Applying genomics to nutrition and lifestyle modification

Personalized nutrition aims to prevent the onset and development of chronic diseases by targeting dietary recommendations to an individual's genetic profile. Gene–diet interactions that affect metabolic pathways relevant to disease risk are continuously being uncovered. Discoveries in the field of nutrigenomics demonstrate that some individuals may benefit from adhering to different dietary guidelines than others, depending on their genotype. Certain industries have already begun to capitalize on the anticipation that knowledge of genomic information could help prevent the risk of developing diseases. Although disclosure of genetic information has been associated with the adoption of positive health-related behaviors under certain circumstances, the effect of providing gene-based dietary advice on motivating adherence to favorable dietary changes is largely unknown.

KEYWORDS: genetic testing ▪ health behavior ▪ nutrigenetics ▪ nutrigenomics ▪ personalized nutrition

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Variability between individuals in response to dietary intervention is a well-documented occurrence in nutrition research and practice [1]. The effect of diet modification on health-related markers such as blood cholesterol, body weight and blood pressure can differ significantly between individuals [2]. These differences partially account for the limited effectiveness of the current one-size-fits-all population-based model of nutritional guidance for health promotion. Factors such as age, sex, physical activity and smoking are known to affect one's response to diet, but the influence of genetics is becoming an increasingly important consideration. Nutrigenomics (or nutritional genomics) is the study of the relationship between genes and diet, and is used as an umbrella term for two complimentary approaches: how nutrients affect gene function and how genetic variation affects nutrient response [3]. The latter is referred to as nutrigenetics [4] and includes the study of how genetic variation affects food intake and eating behaviors, in addition to the biological response to nutrients and food bioactives [5,6]. Recent advances in nutrigenomics have shown that some individuals benefit more by following different dietary recommendations than others based on their individual genotype. This method of personalizing dietary recommendations based on 'responders' and 'nonresponders' is one of the primary goals of nutrigenomics. While the term 'personalization' refers to the delivery of information of high relevance to an individual and can be based on several factors such as phenotypes and individual preferences, this review will focus only on the incorporation of an individual's personal genomic information. Personalized nutrition could be useful in both the prevention and treatment of chronic diseases by tailoring dietary advice and designing targeted dietary interventions to an individual's unique genetic profile; however, no studies have examined the effect of providing gene-based dietary advice on dietary intake behavior. This review will highlight the available evidence for personalized nutrition and summarize the literature that has investigated the effect of genomic information on health-related behaviors. Studies that provided subjects with their own genetic information and had follow-up assessments on health behavior outcomes are reviewed. Studies that did not provide subjects with real genetic information (i.e., analogue studies that ask subjects to imagine they are informed of a genetic test result) or studies that were cross-sectional in design are not included in this review.

Evidence for personalized nutrition

The concept of nutrigenomics has been around for some time, although the term is relatively new. One familiar example is lactose intolerance, which is a condition resulting from an inadequate production of the enzyme lactase in the small intestine due to genetic variation in the lactase gene [7]. Lactose intolerant individuals are unable to efficiently break down lactose, the primary milk sugar from dairy products. This can lead to gastrointestinal discomfort if lactose-containing

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products are consumed. As a result, the dietary recommendation is to limit consumption of lactose-containing foods, choose lactose-free dairy products or use lactase supplements [8]. Another classic example of nutrigenomics is phenylketonuria (PKU), which is an inborn error of metabolism that results in reduced activity of the enzyme phenylalanine hydroxylase, which is needed to convert phenylalanine to tyrosine. Rare genetic variations in the phenyalanine hydroxylase gene are primarily responsible for the condition [9]. Individuals with PKU can develop neurological damage from excess phenylalanine [10] and are therefore advised to follow a low-phenylalanine diet for life [11]. Lactose intolerance and PKU are examples of gene–diet interactions that result from a single gene and involve a single dietary exposure. A major objective of nutrigenomics, however, is to identify gene–diet interactions that affect complex disorders that are polygenic in nature and involve a number of dietary exposures such as cardiovascular disease, Type 2 diabetes, obesity and cancers.

