Protein intake is more stable than carbohydrate or fat intake across various US demographic groups and international populations

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ABSTRACT

Background: The optimal macronutrient composition of the diet is controversial and many adults attempt to regulate the intake of specific macronutrients for various health-related reasons.

Objective: The objective was to compare stability and ranges of intakes of different macronutrients across diverse adult populations in the USA and globally.

Methods: US dietary intake data from NHANES 2009–2014 were used to determine macronutrient intake as a percentage of total energy intake. Variability in macronutrient intake was estimated by calculating the difference between 75th and 25th percentile (Q3–Q1) IQRs of macronutrient intake distributions. In addition, intake data from 13 other countries with per capita gross domestic product (GDP) over $10,000 US dollars (USD) were used to assess variability of intake internationally since there are large differences in types of foods consumed in different countries.

Results: Protein, carbohydrate, and fat intake (NHANES 2009–2014) was 15.7 ± 0.1, 48.1 ± 0.1, and $32.9 \pm 0.1\%$ kcal, respectively, in US adults. The IQR of protein intake distribution ($3.73 \pm 0.11\%$ kcal) was 41% of carbohydrate intake distribution ($9.18 \pm 0.20\%$ kcal) and 58% of fat intake distribution ($6.40 \pm 0.14\%$ kcal). The IQRs of carbohydrate and fat intake distributions were significantly ($P < 0.01$) influenced by age and race; however, the IQR of protein intake was not associated with demographic and lifestyle factors including sex, race, income, physical activity, and body weight. International mean protein intake was $16.3 \pm 0.2\%$ kcal, similar to US intake, and there was less variation in protein than carbohydrate or fat intake.

Conclusion: Protein intake of the US population and multiple international populations, regardless of demographic and lifestyle factors, was consistently ∼16% of total energy, suggesting biological control mechanism(s) tightly regulate protein intake and, consequently, influence intake of other macronutrients and food constituents. Substantial differences in intake of the other macronutrients observed in US and international populations had little influence on protein intake. This trial was registered at the ISRCTN registry as ISRCTN46157745 (https://www.isrctn.com/ISRCTN4615774). *Am J Clin Nutr* 2020;112:180–186.

Introduction

The optimal macronutrient composition of the diet is a controversial topic. Many individuals attempt to modify the intake of specific macronutrients based on their perception of nutritional recommendations, such as reducing fat or carbohydrate or increasing protein intake. Radical shifts in macronutrient intake are the cornerstone of many popular fad diets, including the Atkins diet (low carbohydrate), the paleo diet (high protein, low grain), and ketogenic diet (high fat, low carbohydrate), that lack adequate scientific evidence for their efficacy and do not appear to be successful on a long-term basis due to a variety of factors, including compliance (1–6). When free-living adults are medically advised to modify their macronutrient intake and supervised by healthcare providers in large clinical trials, dietary compliance is low and attrition high (7–14).

Since macronutrients are acquired from a variety of foods and typically present in complex food matrices, consciously selecting a diet consisting of a specific macronutrient mix is a complex task. However, despite the inherent difficulty of consciously regulating macronutrient intake, humans and other animals effectively and unconsciously regulate the composition of their diet when adequate and varied foods are available (15, 16). Some of the regulatory mechanisms underlying these capabilities have been identified for protein and other macronutrients (15–21). For example, rodents avoid very high- or low-protein diets and, when given the opportunity, select a diet that contains adequate protein (15, 17, 22). The hypothesized biological constraints on protein ingestion, termed the "protein leverage theory," suggest protein is prioritized over fat and carbohydrate intake, which may influence total caloric intake and limit dietary modification (16, 23, 24).

One objective of the current study was to evaluate protein, fat, and carbohydrate intake as a percentage of calories in US adults by age, sex, race-ethnicity, socioeconomic status, body weight status, and physical activity level. In addition, macronutrient intake was evaluated in adults from 14 countries (including the USA) with both accessible dietary intake data, to compare geographically and culturally diverse population groups, and gross domestic product (GDP) over $10,000 USD, to exclude countries where food availability might be restricted by economic factors. We hypothesized the distribution of protein intake as a percentage of calories would be more tightly regulated (i.e., less variation), as assessed by SD and IQR, than that of carbohydrate and fat intake in US adults and independent of demographic characteristics. We also hypothesized adults from other countries would have similar protein intake, as a percentage of total calories, as US adults, despite substantial geographic and cultural differences in dietary preferences, intake patterns, and food supply.

