appliedresearch.cancer.gov/measurementerror/. Accessed January 29, 2015.

141. United States Department of Health and Human Services National Institutes of Health National Institute on Alcohol Abuse and Alcoholism. Recommended Alcohol Questions. http://www.niaaa.nih.gov/research/guidelines-and-resources/recommended-alcohol-questions. Accessed January 29, 2015.

142. Vasan RS. Biomarkers of cardiovascular disease: Molecular basis and practical considerations. *Circulation.* 2006;113:2335-2362.

143. Jones D, Park Y, Ziegler T. Nutritional metabolomics: progress in addressing complexity in diet and health. *Annu Rev Nutr.* 2012;32:183-202.

144. Wishart D, Knox C, Guo A, et al. HMDB: a knowledgebase for the human metabolome. *Nucleic Acids Res.* 2009;37:D603-D610.

145. Hall K, Hammond R, Rahamandad H. Dynamic interplay among homeostatic, hedonic and cognitive feedback circuits regulating body weight. *Am J Public Health.* 2014;104(7):1169-1175.

146. Stroebe W, Papies E, Aarts H. From homeostatic to hedonic theories of eating: self-regulatory failure in food-rich environments. *Appl Psychol.* 2008;57:172-193.

147. Farooqi I, Keogh J, Yeo G, Lank E, Cheetham T, O'Rahilly S. Clinical spectrum of obesity and mutations in the melanocortin 4 receptor gene. *N Engl J Med.* 2003;348(12):1085-1095.

148. Hall P, Fong G. Temporal self-regulation theory: a model for individual health behavior. *Health Psychol Rev.* 2007;1(1):6-52.

149. Dham S, Banerji M. The brain-gut axis in regulation of appetite and obesity. *Pediatr Endocrinol Rev.* 2006;3(Suppl 4):544-554.

150. Mann T, de Ritter D, Fujita K. Self-regulation of health behavior: social psychological approaches to goal setting and goal striving. *Health Psychol.* 2013;32(5):487-498.

151. Thaler R, Sunstein C, Balz J. Choice architecture. *Social Service Research Network*. April 2, 2010. http://dx.doi.org/10.2139/ssrn.1583509. Accessed September 28, 2014.

152. Mattes R. Appetite: measurement and manipulation misgivings. *J Am Diet Assoc.* 2005;105(5 Suppl 1):S87-S97.

153. Anderson E, Winett R, Wojcik J. Self-regulation, self-efficacy, outcomes expectations, and social support: social cognitive theory and nutrition behavior. *Ann Behav Med.* 2007;34(3):304-312.

154. de Lartigue G. Putative roles of neuropeptides in vagal afferent signaling. *Physiol Behav*. 2014;136:155-169.

155. Cornier M, Salzberg A, Endly D, Bessesen D, Rojas D, Tregellas J. The effects of overfeeding on the neuronal response to visual food cues in thin and reduced-obese individuals. *PLoS ONE.* 2009;4(7):e6310.

156. Chaput J, Tremblay A. The glucostatic theory of appetite control and the risk of obesity and diabetes. *Int J Obesity.* 2009;33:46-53.

157. Corniera M. The effects of energy balance, obesity-proneness and sex on the neuronal response to sweet taste. *Behav Brain Res.* 2014;278(1):446-452.

158. Low Y, Lacy K, Keast R. The role of sweet taste in satiation and satiety. *Nutrients.* 2014;6(9):3431-3450.

159. Drewnowski A. Human perceptions and preferences for fat-rich foods. In Montmayeur J-P, Le Coutre J, eds. *Fat Detection: Taste, Texture, and Post Ingestive Effects*. Boca Raton, FL: CRC Press; 2010.

160. Venditti E, Kramer M. Necessary components of lifestyle modification interventions to reduce diabetes risk. *Curr Diab Rep.* 2012;12(2):138-146.