The main goal of nutrigenomics is to prevent the onset and progression of chronic disease through proper dietary advice. Research strategies employing nutrigenomics methodologies contribute to this goal by building upon the body of evidence that links nutrients to metabolic pathways relevant to disease outcomes. Furthermore, the incorporation of high-throughput 'omics' technologies into nutritional epidemiologic studies aims to improve the consistency of findings. Knowledge gained from current research in the field could lead to the development of personalized nutritional guidelines for individuals and specific subpopulations, which may ultimately reduce the burden of chronic disease.

Several significant findings in the field of nutrigenomics have paved a path towards personalized nutrition. For example, the relationship between coffee consumption and cardiovascular disease risk had been controversial for some time, due to inconsistent findings across studies. Applying a nutrigenomics framework to this area of study resulted in more consistent findings. A study examining the association between *CYP1A2* genotype, coffee intake and myocardial infarction found that carriers of the variant allele ('slow' caffeine metabolizers) were at an increased risk of myocardial infarction when consuming two or more cups of coffee per day [12]. A different study found that risk of hypertension associated with coffee intake also varies according to *CYP1A2* genotype, with carriers of the slow allele being at increased risk when consuming one to three cups of coffee per day [13]. These results suggest that individuals carrying a slow allele should limit their consumption of caffeine, potentially to no more than two cups of coffee per day.

Another example comes from studies on the effects of genetic variation in vitamin C metabolism where individuals with either a *GSTM1* or *GSTT1* deletion polymorphism are at increased risk of vitamin C deficiency if they do not meet the recommended dietary allowance for vitamin C [14]. The recommended dietary allowance for vitamin C protects against serum ascorbic acid deficiency regardless of genotype, yet these results suggest that individuals with deletion genotypes for *GSTM1* or *GSTT1* could benefit from being particularly mindful of meeting the daily recommendation. Inadequate levels of serum ascorbic acid have been associated with several markers of cardiometabolic disease, including glucose homeostasis [15], high blood pressure [16,17], oxidative stress [18], high-sensitivity CRP [19] and indicators of obesity such as a higher BMI and waist:hip ratio [20,21].

An intriguing area of study that is rapidly expanding is the science of chemical senses and its relation to individual food preferences [6]. There is growing evidence that genetics plays a significant role in one's detection of taste and smell, in turn affecting food preferences and dietary intake [22]. A study examining the role of genetic variation on sugar consumption found that a polymorphism in the *TAS1R2* gene (which encodes the sweet taste receptor) affects habitual consumption of sugars [23]. Individuals possessing a variant in the *TAS1R2* gene consumed more sugars than those without the genetic variant [23]. Although the mechanism for this variability in consumption is unknown, it is plausible that genetic variation in *TAS1R2* affects sweet taste perception which may play a role in an individual's preference for sweet tasting foods. Knowing whether one is genetically predisposed to prefer sweet foods due to variation in taste receptor genes may assist in controlling the desire to consume such foods.

The role of genetic variation in salt-sensitive hypertension has also been explored [24,25]. One study found that hypertensive patients with a variant of the *ACE* gene had a significantly higher increase in blood pressure with high salt intake compared with those without the variant [24]. The prevalence of salt-sensitive hypertension, as determined by 24-h ambulatory mean blood pressure after high salt intake, was also significantly higher in patients with the *ACE*

variant [24]. The same results were observed when this sample size was increased from 50 patients to 71 patients, and additional genotypes were examined [25]. These results suggest that the *ACE* polymorphism may serve as a potential genetic marker of salt sensitivity. Informing an individual about his/her genetic susceptibility to salt-sensitive hypertension may motivate the adoption of behaviors, such as limiting dietary sodium intake, which could mitigate the chance of developing this condition later in life.

The evidence highlighted above demonstrates the ability to provide different dietary recommendations depending on genotype to target different health indicators, and several other examples of gene–diet interactions have been documented [26–34]. A potential outcome of personalized nutrition is a decrease in the prevalence of chronic diseases; however, this result is contingent upon adherence to the dietary recommendations. Disclosure of genetic information relating to disease risk has been shown to motivate the adoption of favorable health-related behaviors; however, the extent to which personalized nutrition is able to motivate individuals to make and adhere to dietary modifications is a key gap in the literature.