Methods

US macronutrient intake methods

Macronutrient intakes as a percentage of energy consumed per day by US adults were estimated using the 24-h dietary recall data collected from the dietary interview component of NHANES (25). NHANES is a continuous series of cross-sectional surveys that uses a complex, stratified multistage probability sample of a nationally representative, civilian noninstitutionalized US population identified from specified household clusters. A detailed description of NHANES study design and methods is available elsewhere (25).

Adult data from NHANES 2009 to 2010, 2011 to 2012, and 2013 to 2014 were combined to estimate recent macronutrient intake ($n = 15,774$). Data from all adults aged 19 y and older, excluding pregnant or lactating females and those with incomplete records, were used (**Supplementary Figure 1**). All participants or proxies provided written informed consent and the Research Ethics Review Board at the National Center for Health Statistics approved the protocol.

Statistical analyses were carried out with SAS 9.2 (SAS Institute Inc) using PROCSURVEY means. Appropriate weighting factors were used to adjust for oversampling of selected groups, survey nonresponse of some individuals, and day of the week when the interview was conducted. Individual usual intake (UI, habitual intake) of macronutrients was determined using the National Cancer Institute (NCI) method for a single dietary component (26) using both days of 24-h recall and day 1 sample weights. Covariates used in the UI estimations were day of the week of the 24-h recall [coded as weekend (Friday to Sunday) or weekday (Monday to Thursday)] and sequence of dietary recall (first or second). Percent kcal from protein, carbohydrates, and fat were analyzed separately by age/sex group, race-ethnicity, income quartile, physical activity level, and weight status. SDs and CIs for these distribution measures were also generated. IQRs of macronutrient intake distribution were calculated as the difference between the 75th and 25th intake percentile (Q3–Q1) as a measure of variability of intake. SAS PROC SGPLOT was used to output figures of intake distributions. To avoid considering very small differences to be statistically significant given the large number of observations used in these analyses, significance was set at $P \leq 0.01$ and t tests were used to assess differences in intakes based on various demographic characteristics.
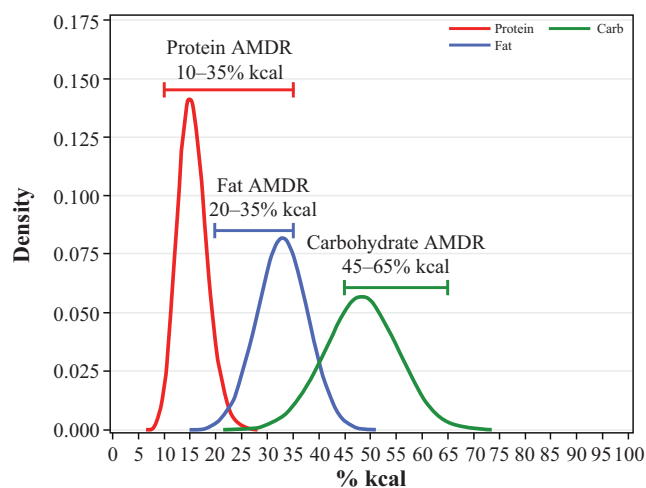
FIGURE 1 Distribution of usual macronutrient intake among adults aged 19+ y, NHANES 2009–2014 ($n = 15,774$). The narrower and steeper peak, and smaller tails, of the protein distribution compared with the fat and carbohydrate distributions are readily apparent and verified by the various statistical comparisons provided in the text. The Acceptable Macronutrient Distribution Range brackets indicate percentage of total energy and are 45–65% for carbohydrate, 20–35% for fat, and 10–35% for protein (45). AMDR, Acceptable Macronutrient Distribution Range.

