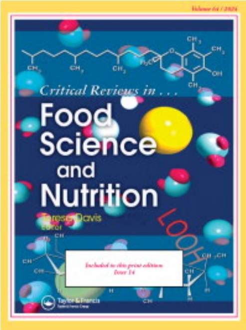

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REVIEW

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The whole food beef matrix is more than the sum of its parts

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ABSTRACT

Foods are not simply a delivery vehicle for nutrients; they consist of a matrix in which nutrients and non-nutrient compounds are presented that induce physiologic effects different from isolated nutrients. Dietary guidance is often based on effects of single nutrients that are considered unhealthy, such as saturated fat in beef. The purpose of this paper is to propose a working definition of the whole food beef matrix whose consumption has health effects distinct from those of isolated nutrients. The beef matrix can be defined as: the collective nutritive and non-nutritive components of the beef food structure and their unique chemical and physical interactions that may be important for human health which are distinguishable from those of the single components in isolation. Background information supporting this approach is summarized on multiple components provided by beef, temporal changes in beef consumption, dietary guidance that restricts beef, and how the background diet determines healthfulness rather than a single food. Examples of research are provided on other whole foods that differ from their constitutive nutrients and lay the groundwork for studies of beef as part of a healthy dietary pattern.

KEYWORDS

Beef; food matrix; meat; nutrients

Defining the beef matrix

The term "matrix" is used in multiple fields, with many definitions whose usage depends on the field of study, which contributes to a lack of clarity or unified use of the term. In medicine and biology, the usual reference is to the material or tissue between or within a eukaryotic organism's cells, i.e., the extracellular or intercellular matrix (Dorland's Illustrated Medical Dictionary). In the discipline of cell biology, the matrix is an insoluble, dynamic gel in the cytoplasm believed to be involved in cell shape and locomotion and is sometimes called the ground substance (Alberts et al. 2002). In chemistry, the matrix consists of components of a sample other than an analyte of interest (IUPAC 1997). According to the USDA National Agricultural Library's Agricultural Thesaurus, the food matrix comprises the nutrient and non-nutrient components of foods and their molecular relationships, i.e, chemical bonds, to each other (USDA NAL). Food matrix is a term often used to infer the total food instead of the constituents, and specifically the nutrients contained in it. Aguilera provided clear descriptions of usage of the term and pointed out that nutrients are neither homogeneously dispersed nor in a free form within a food matrix, but are part of complex microstructures (Aguilera 2019). His characterization scheme included meat as having a fibrous, extracellular matrix but did not specify the type of meat. Multiple structural and compositional differences exist between and among red meats and white meats, indicating finer detail on this category is needed. He discussed the effect of the food matrix in reference to food processing, oral processing and flavor perception, satiation and satiety, and digestion in the gastrointestinal tract. The food matrix effect also has implications in nutrition, food allergies and intolerances, and in the quality and relevance of results of analytical techniques. Despite Aguilera's clarification of issues in use of the term food matrix and a general meat matrix, there are a number of additional factors directly relevant to the whole food beef matrix that will be examined in this review.

Scientists usually do not think about the beef matrix because the default approach is to evaluate beef as a delivery vehicle for one or more of several nutrients. Those nutrients include either ones most limiting in people with poor diets resulting from poverty or inappropriate choices such as iron, zinc, selenium, vitamin B12, or those nutrients that may have adverse health consequences when consumed in excess, such as saturated fat, cholesterol, or heme iron. A virtual meeting of nutrition science experts in August 2021, organized by the National Cattlemen's Beef Association, was held to develop a working definition of the beef matrix. The working definition unanimously agreed upon was the collective nutritive and non-nutritive components of the beef food structure and their unique chemical and physical interactions that may be important for human health and are distinguishable from those of the single components in isolation. Research topics under this definition are shown in Table 1. It was acknowledged that the cut of beef, amount or type of processing, and context of meal/dietary pattern should be taken into consideration. Therefore, the definition includes all nutrients

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Table 1. Research interests under the beef matrix.

