REVIEW

Can a carnivore diet provide all essential nutrients?

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Purpose of review
The aim of this study was to summarize current contributions affecting knowledge and predictions about the nutritional adequacy of plant-free diets, contextualized by historical accounts.

Recent findings
As demonstrated in recent experiments, nutrient interactions and metabolic effects of ketogenic diets can impact nutritional needs, sometimes resulting in nutrient-sparing effects. Other studies highlight conflicting hypotheses about the expected effect on metabolic acidosis, and therefore mineral status, of adding alkaline mineral-rich vegetables.

Summary
A carnivore diet is a newly popular, but as yet sparsely studied form of ketogenic diet in which plant foods are eliminated such that all, or almost all, nutrition derives from animal sourced foods. Ketogenic diets are already nutritionally controversial due to their near-complete absence of carbohydrate and high dietary fat content, but most ketogenic diet advocates emphasize the inclusion of plant foods. In this review, we discuss the implications of relying solely on animal sourced foods in terms of essential nutrient status.

Keywords
acidosis, carnivore diet, ketogenic diet, nutritional adequacy, vitamin C

INTRODUCTION

A carnivore diet is based on animal sourced foods (ASFs), drawing no significant contribution from plants. Plant elimination is considered a key to the immunological benefits imputed to the diet, which is often promoted as effective against autoimmune conditions. This has been attributed to the exclusion of xenobiotic secondary metabolites [1▪]. Because ASFs are largely devoid of carbohydrate and relatively high in fat, carnivore diets are typically ketogenic as a side effect. The degree of ketogenesis on a carnivore diet varies mostly with the amount of protein consumed. Some varieties of the carnivore diet, such as the 'Paleolithic Ketogenic Diet' (PKD), explicitly require highly ketogenic macronutrient ratios (low protein, high fat) [2▪▪]. Whether a diet is considered ketogenic depends only on whether it causes sufficient ketogenesis such that serum ketone bodies rise above a clinically defined threshold, typically 0.5 mmol [3]. As such, its definition is agnostic about other dietary qualities, including nutritional completeness. For this reason, researchers often emphasize the importance of ketogenic diets being 'well formulated' [4].

Encouraging the inclusion of low-starch vegetables in ketogenic diets has been used as a point of agreement bridging otherwise clashing nutritional paradigms, because they are compatible with ketogenesis, and because there is a perceived consensus on their health benefits [5]. We argue here that although plants can certainly be used as sources essential nutrients, and can help with compliance by providing variety and pleasure, a well formulated ketogenic diet need not contain them to be nutritionally adequate. Historical data, biochemistry and physiology are considered.

Most essential nutrients are found in abundance in animal sourced foods

A cursory examination of food nutrient databases, such as the one provided by the United States Department of Agriculture [6], shows that technically speaking, there are no essential nutrients that cannot be found in at least some quantity in some ASF. Indeed, most are more available from animal

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KEY POINTS

- All essential nutrients can be found in animal sourced foods.
- Some such nutrients are not commonly eaten in high enough amounts to meet recommended intakes.
- Studies on individuals eating only meat did not reveal nutrient deficiencies.
- Carnivore diet nutrient profiles and effects on metabolism may reduce or increase the needs for some nutrients.
- More study is warranted to understand long term implications of plant-free diets.

sources. Some examples are provided in Table 1. This is intuitive in part because animals are made up of the components they require, and humans are similar enough to the animals we eat that there is no major divergence between needs and composition.

Nonetheless, some nutrients are more common than others, or are distributed to more commonly eaten parts than others. Further, the rate of use of a given nutrient is not necessarily proportional to its ongoing level in the body. Moreover, it would be a mistake to automatically assume that all nutrients are efficiently extractable from a given source. Absorption, extraction and interconversion of nutrients depend on specific anatomy and physiology.

Generally speaking, for humans, most required nutrients are more available and more bioavailable from ASF sources than from plant sources. Two notable exceptions we will consider in depth below are calcium and vitamin C. Whether it is possible to obtain adequate levels of all nutrients without extraordinary measures is contentious even within online communities promoting carnivore diets, in part because nutrient requirements are context dependent.

Nutrient requirements depend on context

As the recent discovery of vitamins last century, intensive initiatives have helped determine human nutrient needs across a variety of conditions [7]. Guidelines in the form of daily intake references are designed probabilistically [8]. That is, for an individual, meeting a recommended intake will ensure that the chances of inadequacy are very small. As such, they are necessarily overestimates for the average consumer. This is particularly desirable when designing a diet to be administered to many people, because there is little cost incurred by some people getting more than necessary for the benefit of ensuring that the vast majority get enough. Moreover, it is not possible to determine exact needs for each individual on every occasion. A particular individual has no basis for expecting to fall below the higher end of the spectrum, and would therefore be prudently advised to act as though he or she requires more than average. However, if the population receiving the recommendation differs systematically from the population on which the recommendations were derived, these recommendations may be significantly in error in a predictable way. Plant-free diets may thus entail some different rates of use for some nutrients due to nutrient interactions and metabolic effects.