TABLE 1 Usual intake of macronutrients (% kcal) among adults aged 19+ y, NHANES 2009–2014 ($n = 15{,}774$)

	Protein	Carbohydrate	Fat
1 SD—left tail % of population	12.9 ± 0.09	41.3 ± 0.24	28.2 ± 0.16
2 SD—left tail % of population	10.1 ± 0.15	34.5 ± 0.38	23.5 ± 0.25
1 SD—right tail % of population	18.5 ± 0.14	55.0 ± 0.17	37.7 ± 0.15
2 SD—right tail % of population	21.3 ± 0.22	61.8 ± 0.29	42.4 ± 0.23

Data presented as estimated mean ± SE of estimated mean.

International macronutrient intake methods

Macronutrient intake (% kcal) from international populations was obtained from peer-reviewed published literature identified via PubMed and other databases or from publicly available national government reports. The following inclusion criteria were used to select data: macronutrient intake information was reported by sex; information was provided separately for adults aged between 18 and 70 y; and alcohol intake was either not legal in the country or calories from alcohol were separately provided. In addition, the survey methods used to determine macronutrient intake had to be based on either >1 dietary recall record, self-recorded dietary recall, diet history, or a scan of purchased foods. If the macronutrient intake in percent kcal was not reported directly in the publications, these values were calculated from data presented as kcal/d or g/d using conversion factors of 4 kcal/g for protein and carbohydrate, 9 kcal/g for fat, and 7 kcal/g for alcohol. If the caloric contribution of alcohol was not reported in the publications, it was estimated by recalculating the relative contributions of macronutrients. To eliminate countries where ad libitum selection of foods by a significant portion of the population could be limited for purely economic reasons, only countries with a GDP over $10,000 USD were considered (25, 27–40). Macronutrient intakes were plotted against their per capita GDP in US dollars and linear regression equations generated for males and females separately.

Results

Variability of US macronutrient intake

Recent (NHANES 2009–2014) macronutrient intake distributions as a percentage of calories are presented in **Figure 1**. The protein intake distribution range was the narrowest of the macronutrients, the carbohydrate intake range was the widest, and the intake range for fat was intermediate. The range of intake between 2 SD above and below the mean intake (calculated by subtracting the value of the left 2 SD tail from the right 2 SD tail) was the lowest for protein (11.2%) compared with carbohydrate and fat (27.3% and 18.9%, respectively) (**Table 1**). Quartile 1 and quartile 4 intakes were <13.7 and >17.4% kcal for protein; <43.6 and >52.8% kcal for carbohydrate; and <29.8 and >36.1% kcal for fat, with mean intakes being 15.7 ± 0.1, 48.1 ± 0.1 and $32.9 \pm 0.1\%$ kcal for protein, carbohydrate, and fat, respectively. The IQR intake distribution was the smallest (3.73 ± 0.11 percentage units) for protein intake and was 41% of the IQR of the carbohydrate intake distribution (9.18 ± 0.20 percentage units) and 58% of the IQR of the fat intake distribution (6.40 ± 0.14 percentage units) (**Table 2**). Excess kurtosis (kurtosis-3), an indicator of a narrower and steeper peak of a distribution compared with other distributions, was highest for the protein distribution with nonoverlapping CIs compared with carbohydrate and fat intake distributions (Table 2).

In the NHANES 2009–2014 data, mean intakes of macronutrients as a percentage of calories were not influenced by various demographic factors (**Table 3**). Protein intake as a percentage of calories, although statistically significant ($P \leq 0.01$), was only 0.5 percentage units lower in female than in male adults. Carbohydrate intake was 2.3 percentage units higher in females than males ($P \leq 0.01$). Protein intake was not affected by age ($P > 0.01$), whereas older adults (≥ 71 y) consumed more carbohydrate than adults aged 31–50 and 51–70 y, and adults 51–70 y consumed more fat as a percentage of calories than adults aged 19–30 and 31–50 y. Protein intake was highest among Asians, followed by Hispanics and was lowest among non-Hispanic (NH)-whites and NH-blacks, but the widest difference in protein intake in these groups was only 1.8 percentage units. Carbohydrate intake was higher and fat intake lower for Asians and Hispanics than for NH-whites and NH-blacks. Adults in lower income groups [poverty income ratio (PIR) <1.35] consumed less protein (but only 0.4 percentage units) and fat, and more carbohydrate as a percentage of calories than adults in higher income groups (PIR >1.85). Intake of protein or fat as a percentage of calories was not affected by physical