Disclosure of genetic information & health behavior change

Since the mapping of the human genome was completed, diagnostic tests that estimate an individual's risk of developing certain diseases based on genetic variants have been produced and used in clinical settings. Perhaps the most well-known tests of this nature are the *BRCA-1* and *BRCA-2* tests that detect mutations in genes that are known to increase the risk of breast and ovarian cancer development [35]. The ability for these tests to motivate favorable changes in health behaviors has been a subject of great interest to health researchers and behavioral scientists. A number of studies have evaluated the effects of providing genetic information related to genetic variants involved in hereditary breast, ovarian and colon cancers, on cancer screening behaviors. Genetic feedback of carrier status and cancer risk has been associated with improved screening behavior among those carrying an at-risk gene variant [36–41]. Regular cancer screenings are known to lead to earlier detection of cancer onset, which ultimately improves the prognosis of the disease [42].

In addition to cancer screening behavior, studies have also examined the effect of incorporating genetic testing information in smoking cessation trials [43,44]. McBride *et al.* incorporated genetic susceptibility feedback to tobacco-related cancers into a smoking cessation program in a group of African–American smokers and compared cessation rates with a group that received a standard cessation intervention [43]. Participants in the genetic information group were counseled on their *GSTM1* genotype as previous studies have shown that individuals with lung cancer are more likely to have the *GSTM1* deletion genotype [45,46]. Smoking cessation was found to be greater in the group that received genetic information in the short-term (6 months following intervention), but not at the 12-month follow-up [43]. In a different study, Sanderson *et al.* examined the effect of *GSTM1* genetic test feedback on smokers' motivation to quit smoking. Those missing *GSTM1* reported a greater motivation to quit smoking compared with subjects with a functional *GSTM1*, and also smoked fewer cigarettes at 1-week follow-up [44]. These differences were not significant at 2-months follow-up [44].

The ineffectiveness of these trials to yield longer-term abstinence is not unique to these particular programs. Smoking relapse is a common occurrence among cessation programs that initially result in a reduction in or cessation of smoking, due to a variety of psychological and social factors [47]. A recent Cochrane review concluded that there is a lack of evidence to support the efficacy of any specific behavioral interventions aimed at preventing smoking relapse [47]; however, interventions of a complex psychoeducational nature, such as cognitive–behavioral coping skills training, have been effective in certain target groups [48], as well as postcessation treatment with pharmacological agents [49]. Cessation programs utilizing genetic information combined with more intensive behavioral therapy or pharmacological aid may result in increased rates of long-term smoking cessation.

Consultations with genetic information have also been used in weight loss interventions among obese individuals [50,51]. Conradt *et al.* found that incorporating genetic information about obesity into a weight loss consultation led to more realistic weight loss goals and greater satisfaction with a 5% weight loss. In addition, subjects with familial predisposition to obesity reported less self-blame about eating after receiving consultations with genetic information [50]. Rief *et al.* also found an improvement in negative mood in obese subjects with a family history of obesity when consultations included genetic information [51]. This is important as negative

thoughts and feelings about current weight have been shown to predict future weight gain [52]. Rief *et al.* also reported that subjects who received a consultation with genetic information of the etiology of obesity developed new insights about weight issues, suggesting the information was well received.

Pertinent to personalized nutrition, one study conducted in Greece evaluated the effect of personalized diets based on genetic information on weight loss among obese individuals who had a history of weight loss failures [53]. Individuals who opted for a commercial nutrigenetic screening test were given genotype-based weight loss recommendations and were compared with individuals who did not take the genetic test, but were following a weight loss diet [53]. There were no significant changes in BMI between the two groups in the first 100–300 days after the intervention; however, weight loss was more likely to be maintained in the nutrigenetic-tested subjects who were followed for more than 300 days [53]. Fasting blood glucose levels were also significantly improved among subjects who underwent nutrigenetic testing [53].