161. Stoeckel L, Garrison K, Ghosh S, et al. Optimizing real time fMRI neurofeedback for therapeutic discovery and development. *Neuroimaging Clin.* 2014;5:245-255.

162. Val-Laillet D, Aarts E, Weber B, et al. Neuroimaging and neuromodulation approaches to study eating behavior and prevent and treat eating disorders and obesity. *Neuroimage: Clinical.* 2015;8:1-31.

163. Kahneman D. *Thinking Fast and Slow.* New York, NY: Farrar, Strauss, Giroux; 2011.

164. Just D, Mancino L, Wansink B. *Could Behavioral Economics Help Improve Diet Quality for Nutrition Assistance Program Participants?* Economic Research Report No. 43. Washington, DC: US Department of Agriculture, Economic Research Service; 2007.

165. Wansink B. *Mindless Eating: Why We Eat More Than We Think.* New York, NY: Bantam-Dell; 2006.

166. Labiner-Wolfe J, Jordan Lin C, Verrill L. Effect of low-carbohydrate claims on consumer perceptions about food products' healthfulness and helpfulness for weight management. *J Nutr Educ Behav.* 2010;42(5):315-320.

167. Hanks A, Just D, Wansink B. Smarter lunchrooms can address new school lunchroom guidelines and childhood obesity. *J Pediatr.* 2013;162(4):867-869.

168. United States Department of Agriculture Food and Nutrition Service. HealthierUS School Challenge: Smarter Lunchrooms. http://www.fns.usda.gov/hussc/healthierus-school-challenge-smarter-lunchrooms. Accessed October 22, 2014.

169. Krumholz H. Big data and new knowledge in medicine: The thinking, training, and tools needed for learning a health system. *Health Aff (Millwood).* 2014;33(7):1163-1170.

170. Dube L, Labban A, Moubarac J, Heslop G, Ma Y, Paquet C. A nutrition/health mindset on commerical Big Data and drivers of food demand in modern and traditional systems. *Ann N Y Acad Sci.* 2014;1331:278-295.

171. American Association for the Advancement of Science in conjunction with the Federal Bureau of Investigations and the United Nations Interregional Crime and Justice Research Institute. *National and Transnational Security Implications of Big Data in the Life Sciences: A Joint AAAS-FBI-UNICRI Project*. Washington, DC: American Association for the Advancement of Science; 2014. http://www.aaas.org/sites/default/files/AAAS-FBI-UNICRI_Big_Data_Report_111014.pdf. Accessed April 27, 2015.

172. Ahuja J, Moshfegh A, Holden J, Harris E. USDA food and nutrient databases provide the infrastructure for food and nutrition research, policy, and practice. *J Nutr.* 2013;143(2):241S-249S.

173. Thomas PR, Earl R, eds; Committee on Opportunities in the Nutrition and Food Sciences; Institute of Medicine. *Opportunities in the Nutrition and Food Sciences: Research Challenges and the Next Generation of Investigators*. Washington, DC: The National Academies Press; 1994.

174. Committee to Review the State of the Postdoctoral Experience in Scientists and Engineers; Committee on Science, Engineering, and Public Policy; Policy and Global Affairs; National Academy of Sciences; National Academy of Engineering; Institute of Medicine. *The Postdoctoral Experience Revisited*. Washington, DC: The National Academies Press; 2014.

175. Kushner R, Van Horn L, Rock C, et al. Nutrition education in medical school: a time of opportunity. *Am J Clin Nutr.* 2014;99(5):1167S-1173S.

176. Lenders C, Deen D, Bistrian B, et al. Residency and specialties training in nutrition: a call for action. *Am J Clin Nutr.* 2014;99(Suppl 1):1174S-1183S.

177. Kris-Etherton P, Akabas S, Bales C, et al. The need to advance nutrition education in the training of health care professionals and recommended research to evaluate implementation and effectiveness. *Am J Clin Nutr.* 2014;99(Suppl 1):1153S-1166S.