TABLE 2 Usual intake of macronutrients (% kcal) among adults aged 19+ y, NHANES 2009–2014 ($n = 15{,}774$)

	Protein	Carbohydrate	Fat
Mean intake	15.7 ± 0.1	48.1 ± 0.1	32.9 ± 0.1
Intake quartile 1	<13.7	<43.6	<29.8
Intake quartile 2	13.7–15.5	43.6–48.2	29.8–33.0
Intake quartile 3	15.6–17.4	48.3–52.8	29.9–36.1
Intake quartile 4	>17.4	>52.8	>36.1
IQR	3.73 ± 0.11	9.18 ± 0.20	6.40 ± 0.14
Excess kurtosis (95th CI)	0.32 (0.18, 0.45)	0.05 (−0.02, 0.12)	0.07 (−0.02, 0.16)

Data presented as estimated mean ± SE of estimated mean.

TABLE 3 Mean usual intake of macronutrients (% kcal) among adults aged 19+ y in various demographic groups, NHANES 2009–2014 ($n = 15{,}774$)

Demographic groups	Protein	Carbohydrate	Fat
Sex			
Male	15.9 ± 0.1^a	47.0 ± 0.2^a	33.0 ± 0.2
Female	15.4 ± 0.1^b	49.3 ± 0.2^b	32.9 ± 0.2
Age groups			
19–30 y	15.4 ± 0.2	48.9 ± 0.2^{ac}	32.5 ± 0.2^a
31–50 y	15.7 ± 0.1	48.2 ± 0.2^a	32.5 ± 0.2^a
51–70 y	15.8 ± 0.1	47.2 ± 0.2^b	33.6 ± 0.2^b
71+ y	15.7 ± 0.2	49.2 ± 0.3^c	33.2 ± 0.2^{ab}
Ethnicity			
Hispanic	16.4 ± 0.1^a	49.8 ± 0.3^{ad}	31.8 ± 0.2^a
Non-Hispanic white	15.5 ± 0.1^b	47.4 ± 0.2^b	33.4 ± 0.2^b
Non-Hispanic black	15.3 ± 0.1^b	48.6 ± 0.2^c	33.2 ± 0.3^b
Asian	17.2 ± 0.2^c	50.3 ± 0.5^d	30.4 ± 0.4^c
Poverty income ratio			
<1.35	15.4 ± 0.1^a	50.0 ± 0.2^a	32.1 ± 0.2^a
1.35–1.85	15.4 ± 0.2^{ab}	49.2 ± 0.3^a	33.1 ± 0.3^b
>1.85	15.8 ± 0.1^b	47.1 ± 0.2^b	33.3 ± 0.2^b
Physical activity level			
Sedentary	15.5 ± 0.1	49.1 ± 0.3^a	33.3 ± 0.2
Moderate	15.6 ± 0.1	48.2 ± 0.3^{ab}	33.1 ± 0.2
Vigorous	15.9 ± 0.1	47.6 ± 0.2^b	32.6 ± 0.2
Body weight status			
Normal weight	15.3 ± 0.1^a	49.0 ± 0.2^a	32.0 ± 0.2^a
Overweight	15.8 ± 0.1^b	47.5 ± 0.2^b	33.1 ± 0.2^b
Obese	15.9 ± 0.1^b	48.0 ± 0.2^b	33.6 ± 0.2^b
Overweight or obese	15.9 ± 0.1^b	47.7 ± 0.2^b	33.3 ± 0.1^b

Data presented as estimated mean $\pm$ SE of estimated mean. [a-d]Values with different superscripts are significantly different for a nutrient within a demographic group at $P < 0.01$ via t tests.