Table 1. Common plant and animal nutrient sources (per 100 g)

Nutrient	Plant source		Animal source	
Thiamin	Macadamia nuts	1.2 mg	Pork loin	0.6 mg
Riboflavin	Raw spinach	0.2 mg	Beef liver	3.4 mg
Niacin	Green peas	2.1 mg	Beef liver	17.5 mg
B6	Potato	0.3 mg	Beef liver	1.0 mg
Folate[a]	Raw spinach	194 μg	Beef liver	253 μg
Iron[a]	Raw spinach	2.7 mg	Beef liver	6.5 mg
Vitamin A[a]	Sweet potato	961 μg	Beef liver	9442 μg
Calcium	Sesame seeds	975 mg	Parmesan cheese	1184 mg
Potassium	Potato	535 mg	Beef top round	330 mg
Zinc	Green peas	1.2 mg	Oysters	16.6 mg
Vitamin C	Oranges	53.2 mg	Beef tongue	1.3 mg

Items chosen to represent common top sources, not necessarily the highest nor sole good sources. Not intended to be comprehensive.
[a]Vitamin A, folate and iron plant forms are precursor forms and less bioavailable than animal sources.
Source [6].

For example, ingestion of fibre can negatively affect the absorption of many vitamins and minerals [9], which could lower requirements of those nutrients for those not consuming fibre. Mineral absorption is also impaired in the presence of phytates [10]. Zinc absorption is particularly affected [11]. In a document jointly published by the WHO and the Food and Agricultural Organization of the United Nations examining when fortification is warranted, it is estimated that those with diets very high in grains and legumes may absorb less than one-third as much zinc as those with more typical phytate intake [12]. It can therefore be inferred that those on a diet completely devoid of grains and legumes ought to require significantly less zinc than average.

Metabolic effects can take various forms. It has been proposed [13] that as iodine is primarily used for the thyroid hormone triiodothyronine (T3) [12], and as ketogenic diets require less T3 for carbohydrate metabolism [14], the iodine requirement on a low carbohydrate diet may be much lower than on a high carbohydrate diet. Similarly, blood levels of the omega 3 fatty acid DHA are elevated on ketogenic diets [15]. This is thought to be due to reduced conversion to inflammatory eicosanoids [16]. Such preservation could impact essential fatty acid requirements.

A second way metabolism can affect nutrient requirements is when there is contribution from synthesis by intestinal bacteria, and this bacterial activity changes due to the diet. Folate levels are increased significantly by ketogenic diets [17], and even by the intermittent fasting of Ramadan [18]. As shown by Mardinoglu *et al.* [19▪▪], this is due to increased intestinal microbial production, not intake.

Vitamin C

Vitamin C is an interesting case because despite the fact that meat is a relatively poor source, it has been recognized for centuries that meat has antiscorbutic properties. The following observations from C. Ralfe in an 1882 issue of the *Lancet* discussing this phenomenon [20] are representative:

'Sir, — I was struck by two independent observations which occurred in your columns last week with regard to the etiology of scurvy, both tending to controvert the generally received opinion that the exclusive cause of that disease is the prolonged and complete withdrawal of succulent vegetables from the dietary of those affected. Thus, Mr. Neale, of the Eira Arctic Expedition, says: ''I do not think that spirit or limejuice is of much use as an antiscorbutic; for if you live on the flesh of the country, even, I believe, without vegetables, you will run very little risk of scurvy'''. Dr. Lucas writes: 'In the case of the semi-savage hill tribes of Afghanistan and Beluchistan their food contains a large amount of meat and is altogether devoid of vegetables. The singular immunity from scurvy of these races has struck me as a remarkable physiological circumstance, which should make us pause before accepting the vegetable doctrine in relation to scurvy'' These observations do not stand alone. Arctic voyagers have long pointed out the antiscorbutic properties of fresh meat, and Baron Larrey, with regard to hot climates, arrived at the same conclusion in the Egyptian expedition under Bonaparte, at the end of last century.

A candidate explanation for these observations is that many of the symptoms of scurvy are due to lack of carnitine, which can be derived endogenously using vitamin C, but can also be absorbed in large quantities from meat in the diet [21]. Given that meat is an excellent source of carnitine, it may be that the carnitine spares vitamin C that would otherwise be needed for its synthesis, while the small amounts of vitamin C it provides are enough for the remaining functions. Precipitous drops in muscle carnitine have been proposed to explain the early symptoms of scurvy, severe fatigue and muscle weakness, long before tissue lesions from impaired collagen synthesis appear [22]. On the contrary, because carnitine is used for fatty acid oxidation, which is upregulated in ketosis, it may be an example of a substance in higher demand in the ketogenic context, meaning that if carnitine itself is not adequately supplied, vitamin C requirements may instead be increased.