178. DiMaria-Ghalili R, Mirtallo J, Tobin R, Hark L, Van Horn L, Palmer C. Challenges and opportunities for nutrition education and training in the health care professions: intraprofessional and interprofessional call to action. *Am J Clin Nutr.* 2014;99(Supp 1):1184S-1193S.

179. Biomedical Research Workforce Working Group Report: A Working Group of the Advisory Committee to the Director; National Institutes of Health. June 14, 2012. http://acd.od.nih.gov/biomedical_research_wgreport.pdf. Accessed August 10, 2015.

180. Alberts B, Kirschner M, Tilghman S, Varmus H. Rescuing US biomedical research from its systemic flaws. *Proc Natl Acad Sci USA.* 2014;111(16):5773-5777.

181. United States Department of Health and Human Services National Institutes of Health Office of Extramural Research. Biomedical Research Workforce. Supporting the Biomedical Research Workforce. http://biomedicalresearchworkforce.nih.gov/index.htm. Accessed August 10, 2015.

182. Kris-Etherton P, Akabas S, Douglas P, et al. Nutrition competencies in health professionals' education and training: a new paradigm. *Adv Nutr.* 2015;6(1):83-87.

183. Kris-Etherton P, Pratt C, Saltzman E, Van Horn L. Introduction to nutrition education in training medical and other health care professionals. *Am J Clin Nutr.* 2014;99(Supp 1):1151S-1152S.

184. Levy M, Loy L, Zatz L. Policy approach to nutrition and physical activity education in health care professional training. *Am J Clin Nutr.* 2014;99(Suppl 1):1194S-1201S.

185. Fleischhacker S, Ammerman A, Perdue W, et al. Improving legal competencies for obesity prevention and control. *J Law Med Ethics.* 2009;37(Suppl 1):76-89.

186. Rogerson B, Lindberg R, Givens M, Wernham A. A simplified framework for incorporating health into community development initiatives. *Health Aff.* 2014;33(11):1939-1947.

187. Sorensen G, Barbeau E. Steps to a healthier US workforce integrating occupational health and safety and worksite health promotion: state of the science. *Research Compendium: the NIOSH Total Worker Health™ Program: Seminal Research Papers 2012*. May 2012. Washington, DC: US Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention. No. 2012-146. http://www.cdc.niosh/docs/2012-146/. Accessed June 29, 2015.

188. Barlow S. Expert committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: summary report. *Pediatrics.* 2007;120:S164-S192.

189. Smith S, Zwart S, Heer M. *Human Adaptation to Spaceflight: The Role of Nutrition*. Houston, TX: National Aeronautics and Space Administration Lyndon B. Johnson Space Center; 2014.

190. Smith S, Zwart S, Kloeris V, Heer M. *Nutritional Biochemistry of Space Flight*. New York, NY: Nova Science Publishers; 2009.

191. Smith S, Zwart S, Block G, Rice B, Davis-Street J. The nutritional status of astronauts is altered after long-term space flight aboard the international space station. *J Nutr.* 2005;135:437-443.

192. Alexander N, Rowe S, Brackett R, et al. Achieving a transparent, actionable framework for public-private partnerships for food and nutrition research. *Am J Clin Nutr.* 2015;101(6):1359-1363.

193. Raiten D, Raghavan R, Porter A, Obbagy J, Spahn J. Executive summary: evaluating the evidence base to support the inclusion of infants and children from birth to 24 mo of age in the Dietary Guidelines for Americans—"the B-24 Project". *Am J Clin Nutr.* 2014;99:663S-691S.

194. Joyce T, Reeder J. Changes in breastfeeding among WIC participants following implementation of the new food package. *Matern Child Health.* 2015;19(4):868-876.

195. Odoms-Young A, Kong A, Schiffer L, et al. Evaluating the initial impact of the revised Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) food packages on dietary intake and home food availability in African-American and Hispanic families. *Public Health Nutr.* 2014;17(1):83-93.