TABLE 4 IQR of usual intake of macronutrients (% kcal) among adults aged 19+ y by various demographic groups, NHANES 2009–2014 ($n = 15{,}774$)

Demographic groups	Protein	Carbohydrate	Fat
Sex			
Male	3.73 ± 0.16	9.41 ± 0.32	6.58 ± 0.27
Female	3.70 ± 0.13	8.81 ± 0.25	6.20 ± 0.21
Age groups			
19–30 y	3.94 ± 0.20	8.39 ± 0.45^{ab}	5.80 ± 0.35^a
31–50 y	3.68 ± 0.17	9.74 ± 0.30^a	6.20 ± 0.25^{ab}
51–70 y	3.60 ± 0.20	9.33 ± 0.25^a	7.00 ± 0.30^b
71 + y	3.59 ± 0.18	8.01 ± 0.34^b	5.85 ± 0.36^{ab}
Ethnicity			
Hispanic	3.83 ± 0.20	8.07 ± 0.36^a	5.87 ± 0.25^a
Non-Hispanic white	3.68 ± 0.13	9.46 ± 0.28^b	6.47 ± 0.21^{ab}
Non-Hispanic black	3.45 ± 0.19	8.14 ± 0.26^a	5.73 ± 0.28^a
Asian	4.02 ± 0.44	8.96 ± 0.62^{ab}	7.27 ± 0.45^b
Poverty income ratio			
<1.35	3.81 ± 0.13	8.62 ± 0.34	6.30 ± 0.20
1.35–1.85	3.58 ± 0.40	8.12 ± 0.51	6.29 ± 0.51
>1.85	3.60 ± 0.13	9.21 ± 0.24	6.26 ± 0.19
Physical activity level			
Sedentary	3.70 ± 0.20	8.93 ± 0.32	6.64 ± 0.32
Moderate	3.43 ± 0.17	9.25 ± 0.35	6.29 ± 0.20
Vigorous	4.00 ± 0.17	9.21 ± 0.21	6.28 ± 0.26
Body weight status			
Normal weight	3.74 ± 0.19	8.81 ± 0.34	5.89 ± 0.34
Overweight	3.41 ± 0.16	9.58 ± 0.32	6.74 ± 0.26
Obese	3.90 ± 0.16	9.16 ± 0.34	6.37 ± 0.26
Overweight or obese	3.70 ± 0.13	9.37 ± 0.28	6.54 ± 0.18

Data presented as estimated mean $\pm$ SE of estimated mean. [a-b]Values with different superscripts are significantly different for a nutrient within a demographic group at $P < 0.01$ via t tests.

activity. However, sedentary adults consumed more carbohydrate as a percentage of calories than those in the vigorous activity group. Adults with normal body weight consumed less protein (but only 0.6 percentage units) and fat, and more carbohydrate as a percentage of calories than overweight or obese adults.

In US adults, protein intake distribution (i.e., IQR for UI) was not affected ($P > 0.01$) by any demographic or lifestyle factors including sex, race, income, physical activity, and body weight status (**Table 4**). IQRs for carbohydrate and fat intake distribution were significantly influenced by age and race-ethnicity. The IQR for carbohydrate intake was greater for adults aged 31–50 and 51–70 y than adults ≥ 71 y, as well as for NH-white adults compared with NH-black and Hispanic adults. The IQR for fat intake was higher for adults aged 51–70 y than 19–30 y, as well as for Asian adults than NH-black and Hispanic adults. Other demographic and lifestyle factors did not affect the IQR of carbohydrate or fat intake. It should also be noted that mean intakes of protein, carbohydrate, and fat have not changed significantly over the last decade among the US population (41).

Variability of international macronutrient intake

Per capita GDP in the international populations examined varied from slightly over $12,000 USD in Poland to over $71,000 USD in Norway (**Table 5**). The range of protein intake in the

14 international populations (including the USA) was narrower than for carbohydrate and fat as a percentage of calories. Protein intake ranged from 13.6% kcal for Japanese males to ~18.5% kcal for Australian females, whereas carbohydrate intake ranged from 42.9% kcal for males of the Czech Republic to 68.0% kcal for Korean females, and fat intake ranged from 17.6% kcal for Korean females to 38.0% kcal for females from the Netherlands (Table 5). For each country, macronutrient intake data were plotted against per capita GDP in US dollars and the slopes for each macronutrient were similar for males and females. Intake of protein did not change substantially with per capita GDP, whereas the intake of carbohydrate decreased, and intake of fat increased with GDP (**Figure 2**). The steepness of the slopes of the regression lines for protein intake were 88–90% less than carbohydrate and 75–82% less than that of fat.