Even though these kinds of sparing effects are plausible mechanistically, aside from folate, which has been clinically measured, it is impossible to know whether and to what extent they actually occur in practice. Empirical study under this dietary condition is sparse.

Empirical evidence

What little evidence exists for the sustainability of plant-free diets comes in three forms: reports on Arctic or nomadic societies, such as the Inuit or Mongolians or mountain herders as mentioned in the *Lancet* above, clinical case studies and anecdotes. The debates surrounding the degree of inclusion of plants in Arctic and nomadic societies are beyond the scope of this review. However, it is clear that in these environments, plant food sources would be exceedingly rare. Anecdotal evidence is also riddled with problems and won't be considered further here. Of the clinical studies, one of the most informative is from early last century.

In 1928, two Arctic explorers, the Harvard anthropologist Vilhjalmur Stefansson and his coexplorer Karsten Andersen, agreed to participate in a year-long study of eating only meat, after having been challenged about their claims to excellent health on plant-free, high-protein diets while living with indigenous people in the Arctic. Part of the experiment was conducted in a ward in Bellevue hospital. Several reports were published on different aspects of the results, including one in which it was specifically noted that there was no clinical evidence of vitamin deficiency [23]. The only comment related to a potential deficiency pertained to calcium, because the amount of calcium they ate was reportedly only a quarter of 'the average mixed diet', and, more importantly, they appeared to be in negative calcium balance [24]. According to another study [25], their blood calcium levels remained stable, but normal blood calcium levels are not necessarily an indication of sufficiency, because bone resorption can be used as a source to keep blood calcium at well tolerated levels [26]. Moreover, low carbohydrate diets have at least in one case been found to decrease calcium balance, which was presumed to be a function of acid load [27]. For this reason, high calcium, nonstarchy vegetables have been strongly recommended recently for inclusion in ketogenic diets [28].

On the contrary, another study measuring the effect of a high meat diet on calcium flux concluded that increased calcium absorption precisely compensated for increased excretion leaving no change in bone resorption [29]. Likewise, as discussed in a recent review of evidence for and against the hypothesis that meat eating causes bone resorption [30▪], it has been found that in ketogenic conditions, ketone generation increases or decreases dynamically as a compensatory response to challenge loads of exogenous acid or base [31]. Therefore, attempting to change acid balance through vegetable intake may be futile. In fact, it could actually add acidity despite containing alkaline minerals, as the detoxification of plant secondary compounds requires the production of organic acids that then must be buffered [32]. Increased protein intake can itself provide bicarbonate for this purpose, which is used by some animals when eating plants with high toxic loads [33]. In other words, there are plausible mechanisms predicting both an increase and a decrease of acidity, and so, the net result on acid-base balance by the addition of plant sources of bicarbonate to a meat-only diet remains unknown.

As exemplified by the acid-buffering considerations, calcium balance is complicated by biochemically motivated changes in absorption or excretion. Other examples are reviewed in [26], including that absorption is positively affected by vitamin D status and exercise, whereas excretion is enhanced by simple lack of growth stimulus as seen in astronauts, reduced oestrogen levels and high sodium intake.

Nonetheless, given that calcium balance was negative in the Bellevue study, and that calcium intake from meat alone is low, it may be a nutrient of concern, particularly in variations of the diet with no dairy intake, and no consumable bones for example from fish. Traditionally, Mongolians [34] and Bedouins [35] made extensive use of dairy, and Inuit ate small bones and reportedly chewed bones as well [36]. These animal sources of calcium may not be present in modern carnivore diets.

Other clinical studies in which no nutrient deficiencies were observed include case reports from the International Center for Medical Nutritional Intervention (ICMNI), in which autoimmune patients are treated with low-to-no plant diets, for example [37,38]. These studies differ from the previous in that the individuals already present with substantial disease and may therefore have more acute nutrient needs. Organ consumption for nutritional adequacy is emphasized.

CONCLUSION

Every essential nutrient can be found in ASFs, but not always in high levels in commonly eaten ones. Some nutrients are rarer than others and may require planning if the goal is to guarantee meeting established recommended daily allowances. Because of systematic differences in metabolism and food matrix contexts, requirements on a carnivore diet may likewise differ systematically. Historical and clinical data suggest that all acute micronutrient needs can be met without plants, but long-term consequences are unknown. Calcium levels in particular may be compromised over time, and merit further study, especially in order to disentangle effects of acidity, bone growth stimulation and interacting nutrients.

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Conflicts of interest

There are no conflicts of interest.

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▪ of special interest

▪▪ of outstanding interest

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