Additional studies examining genetic information and behavior have been related to Alzheimer's disease (AD) and familial hypercholesterolemia [54,55]. Chao *et al.* examined whether disclosure of *APOE* genotype altered health behavior among asymptomatic individuals at high risk for AD. It has been shown that first-degree family members and those carrying one or two copies of the *APOE* ε4 allele are at increased risk of developing AD [56,57]. Participants who learned they were ε4-positive were significantly more likely to report AD-specific health behavior change, such as changing medication or vitamin use, 1-year after disclosure [54]. Adding a vitamin E supplement was the most common change [54]. Marteau *et al.* examined whether clinical diagnosis of familial hypercholesterolemia, as confirmed by a genetic mutation in the *LDLR* or *APOB* genes, affected patients' adherence to risk-reducing behaviors. Subjects with a mutation believed less strongly in the efficacy of diet in reducing cholesterol levels, but showed a trend in believing more strongly in the efficacy of medication [55].

It is clear that the disclosure of genetic information is able to motivate some favorable changes in a number of health-related behaviors. However, the genetic information used in the evidence summarized above was provided in clinical settings and, for the most part, was used as part of a research study. Personal genetic information is currently easily obtainable, due to the rapid growth of the direct-to-consumer (DTC) genetic testing industry. The effect of genetic information obtained from a DTC source may be markedly different from the effect seen in a clinical or research setting and, therefore, studies that deliver genomic information in a manner more closely resembling a DTC method are needed to assess the impact of this industry on populations.

DTC genetic testing

DTC genetic tests claim to provide consumers with an analysis of either a select number of their genes, or a full-genome scan, that will reveal information about their ancestry, ability to metabolize nutrients and drugs, and risk for developing diseases [58]. One class of these genetic tests offers to provide personalized dietary advice based on an individual's DNA [59]. The DTC method of marketing facilitates the sales of these tests without involvement of a healthcare professional [60]. DTC genetic testing for disease susceptibility remains controversial, with opponents arguing that the tests currently possess limited value due to their questionable clinical validity and utility [61–63]. Critics note that predicted risk estimates will continue to change as new genetic variants are discovered, and thus risk calculations for disease based on currently known variants are premature [64,65]. Furthermore, environmental factors such as diet, smoking and physical activity can have a far greater impact on risk, but are often not considered when providing estimates of disease susceptibility. Another main criticism of most DTC genetic tests is that the corresponding advice is not genuinely personalized since the lifestyle recommendations are generally the same, regardless of genotype. Despite these criticisms, some propose that direct access to genetic information may motivate consumers to adopt favorable lifestyle behavioral changes that aim to prevent the onset and development of disease [66,67]. Therefore, a potential outcome of these genetic tests is a decrease in the prevalence of chronic diseases, such as cardiovascular disease, Type 2 diabetes and obesity, due to an increase in preventative measures through lifestyle modification such as adopting a healthier diet or increasing physical activity.

To date, only one study has examined the effect of genetic information obtained from a DTC genetic test on behavioral outcomes [68]. Subjects in this study purchased a commercially available DTC genetic test at a reduced price.

The test screens DNA for 23 different health conditions (e.g., Type 2 diabetes, heart disease, obesity and certain cancers) and provides estimates of one's risk for developing them over their lifetime. Prior to genetic testing, questionnaires were completed to measure initial health indicators and behaviors such as level of anxiety, dietary fat intake and time spent exercising. These questionnaires were repeated at a mean follow-up point of 6 months after the test results were disclosed and scores were compared to determine if the genetic information affected any outcome variable. No changes in scores were seen and the investigators concluded that the genetic information had no effect on the behavioral outcomes of interest.

This was the first study to evaluate the effect of DTC genetic test information on behavioral outcomes; however, the study had a number of limitations. Notably, the study did not include a control group, making it difficult to interpret the results. Furthermore, no truly personalized advice was provided to subjects who were found to be at greater risk of a condition. Therefore, these subjects may not have made changes to their diet or exercise patterns because they were not aware of what specific changes they should make that would mitigate their risk for the conditions.

Despite the null findings from Bloss *et al.* [68], there is evidence supporting the hypothesis that information from a DTC genetic test may result in lifestyle modification. A recent survey of readers of the journal *Nature* showed that 18% of respondents had their genomes analyzed in some way [69]. Of those 18%, 71% had the analysis performed by a commercial firm or company. Half of those who had undergone genetic testing reported learning of a health risk from the test results, and 27% reported changing their diet, lifestyle or medication use based on their genetic test results, despite not receiving specific recommendations to do so. These findings suggest that genetic information obtained from a DTC source could impact lifestyle behaviors.