A) Beef matrix composition and/or structure
Characterize the unique nutritional and structural profile of the beef matrix
Possible areas of exploration:

- Identification of nutrients and non-nutrients in beef and potential role of each component may have on health outcomes
- Characterize physical structure of beef
  - Chemical diversity
  - Structure/function
  - Beef cut and degree of processing and impact on nutrients and non-nutrients (e.g. whole muscle vs ground)
- Description of nutrient and non-nutrient quantity, quality, bioaccessibility in beef
  - Amino acid composition/density
  - Protein quality
  - Digestion/absorption of nutrients

B) Dietary interactions of beef as a whole food
Evaluate the function and interaction of the beef matrix as compared to other common food matrices.
Possible areas of exploration:

- Understand benefits of beef's unique composition on nutrient/diet quality
  - Iron bioavailability and accessibility in beef vs other foods
- Explore function of beef's matrix on health outcomes and compare with other foods
- Impact of amino acids in beef as they interact with other foods on micronutrients bioavailability
- Iron bioavailability and accessibility in beef vs other foods, in different life stages
- Functional benefits of beef matrix interactions (e.g. growth, cognitive function, weight management)

C) Beef matrix discovery
Impact of beef whole food matrix on outcomes, life stages, etc.
Possible areas of exploration:

- Describe the beef metabolome and interaction with the human metabolome and health implications
  - Identify what amino acid mix does to support muscle, etc.
- Analyze benefits of beef within meals and/or dietary patterns
  - Meal-based dietary patterns vs snacking
- Identification of beef specific compounds and evaluation of their role as useful biomarkers of health in various tissues (e.g., blood, breastmilk, urine)
- Interaction of beef specific compounds and personalized nutrition

and non-nutrient components of beef combined and excludes single factors as those are not consumed in isolation in a normal diet. Issues that differentiate the food matrix from individual components have been well detailed for dairy foods (Peters 2017; Thorning et al. 2017). A final component of the beef matrix is its taste, which is rarely, if ever, considered in making dietary recommendations. One can readily speculate that people who prefer the taste of beef may be more satisfied with reasonably-sized portions as defined by the Dietary Guidelines for Americans (DGA) that encourage variety and flexibility within the protein foods recommendations, and may feel less stress if they are not forced to substitute a less desired protein-food. The entire concept of a food matrix is still understudied, especially for that of beef. Although meat is muscle of any animal, it usually excludes poultry and fish in dietary studies and is frequently used as a catchall for red meat types as in the Dietary Guidelines for Americans; it should be obvious that not all red meats have the same composition. In the text below, wherever the term meat is used, the original study did not provide greater specificity; when beef is used, that detail is included.

Dietary guidance often restricts beef

Dietary guidance is usually categorized as about foods rather than nutrients but most guidance either recommends or restricts isolated nutrients and many non-nutritive bioactives for which there are no recommended amounts across categories of foods. Several foods matrices have been suggested to have benefits distinct from their individual components, including berries containing anthocyanins, tomatoes providing lycopene, avocados having lutein, and dairy foods with their saturated fat content. Research on the dairy food matrix is the most developed and has shown distinguishable differences in physiological responses based on the form fed. That is, consumption of milk, cheese, homogenized cheese, or a micellar gel of casein results in different plasma metabolomic profiles and ingestion of butter, milk, yogurt, or cheese has different effects on serum lipids (Astrup et al. 2020; Thøgersen et al. 2020). Differences in lipid content play less of a role in modulating serum cholesterol concentrations than was previously believed, even though the DGA still stress nonfat or lowfat dairy and the leanest cuts of meat as the only recommended choices in Federal dietary advice, with all meats being considered more or less equivalent as protein foods (www.DietaryGuidelines.gov). The DGA were short pamphlets for the first two decades and were expert opinions that gave limited explanation, and no references, for the recommendations. The basic recommendations of the DGA have not changed over 40 years despite many advances in the science. There are numerous reasons to believe that the beef matrix is more than the sum of its nutrients and ingestion of it in a healthy, balanced dietary pattern is not only without harm but may promote health in a variety of ways. A recent paper on the knowledge gaps concerning meat and health focused on matrix effects on digestion and absorption of nutrients and included the important observation that "food matrix effects are important, but meal composition, as well as interactions between foods in the meal, also affect bio-accessibility and bioavailability" (Geiker et al. 2021). The main reason given by the DGA to restrict red and processed meat is the saturated fat content but the contribution of beef to saturated fat intake is only 2.1% of energy (2.1–2.2%, 95%CI) in men and 1.6%

of energy (1.6–1.7%, 95%CI) in women with two categories of mixed grain dishes (including pasta with sauce, pizza, nachos, etc.) and dairy dishes providing more than three times the saturated fat as beef in the American diet (Casperson et al. 2020).