Discussion

In the USA, protein intake varies substantially less than carbohydrate and fat intake as assessed by the distribution of intake, SD, and IQR, standard measures of variability (Figure 1; Tables 1 and 2). These data support that, on a population level, protein intake is less variable than carbohydrate or fat. Differences in macronutrient intake associated with a variety of demographic variables were minimal but were greater for carbohydrate and fat (3% or less) compared with protein (2% or less) (Table 3). The IQR of protein intake in US adults was

TABLE 5 Macronutrient intake (% kcal) and per capita gross domestic product in multiple international populations. Data adapted from various national surveys

Country	Per capita GDP (US dollars)[1]	Sample year	Macronutrient intake (% kcal) for males/females			References
			Protein	Carbohydrate	Fat	
Australia	51,592	2011–12	18.3/18.5	43.2/43.5	30.4/31.1	(27)
Canada	42,319	2004	15.9/15.5	47.3/50.0	31.3/30.9	(28)
Czech Republic	18,326	2002–05	17.2/16.8	42.9/47.1	35.7/35.1	(29)
Finland	43,492	2007	16.8/17.2	47.1/50.2	33.1/31.2	(30)
France	38,537	2006–07	16.2/17.1	43.5/44.6	35.2/37.1	(31)
Germany	42,326	2005–07	13.9/13.9	43.3/45.1	36.7/36.3	(32)
Ireland	65,871	2008–10	16.6/16.6	44.1/46.4	34.3/35.4	(33)
Japan	37,304	2012–13[2]	13.6/15.9	55.0/58.9	23.5/24.4	(34, 35)
Korea	27,633	2007–09	15.0/14.3	63.0/68.0	18.0/17.6	(36)
Netherlands	45,210	1987–98	14.5/15.5	43.0/43.5	37.0/38.0	(37)
Norway	71,497	2010–11	18.0/18.0	43.0/44.0	34.0/34.0	(38)
Poland	12,309	2002–05	17.6/17.4	45.1/48.2	36.1/34.1	(29)
United Kingdom	40,411	2008–12	16.4/16.6	45.1/46.3	32.8/33.0	(39)
United States	57,294	2011–14	16.1/15.6	47.4/49.6	33.6/33.7	(25)

[1] https://knoema.com/sijweyg/world-gdp-per-capita-ranking-2016-data-and-charts-forecast.
[2] Sample year was 1990 for females.
GDP, gross domestic product.

unaffected by age, ethnicity, income, physical activity, and weight status; however, carbohydrate and fat intake did vary significantly across age and ethnicity (Table 4).

The international macronutrient intake data presented from 13 countries with per capita GDP of over $10,000 USD and the USA also support the hypothesis that protein is the most tightly regulated macronutrient (Table 5). In countries with very different staple foods and cuisines, variation in protein intake was much less than either carbohydrate or fat. Furthermore, differences in per capita GDP had substantially less impact on protein intake than intake of the other macronutrients (Figure 2), even though foods with higher protein content, such as lean meats and dairy, generally have a greater energy cost than those that contain greater amounts of carbohydrates and fats, such as grains, sweets, butter, and oil (42, 43). The trend of decreased carbohydrate intake and increased fat consumption with increased per capita income in the international populations examined here is consistent with the literature on this issue (40). The stability in the proportion of protein intake in the human diet is consistent with a great deal of experimental data from humans and other mammals. For example, a very large, carefully controlled clinical trial comparing weight loss diets was conducted to examine the effects of varying protein intake from 15% to 25% of total caloric intake. However, in 2 y, when the study was complete, the actual variation in protein intake consumed by the different treatment groups was only 1.6 percentage units, demonstrating the difficulty of intentionally intervening to alter protein intake (7).