Applications for nutrition

The finding that individuals report making changes to their diet following disclosure of DTC genetic test results for disease susceptibility merits further investigation. There is overwhelming evidence that cardiometabolic disease, including heart attack, stroke, heart failure, obesity and diabetes, is associated with a number of common, modifiable health behaviors, including diet [70]. Owing to the great deal of media attention that the field of nutrition attracts, research findings relating diet and health are often translated to the public shortly after publication. However, dietary interventions aimed at reducing the risk of chronic disease have shown varying levels of effectiveness in clinical practice [71]. Poor compliance to dietary advice is commonly cited as an explanation for the ineffectiveness of these interventions to improve health outcomes. Biomarkers of nutritional exposure are often used in nutritional epidemiological studies to assess nutrient status, participants' adherence to assigned diets, and also to determine the validity of dietary intake questionnaires. Traditionally, surrogate indicators of nutritional intake have been measured individually from samples of urine (e.g., sodium, potassium, nitrogen) or blood (e.g., vitamins, carotenoids, fatty acids), although a great deal of interindividual variation exists between measurements [72]. This variability may be a result of genetic factors influencing an individual's response to various nutrients and may affect the utility of a biomarker to accurately reflect dietary exposure and adherence. Considering an individual's genotype when measuring nutritional biomarkers may improve the accuracy of assessing adherence to dietary advice. Furthermore, advances in the fields of proteomics and metabolomics offer new methods of quantitatively measuring several biomarkers or 'profiles' of an individual and relating them to nutritional patterns and exposures [73,74].

In addition to utilizing genomics and related technologies to improve assessment of nutritional exposures and dietary adherence, personalizing dietary advice by incorporating an individual's personal genomic information provides a unique opportunity to address issues of adherence and effectiveness of dietary interventions. As previously summarized, disclosure of genetic information related to disease risk can motivate individuals to adopt favorable health-related behaviors; however, the ability of genetic information to motivate changes in dietary habits has not been adequately explored.

A randomized controlled trial (NCT01353014) is currently exploring the effects of genotype-based dietary advice on dietary intake behavior [101]. Participants in the intervention (I) group receive a dietary advice report providing recommendations for daily intakes of caffeine, vitamin C, sugar and sodium based on genotypes for *CYP1A2* [12,13], *GSTM1* and *GSTT1* [14,75], *TAS1R2* [23] and *ACE* [25], respectively. The reports were developed in collaboration

with Nutrigenomix, Inc. (Toronto, Canada), a company that is developing a nutrigenomics test kit for registered dietitians. The advice reports provide participants with their genotype for each gene, an explanation of what the genotype means in terms of the dietary component and a personalized recommendation for daily intake of the dietary component. Participants in the control (C) group receive general dietary recommendations from recognized health organizations for the same dietary components without genetic information. Dietary intakes and adherence are being assessed using a Toronto-modified Willett food frequency questionnaire (FFQ) that has been used previously in several studies demonstrating gene–diet interactions [30–32,76–78]. FFQs were collected at baseline, prior to intervention, and collected again at 3-month and 12-month follow-up points after the dietary advice reports were distributed. Changes in intake by the intervention group will be compared with the control group to determine the short- and long-term effect of gene-based dietary advice. Surveys are also being collected throughout the study to examine the perceptions of individuals toward genetic testing for personalized nutrition.

Preliminary findings from this study have recently been published [79]. Briefly, dietary recommendations based on genotype were reported to be more understandable than general dietary recommendations (93% agree [I] vs 78% agree [C]; $p = 0.009$) and were also reported to be more useful (88% agree [I] vs 72% agree [C]; $p = 0.02$). Participants reported that they would not be uncomfortable learning about their own genetic information. Consistent with this, participants in the intervention group did not express discomfort in learning about their genetics and were more likely to report enjoyment in learning about the dietary recommendations they were given (96% agree [I] vs 72% agree [C]; $p < 0.0001$), as well as a greater desire to know more about the recommendations (95% agree [I] vs 76% agree [C]; $p < 0.0001$). The FFQ analysis to investigate changes in dietary intake is currently underway, yet initial survey results demonstrate an appreciable difference in the way gene-based dietary advice is valued in comparison to general dietary advice [79]. Genetic tests for personalized nutrition may, therefore, be more valuable than those based solely on disease risk predictions.