There is substantial evidence from meta-analyses of dozens of randomized clinical trials that low-carbohydrate diets high in total and saturated fat can result in significantly reduced weight and cardiometabolic risk factors (Gardner et al. 2018; Jayedi et al. 2022; Pan et al. 2019). This evidence is not to counter the prevailing thought that reduction of saturated fat should reduce risk of cardiovascular disease (CVD), promulgated in the DGA and many other recommendations. The reduction in saturated fat is likely dependent on the overall dietary pattern. In other words, on the background of a typical American diet, saturated fat likely results in elevated LDL-cholesterol and heart disease but perhaps not when consumed as part of a different background diet in one randomized clinical trial (O'Connor, Kim, and Campbell 2017). A meta-analysis of 36 randomized clinical trials, with over 1,800 participants, of red meat intake as a factor in several CVD risk factors concluded that some lipid parameters improved when red meat was consumed versus combined animal protein, usual diet, or carbohydrates; and mixed effects were found in comparison with fish or poultry (Guasch-Ferré et al. 2019). The authors interpreted that finding as emphasizing the importance of considering the comparison diet interventions as a determinant of the relative effects of red meat on CVD risk factors.

One limitation of many observational studies is that red meat is considered a homogeneous food category when red meat comes from several different species, some of which are ruminants and some are monogastrics, which has an effect on fatty acid composition of the meat, and probably other unstudied components that are beginning to be revealed via metabolomics (Cuparencu, Rinnan, and Dragsted 2019). Furthermore, the standard approach to dietary guidance is that if high intake of nutrients such as saturated fat or sugar have adverse effects, linear extrapolation to zero is the default even in the absence of evidence on intake at the lower end of the range and in contradiction to almost all known biological relationships that are generally better expressed in a curvilinear manner.

Key linked questions not satisfactorily addressed in dietary recommendations occur when a reduction of one food source of nutrients is suggested. What will be the substitute and how will the overall quality of the diet change? As will be noted below, the premise that protein foods are essentially interchangeable is not supported by several recent studies. In fact, the premises of nutritional benefits of reducing red meat have been seriously questioned (Leroy and Cofnas 2020).

Beef as a source of protein/essential amino acids

The most important nutrients comprising muscle are amino acids, and beef is particularly rich in essential amino acids. The DGA and most other dietary recommendations consider all proteins interchangeable when considered as ounce-equivalents yet recent studies find that is not the case. Both the proportions and density of essential amino acids in a meal appear to be major factors in physiologic and muscle anabolic responses, with beef being significantly superior to plant protein sources when considered as ounce-equivalents (Gwin et al. 2021; Park et al. 2021). In addition, consumption of beef decreases circulating myostatin levels, a hormone that inhibits muscle anabolism, and decreases adiposity in adults, although at present mechanisms remain unknown (Perry, Van Guilder, and Butterick 2022). A systematic review of intervention and observational studies found strong and consistent evidence that consumption of beef was beneficial for muscle mass in older adults and recommended developing nutritional guidelines based on whole foods rather than nutrients (Granic et al. 2020). The foregoing observations have raised the issue of whether there is a false equivalence in considering plant-source proteins as useful to the body as those from beef since even plant sources deemed complete proteins were inferior to beef (Courtney-Martin 2021). The suggestion has been made recently to avoid the term protein in food policy and replace it with protein-rich foods but there remains the issue that plant proteins do not appear equivalent to beef for muscle anabolism (Leroy et al. 2022). In addition, many amino acids in beef are found in peptides which may have different biological effects following consumption than individual amino acids (Wu et al. 2016). Muscle, whether intact or ground, in addition to protein-derived amino acids, provides extracellular collagen and elastin. Cooking converts some collagen to gelatin but the remaining collagen is digested and absorbed partially as dipeptides which have demonstrated physiological effects (Koyama 2016). The foregoing results suggest that newer analytical methods, such as metabolomics, may be better at analyzing the health effects of beef consumption than traditional markers in blood such as serum lipids or indicators of inflammation. Metabolomic analysis of beef or a plant-based substitute revealed that beef had higher concentrations of multiple metabolite classes with physiologic benefits despite the foods having similar macronutrient compositions on the food labels (van Vliet et al. 2021). A more recent study confirmed that plasma metabolites from volunteers who consumed beef, lamb, grains, or a plant-based meat substitute had clearly distinguishable profiles that primarily reflected bioavailability of essential amino acids (Pham et al. 2022). Currently, metabolomics are generally limited to finding qualitative, rather than quantitative, differences in plasma but urine or feces may offer analytical windows over longer times although neither is likely an optimal sample for individual amino acids or small peptides derived from food due to their metabolic fates. Fecal samples will also reflect microbial transformations and metabolites, which could be better or worse depending on the question being addressed.