In aggregate, protein intake as a percentage of calories of the diet is tightly regulated and largely independent of a variety of factors including sex, age, socioeconomic status, ethnicity, physical activity, and body weight. In addition, despite cultural differences in dietary preferences, intake patterns, and food availability internationally, protein intake, relative to the other macronutrients, is remarkably stable. The data presented here indicate protein intake is more tightly regulated than carbohydrate and fat, consistent with prior studies (for examples see 16, 23, 24). Furthermore, the substantial variability in fat and carbohydrate intake observed, compared with protein, indicates
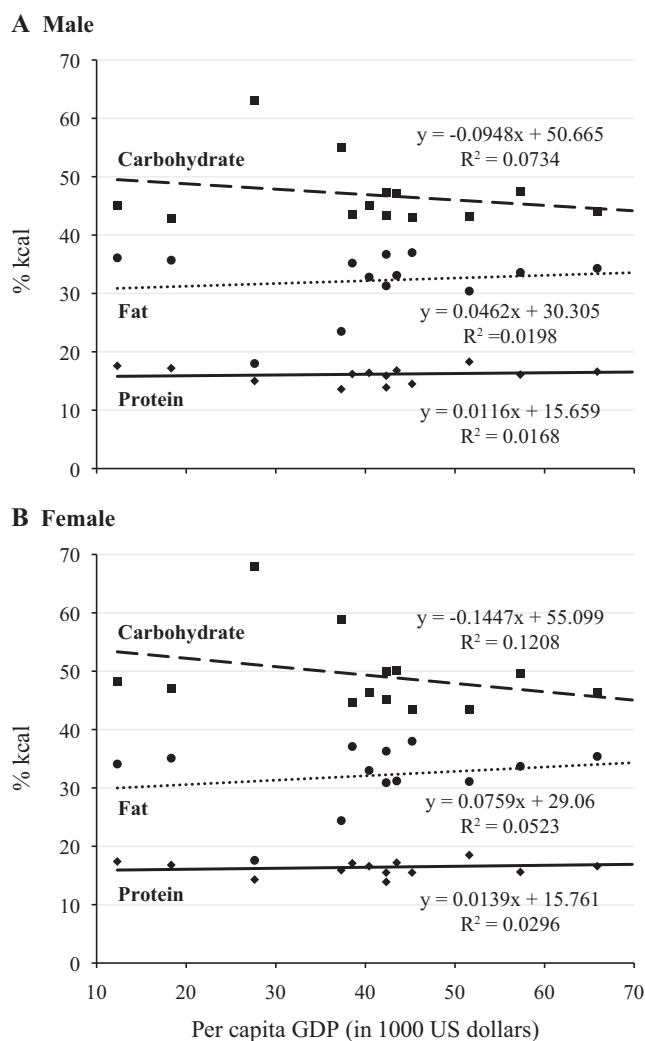

FIGURE 2 Protein, carbohydrate, and fat intake (% kcal) in 14 populations by per capita gross domestic product. Data adapted from various national surveys (25, 27–39). Squares represent carbohydrate intake, circles represent fat intake, and diamonds represent protein intake. Panel A for males and panel B for females. GDP, gross domestic product.

intake of these macronutrients has relatively little influence on protein consumption.

There were a number of limitations in this study. Intake data from NHANES are self-reported, and although the best procedures were used to assess dietary intake, self-reported dietary data rely on memory and the ability of subjects to accurately report the foods and amounts of foods consumed, and are subject to reporting bias (44). Another limitation was the variability in methods used to collect the international macronutrient data. Although we restricted our selection of international data to the most accurate methods, there is undoubtedly added variability in the data reported here attributable to methodical differences in collecting and analyzing such complex data across such diverse populations. This type of measurement error may have created greater differences in estimates of macronutrient intake than would have been observed if identical procedures were used across all the nations studied. Major strengths of our study were use of a large nationally representative, population-based sample of adults to obtain US intake data and data from multiple international populations.

In conclusion, in US and international populations, converging evidence suggests protein intake is more tightly regulated than intake of the other macronutrients. The lack of substantial variation in protein intake across a variety of demographic variables in the US population and in 14 nations (including the USA) supports this finding and lends credence to the protein leverage hypothesis. A better understanding of the biological constraints on protein ingestion may improve formulation of practical guidance regarding optimal macronutrient intake.

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