Issues for consideration

A new era of genomic medicine is upon us. The potential for genomics technologies to personalize prevention and treatment of disease is apparent and certain industries are already putting these advancements to commercial use. While current available evidence shows some benefit of disclosing genetic information related to disease risk, results should be considered cautiously as additional scientific questions have yet to be investigated in more detail. The field of genomics is relatively new and constantly changing. As new findings are discovered, it is likely that current estimates for disease risk or personalized advice for nutrition will be affected and may require updating. Additional factors, such as the gut microbiome and its interaction with the host genome, could impact response to nutrition as well and should be considered in future work.

Many ethical considerations regarding the use, access and storage of genomic information are being debated [80,81]. The DTC genetic testing industry is currently largely unregulated, although significant measures are being taken to regulate the market in certain jurisdictions [82]. In addition, concerns have been raised over the consumer's ability to accurately recall and interpret the meaning of the test results, given that no healthcare professional involvement is required [83]. Coupled with this concern is the recent finding that the literacy demands and quality of informational content across DTC genetic testing websites have been shown to vary and users may struggle to find and understand the important information on the sites [84]. A recent study examined understanding of genetic susceptibility test results among individuals who underwent free genetic testing for eight common health conditions [85]. More than 80% of the participants ($n = 199$) correctly recalled their test results 10 days after receiving them and were unlikely to interpret the results as deterministic of health outcomes at the 3-month follow-up assessment. A subset of the participants who had lower educational status and were members of ethnic minority groups reported a more deterministic interpretation of the results and were more confused by the information. This finding suggests that certain target groups may benefit from a consultation with a healthcare professional before and after genetic testing to ensure that the information is not misinterpreted. Furthermore, consumer attitudes toward genetic testing and personalized nutrition must be well understood to ensure that emerging technologies are successfully integrated into commercial use. A survey conducted among European consumers reported that 66% of individuals would be willing to undergo genetic testing and 27% to

follow a personalized diet [86]. Of note, individuals who were aware that they had health problems associated with the metabolic syndrome were more favorable toward nutrigenomic intervention [86]. In addition, a study assessing consumer acceptance of personalized nutrition found that acceptance was enhanced when consumers were able to make their genetic profile available free by their own choice, and if the products of testing provided an advantage to the consumer and could be easily implemented into daily routines [87]. Key areas to address in future studies include individual perceptions toward the acquisition and storage of genomic information, as well as opinions of the most trusted sources of delivery (i.e., healthcare professionals, research institutes, or DTC companies).

In addition to considering ethical, social and consumer questions, research geared at examining the effect of applying genomics for lifestyle modification would benefit from an investigation of behavioral change theories. Three major theories exist: the social cognitive theory, the theory of planned behavior and the transtheoretical model [88]. These theories have been applied to interventions aimed at improving physical activity patterns [89,90], mental health status [91] and addictive behaviors [92], as well as eating behavior [93,94]. Including assessments of stages of behavior change will inform researchers and clinicians of what barriers are present that may prevent an individual from adopting a favorable health behavior, and what strategies could assist in overcoming those barriers. Indeed, the National Human Genome Research Institute has recently highlighted the need to investigate the use of genomic information to improve behavior change interventions as part of its 2011 strategic vision for the future of genomics research [95]. Stemming from this, behavioral scientists have taken an interest in the relationship between genetic variation involved in adherence behaviors and intervention outcomes (e.g., dopaminergic rewards associated with eating behavior [96]) in order to further our understanding of the individual characteristics that predict the likelihood of a successful lifestyle intervention [97].

Conclusion

Advances in genomics offer many novel avenues toward personalized medicine. Personalized nutrition is one such application that holds much potential to deliver tailored dietary recommendations to individuals and subpopulations that can effectively prevent and manage the development of chronic diseases. The extent to which personalized nutrition is able to motivate individuals to adopt healthier dietary habits is currently being investigated, yet remains a topic of intense interest and will play a significant role in determining strategies for designing and implementing successful lifestyle interventions in the future.