Proteins display ionic bonding, hydrogen bonding, and hydrophobic binding; the relevance of the different bond types for postprandial digestion remains unclear but they could be potential mediators of differential digestion. Beef being a food with a firm texture also contributes to satiety more than liquid sources of energy such as protein drinks due to both necessary chewing and the time it takes for acid hydrolysis in the stomach, intestinal digestion, and absorption. Protein co-presented with lipid also slows both gastric digestion and emptying, which contribute to satiety (Meyer, Stevenson, and Watts 1976). Higher fat cuts of beef are considered by some consumers more palatable and hedonically rewarding, so might be consumed in smaller portions. The amount of chewing needed for ingestion of most cuts of beef may contribute to slower eating, which is a characteristic of lesser food and total energy consumption. On the other hand, minced beef is more rapidly digested and absorbed than intact beef muscle in elderly men who had dentures, suggesting they also had some limitation of chewing, so those results may not be universally applicable to people with their own teeth (Pennings et al. 2013).

Dietary patterns for good health

It should be clear that variety and moderation of food sources of most nutrients are the basis of healthy dietary patterns. However, those two concepts do not get much attention from researchers or consumers. Nevertheless, diets that exclude specific food groups, such as ketogenic or vegetarian diets, have proved popular. Just as dietary recommendations and individual decisions about what to eat for good health have evolved away from individual foods to dietary patterns, the overall dietary pattern should also be considered as the background upon which recommendations are made, which should inform future research designs. When beef is included in otherwise healthy baseline regimens such as the DASH or Mediterranean diets, there is no adverse effect of including beef on any parameters measured even when beef is added at more than twice the recommended daily amounts and in subjects who are overweight or obese (Roussell et al. 2012 and Roussell et al. 2014; Hill et al. 2015; O'Connor, Kim, and Campbell 2017 and 2018; Maki et al. 2020; Perry et al. 2021; Fleming et al. 2021). Based on the preceding data, beef consumption may not reveal obvious health benefits when consumed on a background of the typical American diet but may do so when consumed as part of an otherwise healthier diet even in amounts more than double usual intakes, although no explicit dose-response studies were among the cited references. One surprising aspect of those recent studies was the apparent need to demonstrate this when the lack of adverse responses to beef consumption had been documented several decades ago even when part of a typical American diet (O'Brien and Reiser 1980; Flynn et al. 1981) and a recent meta-analysis found no effect of red meat intake on LDL-cholesterol in randomized controlled trials (Schoeneck and Iggman 2021). This lack of effect on LDL-cholesterol may be attributed, at least in part, to the high stearic acid content of beef which is neutral with regard to serum cholesterol concentrations. The combination of stearic acid with monounsaturated and polyunsaturated fatty acids in beef tenderloin yields 69% of total fatty acids according to the USDA (Food Data Central 2022); those fatty acids are generally acknowledged to not contribute to elevated LDL-cholesterol levels (Mensink 2005). In addition, it is unclear if dietary palmitate is an important risk factor for CVD or only endogenously synthesized palmitate, which would be over-synthesized from ingestion of excess carbohydrate (Wu et al. 2011). Of course, the importance of LDL-cholesterol levels as a predictor of cardiovascular disease has come under renewed scrutiny (Astrup et al. 2020).

While it appears that rendered beef tallow may be hypercholesterolemic when added at 20% of daily energy (two-thirds of total fat intake), it is likely that the starting material – the whole food beef matrix - is not since the basal diet that included 500 g/d of lean beef led to a statistically significant drop in both total and LDL-cholesterol (O'Dea et al. 1990). Similar findings have been reported for butter raising serum cholesterol but milk fat in other dairy products did not raise LDL-cholesterol or total cholesterol. Milk fat is found in globules surrounded by membranes and it has been hypothesized that the membranes synthesized in the mammary gland play a role in maintaining normolipidemia (Rosqvist et al. 2015). Fat, when consumed in meat, is also surrounded by membranes from the cells of adipose tissue that are relatively enriched in phospholipids. There are no experimental data in which beef has been added to the diet that show increased lipidemia, only when tallow is added. But even high amounts of tallow do not raise serum cholesterol or triglycerides compared to highly polyunsaturated safflower oil (Reiser et al. 1985). Tallow is rendered from adipose depots and has lost the cellular membranes that surround fat *in situ* and some of the polyunsaturated phospholipid fatty acids are oxidized, so this is a possible mechanism explaining how beef tallow, but not fat within muscle, could raise serum LDL-cholesterol following consumption. It is unknown if this loss of membrane fatty acids has an effect on digestion and absorption of fatty acids from tallow.

Nutrient density of beef

Beef is a nutrient-dense food, an inherent source of high-quality protein, iron, zinc, vitamins B6 and B12, and choline. Despite this, the nutrition field is replete with claims that fruits and vegetables are nutrient dense foods, despite analytical data not substantiating that claim (Beal and Ortenzi 2022). But claims about nutrient density of fruits and vegetables are irrelevant to health since health is not based on nutrient density of those foods. Diets high in fruits and vegetables are consistently associated with better health but the causative factor(s) remain unidentified. One of the best studied examples is the extrapolation from observations that eating vegetables was associated with less cancer which led to the hypothesis that beta-carotene prevented cancer. This was refuted by two randomized controlled trials that found increased risk in former smokers or men exposed to asbestos and several others that showed no benefit in lower risk people (Alpha-Tocopherol and Beta-Carotene Cancer Prevention Study Group 1994; Omenn et al. 1996); nevertheless, peer-reviewed papers continue to be published on the cancer-preventive properties of beta-carotene, as a recent PubMed search shows that over 2,500 papers on this topic have appeared in the last 25 years. Observational studies are confounded by multiple health behaviors that correlate with diet that are either not measured at all or imprecisely estimated (Händel et al. 2021). In addition, the food frequency questionnaire's ability to identify associations is limited to a relative risk level of ≥1.8 in large cohorts, which is greater than most claimed dietary associations, yet this is ignored by most researchers in the field, presumably because few dietary associations are greater than 1.5 (Thompson et al. 2008). Over-reliance on observational studies for making nutritional recommendations even in the face of either no experimental evidence or contradictory data from randomized controlled trials is a major issue in disagreements over many dietary guidelines (Brown et al. 2021). The main limitation that has led to over-reliance on observational studies is the absence of randomized controlled trials for hard endpoints like chronic diseases or mortality, rather than short-term intermediate biomarkers, and the claims from many prominent researchers that those studies are too long and expensive to be done, which makes such studies unlikely to ever be funded.

In contrast, a single serving of beef is a nutrient dense food providing multiple nutrients including highly functional protein, readily absorbed heme iron, several B vitamins especially B12, zinc, selenium, and choline, all high in proportion to the calories in a serving of beef. In the United States, it is generally thought that iron status is adequate and both animal and plant sources of iron contribute substantially to the body stores of the mineral. However, as beef intake has declined over the last several decades and been replaced primarily by poultry, iron status has become more compromised even in the face of increased iron fortification of various foods and adequate intake of vitamin C, which enhances non-heme iron absorption (Sun and Weaver 2021). Chicken has about 38% of the iron that beef provides and that is not in the heme form so the mineral is less bioavailable. Selection of plant protein sources can result in even lower iron absorption. While it is generally known that iron from beef is much more efficiently absorbed than iron from plant sources, a similar observation has been made for zinc in adults and breast-fed infants given complementary foods, even though absorption of the two minerals occurs via different mechanisms. Beef is not commonly recommended as a good source of zinc even though data indicate it should be (Zheng et al. 1993; Jalla et al. 2002; Krebs et al. 2006). Of particular importance to normal development of the immune system is the observation that dietary iron deficiency during weaning results in reduced microbiome diversity that is not corrected by supplemental iron (Pereira et al. 2015). Additional conditionally essential or nonessential nutrients important in human metabolism that are supplied by beef include taurine, creatine, carnosine, cysteamine, 4-hydroxyproline, squalene, anserine, and multiple membrane-derived phospholipids. Of course, it is not possible to estimate the health effects of the non-nutrients and structural aspects of the beef matrix because of an absence of any biomarkers for influence of those parameters. However, creatine has recently been proposed as a conditionally essential nutrient (Ostojic and Forbes 2022).