Future perspective

There is growing recognition amongst researchers, healthcare professionals and consumers that the one-size-fits-all population-based model of nutritional guidance for health promotion is inefficient and often ineffective. Research in nutrigenomics has shed light on the role of human genetic variation within a population and its ability to explain why some individuals respond differently than others to the same foods and beverages consumed. This area of research is revolutionizing the science of nutrition and we envisage there will be a strong demand for diagnostic kits that can provide this kind of personalized information in the near future. A tangible output of this research will be the commercialization of genetic tests for personalized nutrition. Unlike existing genetic tests that have been fraught with difficulties because of their questionable ability to accurately predict disease risk, the tests for personalized nutrition will be much more reliable and beneficial because the predicted phenotype will be based on dietary responsiveness, which is much more consistent and robust than gene-disease association studies. This information is likely to be delivered by a qualified healthcare professional, such as a registered dietitian, in order to ensure appropriate communication of test results to the consumer, as well as handling and storage of the genetic information. Collaborations with various partners, such as dietetics associations and public health agencies, will be essential to integrate personalized nutrition into clinical use in the near future.

Financial & competing interests disclosure

This article was supported by a grant from the Advanced Foods and Materials Network (AFMNet). A El-Sohemy holds a Canada Research Chair in Nutrigenomics. A El-Sohemy holds shares in Nutrigenomix, Inc. The authors have no other relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript apart from those disclosed.

No writing assistance was utilized in the production of this manuscript.

Executive summary

Background

- Variability between individuals in response to dietary intervention is well documented in nutrition research and practice and partially accounts for the limited effectiveness of the current one-size-fits-all population-based model of nutritional guidance for health promotion.
- Personalized nutrition could be useful in both the prevention and treatment of chronic diseases by tailoring dietary advice and designing targeted dietary interventions to an individual's unique genetic profile.

Evidence for personalized nutrition

- Gene–diet interactions that affect metabolic pathways relevant to disease risk are continuously being uncovered and offer new insights into personalizing dietary recommendations according to genotype.
- Applying a nutrigenomics framework to nutritional epidemiological studies has resulted in more consistent findings relating diet and markers of health.
- The relationship between coffee consumption and cardiovascular disease risk is one example of findings that have been clarified by taking genotype into account.

Disclosure of genetic information & health behavior change

- Since the mapping of the human genome was completed, diagnostic tests that estimate an individual's risk of developing certain diseases based on genetic variants have been produced and used in clinical settings.
- Disclosure of results from these tests has been shown to motivate favorable changes in health behaviors under particular circumstances, such as increasing cancer screenings and affecting vitamin and medication use.

Direct-to-consumer genetic testing

- Diagnostic tests that predict disease susceptibility have also been produced for commercial use. The marketing and distribution of these tests has been highly controversial, due to their questionable clinical validity and utility.
- Critics argue that the use of these tests to estimate disease risk is premature, while proponents note that direct access to genetic information may result in favorable lifestyle modifications that could reduce the risk of developing chronic diseases.
- Very few studies have examined the effect of direct-to-consumer (DTC) genetic test information on health behaviors.

Applications for nutrition

- A recent survey demonstrated that a proportion of individuals who had undergone genetic testing for disease susceptibility, mostly by means of a DTC genetic testing company, reported making changes to their diets and lifestyles despite not being given specific recommendations to do so.
- When informed of a health risk, diet is one of the first modifiable lifestyle factors that is taken into consideration.
- Genetic testing for personalized nutrition will be much more reliable and beneficial than disease-susceptibility tests because the predicted phenotype is based on dietary responsiveness, which is much more consistent and robust than gene–disease association studies.

Issues for consideration

- Issues of communication such as health literacy and healthcare professional involvement are important factors that can affect the way results from genetic tests are interpreted and applied. Furthermore, ethical issues surrounding the DTC genetic testing industry, such as privacy and regulatory standards, are currently being debated.
- Theories of behavior change may be important to consider when investigating the utility of genetic testing for lifestyle modification.

Conclusion

- Personalized nutrition holds much potential to deliver tailored dietary recommendations to individuals and subpopulations that can effectively prevent and manage the development of chronic diseases. The extent to which personalized nutrition is able to motivate individuals to adopt healthier dietary habits is currently being investigated.
- In the future, genetic tests for personalized nutrition will be in demand and qualified healthcare professionals, such as registered dietitians, will likely be the providers of this service.

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