Consumption of beef over time

The overall implications of the data presented in this review are potentially important for all dietary recommendations and especially for consumption of beef, which has declined in the United States since the 1970s, primarily replaced by chicken and turkey and more recently by vegetable proteins, as a result of health advice from multiple government and health groups, as well as a result of economics (USDA Economic Research Service). Estimated beef intake, based on per capita availability, dropped continuously from a peak in 1976 until 2019 by 37 percent (USDA Economic Research Service). One hundred years ago, chicken was a luxury food and now costs much less than beef and has become the most commonly consumed meat in the U.S., exceeding beef intake since 2008 (USDA Economic Research Service). Implications for consumption in the majority of countries that consume less beef are perhaps even more significant where animal-source foods are limited and micronutrient deficiencies are major public health problems suggesting that even modest intake of beef and other animal-source foods would contribute substantially to overall health (Beal and Ortenzi 2022). Despite widespread acceptance of purported adverse health effects of beef consumption, overall analysis of meat intake with life expectancy world-wide shows a strong positive correlation (You et al. 2022).

Perspectives and synthesis

Despite numerous epidemiologic studies associating beef consumption with dozens of chronic illnesses and shorter life span, randomized controlled feeding trials do not support those associations (Klurfeld 2018). A likely explanation of this conundrum is that those in the highest quantile of beef consumption also have multiple other health habits that are not recommended, such as greater obesity, less exercise, more tobacco smoking, more alcohol intake, fewer whole grain foods, and less vegetable and fruit intake (Klurfeld 2015). This appears to be the case no matter what the absolute intake of beef is in a population; those in the highest quantile have unhealthier lifestyles than those consuming the lowest amount of beef (Klurfeld 2015). The same reasoning should be applied to the stronger associations of processed meat intake with multiple chronic diseases. Because processed meat products tend to be higher in fat and sodium and the subject of more recommendations to curtail, frequent consumers are more likely to ignore other recommended aspects of a healthy lifestyle. Given the publicity surrounding these associations, many people equate them as causal, despite failing most of the standard criteria to attribute causality (Klurfeld 2015; Geiker et al. 2021). A

Table 2. Beef matrix research questions.

1. Is the beef food matrix, as a whole, distinct, in its ability to contribute to optimal health and/or specific at all (or key) life stages?
2. Does real beef, as a whole food, nourish on its own or can its nutrients be delivered individually in other forms (e.g., plant substitutes, supplements) as effectively?
3. Can the health benefits of consuming whole beef be replicated by providing a plant-derived protein product, even if nutrient labels are similar?
4. Are beef nutrients and non-nutrients complimentary to fruits, vegetables, and whole grains, increasing the absorption of several key nutrients when included in a diverse and balanced diet?
5. Can the components of the beef matrix simply be replaced in the diets of Americans regardless of life stage or health condition?
6. Is the combination of beef's nutrients and bioactive food components in its whole food matrix uniquely synergistic (or antagonistic) and beneficial for specific health outcomes?
7. Is there an enhanced biofunctionality of beef's food matrix?

recent analysis of an epidemiological association of red meat intake with various chronic diseases that applied serum and urine metabolomic biomarkers to correct for misclassified intake amounts based on a food frequency questionnaire found that almost all the associations were weak and became nonsignificant when corrected for other confounding diet-related factors, especially body-mass index (Zheng et al. 2022). This contradicts the usual defense that associations of diet determined by food frequency questionnaires with disease are always attenuated due to misclassification. Similarly, the claimed association of red meat intake as a component of an inflammatory diet is small and virtually disappears when corrected for adiposity (Papier et al. 2022). A randomized controlled trial supporting that finding included beef daily in a diet high in green vegetables and full-fat dairy, which resulted in significantly fewer upper respiratory tract infections, antibiotics used to treat them, and physician visits in children one to four years of age who had suffered from recurrent upper respiratory infections (van der Gaag et al. 2020).

The clinical trials cited above all show that in an otherwise healthy lifestyle and background diet, beef, even in a wide range of amounts, can be incorporated without adverse effects and improves nutrient status. Also, meat eaters have been shown to have better nutritional status for multiple nutrients than those who avoid eating meat (Neufingerl and Eilander 2021). A recent review concluded that results from randomized controlled trials showed that overall diet quality was more influential for improving cardiovascular disease risk factors than intake of red meat (Wang et al. 2022). Subpopulations may have special needs that differ from adults who may be concerned with lowering risk of chronic disease. For instance, young children need proportionally more fat for growth, so restricting fat from beef is not justified based on any existing evidence. Young children also need proportionally greater intake of multiple nutrients than adults and beef provides highly bioavailable forms of some of the most important micronutrients this age group is most likely to under-consume (Obbagy et al. 2019). Teenage girls also have high nutrient needs and poor diet quality, so would benefit from regular incorporation of beef into a healthy diet. The elderly, who have a high prevalence of sarcopenia that increases with age, would benefit from increased intake of beef combined with more exercise (Perry, Van Guilder, and Butterick 2022) but muscle mass often declines much earlier so younger adults may also benefit from the higher quality protein in beef.

Some part of the contradictory interpretations facing nutrition researchers can be attributed to the reductionist approach most use to test hypotheses. Since adding one food requires reduction of others to maintain energy balance, a solution-oriented approach to diet such as an improved dietary pattern, as part of an overall healthy lifestyle, is more likely to provide practical information about diet-health effectiveness than a single addition or elimination, in line with recent recommendations (Astrup et al., 2021). The seemingly endless debate about whether humans have evolved to eat meat or be vegetarians is strongly supported toward being omnivores by both dental and anatomical differences between people and non-human primates (Milton 2003). The proportionally much larger small intestine and smaller large intestine in humans compared to other primates indicates less bulk is a primary feature of the human diet. Of course, this does not indicate fiber is unessential. If one is going to eat meat, the type providing the most nutrients, other health-promoting components, and physical characteristics that contribute to the absence of overeating should be favored so that a wide variety of fiber-rich, plant-sourced foods can be included to provide the diverse dietary pattern that seems to be associated with the best health outcomes.

Conclusions

To address these unresolved issues, the National Cattlemen's Beef Association sponsored a meeting that developed the working definition of the whole food beef matrix specified above and outlined a research strategy to fill important knowledge gaps. The categories of research needed are: studies on beef matrix structure and composition, dietary interactions of beef as a whole food in the context of the overall dietary pattern, and discovery of how the beef matrix affects health outcomes of various types across the life stages, especially in younger and older consumers who are most vulnerable to deficiencies of the traditionally considered nutrients that beef supplies. Some examples of important research questions are in Table 2. Given the scarcity of research on the beef matrix, there are numerous questions that deserve to be studied. Mechanistic studies of how consumption of the beef matrix affects the gut microbiome, inflammatory mediators, and cardiometabolic risk factors must be conducted on a background diet of a healthy diet, not the typical American diet which seems to exacerbate many negative findings. It seems fairly clear that the current observational studies are very limited in accurately assessing a causal role of any specific food and health with a large portion of existing controlled studies not supporting elimination of beef, nor in many cases, limitation of its intake as long as an otherwise healthy diet and lifestyle is maintained. The key factors appear to be that the background diet determines health more than single components and the typical American diet, and that of many other affluent countries, needs substantial improvement. The research agenda addressing the beef matrix is intended to form the basis for making recommendations for healthful consumption of beef by demonstrable effects on health outcomes due to the role of the beef matrix within an otherwise healthy diet. That implies a reassessment of past inaccuracies derived primarily from observational studies that extrapolate claims of small or moderate amounts of beef being harmful which can be corrected through employment of better-designed and analyzed observational and randomized controlled studies that consider the overall dietary pattern and health-related lifestyle factors.

Disclosures

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Disclosure statement

No potential conflict of interest was reported by the author.

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